DEVELOPMENT OF A HYBRID FUZZY-MATHEMATICAL CLEANER PRODUCTION EVALUATION TOOL FOR SURFACE FINISHING

BY

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DECLARATION

I, ARNESH TELUKDARIE, REG NO.19051126, hereby declare that the dissertation entitled DEVELOPMENT OF A HYBRID FUZZY-MATHEMATICAL CLEANER PRODUCTION EVALUATION TOOL FOR SURFACE FINISHING is the result of my own research.

This thesis has not been submitted to any other university or institution for degree purposes.

A TELUKDARIE

ABSTRACT

The metal finishing industry has been rated among the most polluting industries worldwide. This industry has traditionally been responsible for the release of heavy metals such as chrome, nickel, tin, copper etc into the environment. The application of cleaner production systems to a range of industries, including the metal finishing industry has provided significant financial and environmental benefits. An example of a successful application of cleaner production in the metal finishing industry is the reduction in the typical water consumption from 400 l/m^2 to less than 10 l/m^2 of plated product.

The successful application of cleaner production to the metal finishing industry has encountered many barriers. These barriers include the need for a highly skilled cleaner production auditor and the need for rigorous plant data to effectively quantify the cleaner production potential of the company under consideration.

This study focuses on providing an alternate user-friendly audit system for the implementation of cleaner production in the metal finishing industry. The audit system proposed eliminates the need for both a technical auditor and rigid plant data. The proposed system functions solely on plant operator inputs. The operator's knowledge is harnessed and used to conduct an efficient and effective cleaner production audit.

The research is based on expert knowledge, which was gained by conducting audits on some 25 companies using traditional auditing tools. This company audits were used to construct a database of data that was used in the verification of the models developed in this study.

The audit is separated into different focus components. The first system developed was based on fuzzy logic multi variable decision-making. For this system the plant was categorized into different sections and appropriate fuzzy ratings were allocated based on experience. Once the allocations were completed multi variable decision analysis was used to determine the individual variable impact. The output was compared and regressed

to the database equivalent. Operator inputs can then be used to determine the individual category outputs for the cleaner production rating for the company under consideration.

The second part of this study entails the development of mathematical models for the quantification of chemical and water consumptions. This was based on the present and ideal (cleaner production) plant configuration. Cleaner production operations are compared to present operations and potential savings quantified. Mathematical models were developed based on pilot scale experiments for the acid, degreaser and zinc plating process. The pilot experiments were carried out on a PLC controlled pilot plant. These models were developed from factorial experimentation on the variables of each of the plating processes. The models developed aid in the prediction of the relevant optimum consumptions.

The key challenge in traditional evaluation systems has been the quantification of the plant production. The most effective measure of production is by means of the surface area plated. In this study a novel approach using the modeled acid consumption is proposed.

It was assumed that the operator inputs for the above models would not be precise. The models developed allowed for input variations. These variations were incorporated into the model using the Monte Carlo technique. The entire cleaner production evaluation system proposed is based on an operator questionnaire, which is completed in visual basic. The mathematical model was incorporated into the visual basic model. For the purpose of model verification the mathematical models were programmed and tested using the engineering mathematical software, Mat Lab.

The combined fuzzy logic and mathematic models prove to be a highly effective means of completing the cleaner production evaluation in minimal time and with minimal resources. A comparative case study was conducted at a local metal finishing company.

The case study compares the input requirements and outputs from the traditional systems with the system proposed in this study. The traditional model requires 245 inputs whilst the model proposed in this study is based on 56 inputs. The data requirements for the model proposed in this study is obtained from a plant operator in less than one hour whilst previous models required high level expertise over a period of up to two weeks. The quality of outputs from the model proposed is found to be very comparable to previous models. The model is actually found to be superior to previous models with regards predicting operational variations, water usages, chemical usages and bath chemical evolution.

The reseach has highlighted the potential to apply fuzzy-mathematical hybrid systems for cleaner production evaluation. The two limitations of the research were found to be the usage of a linear experimental design for model development and the availability of Mat Lab software for future application. These issues can be addressed as future work. It is recommended that a non-linear model be developed for the individual processes so as to obtain more detailed process models.

This thesis is dedicated at
the lotus feet of the divine lord
without whom nothing in
this world would really
be possible

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Firstly, my most humble gratitude is extended to the Divine Lord for granting me the strength, guidance, wisdom and inspiration to complete this study.

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Numerous company audits were carried out as baseline studies for this thesis. I wish to thank the South African Metal Finishers Association for facilitating these audits. A special thanks to John Danks from Saayman Danks Electroplaters for allowing the testing of the tool developed in this study at his company.

Numerous discussions took place with Trudy Hatting from Chemserve systems on the chemicals used in plating processes. This valued technical information proved significant in carrying out the various experiments for the mathematical models.

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NOMENCLATURE

A_M^D	Power into bath (W)
AG	Agitation
AI	Artificial Intelligence
BM	Back-mix
C_{H2SO4}^A	Concentration of acid (g/ l)
C_{Fe}^A	Concentration of iron (g/ l)
C_{H2SO4}^0	Initial acid concentration (g/ l)
C_{H2SO4}^r	Acid reacted (g)
C_{H2SO4}^{t1}	New acid concentration (g/ l)
C_{H2SO4}^{t2}	Acid concentration after drag-out (g/ l)
C_{Fe}^0	Initial iron concentration in acid (g/ l)
C_{Fe}^r	Iron reacted from metal surface (g)
C_{Fe}^{t1}	New iron concentration (g)
C_{Oil}^{D0}	Initial degreaser concentration (g/ l)
C_{Oil}^{Dr}	Degreaser reacted (g/ l)
C_{Oil}^{Dt1}	New degreaser concentration (g/ l)
C_{Oil}^{Dt2}	Degreaser concentration after drag-out (g/ l)
C_{Cl}^{D0}	Initial oil concentration in degreaser (g/ l)
C_C^{Dr}	Oil added to solution from metal surface (g)
C_C^{D1}	New oil concentration in degreaser (g/ l)
C_{Zn}^E	Zinc concentration (mol/l)
C_{OH}^E	Caustic concentration in electroplating tank (mol/l)
C_{Bright}^E	Brightener concentration (mol/l)
$C_{Na_2CO_3}^E$	Sodium carbonate concentration (mol/l)

C_{Oil}^{D}	Concentration of degreaser (g/ l)
C_{Zn}	Zinc concentration in plating tank (g/ l)
C_{Zn}^{R1}	Concentration of zinc in rinse 1 (g/ l)
C_i	Concentration of component i (g/ l)
C	Cost for wastewater treatment and due to production loss
CC	Chemical consumption
CP	Cleaner Production
D_f	Dilution factor
D_o	Drag-out (l/m^2)
DANIDA	Danish International Development Agency
DT	Dripping
F	Current (Faradays)
FC	Flow-control
HG	Hanging
H_y	Hours per year
IN^A	Inhibitor concentration (g/ l)
IN	Inlet/outlet
NASA	North Atlantic Space Agency
O_C^D	Concentration of oil in solution (g/ l)
O_R	Oil removal (g)
OHS	Occupational Health and Safety
P	Production rate
P_R	PARCOM rating
P_{WC}	Present water consumption
R_a	Anode efficiency
R_c	Cathode efficiency
Rin_{sys}	Rinse system
R^{R1}	Recovery of rinse water (l)
S_{RS}^{n1}	Intermediate calculation

S_{RS}^{F}	State of the final rinsing system
S_a	Surface area (m^2)
SME	Small to medium enterprises
t^A	Time in acid bath (s)
t^D	Time in degreaser bath (s)
T^D	Degreaser temperature (^OC)
T^A	Temperature of bath (^OC)
T^E	Temperature of Zinc tank (^OC)
T_n	Tank Number
T_{Vol}	Tank volume (l)
UNEP	United Nations Environmental Program
V_p	Volume of plating tank (l)
W_c	Water consumption
W_{int}	Input water type
W_{SR}	Water savings rating
WWTP	Waste water treatment plant
WWTP Chem	Waste water treatment plant chemicals

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CHAPTER ONE

INTRODUCTION

In this chapter, background information to the metal finishing industry and cleaner production is detailed (Section 1.1). In section 1.2 and 1.3 current methodologies employed in conducting cleaner production evaluations is discussed with a focus on the application of cleaner production evaluation tools in South Africa. Section 1.4 highlights the need for an alternate tool for cleaner production evaluation for the metal finishing industry. Section 1.5 details the objectives and approach of this study. The approach is discussed with reference to the different chapters in this thesis.

1.1. Introduction

The services provided by the metal finishing industry range from basic metal plating to more advanced non metallic plating and pulse plating. The metal finishing industry supplies a variety of products for various industrial/domestic sectors including the motor, clothing, building, aviation, electronic and military. Metal finishing processes entails preserving the usable lifespan of a metal component by the application of a surface coating. These coatings include nickel, chrome, cadmium, zinc etc. The process of metal deposition entails the use of various raw materials including toxic chemicals, heavy metals and large amounts of water. The process results in the generation of large amounts of toxic waste products, which has proven to be difficult to dispose off safely.

The generation of toxic waste that is potentially harmful to humans is typical of most industrial processes, including the metal finishing industry. The metal finishing industry, however is regarded as one of the most polluting industries worldwide.[1-3] Metal finishing processes continuously generates huge amounts of hazardous or toxic waste which range from volatile organics, acid/alkali fumes, wastewater containing metal/cyanide, sludge with high metal contents, oil/grease, paint residue etc. Most important to the profitability of the company is the fact that waste generated implies profit losses. This is mainly due to poor plant operations, which result in the wastage of raw materials. This waste material has to then be treated at the wastewater treatment plant, resulting in further costs. It can be stated that the most effective means of dealing with waste is by curbing the production of waste.

1.1.1. Introduction to metal finishing

The metal finishing process entails the preparation or cleaning of the metal surface followed by the deposition process. The cleaning process is conducted in two phases. The first is the oil removal by degreasing, followed by the acid cleaning process and electro-deposition. The degreaser is usually caustic based and is disposed off, once the oil content makes the solution ineffective. The acid is either sulfuric or hydrochloric acid which is disposed off once the metal content renders it ineffective. The plating tank consists of a metal in solution. The plating tank chemicals are designed to last for extended periods provided the process is managed effectively i.e. no contamination occurs. The component to be plated is rinsed with water between each of the above processes. The wastewater is sent to a central waste treatment facility where pH adjustment, cyanide and chrome treatment is conducted.

The main source of waste from the metal finishing industry is drag-out (the liquid trapped on the surface of a component as it emerges from a tank) and disposal of spent process baths. In order to comply with effluent discharge regulations, the metal finishing industries response was initially the development of end-of-pipe technologies, which generated toxic sludge requiring careful disposal.[4] This process encouraged the construction of large treatment plants with high running costs. End of pipe treatments also encourage inline losses. The ideal would be to reduce this waste generated at source.

The alternate was to dilute the waste to such a degree that discharge limits to municipal sewers were met. This solution has demanded the use of excessive amounts of water resulting in further costs and wastage of water. A cost effective solution to the waste problem needed to be sourced.

International trends are to minimize the production of waste at source so as to reduce the environmental risk. The philosophy of what cannot be measured cannot be optimized leads to the quantification of raw material usage by some kind of evaluation system.

According to the United Nations Environment Program, Cleaner Production (CP) is defined as "the continuous application of an integrated preventive environmental strategy to processes, products and services, so as to reduce the risks to humans and the environment".[7]

Internationally, the application of cleaner production systems in metal finishing has resulted in significant reductions on the demand for natural resources. These resources include water, energy and raw materials. Cleaner production applications have also resulted in significant reductions in the release of toxic waste into the environment.

1.2. Cleaner production in South Africa

Janisch[5] conducted a survey of the South African metal finishing industry in 2000. The results regarding metal finishing process types indicated that the processes in South Africa are similar to those in other countries.[5] electro-platers makes up the largest group (40%) in terms of total number of firms. Other significant sectors are anodising and galvanizing, though they are much smaller in number (<10%). Zinc, nickel, copper and hard-chrome metal finishing appear to be the most common types at 25, 21, 16 and 13% respectively.[5]

In South Africa, and in the other countries investigated by Janisch, over 90% of the metal finishing shops are SMEs, and the majority has less than 50 employees. Of these, 20% have <10 employees and 60% have <50 employees. Results indicated that there were a greater number of independent metal finishers than in-house metal finishers; however, the difference is not large. From this study it was concluded that metal finishers impact significantly on the economy as well as on the environment. It was also concluded that due to the size of the metal finishing companies financial constraints were a priority in implementation of waste reduction systems[5]. The study also reflected the limited resources available to conduct tasks not directly linked to production.

The metal finishing community in Durban, South Africa has benefited from two significant efforts to reduce the impact of metal finishing waste on the environment. The first mission was conducted by Barclay[6], from 1998 to 2001, the second by DANIDA[1] from 2000 to 2003.

Barclay recorded a total cost saving of over two million Rand. Water savings were more than a quarter of a million Rand and process chemical savings were in excess of one million Rand. Senior students conducted this project. They were employed to conduct cleaner production assessments over a period of six weeks at participating companies.

The second effort by DANIDA resulted in similar reductions on raw material demands. The overall impact was measured by noting an 86% reduction of metal load to the Umbilo municipal treatment facility.[1] This facility receives waste from a large percentage of electroplaters in the greater Durban area.

These cleaner production initiatives required audits to be carried out at the companies under consideration. The focus of the audits was to quantify operations by measuring chemical and water usages. The auditing methodology was considered to be the key to CP implementation.

1.3. Cleaner production auditing

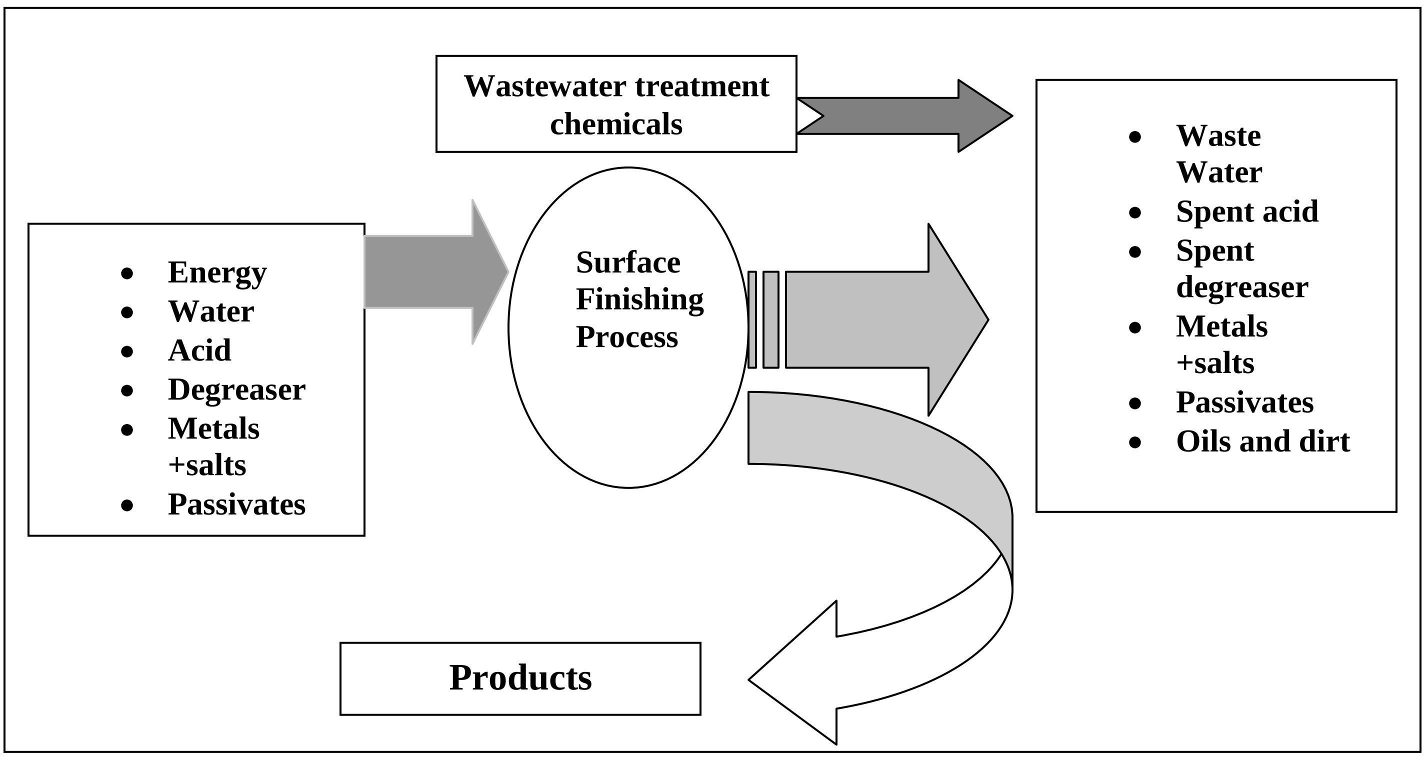
A critical step towards CP is environmental impact assessment, which requires an evaluation of process operation and management in a systematic way so that specific needs for improving operational efficiency and waste reduction can be indentified.[9,7] Industrial practice has shown that the metal finishing industry has been the subject of many types of environmental auditing, ranging from a simple half-hour questionnaire survey to a sophisticated month-long detailed study.[10-11]

Local municipalities usually require a simple audit for monitoring general compliance for environmental permits in plating companies, while a detailed CP audit may need much more detailed information on chemical, water, energy consumption, along with operational statistics. The detailed studies are performed to compare the company's operations to some best-known practice.

A detailed environmental evaluation always requires the company under consideration to make available the required data. This data must be accurate and in an acceptable format. Due to various limitations, this data is usually difficult for most small or medium-sized plating companies to provide. With limited data, only highly skillful auditors may be able to extract valuable information about plant environmental performance and conduct an adequate evaluation.

Figure 1.1 depicts a typical metal finishing process, where major process operations (cleaning, rinsing, and plating), process inputs (metal parts, water, chemicals, and electricity) and outputs (plated parts and waste) are detailed. In a stepwise operation, the parts in barrel or on rack are cleaned in alkaline and acidic solutions before plating. After each step of cleaning or plating, parts are rinsed in a rinse system that may contain one or more rinse units. In the plating unit, metal coating is developed on the surface of parts. The plated parts undergo post processing before leaving the line.

Figure 1.1: Illustration of the general plant inputs and outputs



In order to determine the efficiencies of chemical, water, and energy use, or to identify the bottlenecks for waste minimization in production, all operational units and determining factors should be carefully evaluated.

Two main considerations usually drive the application of any improvements at any company; these are profitability and environmental impact. The prioritizing of these two drivers depends on the culture of the company concerned.

For the development of cleaner production options it would be ideal to incorporate the financial and environmental benefits to the company. It would thus be ideal if the cleaner production evaluation system would quantify the potential savings and reduced environmental impact. The Danish CP evaluation system was successful in conducting such CP evaluations in the metal finishing industry.

1.3.1. Application of the Danish tool in South Africa

The Danish tool for CP in the metal finishing industry was applied to various metal finishing companies in South Africa. Due to the comprehensive approach the application of the CP tool enjoyed significant success.

The application of the Danish CP evaluation process was in three stages. The CP evaluation process, for each stage, required data gathering at the plant and analysis and reporting offsite. The three stages are described in Table1.1.

Table 1.1: Danish system of CP evaluation for metal finishers

Stage	**Time requirements (Data gathering)**	**Time requirements (Reporting)**	**Description**
1: Walkthrough	1 Day	1 Day	A walkthrough details a basic qualitative overview of the plant. The walkthrough report highlights areas of potential improvements as seen by an expert in cleaner production.
2: Review	3-5 Days	2-6 Days	The review entailed a detailed quantitative analysis of the operations at a company. Detailed consumption and operations is quantified and entered into a spreadsheet. The report highlights over consumptions and non ideal operational practices.
3: Feasibility	3-5 Days	2-6 Days	The feasibility study aimed at providing the company

			with details on process modifications for near zero waste(CP). The feasibility details a new plant layout and operations plan that determines chemical and utility consumption for an equivalent ideal process. The potential savings/environmental impacts as compared to current operations are detailed.

The findings of each stage were presented to companies in the form of reports. Companies were then required to make a decision on plant modifications based on the feasibility report.

1.4. Cleaner production limitations

The success of CP implementation depends on various factors such as data availability, skills, etc. From the final report by Barclay[6] and Koefoed,[1] it was stated that success for both these cleaner production initiative was limited by the availability of data.[6,1] Thus the application of cleaner production could have enjoyed greater success had the barrier of rigid data requirements been overcome.

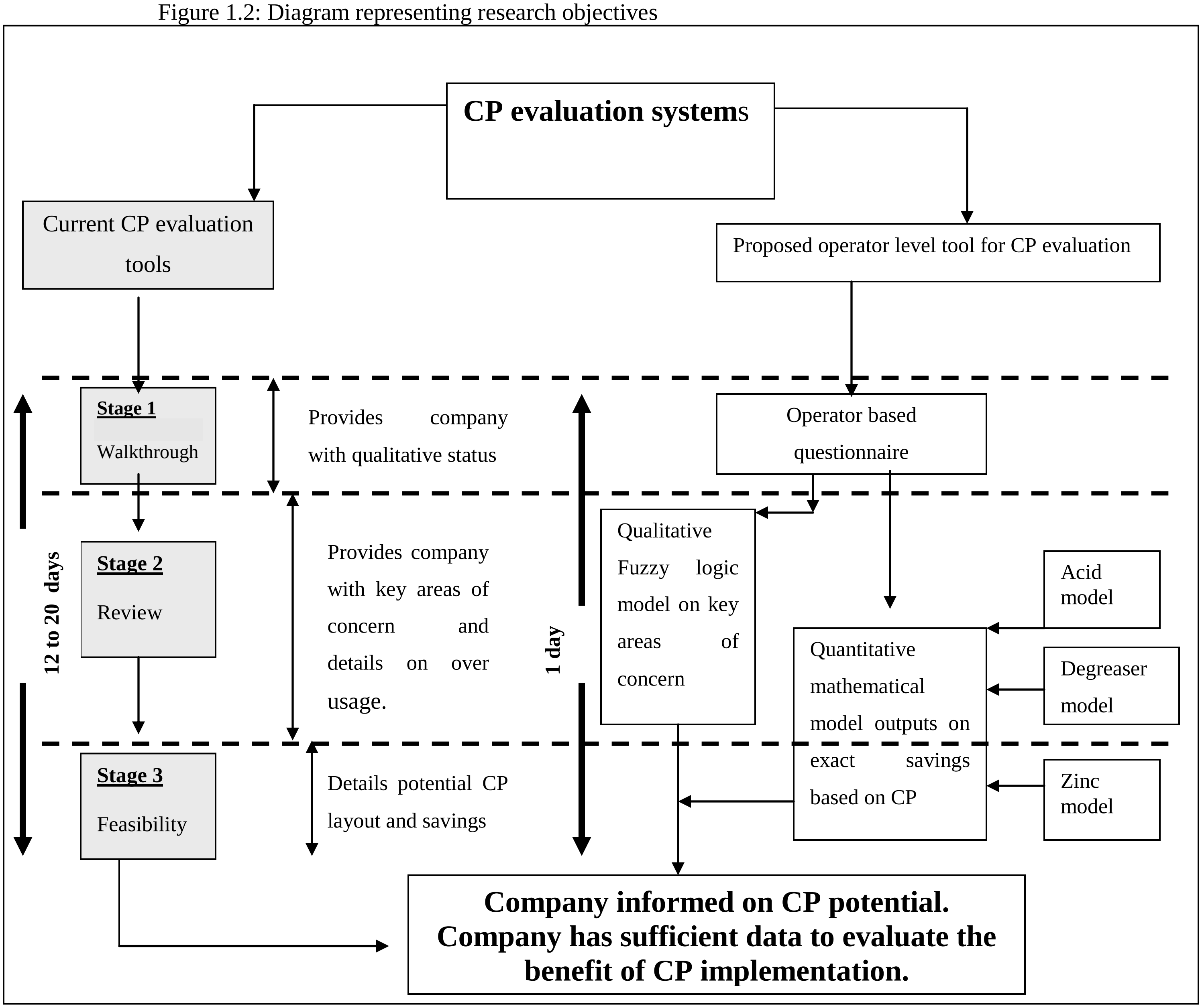
The evaluation of environmental cleanness of a metal finishing facility, as compared to the best available practice, has been a challenge, particularly in small or mid-sized plants. This is mainly due to the fact that, at these facilities, precise and comprehensive plant data is always difficult to obtain. In order to overcome the above constraints a new cleaner production evaluation system must be designed to meet the needs of the diverse plating industry. A key requirement for application of cleaner production evaluation systems is reductions in rigid data requirements. The CP evaluation system should still be specific enough to outline potential savings and environmental impact. These need to be strongly justified so as to persuade the company to change to environmentally friendly options.

To alleviate the data-scarce and lack-of-skill related problems in environmental performance evaluation for cleaner production, a system that requires minimum data for decision analysis would be ideal. The approach should be general and thus suitable for any type of environmental cleanness problems in the metal finishing industry. Applications of effective pollution prevention strategies in plants have been considered urgent and continuous effort is required for effective cleaner production.[7,8]

1.5. Study objectives and approach

The aim of this study was to develop a modified tool for CP assessment for the metal finishing industry. The main focus of this tool would be to potentially replace current CP evaluations systems that have been found to be effective but limited. These limitations include; the need for rigid data, time and high skills levels. The proposed system has to provide outputs that can be described as equivalent as or better than current CP evaluation systems.

Figure 1.2: Diagram representing research objectives



The aim of the research proposed in this thesis, as illustrated in Figure 1.2, is to replace the current three-stage process, walkthrough-review-feasibility, with an alternate CP tool. The alternate tool would require significantly less data but allow the company, under consideration, to have the same level of information for CP decision-making.

This study can be divided into two main categories. Firstly there is the fuzzy logic component, which develops a fuzzy logic strategy for plant evaluation. The second component of this study can be described as the formulation component. This consists of models that were developed specifically for predictions of savings and optimization of individual process.

This thesis commences, in Chapter 1, with an introduction to metal finishing and cleaner production. Chapter 1 also outlines the problem associated with cleaner production evaluation in metal finishing.

The literature search in Chapter 2 includes; a detailed status of the metal finishing industry, the need for CP in metal finishing and highlights the challenges of conducting CP evaluations in the metal finishing sector. This literature search also details fuzzy logic and fuzzy logic application. Chapter 2 is by no means comprehensive enough to cover the individual model literature reviews. The literature review is thus extended to each chapter, as appropriate literature reviews are required for each of the technical aspects being addressed in that chapter.

Chapter 3 details the background work conducted for the development of this study. This includes an analysis of the CP tool used, together with the development of a database of companies audited, using existing auditing techniques. The sensitivity of the chosen model to non-rigid data is also evaluated in Chapter 3.

Chapter 4 covers the formulation and application of the fuzzy logic evaluation model. The model is based on fuzzy multi decision analysis. The outputs from the model are compared to outputs from the database of companies. The chapter also details the process of ensuring equivalent results between previous and the proposed CP tools.

Chapters 5,6,7 details the formulations of models for the acid, degreaser and zinc processes. These models were developed from pilot scale trials. The models details multivariable predictions on process operations. Each chapter details Mat Lab simulation of models specific to that chapter.

Chapter 5 details the development of a mathematical model for quantification of acid consumption at a metal finishing facility. The application of the acid model is key to the quantitative component of this study. The surface area generated in this chapter is used in Chapter 6 and 7. Chapter 5 details the application of factorial experimental design for model development.

Chapter 6 and 7 details the degreaser and zinc plating models. These models are used for the quantification of chemical and water consumptions in their respective areas of the plant. The details of the application of factorial experimentation for these model developments are detailed.

Chapter 8 describes a case study on the application of the proposed CP tool as compared to previous CP evaluation tools. The limitations and advantages of the proposed system are illustrated together with tables of comparative inputs and outputs.

The thesis conclusion, discussion and future work is detailed in Chapter 9.

A detailed list of publications, the relevant appendices and a compact disk is attached at the end of this thesis. Model simulation can be described as a pillar to the development of this study. The relevant simulations are found on the attached compact disc as referenced in the difference chapters.

In order to develop an effective model, expert practical knowledge had to be gained. This was achieved by evaluating twenty-five metal finishing companies, see attached compact disc. This database of information is also summarized and appended in a database format.

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CHAPTER TWO

LITERATURE REVIEW FOR CLEANER PRODUCTION AND FUZZY APPLICATIONS

The aim of this chapter is to review literature on current developments in the different areas under consideration in this study. These include work on cleaner production, metal finishing and artificial intelligence. Important components of the literature include the need for CP in metal finishing; section 2.4.1 and the use of tools as quick indicators, section 2.6. The literature review culminates with examples of the application of artificial intelligence for other industrial application, section 2.9.1.

2.1. Introduction

This thesis aims at introducing a hybrid tool for CP evaluation of metal finishing processes. The tool comprises of an artificial intelligence and a mathematic model for cleaner production evaluation. This thesis proposes development of these models so as to present a CP tool that would be effective, efficient and accurate in conducting cleaner production audits. With this consideration in mind, the literature reviewed in this chapter can be described as diverse.

It must be noted that the literature search for this thesis extends beyond this chapter. This chapter focuses mainly on literature on different CP evaluation systems, available internationally, to conduct cleaner production audits at metal finishing facilities. The literature in this chapter also contains details on metal finishing, cleaner production in metal finishing, cleaner production tools, CP audits and fuzzy logic. Further literature, relevant to each chapter, is found at the beginning of each chapter.

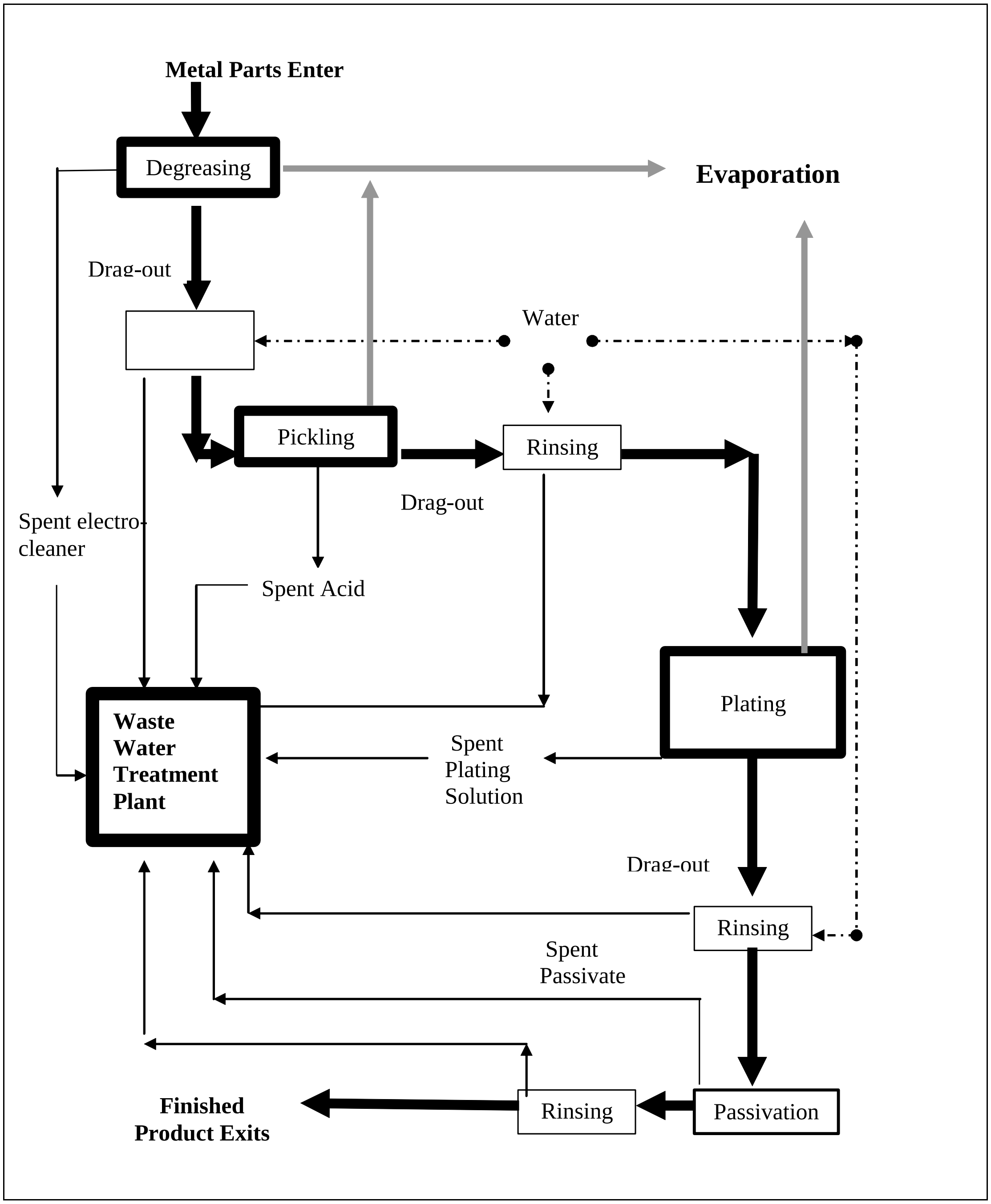
2.2. Introduction- metal finishing

The metal component to be plated has undergone various processes to convert it into a high value product. This entails the use of any combination of the following processes; cutting, molding, machining, etc. These processes are employed to convert the metal into a usable component. A protective coating would then extend the component's usable life, ensuring a cost effective product with an extended life. Metal finishing is the process of adding on this protective coating.

The metal finishing process can be separated into two phases. The first phase entails the preparation or cleaning of the metal surface. This is followed by the deposition of a protective coating. The cleaning process starts with removal of oil by degreasing, followed by the acid cleaning. The degreaser is usually caustic based with a caustic strength of 60-120 g/ l. The degreaser is disposed off once the oil content makes the solution ineffective. The acid is either sulphuric or hydrochloric acid operating at between 60-120 g/ l. The acid is disposed off once the metal content renders it ineffective. The plating process is usually the electro deposition of a metal onto the component. The plating tank comprises of various chemicals that aid in the plating process. The plating tank chemicals are designed to last for extended periods of time, with some purification process. See Figure 2.1 for a typical flow sheet of a plating process.

After each process step above, the process chemicals are washed off the components by rinsing. This is achieved by dipping the components in a water rinse tank after each of the process chemical tank. The rinse tanks are either static or running rinses, depending on the process requirements. The flow of components to be plated is as indicated in Figure 2.1.

Figure 2.1: A typical operations flow for a plating process.



2.3. Cleaner production

The chemical industry has traditionally been responsible for meeting market demands for various products. These demands have been continually growing and hence production processes are turning out an ever-increasing volume of products.[1,2,3] The environmental impact is usually significant [4,5,6,7] and monetary costs, for the purpose of cleaning up of industrial waste, are high.

In some instances cleaning up is not possible and the resultant environmental impact is an ugly permanent feature.[8,9,10,11] The hazards of these chemicals cannot be underestimated. It would thus make sense to reduce the amount of waste generated during production.

The concept of cleaner production is gaining recognition world wide as a means to reduce waste whilst improving cost effectiveness. The United Nations Environment Program[12] defines cleaner production as "the continuous application of an integrated preventive environmental strategy to processes, products and services, so as to reduce the risks to humans and the environment".

The concept of cleaner production aims at addressing the needs of production whilst reducing the demand on resources. This is achieved by process improvements, which results in improved production efficiencies. The key focus of cleaner production is improved basic operations; this translates into low cost improvements such as improved housekeeping. These improvements usually imply small/negligible pay back periods. Various studies have indicated that up to 50% of potential cleaner production savings are achieved by improved housekeeping.[13,14,15] The areas of concern for the application of cleaner production are[14,16,13]:

- Housekeeping: Improved organization implies reduced wastage and lower potential risks.
- Recycling/reuse: All raw materials (water, chemical, energy) must be optimiumly used.
- Process optimization: Improved process operating efficiencies
- Product quality: Improved processes result in a better quality product with lower rejects.
- Chemical substitution: Replacement of toxic chemicals with lower risk chemicals

These can be described as the general areas that are addressed within a production facility.

2.4. A review of cleaner production applications

The Journal of Cleaner Production published various case studies on successful application of cleaner production initiatives. Among these was a paper on the Cleaner production in the food[17] and drink industry. In these projects a total of £1.1m was realized in annual savings. This was spread over 13 companies in the East Anglican Cleaner production project. Direct savings of £1.1 million exceeded the project investment of £412,000 plus the £335,000 invested by companies in cleaner technologies. The 13 food and drink companies reduced annual raw materials and solid waste by 1400 tons. The study also resulted in reductions of CO_2-emissions by 670 tons together with a reduction in water use by 70,000 m^3. The average payback period was 2.3 months.

Cagno[18] conducted a comprehensive study on the impact of cleaner production across a broad range of industries. Table 2.1 shows the significant impact of cleaner production across a broad range of industries from petrochemical to surface finishing.

Table 2.1. Total savings in operating costs generated by P2 projects (k€/year; 118 cases; exchange rate: 0.92 €/US$)[18]

Sector	Reduction at source		Recycling		Treatments		Total	%
	Total	Average	Total	Average	Total	Average		
Chemical processing, manufacturing	3007	251	40015	6669			43022	47
Metal finishing, fabrication	17 949	945	337	48	68	23	18 354	20
Electronics	6772	564					6772	7
Health care products	6119	3060	39	39			6158	7
Oil/petroleum	2591	1296	795	795			3386	4
Forest products	1423	712	1035				2458	3
Automanufacture	1465	293	453	227			1918	2
Food and kindred products	985	246	368	123			1353	1
Electrical utilities	1253	1253					1253	1
Printing	449	112	510	128			959	1
Electronic and other electric equipments	524	87	164	164			688	1
Textile mill products	261	261					261	0
Jewelery, silverware and other			21	21			21	0
Pharmaceuticals	48	48					48	0
Other	3116	260	1053	263			4169	5
Total and average	45 962	722	44 790	848	68	23	90 820	100

The survey was a result of cleaner production initiatives over a period of 11 years and some 134 companies. From Table 2.1, it can be seen that the metal finishing sector benefited significantly from this investigation. It indicates the potential direct saving as a result of cleaner production.

The mining industry has also successfully implemented cleaner production, Hilson[19] conducted a detailed investigation on cleaner production and its impact in Canadian and United States mines. This showed significant impacts of cleaner production initiatives. These studies showed significant reductions in air emissions in Canada e.g. in a group sampled, for a two year period between 1996 to 1997, a 17 % reduction in air emission was noted. In other cases between 1993 and 1997, heavy metal release was reduced from 4753 to 2585 tons / year.

The paper industry has also achieved major success in cleaner production application. Ghaleb[20] is a detailed paper on savings achieved in the paper industry. The estimated expenditure was $210 000 and the potential savings in raw materials $450 000/pa.

2.5. The need for cleaner production in metal finishing

The surface finishing industry consumes a range of chemicals that are considered harsh to the environment. These chemicals don’t always end up on the surface of the product. This implies that there is wastage of these toxic chemicals into the environment[21,22]. The waste from a metal finishing facility contains acids, alkalis, cyanide[23], hexavalent chrome, nickel and a range of other metals and toxic chemicals. In some instances these chemicals are treated and disposed of via wastewater treatment facilities to municipalities[24] or they are removed to landfill sites. With either option these chemicals are wasted and end up in our natural environment. This could be prevented if the chemicals were optimally used. The generation of waste chemicals implies further treatment with the use of treatment chemicals. This results in a double cost to the company.

Poor process operations contribute to the wastage of chemicals. This results in the generation of waste, contributing to waste release into the environment. Water usage increases with poor process operations such as short drag-out times.

The net result of operating a plant without the application of cleaner production[13,12] is the loss of toxic chemicals, higher financial implications, a higher risk environment for staff, reduced product quality and avoidable environmental releases. The application of cleaner production principles to metal finishing processes can reduce or eliminate these factors.

2.5.1. Application of cleaner production in metal finishing

The application of cleaner production systems to the surface finishing industry can be elaborated upon under the general cleaner production areas listed above (Section 2.3).

2.5.2. Improved housekeeping

Good housekeeping implies the practice of minimizing raw material losses and thus preventing unnecessary waste generation. Good housekeeping also implies improved operating environments and reduced accident potential.

For the metal finishing industry good housekeeping includes[12]:

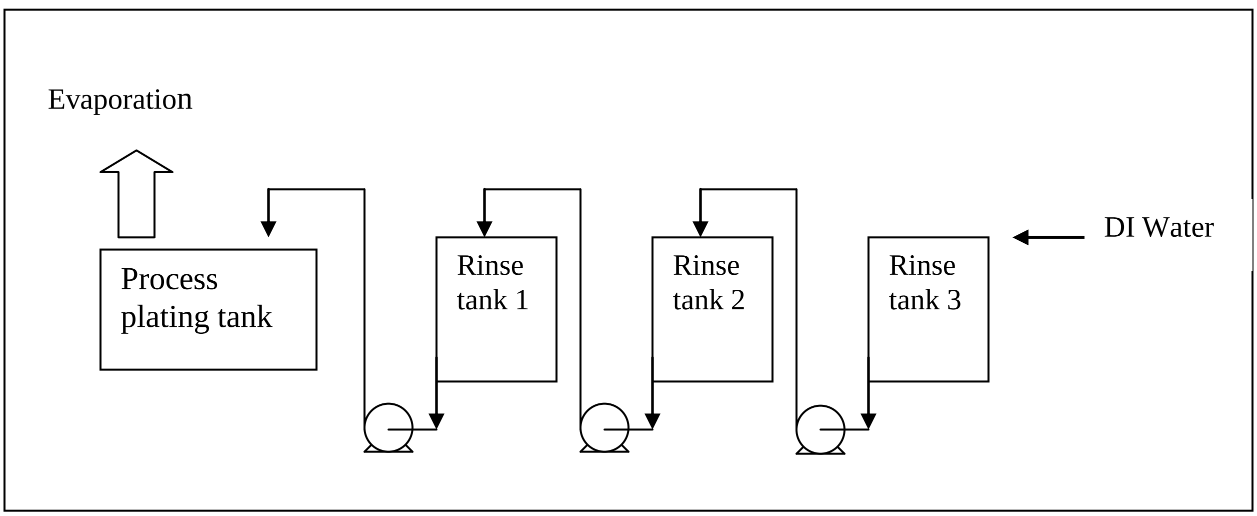
- Segregation waste – Mixing of waste results in excess waste treatment chemical usage
- Monitoring of usage of dosing chemicals- This would ensure optimum dosing
- Production based on surface area measurement- Plant production needs to be determined by surface area as compared to mass of components.
- Lengthen drip times- Reduces the losses of process chemicals by allowing for longer drip-off times above the tanks.
- Position pieces so as to optimize dripping- Optimum liquid run off can be facilitated by ensuring components are hung properly.
- Ensure adequate training of staff- This ensures awareness on all operations and need for operating efficiently.
- Optimum temperature regulation- Prevent excessive vaporization of chemicals and ensure optimum chemical efficiency.

2.5.3. Chemical/water reuse/recycle/recovery

Wastewater that is used in the process is usually treated before being released into municipal waste collection systems. The reuse of chemicals and water include the following considerations[25,26]:

- Usage of low flow counter-current rinses throughout the plant. This implies that the process liquid that has been dragged out can be recovered through the rinse system, see Figure 2.2.
- The acid/ degreaser can be stored and used as dosage chemicals for the wastewater treatment facility.
- The rinse water from the acid system can be re-used as a reactive rinse in the degreaser section

Figure 2.2: Illustration of low flow counter current rinse



The quality of the treated wastewater may be sufficient for reuse in areas of the plant.

2.5.4. Process optimization

Process optimization implies changes to the process to ensure the efficient operations of the various units. Typical process optimizations include[12,25,26]:

- Optimum bath chemistry ensures anode and cathode efficiency are maintained as per supplier specifications.
- Optimum mixing and dilution of rinse water by agitation, inlet/outlet location and prevention of back mixing. This ensures the components are effectively cleaned in the rinse tanks.
- Maintaining optimum chemical concentrations for all processes would ensure product quality and production efficiency.
- Optimum measurement and dosing of wastewater ensure optimum chemical usage and reduces the risk of fines due to irregular releases.
- Regulation of water flow into process ensures minimum water usage
- Optimum process tank temperatures ensure efficient cleaning/plating whilst maintaining sufficient evaporation for closed circuit operations.

2.5.5. Optimum use of resources

The raw materials, such as water and chemicals, must only be used as required in the process[27,28]. Excess chemicals must be recovered for reuse. Chemicals designed for process usage must not be lost to wastewater.

2.5.6. Improved product quality.

The plant product quality is a result of optimum operations. Optimum operations ensure improved product quality. Typical quality issues are[27,28]:

- Optimum cleaning ensures proper adhesion of coating.
- Measurement of plated thickness, on a regular basis, ensures quality of finished product and reduces the wastage of raw expensive materials.
- Optimum temperatures and chemical dosages reduce the risk of exposure of operators to chemicals.
- Improved staff training results in motivated, effective and efficient workforce.

2.5.7. Chemical substitution

Toxic and hazardous chemicals must be replaced with environmentally friendly chemicals.[29] These include the replacement of cadmium, cyanide and hexavalent chrome.

2.5.8. Cleaner production application-metal finishing

The above detail areas of cleaner production applications, in metal finishing, can be described simply as a methodology of maintaining or improving current production. This is achieved whilst reducing environmental impact by optimum use of raw materials. These concepts have been successfully applied throughout the world to various metal finishing processes. The successful application of these CP principals to metal finishing companies is however limited by the ability to convince companies to apply these CP principles.

2.6. Use of tools as quick indicators

The application of cleaner production can follow various methodologies. Consultants choose to use past experience to conduct cleaner production audits and feasibility studies. Cleaner production centers follow various guidelines as per documented practice, usually in the form of checklists.[30]

The audit by Berkel[31] in the food industry used a three-phase approach. The author used industry specific questionnaires with comparative process parameters as an initial indication of potential cleaner production application. A cleaner production consultant scanned the results of this and the most feasible options were followed up on. This was followed by a pre-assessment and full assessment using various tools. These involved material and energy flow analysis etc. The author confirms that the time taken for the completion of the assessment phase was almost one year as company information was difficult to obtain and not in a usable format. The author recommends a formal methodology, as time taken for company audits were very long.

The New South Whales Environmental Protection[32] Agency has formulated a general cleaner production procedure that is 68 pages long and comprises of details on how to conduct a cleaner production audit. This document is mostly in the form of questions and data logging sheets. The company is guided along a qualitative audit without quantitative outputs.

The guideline is said to aim at SMME's. It is limited by time requirements and detailed data inputs. The potential savings etc are not quantified.

Kolominskas[33] uses a "register reporting process" to conduct cleaner production audits at companies. This was basically an inventory report of releases from a facility. Thresholds are marked and comparisons conducted. This process is highly technical and time consuming as huge amounts of data is required.

There are various other audits and system methods that have been documented. For example: Russel:[34]Using process integration technology for cleaner production and Rene:[35] Application of an industrial ecology toolbox for the introduction of industrial ecology in enterprises. The number of cleaner production systems are varied and too many to list in this study.

2.7. Existing auditing systems-surface finishing

The surface finishing industry, like most chemical industries has been subject to various initiatives for process improvements. The main aim is to reduce the chemical impact on the environment.

The metal finishing industry has been a subject of many types of environmental auditing systems, ranging from a simple half-hour questionnaire survey[36] to detailed studies of +/- a month long.[37,38,32] It has been noted that local municipalities often require a simple audit for monitoring[36] general compliance for environmental permits for plating companies, while cleaner production audits require much more detailed[37,38,39] information on chemical, water, energy consumption, along with operational statistics. These detailed studies are normally performed to compare the company operations to some known best practice, so that improvements can be detailed.

The key drivers for cleaner production vary depending on the location and local bylaws. In the developed countries, North America and Europe, the acceptance of waste avoidance and minimization as a business consideration is principally due to the very strict discharge limits and environmental regulations.[39] In other countries incentive systems are introduced as drivers for companies to conduct cleaner production audits.[25,26] The most practical drivers have been the cost benefit in the form of reduced chemical, water and effluent treatment cost.[40,41]

The study by the Queensland Department of Environment involved some thirty companies with regular sharing of information[26]. The sharing of information assisted the companies to improve. An assessment guide consisting of some 12 tables requiring detailed qualitative inputs from companies carried out the audits. There was no formal comparisons or evaluation system in place. No outputs or potential saving comparators were used. This study does not confirm success or measurements of savings achieved.

The government of western Australia[40] has embarked on various cleaner production projects including the metal finishing industry. Detailed studies of electroplating facilities implied evaluations of consumption of water and chemical consumption. The final output from the audits is a qualitative document on areas of improvement. This document does not calculate the specifics for plating efficiencies or water savings.

Viguri [41] conducted a waste minimization audit on chrome platers in Spain by using basic chemical auditing such as material and energy balances. This involved basic investigations and resulted in suggested improvements. Viguri noted the difficulty in obtaining detailed data required to conduct the study. Viguri also recommends further detailed quantification of the water and chemical flows in order to complete a more comprehensive study.

China International Training Center for Sustainable Development conducted cleaner production audits[42] with UNEP support. The system entailed identifying and targeting 21 areas for improvement at a metal plating facility. The success of the project was significant. The time and level of technical expertise required was also significant in that the consulting cost was 60% of the budget. The results covered selected sections of the plant.

Barclay,[27] conducted waste minimization studies at 29 metal finishing companies in Durban, South Africa. Senior chemical engineering students carried out these audits over a period of six weeks. The project resulted in savings in excess of R 2 million in water, chemicals and energy. Among the key barriers identified by Barclay and her team, was the lack of available data by companies and the lack of available time by senior plant personnel.

Cushnee[28] performed perhaps the most comprehensive study of surface finishers. This study on behalf of the National Metal finishing Resource Center (NMFCE) with US EPA funding, surveyed 134 metal finishing companies and attempted to establish some benchmarking. The questionnaire required inputs on water, sludge, chemicals and energy. The first phase of the questionnaire consisting of eight pages and twelve questions with approximately 50 input data requirements. Phase 2 required very detailed inputs such as surface areas and bath chemistries and consisted of some seven pages with more than 200 data requirements.

Detailed castings and mass consumptions were required from the companies. A summary of the typical consumptions was then established and comparative statistics were distributed. No best available practice benchmarking or flexibility on different plating systems were integrated into the system. The companies, after an intensive data chasing exercise had a set of survey ideals to work towards and not optimum individual calculations. The data requirements for the system required management level inputs and data gathering systems. It is estimated that each company required more than two weeks to complete the information sheets. The final outputs were general and not individualistic. The companies received a 145-page document on best available practice, based on the investigation.

Dahl[29] introduced the Scandinavian system of cleaner production auditing in South Africa in the year 2000. Three workshop sessions were held on technical training combined with practical plant assessments. Trainees require 10 working days of training before an initial assessment. A total of 25 initial trainees on the system found that it required data inputs that were detailed.[25]

The system is spreadsheet based with different category inputs. The audit consists of an initial seven-page information sheet to companies requiring detailed chemical and water consumptions. A reasonable chemical engineering background is required to complete the audit. It was found to take up to one month to complete individual company audits[25].

The most significant problem with the Flemming system being the data requirements[25]. The initial audit does not quantify potential chemical and water savings in detail and depends on a further detailed study. The success of the system was limited by intensive data requirements.[25] The companies, in most instances found it almost impossible to complete the data required. The greatest difficulty was the determination of the production by measuring the surface area plated. Most companies charge for work on a mass basis and surface areas are rarely measured. Evaluators spent days with the companies to determine the surface area. It was not usual that two different reviewers found different surface areas.

The Flemming model has been applied to a major part of the metal finishers in Denmark and other DANIDA sponsored projects throughout Europe. From all the tools that were reviewed for this study, Flemming's CP tool was found to be the most effective. The Fleming structure was found to contain the most detail expert knowledge for cleaner production auditing for metal finishing.

2.8. The South African metal finishing industry

The South African metal finishing industry comprises +/- 700 electroplating companies. The products range[43] from zinc, tin, nickel, copper, cadmium, chrome plating etc. According to Naumann[44] the plating industry in South Africa is mainly distributed between three major centers, Durban, Gauteng and Cape Town, with the majority in Gauteng. According to Barclay[27] the industry can be described as having a low skills level with low to medium salary scales.

From the results of a survey conducted on 316 metal finishing companies in South Africa, it was found that 48% were SME's. The most common type of plating was found to be nickel, zinc and copper[45]. According to Newman and Janisch the metal plating industry depends on their chemical suppliers for technical assistance. This is mainly due to the lack of technical skills at the small companies.

The metal finishing industry in the greater Durban Metro area have had to implement significant changes since 1999. This was due to the lowering of the discharge limits by the Durban Metro Wastewater Department[27]. These new bylaws stipulated significant reductions in heavy metal discharge to municipal sewers. This change in regulation affected the local metal finishing industry significantly, various efforts were undertaken to fall in line with the new regulations. The lack of landfill sites implied that sludge had to be disposed of in Johannesburg, approximately 600km away, at the expense of the plating company.

Most companies being SME's found it difficult to comply with these strict bylaws. The metro conditionally relaxed these bylaws provided a waste minimization study was conducted resulting in waste reduction.[27] Thus Barclay established waste minimization clubs as a way forward to facilitate improvements. The results of this study were significant as more than R2 million was saved in chemicals, water, energy and effluent. The study was conducted with 16 local companies over a period of three years.

A Danish initiative by DANIDA was started in 2000, which lead to some 45 companies being audited for cleaner production potential. This project resulted in significant reductions in chemicals and water usage at companies and according to Koefoed[25] significant reductions in heavy metals were recorded at municipal wastewater treatment facilities. From Koefoed the following conclusions were drawn:

- Technology is society based. Environmental assessment tools have to be adjusted to local application.
- Environmental assessments in industry require intensive data, in most industries this data is non existent. There is a need to developing environmental assessment tools with user-friendly data input

These conclusions were not unique to South Africa in that Bates[46] in his paper in the American Electroplating and surface-finishing journal reinforced these conclusions in other regions. Hence it can be stated that alternate methodologies are required for CP evaluations.

2.9. Fuzzy logic

There have been many journalistic phrases attempting to define the concept of artificial intelligence including: The exciting new effort to make computers think[47], the art of creating machines that perform the function that requires intelligence when performed by humans,[48] the study of computations that make it possible to perceive reason and act. In essence artificial intelligence aims at acting and thinking humanly.

The field of Artificial Intelligence (AI) can be classified into two categories, traditional AI and modern AI. Modern AI includes neural networks and fuzzy logic whilst classical AI implied the development of intelligent “agents” for decision-making.

AI has been successfully applied to various tasks[49] including, the scheduling of spacecraft operations by NASA, steering a car along a straight line, medical diagnostics, microsurgery and many other operations considered to be impossible for computers to perform without the ability to think like humans.

The main consideration for looking at AI as a framework to represent expert knowledge is that AI systems have proven effective in tackling complexities such as data uncertainties and dynamic components.[50] Available process data pertaining to waste minimization is usually imprecise, incomplete and uncertain due to a lack of sensors, difficulty in measurements and process variations.[51] Lou[52] found that fuzzy logic was successful in dealing with this sort of data.

A closer look at Flemming’s CP tool indicates that the CP tool is precise in that the outputs depend on mathematical formulations. The inputs however are in the form of scores that may be described as fuzzy.

Fuzzy logic has been successfully applied in many other areas such as washing machines, space crafts etc. The use of fuzzy logic has resulted in the ability to simplify and quantify man’s ability to think[49].

Fuzzy logic was introduced in the sixties by Zadeh[53]. The idea behind fuzzy logic is that an element can belong partially to several subsets, unlike Boolean logic where belonging, or not, to a set are mutually exclusive. The degree of belonging to a set is a value between 0 and 1, usually determined by the extent of an element belonging to a fuzzy subset or a category of a variable. Fuzzy logic has been successfully applied to simplifying of decision making in environments characterized by uncertainty and imprecision.[49] It is based on the idea of building a model capable of simulating the way an expert reasons. The main breakthrough of fuzzy inference with respect to traditional mathematical models lies in the fact that the relationship between inputs and outputs is not determined by complex equations, but by a set of logical rules, reflecting an expert's knowledge. A short review of fuzzy inference will be made in Chapter 3 of this thesis.

2.9.1. Some successful applications of fuzzy logic

Faye[54], an approach to managing water reserve and release, was successful in the application of fuzzy logic to a complex situation resulting in better management of water.

Kolokotsa[55], completed a comparative study of fuzzy logic and classical control system for indoor environmental management systems. The fuzzy system proved superior in energy efficiency and overall effectiveness.

Mohamed,[56] used fuzzy logic for a decision analysis based model for polluted sites. This tool was used to evaluate the risks that polluted sites might pose to human health. In this application the model was able to use uncertain parameters to quantify the risk with a high level of accuracy.

González,[57] applied fuzzy logic technology to Life Cycle Assessments(LCA). Fuzzy logic reduced the cost and time required to complete an LCA. The most important criterion was the data availability. As with the metal finishers and cleaner production systems he found that companies did not have the data required for life cycle assessments. Fuzzy logic was successfully applied for LCA’s. The direct result was the availability of LCA’s to small to medium size enterprises.

2.10. Proposed combination of cleaner production and artificial intelligence

From the above literature it can be seen that cleaner production principals have been very successful, when applied to various industrial sectors. It can also be clearly seen, from the above, that the successful application of cleaner production has been reserved for the technically competent experts. Without these skills it would not have been possible to have achieved these cleaner production improvements.

It can be seen that the systems are both time and data intensive. The systems would have been unsuccessful if the data were not accurate and in the required formats. Thus it would be ideal to deal with these barriers by applying systems such as fuzzy logic to conduct CP assessments of a company’s environmental status so as to achieve cleaner facilities.

With this consideration, the key aim of this thesis is to propose an alternate CP evaluation tool that removes the barriers, stated above, to conducting an effective cleaner production audit. These traditional barriers were; technical skills, availability of detailed chemical, water and operational data, time and lack of expertise.

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CHAPTER THREE

BACKGROUND TO FUZZY MODEL DEVELOPMENT

Chapter three introduces the Flemming CP tool (section 3.2) together with a detailed analysis of its application for CP evaluation. The CP tool was found to be the most appropriate to be used as a basis for the development of the proposed fuzzy logic model. Section 3.3 to 3.5 details the review and feasibility process of Flemming. This includes an analysis of the data inputs and outputs. This is followed by a detailed analysis and sensitivity of the Flemming CP tool in section 3.7 and 3.8.

3.1. Introduction

The literature search in Chapter 2 identified the Flemming[1] CP tool as being the most comprehensive for CP evaluation in metal finishing. It can also be described as containing the ideal outputs which any proposed CP tools should also generate. The shortcomings identified were the rigid data requirements, skills level and time required for data collection and interpretation. The proposed CP tool has to overcome these barriers. This chapter is dedicated to conducting a detailed analysis of Flemming's[1] CP tool with the view of using it as a basis for the proposed fuzzy logic model.

For the development of a cleaner production tool the diversity of the plating types has to be considered while exploiting the commonalities between the processes. The main aim of an audit would be to determine the current plant efficiency as compared to best available practice. In order to achieve this, the plant was divided into categories. This was in line with all the evaluations systems reviewed for the purpose of this study. The chapter describes in detail the Flemming's evaluation system. It also provides a basic description of the different categories of plating and an explanation of the operations of the individual categories.

3.2. Introduction to the use of Flemming's CP tool

The Flemming's CP tool was designed for application in Europe and also rated as among the most stringent and comprehensive as compared to all the other CP tools researched for this study, see literature review. This CP tool had a successful[2] track record with application across Europe, Hong Kong, Zimbabwe, Ukraine and Denmark[2].

The Flemming's CP tool is also available in South Africa as cleaner production projects were conducted in South Africa. Technical support for detailed analysis of the Flemming evaluation system was available.

3.2.1. Implementation of Flemming's CP tool

For the purpose of this study, 25 company reviews were carried out using the Flemming's CP tool. These reviews were carried out throughout South Africa for the purpose of obtaining data for the validation of the CP tool proposed in this study, see C:Companies for database. The application of the Flemming CP tool was also beneficial in gaining experience in CP evaluation. The following discussions, on the implementation of the Flemming CP tool, is thus with this experience in mind. Shortcomings and limitations are discussed for each section.

The first stage in the review process entailed a plant visit/walk through by the reviewer. This visit was intended to be a qualitative indication of potential areas for improvement. The reviewer is to identify areas for improvement based on his experience of cleaner production.

The next stage of the audit was the pre-review document, which was used to gather basic plant operations data. The document was to be circulated to companies prior to the actual review process. The document consists of seven pages with a total of nine tables to be completed. The manager, at the company under review, is expected to complete the document prior to the review process.

The first table, see Table 3.1, requires the production rate of the plant in square meters. This production rate is the surface area of material plated at the facility over the period of the last year. The data for this table is difficult to obtain since electroplating companies do not keep or use this type of data for normal operations. All companies in South Africa charge their clients based on mass or number of items to be plated. This is due to the complex sizes and multitude of shapes encountered. The companies reviewed, did not have the skills level or the time available to complete the task of determining the surface area of components to be plated. The companies plate anything from 10 components to thousands of components per year and find it impractical to determine the surface area.

Table 3.1: Data table for pre review document

Name of the process and the line	
Production in m^2/year (if you cannot give the m^2/yr try to give kg/yr or something else)	
Production time, h/day + h/week + h/year	

For the purpose of the environmental review the auditor together with a manager from the company has to estimate the surface area. This is done from records on the components plated over the year. This estimate is often unreliable as the exact components are not usually on hand and records of the exact number plated are not always available. The process of estimating the surface area plated by the company usually requires a time investment of approximately four hours or longer, depending on the variety of components plated.

Another crucial input for the Flemming CP tool is the plated thickness. The company is required to enter the layer thickness plated. Most companies depended on random samples by the chemical suppliers for surface thickness analysis. This analysis requires trained personnel as well as expensive equipment. The company's plate components based on time in the electroplating tank and it is assumed that the surface plated is sufficient. Companies depend on a final visual inspection to ensure coverage of the plated surface. They are not equipped to complete such tests across the range of components plated. It has to be remembered that the spread for plating thickness is dependent on the shape of the component i.e. unequal on corners as compared to the straight sections.

It is thus clear from the above that the Danish model assumes that this data is available. This is not valid for the South African context. The research outputs from this thesis, see Chapter 8, clearly indicates a more practical approach to obtaining the data. This includes a fuzzy mathematical approach to obtaining the thickness and surface area.

3.2.2. The chemical and water consumption tables

The company is to complete the sections on the actual chemical consumption, Table 3.2. The data sheet requires the annual consumption of the different components of each tank.

Table 3.2: Chemical data table for pre review document

Name of process bath	Name of chemical (always)	Chemical formula (if possible)	Consumption kg/year	Unit price R/kg	Total price R/year

The electroplating companies manage their process based on the information received from their chemical suppliers. Weekly dosing usually occurred based on tank analysis carried out by the chemical supplier. To complete this table the company has to obtain the annual consumption figures from their stores or purchasing departments. Companies with large stock reserves find it difficult to obtain data and physical audits have to be carried out to determine the year to date chemical consumptions. Direct measurements of some chemical consumption are unavailable. For example, anodes are not replaced during the audit period and their consumption has to be proportioned according to consumption within a specified period.

3.2.3. Maintenance of the process baths

The third table, Table 3.3, which requires completion, is the maintenance of all the process baths. Typical data requirements include the tank capacity and the exact chemical breakdown of each process tank. The company enters various codes on the current practice of bath management. It is found that the chemical supplier usually completed this table as the suppliers managed the tank chemistry. The suppliers conduct the analysis of the baths on a weekly basis.

Table 3.3: Maintenance of process baths data table for pre review document

Name of bath	Tank volume litres	Bath analysis and chemistry	Bath purification Procedure	Dumping frequency	Total dumping M^3/year	Treatment method for dumped baths

3.2.4. The rinse tables

The audit requires details of the hardware of the rinse system, Table 3.4; this included the tank configuration and flow patterns, the sources of raw water etc. The Flemming system depends on statistics to determine the operations efficiency. This component of the rinse system is reasonably simple to complete but the challenge is in quantifying the exact amount of water required for each individual process.

The company has to estimate the amount of water flowing to each tank. If this data is not recorded then the "bucket and stop watch method" is employed to determine the individual consumptions. The company usually omits this section of the questionnaire and when the reviewer gets to site this data has to be collected.

Table 3.4: Rinse data table

No.	Name of rinse	Type of rinse	Inlet water Quality	Inlet flow litre/h
Sum for total line (calculated form individual measurements above)				
Sum for total line estimated (from account or total water meter)				
Sum for total line measures by separate water meter				

3.2.5. Hazardous waste and waste water treatment

The company has to provide data on the amount and composition of hazardous waste generated, Table 3.5. This includes the steps for the treatment process and the costing associated with the waste treatment and disposal.

The equipment and calibration of equipment used for testing wastewater at the wastewater treatment facility has to be identified, Table 3.6. The exact chemical composition of the waste is required for the audit. The chemical formulation of the treatment chemicals is also required.

This entire questionnaire is to be completed by the company as a pre-audit questionnaire. It was found that the response time from companies ranged from one week to three weeks to complete the data sheet for the pre-audit. This depended on the availability of information and on the organization of the data in the available format.

Table 3.5: Hazardous waste tables

Name and type of waste	ton/year	Disposal and treatment methods (must always be specified)	Unit price for disposal R/ton	Total price for disposal R/year

Table 3.6: Waste water treatment plant equipment table

	Exist: yes/no	Control parameter	Probe cleaning frequency	Probe calibration frequency	Additional check used	Yes or no
Neutralisation		pH			Transportable pH-meter	
Cyanide		pH			Transportable pH-meter	

oxidation		mV			Monitor excess chlorine	
Cr-6 reduction		pH			Transportable pH-meter	
		mV			Monitor residue Cr-6	
					Monitor excess sulphite	
Outlet monitor		pH			Transportable pH-meter	
		Flow				

Whilst conducting the reviews used for this study, it was found that on average two visits had to be made to the companies under consideration to explain the requirements for these data sheets.

3.3. The company visit and audit

The application of Flemming's CP tool requires the completion of the data tables with the guidelines attached in Appendix A1. The data tables were Excel based and are attached as Appendix A2. There were a total of nine tables to be completed. The guideline document contains sixteen pages of details on the methods to be followed in completing the spreadsheet tables.

The completion of the spreadsheet tables, by the reviewer, is carried out at the company concerned, as detailed process information is required. Table 3.7 is an example of a typical table to be completed.

Table 3.7: Typical review table to be completed by auditor

	Chemicals			Thickness in µm		Production		Key figures: kg chemicals/1000m2		
Process bath	Type	kg/yr	R/yr	Calculated	Estimated	m2/yr	m2/h	Calculated	Goal	Score, 1-5
Zinc line:										
Degreasing bath	Chemaline 05	2,250	18,585			220,000	50	10.2	25	1
Sulfuric acid pickling	Sulfuric acid, 96%	4,520	3,345			220,000	50	20.5	50	1
HCl pickling	HCl, 32%	13,700	18,073			220,000	50	62.3	75	1
Electrolytic cleaner	Chemaline 26	3,100	26,536			220,000	50	14.1	25	1
Acid dip	Chemacid 33	175	4,022			220,000	50	0.8	10	1
Zinc bath	Zinc anodes	11,190	91,534	7.1237586	5	220,000	50	50.9		
Zinc bath	NaCN	4,250	73,738			220,000	50	19.3	32	1
Zinc bath	NaOH	8,100	12,960			220,000	50	36.8	39	1
Zinc bath	Brightener	6,425	89,757			220,000	50	29.2	7	5
Zinc bath	Sodium sulphate	200	1,080			220,000	50	0.9		
Deoxidizer	Nitric acid	4,537	5,036			220,000	50	20.6	5	5
Chromating, blue	Concentrate	238	3,506			132,000	30	1.8	2	1
Chromating, blue	Nitric acid	1,713	3,323			132,000	30	13.0		
Chromating, yellow	Concentrate	838	6,101			88,000	20	9.5	5	2
Sum:		61,236	357,596					290.0		2
Operation time: h/yr	4400							Score: 1 = good, 5 = unsatisfactory		

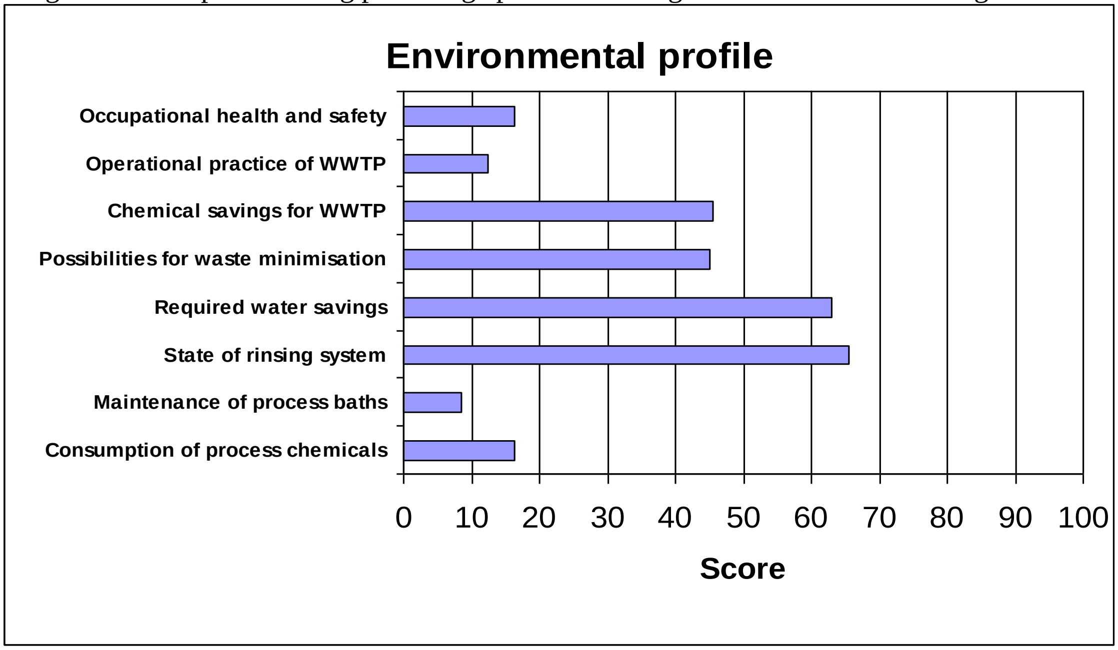
From Table 3.7 it can be seen that accurate plant data is required for the review process but some of the outputs are rated under different categories. For these categories it seems that imprecise data inputs would be acceptable so long as the outputs are within the expected output band. This is the basis of the fuzzy logic component of this thesis and a comprehensive data sensitivity analysis is conducted later in this chapter.

Table 3.7 requires the annual chemical consumption together with details such as plated thickness. The company also needs to provide the surface area plated in order for the spreadsheet to calculate the chemical consumptions. If the surface area is not available or cannot be estimated, the accuracy of the review process is compromised. The exact impact of the level of precision of the data inputted into these spreadsheets is evaluated later in this chapter.

Table 3.7 uses values from a support table to conduct some calculations. The support table values are either default values or values that need to be inputted based on the guideline document. The main inputs for the support tables are values like the dragout, the dilution factors, surface area, production hours, equipment operations details etc. These values have to be determined by the reviewer with reference to the guideline document.

The entire review process, once completed, is reported to the company with estimated potential savings. Figure 3.1 is the final graph indicating potential improvements under the different categories of the plant. The results are indicated on a scale of 0-100. With 100 been most significant room for improvement and 0 none.

Figure 3.1: Graph indicating percentage potential savings under the different categories.



The final review report discusses the different scores with reference to the tables. The final outcome of the review process is the decision to complete a detailed feasibility study on improving the plant so as to improve the environmental profile in Figure3.1, see Appendix A3 for a sample review report. The feasibility study would quantify the exact saving achievable if modifications were conducted on the plant in line with cleaner production systems.

3.4. Review and feasibility of companies

A typical review report is attached in Appendix A3. The information gathered for the reviews was used to compile a database of companies, see Appendix A3(All company reports are on disc :C:/Companies for database). This information was used at various stages of development in this study. The knowledge developed during these reviews helped in the input requirements in the development of the relevant fuzzy logic models. Conducting 15 feasibility studies further enhanced knowledge. See Appendix A3 for a typical feasibility document.

3.5. The Feasibility Study

The feasibility study was compiled as an indication of potential saving and process efficiency improvements achievable at the company. The feasibility study was based on the findings of the review.

The feasibility study detailed cleaner production systems such as low flow counter current rinses and other systems that resulted in reduced chemical and water consumption. The feasibility study quantifies the exact savings achievable with each cleaner production recommendation. Appendix A3 contains a typical feasibility document.

From the feasibility document an informed decision is made on potential implementation. Table 3.8 lists typical results comparing company status, before and after implementation of recommendations listed in the feasibility document.

Table 3.8: Comparative company chemical, water and WWTP chemicals status

Company	Water before (L/ m^2)	Water after (L/ m^2)	Plating chemical before (Rands)	Plating chemical After (Rands)	WWTP chemical before (Rands)	WWTP Chemical After (Rands)
Defy	425	24.3	157951	36389	2965	1000
Abberdare	25	0.2	1294916	1112816	0	0
African Zinc	50	7.1	519153	401082	72207	36103
Fascor ni	62	7.7	164600	112590	41311	12393
Wings	78	7	107533	45254	5040	144
MPS	132	7	526535	408053	28050	1500
Transwerk	550	10	557941	436006	1400	100
Durban wire	371	6	95690	70543	5721	3216
Cascolor	16	0.5	12244	9442	7320	77

3.6. Database of companies

During this study a total of 25 different companies were reviewed and a total of 10 feasibility studies were conducted. The type of plating companies that were reviewed included: nickel, chrome, tin platers and phosphates. The aim was to gather a representative spread of company data so as to obtain good holistic knowledge on the general plating industry.

The results from the above were converted into a useable/accessible format for the purpose of model verification. The information was converted into a Visual Basic/ Microsoft Access format. See Appendix A4, for the summary tables of the Visual Basic program. This data is used for the fuzzy model regression and acid/degreaser/zinc model verification.

3.7. Analysis of the Flemming tool

For the development of the system proposed in this study, two parallel approaches were followed. The first was to identify the sections of the review system that could be conducted using fuzzy or imprecise inputs and the second was to develop mathematical models for the sections that the fuzzy models could not be applied to. The latter is addressed by using operator inputs into mathematical models later in this thesis. The evaluation of the sensitivity of the applicable Flemming's categories to imprecise inputs would now be evaluated.

3.7.1. The rinse tables

For the purpose of this thesis a detailed description of the rinse tables is illustrated. The other systems were based on the exact same methodology and only the key outputs are illustrated.

The cleaner production evaluation of the rinse systems aims at conducting a detailed analysis of the usage and management of water for the purpose of rinsing. The rinse system includes the rinse tanks, water inlet points, water flow rate, drip times, orientation and tank agitation.

The auditor is required to input a range of inputs into the rinse tables. These inputs are based on measurements and observations made by the auditor on the facility under consideration. Table 3.9 details a listing of the typical inputs required for the rinse tables together with a brief description of each input.

Table 3.9: Inputs required for Flemming's rinse tables.

Input No.	Input	Input options	Abbreviation
1	Tank Number	1…n (where n= total number of tanks)	T_n
2	Rise system	1 = running rinse 2 = static rinse (drag-out rinse) 3 = Spray rinse 4 =static + running rinse 5 =static +2-running rinse 6 =static +3-running rinse 11 = 2-step counter current rinse 12 = 3-step counter current rinse 13 = 4-step counter current rinse 14 = static + 2-step counter current rinse 15 = static + 3-step counter current rinse	Rin_{sys}
3	Input water type	T-water = tap water I-water = ion-exchanged water C-water = chemical treated water R-water = reuse water from another rinse tank DI-water = de-ionised water	W_{int}
4	Tank volume	10 Litres 12000 litres	T_{Vol}
5	Dripping	1 = 20-sec 2 = 15-19 sec 3 = 10-14 sec 4 = 5-9 sec 5 = 0-4 sec	DT
6	Hanging	1 = All water run off immediately 2= All water run off after some time 3 = Moderat run off 4 = Slow run off 5 = Slow run off + water pockets	HG
7	Agitation	1 = agitation and motion 2 = agitation and motion 3 = heavy motion, no agitation 4 = some motion, no agitation	AG

		5 = no motion, no agitation	
8	Inlet/outlet	1 = Inlet (top) reverse outlet (bottom) 2 = Inlet (top) reverse outlet (dived) 3 = Inlet reverse outlet, bottom 4 = Inlet reverse outlet, top 5 = Inlet near outlet, top	IN
9	Back-mix	1 = No back-flow 2 = Minimum back-flow 3 = Moderate back-flow 4 = Some back-flow 5 = Heavy back-flow	BM
10	Flow-control	1 = Complete flow-control 2 = Some flow adjustment 3 = Coarse flow-control 4 = Very little flow-control 5 = Totally open valve	FC
11	Water consumption	1-1000l/hr	W_c
12	Dilution factor	100-1.000: After degreasing and pickling 500-2.000: Before electroplating metal finishing baths 200-2.000: After miscellaneous chemical baths 5.000-10.000: Final rinsing after decorative chromium 1.000-5.000: Final rinsing after other galvanic baths	D_f
13	Dragout	25-50: Vertical hanging, good dripping 160 Vertical hanging, bad dripping 50-100: Horizontal hanging, good dripping 200-400: Horizontal hanging, bad dripping 300-1.000: Cup-shaped items, bad dripping 100-200: Typical “normal average” 200-300: Barrels	D_o
14	Surface area	1-1000000 m^2/yr	S_a
15	Hours per year	1-8760 hours/ year	H_y

From table 3.9 it can be seen that the reviewer has to be able to extract the relevant input on the choices available for the observed inputs. These inputs include:

- Tank Number
- Rinse system
- Input water type
- Hanging
- Agitation
- Inlet/outlet
- Back mixing
- Flow control

The auditor has to then determine/ calculate the other inputs. These inputs include:

- Drip times have to be measured using a stopwatch
- Tank volumes have to be measured and calculated
- Dilution factors or "F" values have to be extracted from Flemming's tables based on the process tank located before the rinse tank under consideration.
- Dragout has to be either physically measured or the reviewer has to estimate a value based on the inputs listed by Flemming.
- Surface area is the biggest challenge and needs to be determined by the consultant together with the company representative.
- Hours per year is determined by multiplying the weekly hours by the number of weeks worked

3.7.2. Rinse table calculations:

In order to determine the state of the rinsing system, the abbreviations from table 3.9 are used to conduct the following calculations:

Drip times, hanging times, agitation, inlet/outlet, back mixing, flow control is entered for each rinse tank. The calculations for state of the rinsing system are conducted using the data inputs in table 3.9. The actual calculations are:

The rinse system (R_{in}) is entered, if the rinse system score is >10 then the following calculations are conducted,

S_{RS}^{n1} = Intermediate calculation

$$S_{RS}^{1} = 100 * \{(DT-1)*0.2 + (HG-1)*0.1 + (AG-1)*0.1 + (IN-1)*0.1 + (BM-1)*0.25 + (FC-1)*.25\}/4 \quad (3.1a)$$

If R_{in} <10 then

$$S_{RS}^{1} = 100 * \{(DT-1)*10/75 + (HG-1)*10/75 + (AG-1)*10/75 + (IN-1)*10/75 + (BM-1)*25/75 + (FC-1)*25/75\}/4 \quad (3.1b)$$

The result of the above is used together with the water consumption for each tank (W_c) which is calculated as

$$S_{RS}^{2} = S_{RS}^{1} * W_c \quad (3.2)$$

This is summed over all the tanks to a total for the "LM" factor.

$$LM = \sum_{1}^{n} S_{RS}^{1} * W_c \quad (3.3)$$

Where n = number of rinse tanks

The water consumption for all rinse tanks are summed:

$$S_{RS}^{3} = \sum_{1}^{n} W_c \quad (3.4)$$

The state of the rinsing system is (S_{RS}^{F}) calculated as:

$$S_{RS}^{F} = \frac{LM}{S_{RS}^{3}} \quad (3.5)$$

Determining the actual water savings rating (W_{SR})

The inputs include the actual water consumption, operational hours per year and the production in meters squared/year.

Present water consumption (P_{WC}) is calculated as:

$$P_{WC} = (W_C * H_Y) / S_a \tag{3.6}$$

This is summed for all the rinse tanks

$$P_{WC}^T = \sum_1^n (W_C * H_Y) / S_a \tag{3.7}$$

$$P_{WC}^F = (P_{WC} * S_a) / 1000 \tag{3.8}$$

The PARCOM rating (P_R) is calculated as:

$$P_R^1 = (D_f)^{1/3} * D_0 \tag{3.9}$$

$$P_R^F = P_R^1 * S_a \tag{3.10}$$

$$W_{SR} = (100 * \frac{P_{WC}}{P_R{}^F}) / P_{WC} \tag{3.11}$$

Thus the actual water savings is rated on a scale of 1-100. The inputs are entered into a spreadsheet format, see Table 3.10A&B. There are various such sections in the Flemming CP tool and the aim is to determine the impact of data variation on the specific model output. For the purpose of this investigation a typical company was randomly selected from the database of companies investigated. From the data extracted from this company, the initial rinse table indicated a 46.52 % potential for improvement. The table is illustrated in Table 3.10A&B.

Table 3.10A: Company results for rinse tables

Rinse system	Process bath before rinse	Raw water	Tank litre	Rinse system data score (1=OK, 5=unsatisfactory) Drip-ping	Hang-ing	Agita-tion	Inlet-outlet	Back-mix	Flow-control	Total,% Max100	Waterflow, l/h Actual	Goal	Water consumption: l/m2 Calcu-lated	goal	Savings m3/yr
11		T	570	1	1	1	1	1	1	0	500	72.7355	18.3	2.7	2461.0
2		T	570	1	1	1	1	1	1	0		81.9182	0.0	3.0	0.0
12		T	750	1	1	1	1	1	1	0	300	81.9182	11.0	3.0	1256.2
11		T	570	1	1	1	1	1	1	0	400	81.9182	14.6	3.0	1832.2
1		T	750	4	3	3	4	1	2	52	300	81.9182	11.0	3.0	1256.2
1		T	1000	4	3	3	4	1	2	52	150	103.21	5.5	3.8	269.5
2		T	750	4	3	3	4	1	2	52	270	81.9182	9.9	3.0	1083.4
													0.0	0.0	0.0
													0.0	0.0	0.0
											1920	585.537	70.3	21.4	8158.4

Table 3.10B: Company results for rinse tables-continued

Support table F-value	h/yr	m2/yr	Drag-out, l/m2	L * M	Helping Score	PARCOM Water Consumption, m3/yr	Present Water Consumption, m3/yr
700	5760	157,283	0.3	18,125.00	36	418.96	2,880.00
1000	5760	157,283	0.3	0.00	52	471.85	0.00
1000	5760	157,283	0.3	13,500.00	45	471.85	1,728.00
1000	5760	157,283	0.3	20,500.00	51	471.85	2,304.00
1000	5760	157,283	0.3	15,500.00	52	471.85	1,728.00
2000	5760	157,283	0.3	7,750.00	52	594.49	864.00
1000	5760	157,283	0.3	13,950.00	52	471.85	1,555.20
				0.00	-25	0.00	0.00
				0.00	-25	0.00	0.00
				89,325.00		3,372.69	11,059.20

Possibilities for optimisation, total		46.52
Possibilities for relative savings		69.50
Possibilities for absolute savings		7686.51

From Table 3.10 A&B it can be seen that the reviewer scoring is for individual rinse tanks whilst the final outputs rate the entire rinse system. It is noted that the output for "Possibilities for optimization, total" is 46.52 for the company under consideration. This output is used as an indication of areas to address for potential cleaner production improvements. The ranges for these outputs are listed in Table 3.11. From Table 3.11. it can be seen that the ranges are large, typically in the order of 20. Thus it can be seen that the outputs are imprecise/fuzzy. A detailed analysis of the exact effects of input variation on outputs would indicate the potential to use fuzzy inputs.

Table 3.11: Scoring ranges of output: "Possibilities for optimization, total"

Output range	Implied saving potential
0-20	Very low potential for saving
21-40	Medium potential for saving
41-60	Medium to high potential for saving
61-100	Very high potential for saving

3.8. Sensitivity of the rinse system

In order to determine the sensitivity of the rinse system to input variation, the system has to be looked at holistically. As can be seen in Table 3.11 the range for the output ratings are fairly broad. It would be ideal to investigate the impact of the variation in inputs on the output. This is done by assuming that the inputs are imprecise i.e. randomly changing the input variables. The output rating is then compared to the Flemming rinse table output.

This implies that the reviewer's inputs for the seven rinse tanks under consideration have to be varied(increased/decreased) randomly, remembering that each tank has fifteen potential inputs. This makes the task complex and hence the entire rinse system was programmed in Mat Lab, and the Monte Carlo technique applied to randomly changing the inputs, see Appendix A5 for Mat Lab program.

The aim was to vary the inputs randomly and determine the impact of input variable changes. The values have to be increased and decreased to determine the impact of changes on the output.

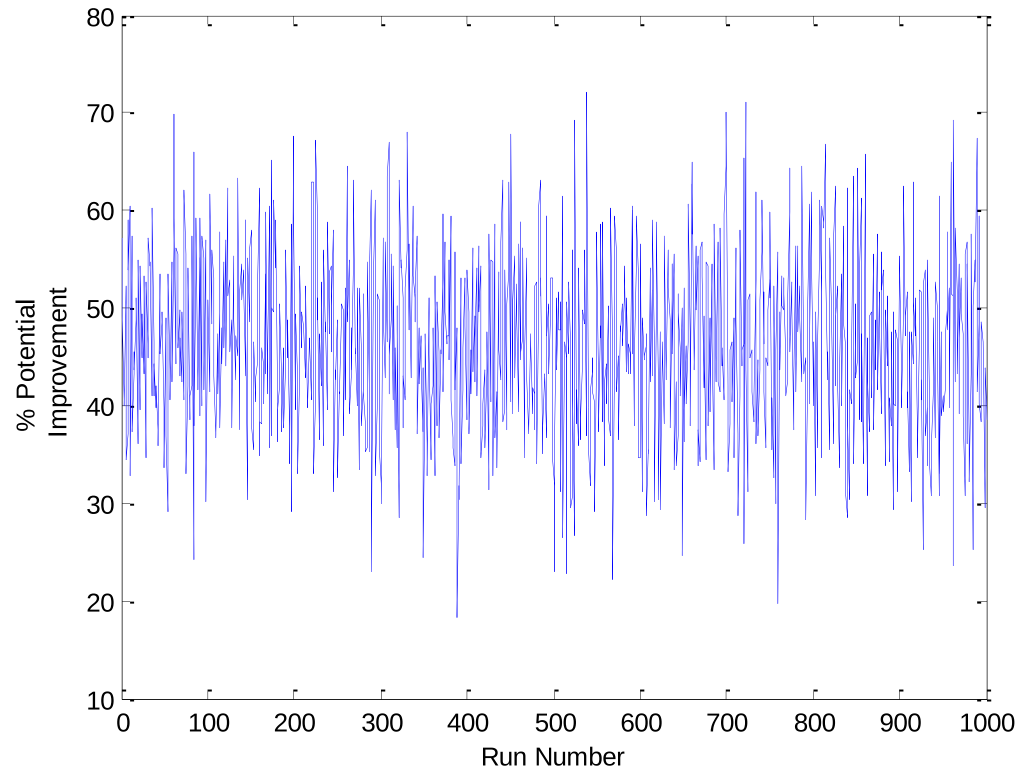
The input values in Table 3.10. were varied to determine the impact of the changes. Initially only five of the input values were increased/decreased. This was done randomly for any input value in Table 3.10. This process was repeated 1000 times and the mean output compared to the initial output of 46.6% from table 3.10. This process was repeated for up to 90 random input changes (15 inputs for six tanks). The average outputs for a total Monte Carlo of 1000 runs are noted in Table 3.12. The values were initially increased/decreased by less than 10% or in the second runs, between 10 and 20%.

Table 3.12: Monte Carlo results for input changes for rinse tables

No. of inputs changed	Mean Output for input change of <10%	Standard Deviation	Mean Output for input change of >10%>20%	Standard Deviation
0	46.6	-	-	-
5	45.86	1.07	45.88	2.19
10	45.92	1.6	45.89	3.01
20	45.76	2.18	45.74	4.24
30	45.95	2.65	45.81	5.41
40	45.73	3.18	45.79	6.4
50	45.92	3.52	46.1	7.1
60	46.03	3.84	46.17	7.43
70	45.91	4.12	46.06	8.34
80	45.94	4.4	45.53	9.09
90	45.68	4.52	45.61	9.48

From Table 3.12. it can be seen that there is no significant change to the output rating of 46.6%. What is clear however was that the increase in standard deviation of the output increases proportionally as the number of inputs changes is increased from 5 to 90. The percentage change in inputs has a significant impact on the outputs i.e. for five random input changes of 10 % from the original value the standard deviation was 1.07 which is doubled to 2.19, when the input is changed by 20% of its original value. Figure 3.2 illustrates the Mat Lab output for a the run where 60 random inputs were changed by +/- 1.

Figure 3.2: Mat Lab results for 60 input changes of +/-1, for the rinse system



It can be seen that variable changes, on average, result in a negligible mean output change for the rinse system. The result indicates that the maximum standard deviation is less than 10 % of the range i.e. 2/3 of the outputs is 10% or less imprecise. From Table 3.11 it can be seen that the output bands are wide (20%) and a net increase or decrease of 10% would usually not impact on the output rating. At worst it would result in the company moving one rating up or down. Thus it can be concluded that for the rinse tables, output would not be significantly compromised if the inputs were not precise.

3.8.1. Analysis of sensitivity for other systems

From the detailed analysis of the rinse system to input data sensitivity, it was clear that limited variations in input data did not impact significantly on the output of the rinse system. A brief investigation of the impact of input changes to the other systems follows. The systems that were investigated are:

- Occupational health and safety
- Waste water treatment chemicals
- Waste generation

Similar to the investigation into the impact of variable changes for the rinse models the above spreadsheets were analyzed with variable changes randomly.

3.8.2. Occupational health and safety

The aims of the Occupational Health and Safety (OHS) tables were to evaluate the risk to employees with regards to chemical exposure and general plant operations. The Flemming OHS spreadsheet addressed many key inputs in order to determine the OHS status. The variables considered were: Reduction of drag-out and drag-in, Optimizing bath chemistry, Concentrating of waste, improved maintenance of process baths and Recovery from waste. The Flemming table for waste generated is illustrated in Table 3.13.

Table 3.13: Waste generated

			Chemistry			Temperature			Noise			Heavy lift			Risk	
			Quantity	Time	Effect	Quantity	Time	Effect	Quantity	Time	Effect	Quantity	Time	Effect	Score	
Zinc1	Alkaline degreaser		2	3	2	3	3	2	3	2	3	3	2	2	18	
	Zinc bath		1	1	3	1	3	1								
Zinc2	Alkaline degreaser															
	Zinc bath															
Cu-Ni-Cr-1	Nickel bath															
	Chromium bath															
Cu-Ni-Sn-1	Alkaline degreaser															
	Nickel bath															
Cu-Ni-Sn-2	Alkaline degreaser															
	Nickel bath															
Phosphating 1	Alkaline pickling															
	Phosphating															
Phosphating 2	Alkaline pickling															
	Phospahting															
	Sum	Total	cores: 3=high, 2=medium, 1=low										Risk score: from 1 -			
Occupational Health and Safety	Total score	53.8														

From Table 3.13 it can be seen that there are 14 inputs for each chemical and a further 6 inputs for the chemical baths. A Mat Lab simulation was set up and random input variable changes were made. The Monte Carlo technique again was used for this simulation.

Similar to the rinse tables the input values in Table 3.13 were varied to determine the impact of the changes. Initially only one of the input value was increased/decreased. This process was repeated 1000 times, and the output, compared to the initial output of 53.8% from Table 3.13. This process was repeated for up to 19 random input changes (OHS tables contain only 19 inputs). The average outputs for a total Monte Carlo of 1000 runs are noted in Table 3.14. The values were initially increased/decreased by 1 or by 2 in the second runs.

Table 3.14: Monte Carlo results for input changes for rinse tables

No. of inputs changed	Mean Output for input change of +/- 1	Standard Deviation	Mean Output for input change of +/- 2	Standard Deviation
0	53.8	-	53.8	-
1	53.85	0.97	53.86	2.05
2	55.87	1.41	54.01	2.92
3	53.87	1.76	54.12	3.57
4	54.04	2.11	54.09	4.26
5	54.02	2.27	54.18	4.86
6	53.87	2.41	54.43	5.36
7	54.01	2.71	54.48	5.76
8	54.02	2.94	54.13	6.67
9	53.96	3.05	53.97	6.86
10	53.87	3.36	54.71	7.43
12	53.96	3.56	54.4	8.39
15	54.07	4.12	54.76	9.93

The mean change in output for the OHS tables is insignificant as can be seen in table 3.14. It can be noted that for an increase/decrease in input by 2 the mean generated by Mat Lab is always higher than the initial value. The input changes for all variables by +/- 2 have a standard deviation of less than 10 %. Thus it can be seen, similar to the rinse system, that fuzzy (imprecise) inputs would not have a significant impact on the model outputs.

3.8.3. Waste generated

The aims of the waste generated tables were to evaluate the amount of the waste produced and the opportunities available to reduce this waste. Flemming addressed many key inputs in order to determine the potential for waste reduction. This included: Reduction of drag-out and drag-in, Optimizing bath chemistry, Concentrating of waste, Improved maintenance of process baths, Amount/type of waste generated and Recovery from waste. The Flemming table for waste generated is illustrated in Table 3.15.

Table 3.15: Flemming's Waste tables

Type of waste	Waste	Disposal methods	Costs		Possibilities for waste reduction: 5=big and 1=sma					
Write the types below	ton/yr		R/ton	R/yr						
					Reduction of drag-out and drag-in	Optimising bath chemistry	Concentrating of waste	Improved maintenance of process baths	Recovery from waste	Relative ranking of saving possibilities
Liquid sludge	34	DL	450	15300	5	2	2	2	3	22
Filter cakes	53	DL	450	23850	5	5	5	2	3	58
Other	20	DL	250	5000	3	4	4	3	4	19
Sum	107			44150						100
					Score: 1 = good, 5 = unsatisfactory					
								Total score		63.6

Taking the company outputs, as in the rinse system, indicated a score of 63.6. This score was used as a comparison for sensitivity. The variables were changed as in the rinse system and the mean of 1000 runs recorded.

Table 3.16: Change in outputs with input changes-Waste tables

No. of inputs changed	Mean Output for input change of +/- 1	Standard Deviation	Mean Output for input change of +/- 2	Standard Deviation
0	63.6	-	63.6	-
1	63.64	1.02	63.77	1.86
2	63.61	1.42	64.31	2.89
3	63.69	1.81	64.3	3.33
4	63.57	1.99	64.8	3.75
5	63.67	2.25	64.79	4.26

6	63.63	2.41	65.37	4.67
7	63.47	2.76	65.42	5.28
8	63.48	2.82	65.72	5.54
9	63.41	3.04	66.10	5.71
10	63.67	3.11	66.60	6.29
12	63.27	3.53	66.66	6.85
15	63.57	3.86	67.72	7.77
18	63.52	4.08	69.58	8.26

The results from Table 3.16 indicate that for a +/- 1 input change, the mean output remains relatively unchanged. The standard deviation for the input change of +/- 2 is more than double that of the +/- 1 input change. The table has a maximum input of 18 and if all inputs are changed randomly, then the standard deviation is still less than 10.

3.8.4. Wastewater treatment plant chemicals

The wastewater treatment plant chemicals table is illustrated in Table 3.17. This table is intended to indicate potential to reduce the chemical consumption at the wastewater treatment plant. The input variables that determine the effectiveness of water treatment chemicals are: using less excess of chemicals, use spent process baths instead for treatment, optimizing the treatment of spent baths, mass of sludge produced, cost of sludge disposal/year and better separation of wastewater streams.

Table 3.17: Waste water treatment plant-Chemicals

Chemicals	Concentration	Consumption	Costs	Possibilities of savings					
		kg/yr	R/year	5=big and 1=small possibilities					
				Using less excess of chemicals	Use spent process baths instead	Optimising the treat-ment of spent baths	Better separation of wastewater streams	Total score, 0-100%	Saving index = consumption * score
Sodium hydroxide	100%	100	200	4	5	3	4	75	75
Sodium hydroxide	28%								
Hydrochloric acid	30%	100	200	4	5	3	4	75	75
Sulfuric acid	96%								
Sodium disulfite	100%	150	800	2	2	3	4	43.75	65.625
Sodium dithionite	100%								
Hydrogen peroxide	35%								
Polymer	100%	100	500	2	2	3	4	43.75	43.75
Iron(III) chloride									
Sodium hypochlorite	15%								
Calcium chloride	100%								
Sum		450	1700						57.6

Table 3.18: Change in outputs with input changes-Waste water treatment plant chemicals tables

No. of inputs changed	Mean Output for input change of +/- 1	Standard Deviation	Mean Output for input change of +/- 2	Standard Deviation
0	57.6	-	57.6	-
1	57.67	1.12	57.62	2.25
2	57.60	2.62	57.60	3.18
3	57.61	1.94	57.53	3.87
4	57.56	2.25	57.66	4.43
5	57.67	2.53	57.60	4.87
6	57.71	2.75	57.50	5.60
7	57.70	2.98	57.66	6.32
8	57.68	3.17	57.87	6.45
9	57.46	3.35	57.23	6.67
10	57.49	3.62	57.91	7.05
12	57.62	3.98	57.50	8.04
15	57.93	4.35	57.56	8.54
18	57.74	4.67	57.50	9.60
20	57.47	4.78	57.47	10.30

From Table 3.18 it can be seen that the results for the sensitivity of Flemming's waste water treatment plant chemicals to variable change does not significantly influence the rating. With a change of +/-2 on input changes the maximum standard deviation is 10. Thus it can be stated that the wastewater treatment plant tables would not be significantly changed if the inputs were not precise.

3.8.5. Summary of sensitivity investigation

From the investigation of the sensitivity of Flemming's CP tool into data inputs, it was seen that the model is not significantly influenced by small input variations. Small changes in inputs have a low to insignificant impact on the outputs on the CP evaluation. This sensitivity analysis implies that the evaluation system can be developed differently i.e. using imprecise inputs. This is now pursued in chapter four.

3.9. Conclusion

The reviews and feasibility studies undertaken were found to be most effective in gaining rapid knowledge of the plating industry. The creation of the database of company data proved to be very useful for the testing of results of models developed during this study.

In this chapter the data requirements for the rinse system is detailed together with the calculations required in determining the rinse outputs. The testing of the Flemming CP tool with regards to input data sensitivity clearly indicated potential for a fuzzy application. From the case presented the output was found to be "essentially fuzzy". This chapter has illustrated that the data requirements for the Flemming CP tool can be imprecise. The random variation in input data does not significantly change the output rating.

The analysis of the Flemming CP tool has proven its comprehensiveness. The rigid data requirements together with the time and skill levels required have been highlighted. It would be ideal to develop a CP evaluation system with equivalent outputs but with reduced input data, time and skills intensity.

Based on this sensitivity analysis, the Chapter 4 develops an alternate fuzzy evaluation system.

Reference

1. Dahl F, Electroplating Audit Tool for Metal Finishing Industry South Africa, DANCED Cleaner Metal Finishing Industry Production Project, 15 Stamford Court, 270 Stamford hill Road, Durban, South Africa. Propriety Documentation, 2000.
2. Danish Technological Institute, Project proposal, Cleaner Production in the Metal Finishing Industry project, South Africa, June 2000, South African Metal Finishing Association South Africa

CHAPTER FOUR

FUZZY LOGIC METHODS FOR CLEANER PRODUCTION EVALUATION

In this chapter a fuzzy logic model, for qualitative cleaner production evaluation, is proposed. The aim of this model was to replace previous data intense models used for cleaner production evaluations. The basic relevant fuzzy logic theory is detailed in section 4.3. The application of the theory to the entire plating process is then proposed and detailed, section 4.4. The outputs from the fuzzy logic model are compared to the output from the Flemming model in section 4.6.

4.1. Introduction

The evaluation of the environmental status of an electroplating facility, as compared to the best available practice, has traditionally been difficult to conduct, particularly in small or mid-sized plants. This was clearly illustrated in the previous chapters. The problem arises mainly due to the fact that the detailed plant data necessary for evaluation was always difficult to obtain completely and precisely.

To alleviate the data-scarcity and lack-of-skills related problems in environmental performance evaluation for cleaner production, a fuzzy-logic-based decision analysis approach is introduced in this chapter. This chapter deals specifically with the various systems that exist in an electroplating plant. The aim was to determine ratings on key variables and then compare these to best available practice. The novelty of the approach lies in the information i.e. the model depends solely on non rigid operator level inputs as compared to traditional rigid data.

The methodology introduced in this chapter is based on multivariable decision making using fuzzy logic. The entire electroplating facility is divided into eight sections that are evaluated individually. The different sections of the plant were considered individually and operator inputs were used to develop a cleaner production assessment. The attractiveness of the approach is illustrated by the analysis of the rinse management system. The evaluation system is suitable for any type of production process in the electroplating industry.

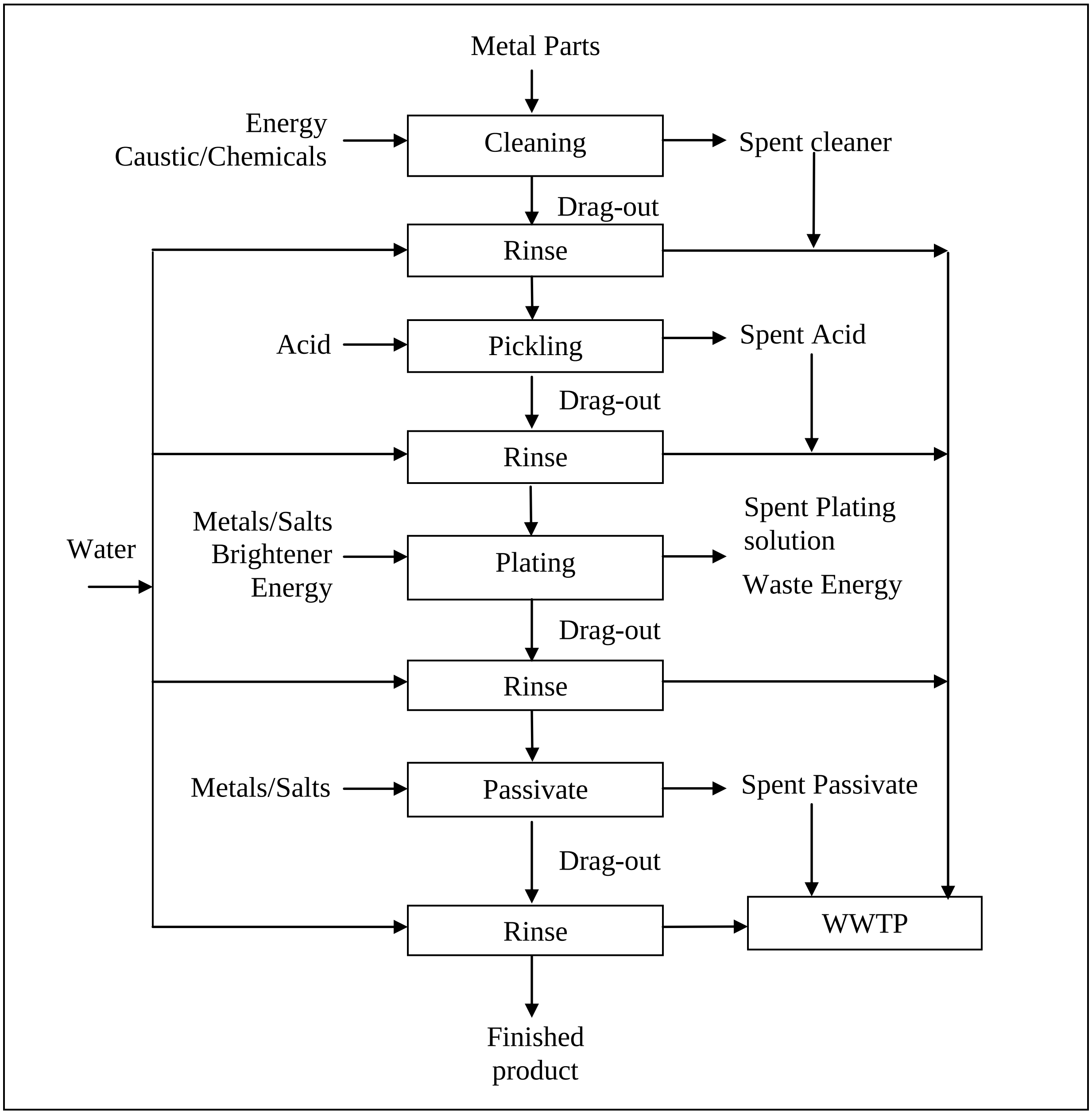
The model is validated using the data from the companies audited for the database, as detailed in Chapter 3. The fuzzy model is established based on fuzzy protocols. The base values for the model are based on the experience obtained during the review of the 25 companies. The model for each category, once complete was compared to the results from the database values. The base values were then adjusted by regression.

4.2. Plating process and the Environment

Figure 4.1 depicts a typical electroplating process, where major process operations (such as cleaning, rinsing, and plating), process inputs (such as metal parts, water, chemicals, and electricity) and outputs (such as plated parts and waste) are detailed. During operations, the parts in barrel or on rack are cleaned in alkaline and acidic solutions. This cleaning that occurs is a step-wise operation. After each step of cleaning or plating, parts are rinsed in a rinse system that may contain one or more rinse units. In the plating unit, metal coating is developed on the surface of parts. The plated parts then undergo post processing before leaving the line. The operations generate chemical- and metal-containing waste in almost all the operational steps.

According to Lou and Huang[1] and Luo *et al.*[2], the waste can be classified into two categories: unavoidable and avoidable. The former comes from dirt removal from the surface of parts after using chemicals, energy and water; the latter is generated due to excessive use of chemicals and water. Waste reduction in an electroplating plant is essentially the minimization of the avoidable waste. In this regard, process optimisation and management improvement is the key for CP.[3,4]

Figure 4.1: Plating process materials in and out.



To determine the efficiencies of chemical, water, and energy use, or to identify the bottleneck of waste minimisation in production, all operational units shown in Figure 4.1 should be carefully evaluated. To assist the evaluation process, a proper system classification will be undertaken. In this work, the following electroplating plant sections, together with their justification, are used.

- Consumption: Process chemical. Large amounts of chemical solutions are consumed daily in cleaning and electroplating operations. The chemicals must be optimally used so that chemical consumption can be minimized while the cleaning and plating qualities are also guaranteed.

- Consumption: Water. The actual water that flows in all the rinse steps must be evaluated. This will be critical for identifying the best opportunities for water use and reuse.

- Rinse management. The rinse effectiveness must be ensured as it is directly related to the use of minimum amount of water to rinse off the chemical solutions carried into the rinse units from the proceeding cleaning or plating units.

- Production. The measurement and control of production (e.g., the total surface area of the parts to be coated) are crucial for CP effectiveness.

- Chemicals for wastewater treatment plant. The efficiency of chemical treatment of wastewater in a WWTP is directly related to waste reduction and thus should also be evaluated.

- WWTP operations. The availability and operational status of the equipment in the WWTP are crucial for waste treatment effectiveness.

- Sludge reduction. The areas where sludge is generated and managed must be checked to ensure minimal sludge generation for disposal.

- Health and safety and environment. This is to evaluate the employee's health and safety. The impact of the types of chemicals and working environment must be investigated.

The classification of the plant created above facilitates the application of fuzzy logic as the plant is now broken down into manageable sections for the evaluation process. While evaluations of the eight categories listed above are essential, the data availability and quality in each category is always questionable. It seems fuzzy logic is a viable tool in CP evaluation when the available information is imprecise, incomplete, and uncertain.[5,6] Fuzzy logic utilizes rigorous fuzzy mathematics to process and manipulate non-ideal information or ill-defined data in a systematic way. By fuzzy logic, expert knowledge, particularly expert's heuristic knowledge, can be readily represented and integrated in a consistent way into a CP evaluation system.[7] The resulting fuzzy models can be used to effectively weigh the factors in each category under consideration. A total impact of the factor importance on CP can be reasonably assessed. It would be most appropriate to define the theory for multi variable fuzzy decision analysis before presenting a case study.

4.3. Fuzzy Logic based Multi-Objective Decision-Making

In the text to follow, a fuzzy-logic-based decision-analysis method is introduced by resorting to a fuzzy-logic-based multi-objective decision making method.[8] The background theory to this fuzzy model is now detailed.

Assume that there are *N* objectives to be considered for CP, e.g., minimum process chemical consumption and minimum sludge generation. The set of objectives, *O*, can be denoted as:

$$O = \{o_1, o_2, \ldots, o_N\} \tag{4.1}$$

Also assume that there are M factors for CP evaluation. These factors are denoted as the set, *A*.

$$A = \{a_1, a_2, \ldots, a_M\} \tag{4.2}$$

In evaluation, the impact of each factor (a_i) on each individual objective (o_j) is first defined by a fuzzy membership function, $\mu_{o_j}(a_i) \in [0,1]$, $i = 1, 2, \cdots, M;\ j = 1, 2, \cdots, N$. The membership functions can be continuous or discrete, and be determined based on engineering knowledge, subjective preference, and/or available data.[5]

The task of evaluation is to assess how the pre-defined objectives are achieved. Mathematically, this evaluation can be obtained through defining the following decision function, *D*:

$$D = o_1 \cap o_2 \cap \cdots \cap o_N \tag{4.3}$$

Where:

$\cap$ = Intersection of sets

Note that the importance of each objective to the overall CP objective may be different in the decision maker’s view. Moreover, data availability and quality for assessment may also be different for each objective-based evaluation. To make the evaluation more reasonable, a set of preference values should be defined as an association with the specific objective set as shown below.

$$B = \{b_1, b_2, \ldots, b_N\} \tag{4.4}$$

Where each preference has a value between 0 and 1.

By incorporating the preferences, the decision-analysis function in Eq. (4.3) can be advanced as follows:

$$D = M_1\left(o_1\left(a_i\right), b_1\right) \cap M_2\left(o_2\left(a_i\right), b_2\right) \cap \cdots \cap M_r\left(o_r\left(a_i\right), b_r\right) \tag{4.5}$$

where the decision measure, M, for the factor, a_i, is defined below:

$$\begin{aligned} &M_j\left(o_j\left(a_i\right), b_j\right) = \left(b_j, o_j\left(a_i\right)\right) \\ &where: o_j\left(a_i\right) = \bar{b}_j \vee o_j\left(a_i\right) \end{aligned} \tag{4.6}$$

Where:

$\vee$ = Maximum operation

$\bar{b} = \dfrac{1}{b}$

The evaluation of each decision measure can be conducted as follows:

$$\mu_{M_j}(a_i) = max[\mu_{\bar{b}_j}(a_i), \mu_{o_j}(a_i)] \quad (4.7)$$

Or more concisely, the decision-analysis model in Eq. (4.5) can be rewritten as:

$$D(a_i) = \bigcap_{j=1}^{M} (\bar{b}_j \vee o_j)(a_i) \quad (4.8)$$

With this decision function, a fuzzy MIN-MAX algorithm is used to identify the most important factor(s) that are critical for CP evaluation. This algorithm has the following two-step operations:

(1) To determine the minimum importance of the objectives, $\mu_{M_j}(a_i)$, for each factor a_i. This can be accomplished by performing the following MIN operation:

$$\mu_D(a_i) = min[\mu_{M_1}(a_i), \mu_{M_2}(a_i), \cdots, \mu_{M_N}(a_i)] \quad (4.9)$$

or

$$D(a_i) = \bigcap_{j=1}^{N} \mu_{M_j}(a_i) \quad (4.10)$$

(2) To identify the most important factor for CP by performing the following MAX operation:

$$\mu_D(a^*) = max[\mu_D(a_1), \mu_D(a_2), \cdots, \mu_D(a_m)] \quad (4.11)$$

or

$$D(a^*) = \bigcup_{i=1}^{M} D(a_i) \quad (4.12)$$

The two-step decision analysis will lead to the identification of the most important factor, a^*, for production improvement. In many applications, it is preferred to give a single score as an indicator of the CP status for the plant. The following formula is suggested to determine the overall CP status.

$$S = \sum_{i=1}^{M} \mu_D(a_i) V(a_i) \times 100\% \qquad (4.13)$$

where $V(a_i)$ is a fuzzy number of factor a_i. The definitions of the fuzzy numbers are based on experience.[9,10-11] In the case study below, a detained example of defining the fuzzy numbers of all six factors are exemplified.

4.4. Application of Multi Objective Decision-Making

For the application of the multi objective decision making the first step would be to declare the operator inputs for the different operator questions. These choices of potential operator answers are referred to as the alternates available. The alternates need to be presented in a user friendly and easily identifiable format for the operator to make his selection. A detailed list of these questions and alternates for the rinse system is described. A detailed list of all the categories is attached in Appendix B1.

4.4.1. Dripping

Dripping is understood to be the length of time where the items are placed above the process bath before being moved to the next bath. If the time of dripping is too short, the liquid will not drip off completely before the item is moved on to the next tank. A score for dripping is, therefore determined by the length of time for which the items are dripping above the bath, before being sent on to the next bath.

Operator alternates for dripping time:

- Jig drip time is between 0-4 Seconds
- Jig drip time is between 5-9 Seconds
- Jig drip time is between 10-14 Seconds
- Jig drip time is between 15-19 Seconds
- Jig drip time is >20 Seconds

The scores above are acceptable for racked goods.

4.4.2. Hanging

By hanging (suspension) it is understood to be the physical orientation in which the items are placed on the rack or jig. By tilting the items in order to avoid as much entrapments as possible, drag-out volume is minimised. For example, a cup-shaped item is always racked upside-down; hollow tubes should be racked horizontal with a slight slope. The score for hanging therefore depends on the efficiency of the liquid to drip off the item, before the items are lead to the next process.

Operator alternates for parts hanging:

- No cup-shaped parts entraining liquid, flat sheets hung with one corner facing down, draining time less than 3 seconds.
- Some liquid entrapment by cup-shaped parts, flat sheets hung with the shortest end facing down, 3~8 seconds of draining time
- Large liquid entrapment by cup-shaped parts, sheets hung with the shortest end facing down, 8~12 seconds of draining time
- Large liquid entrapment by cup-shaped parts, sheets hung with a longer side facing down, 12~15 seconds of draining time
- Large liquid entrapment by cup-shaped parts, sheets hung with a longer side facing down, draining time greater than 15 seconds

4.4.3. Agitation

Agitation is understood to be the physical motion of the liquid. If the liquid is not in motion or being agitated the replacement of the liquid film on the item surface will be very slow, and there is a risk to drag-out the chemicals before they have been exchanged from the surface layer. By aggressive agitation and liquid motion the liquid film is physically replaced much faster. The agitation and liquid motion thus have high influence on the speed of the replacement of the liquid film.

Operator alternates for Agitation:

- No agitation or liquid motion in any tanks
- Visible agitation or jig motion on some cleaning tanks
- Visible agitation or jig motion on all cleaning tanks

- Visible agitation and liquid motion on all process tanks
- Aggressive agitation and liquid motion on all process tanks

4.4.4. Water Inlet/Outlet

Water inlet/outlet is understood to be the way in which the rinse water is physically let in and out of each rinse tank. The inlet/outlet has major influence on the physical passage of water in the rinse tank and on the utilisation as well. This is mainly due to concentration pockets caused by insufficient mixing. If the inlet and outlet are physically placed side by side there can be high water consumption but a very low rinsing efficiency.

Operator alternates for Process Inlet/Outlet:

- Inlet located at the top of the tank and outlet next to it on the top of the tank
- Inlet located at the top of the tank and the outlet on the top of the tank but on the opposite end
- Inlet located at the top of the tank and the outlet on the bottom of the tank but on the opposite end
- Inlet located at the bottom of the tank and the outlet at the top of the tank but on the opposite end and the tank not agitated
- Inlet located at the bottom of the tank and the outlet at the top of the tank but on the opposite end and the tank agitated

4.4.5. Back-Mixing

When two or more rinsing tanks are connected (e.g. counter current rinse), it is important that the water will run from the tank with a lower chemical concentration to a tank with a higher chemical concentration. This is normally controlled by a simple gravity flow where there is a difference in water height. Under normal conditions the flow direction is correct, but if a big rack or even worse a big barrel is submersed in the dirty water, the water level in the dirty tank may increase above the water level of the clean water tank. In this case the water will flow in the wrong direction, and the clean water tank will get polluted with dirty water. In this case there is a very low efficiency of the rinsing process compared to normal conditions for this kind of rinse systems. The construction should be corrected to improve rinsing quality and reduce water consumption.

Operator alternates for Back Mixing:

- Rinse tanks linked across the bottom or top, allowing continuous flow of water
- Small pipes linking rinse tanks, resulting in continuous back mixing; high spills between rinse tanks during jig submersion
- Rinse tanks linked across the bottom or top, allowing moderate water flow, or very small water overflows to the next rinse tank during jig submersion.
- Rinse tanks linked across the bottom or top, allowing very little water flow, or some water overflows to the next rinse tank during jig submersion
- No back mixing, tanks not linked

4.4.6. Flow-control

Controlling the inlet flow of water to a rinse tank is probably the most important factor influencing the water consumption. To control the flow a valve is needed for adjustment and a flow meter to monitor the flow - but more importantly the exact water flow rate is required. The demand of water is determined by the defined water quality (F = dilution factor) and the drag-out from the previous process tank.

The typical situation is a totally open water-valve, and nobody has considered if less water would be sufficient. Some companies implement some kind of water restrictors and this is highly recommended, but it is still very important that the restrictors are allowed to control the water flow. Too often it is seen that the operations staff increasing the water flow by further opening the water-valve, because it was found that the rinse water was too dirty. It is an important task to set up correct instructions and ensure that these instructions are followed.

Operator alternates for Flow Control:

- Rinse water supplied by non-restricted pipe, separate inlet for each rinse tank
- Rinse water supplied by a valve on the end of a pipe with some control
- Static tanks dumped regularly or with moderate flow control but without rinse recovery system, and no rinse water redirecting
- Static tanks dumped regularly or with moderate flow control but without rinse recovery system, and rinse water redirected
- Continuous flow control via predetermined rinse water requirements, all water recovered via low flow rinse back into plating tank

4.5. Rinse management application

The alternates listed above are used to establish the fuzzy model. These alternates are considered for development of the fuzzy rinse management model. The set of alternates are defined as A:

$$A = \{a_1, a_2, \ldots, a_6\} = \{DT, HG, AG, IN, BM, FC\} \quad (4.14)$$

Where:

DT: Drip time that parts stay above a tank before moving to the next tank.

HG: Orientation of the parts hanging on a jig

AG: Agitation of the solution in a tank by air or jig movement

IN: Water flows through a rinse tank

BM: Back mixing of rinse due to connections of the rinse tanks

FC: Flows control of rinse water to a rinse tank

The analysis for CP is to be performed by focusing on the impacts of the six factors on the four objectives below:

$$O = \{o_1, o_2, \ldots, o_4\} = \{CC, P, WC, C\} \quad (4.15)$$

where

CC: the chemical consumption

P: the production rate

WC: the water consumption

C: the cost for wastewater treatment and due to production loss

Available information. In this application, the CP evaluators obtained the level of importance of each factor to each objective. This data is compiled in the following notation suggested by Zadeh.[12]

$$o_1 = \left\{ \frac{0.8}{DT}; \frac{0.5}{HG}; \frac{0.2}{AG}; \frac{0.1}{IN}; \frac{0.1}{BM}; \frac{0.15}{FC} \right\} \quad (4.16)$$

$$o_2 = \left\{ \frac{0.4}{DT}; \frac{0.15}{HG}; \frac{0.2}{AG}; \frac{0.15}{IN}; \frac{0.1}{BM}; \frac{0.1}{FC} \right\} \tag{4.17}$$

$$o_3 = \left\{ \frac{0.7}{DT}; \frac{0.2}{HG}; \frac{0.1}{AG}; \frac{0.7}{IN}; \frac{0.1}{BM}; \frac{0.8}{FC} \right\} \tag{4.18}$$

$$o_4 = \left\{ \frac{0.2}{DT}; \frac{0.2}{HG}; \frac{0.1}{AG}; \frac{0.1}{IN}; \frac{0.1}{BM}; \frac{0.15}{FC} \right\} \tag{4.19}$$

In the above notation, the numerator and denominator of each fraction are, respectively, the fuzzy number ($\mu_{o_j}(a_i)$) as the importance to the objective and the corresponding factor (a_i). The numerator is a subjective value entered, based on experience.

$$B = \{b_1, b_2, \ldots, b_4\} = \{0.9, 0.75, 1, 0.65\} \tag{4.20}$$

The subjective values reflect the following basic analysis for rinse management: (i) the water consumption objective (o_3) as the most important (b_3 = 1), (ii) the chemical consumption (o_1) as very important (b_2 = 0.9), (iii) the production (o_2) due to rinse management considered fairly important (b_2 = 0.75), and (iv) the additional cost (o_4) as the least important (b_4 = 0.65) in evaluation.

4.5.1. Evaluation.

According to Eq. (4.8), or more clearly, Eq. (4.7) and (4.9), the following manipulations are performed:

$$D(a_1) = (0.1 \vee 0.8) \wedge (0.25 \vee 0.4) \wedge (0 \vee 0.7) \wedge (0.35 \vee 0.2) = 0.35 \tag{4.21}$$

$$D(a_2) = (0.1 \vee 0.5) \wedge (0.25 \vee 0.15) \wedge (0 \vee 0.2) \wedge (0.35 \vee 0.2) = 0.2 \tag{4.22}$$

$$D(a_3) = (0.1 \vee 0.2) \wedge (0.25 \vee 0.2) \wedge (0 \vee 0.1) \wedge (0.35 \vee 0.1) = 0.1 \tag{4.23}$$

$$D(a_4) = (0.1 \vee 0.1) \wedge (0.25 \vee 0.15) \wedge (0 \vee 0.7) \wedge (0.35 \vee 0.1) = 0.1 \quad (4.24)$$

$$D(a_5) = (0.1 \vee 0.1) \wedge (0.25 \vee 0.1) \wedge (0 \vee 0.1) \wedge (0.35 \vee 0.1) = 0.1 \quad (4.25)$$

$$D(a_6) = (0.1 \vee 0.15) \wedge (0.25 \vee 0.1) \wedge (0 \vee 0.8) \wedge (0.35 \vee 0.15) = 0.15 \quad (4.26)$$

Where:

$\Lambda =$ Minimum operation

$\vee =$ Maximum operation

The above evaluation results provide detailed, specific directions on where and to what level the rinse management should be improved.

Also, according to Eq. (4.12) :

$$D(a^*) = 0.35 \vee 0.2 \vee 0.1 \vee 0.1 \vee 0.1 \vee 0.15 = 0.35 = D(a_1) \quad (4.27)$$

This evaluation indicates that drip time (*DT*, or a_1) is most critical, while agitation (AG or a_3), the inlet water flow (IN, or a_4), and the back mixing between tanks (BM, or a_5) are the least important in this case.

If the values of the concerned factors are available in a plant, the rating of the given rinse management system can be evaluated using Eq. (4.13) as follows:

$$S = (0.35V(DT) + 0.2V(HG) + 0.1V(AG) + 0.1V(IN) + 0.1V(BM) + 0.15V(FC)) \times 100\% \quad (4.28)$$

Equation 4.28 is the fuzzy rating that would be used to determine the status of the rinse management system.

4.6. Comparison of results with Database values from Flemming's CP tool

The fuzzy results needs to be compared to the results generated by Flemming's[13] CP tool. The initial fuzzy allocation values can be assumed to be test estimate values. These values are aimed at being general inputs of the potential fuzzy allocation for the operator alternates. These values enjoy a low confidence level due to the nature in which they are obtained i.e. they are purely subjective. It would be ideal to regress these values so as to try and replicate values from the database.

These initial input values are used as inputs into the fuzzy model. For example, if the operator selects a low rating under Drip times, such as 0.2, then the drip times (DT) value in equation 4.28 is multiplied by this value. This would be done for each of the categories in the rinse section. Table 4.1, contains a set of input values for the six different categories in the rinse section. For the testing of equation 4.28 four random company case scenarios were extracted form the database.

Table 4.1: Comparative outputs from Flemming's and Fuzzy model

Case No.	Drip Times	Hanging	Agitation	In-Out	Back Mixing	Flow Control	Fuzzy Evaluation	Fleming's Evaluation	Sum of square
1	0.2	0.2	0.4	0.4	0.2	0.2	25.0	6.7	336.0
2	0.8	0.4	0.6	0.4	0.4	0.4	52.0	41.7	106.7
3	0.6	0.8	0.6	0.8	0.6	0.8	71.0	65.0	36.0
4	1	0.8	1	1	1	1	96.0	96.7	0.4
									479.1

As can be seen from Table 4.1, the fuzzy model needs to be improved so as to generate equivalent results as compared to the Flemming CP tool[13].

Using the excel solver and defining the sum of squares as the main objective to minimize, the estimates of the fuzzy allocations can be improved. The solver is then run with the above ranges and the Excel output would, by regression, minimize the difference between the database results and the fuzzy outputs. It can be noted that the operator input ratings were used for the regression. The actual outputs would not change significantly if the expert input factors were regressed. This implies that the output would remain unchanged as the operator input ratings and the expert inputs can be considered to be a ratio.

The regression results for the alternates are summarized in Table 4.2.

Table 4.2: Summary of regressed values:

General segregation	Drip times	Hanging	Agitation	Inlet	Back mixing	Flow control
Low	0	0	0	0	0	0
	0.05	0.05	0.18	0.2	0.05	0.05
Medium	0.3	0.3	0.3	0.3	0.3	0.3
	0.51	0.5	0.5	0.6	0.56	0.6
High	0.7	0.83	0.81	0.7	0.8	0.72
	1	1	1	1	1	1

From Table 4.3 it can be seen that the regression has resulted in some changes to the fuzzy alternate allocations. These values are all within the initial estimated range. It can also be seen that if the database values are used then the sum of square differences is considerably reduced.

Table 4.3: Comparative results after regression.

Case No.	Drip Times	Hanging	Agitation	In-Out	Back Mixing	Flow Control	Fuzzy Evaluation	Fleming's Evaluation	Sum of square
1	0.05	0.05	0.3	0.3	0.05	0.05	11.25	6.7	21.0
2	0.7	0.3	0.5	0.3	0.3	0.3	42.0	41.7	0.11
3	0.51	0.83	0.5	0.56	0.56	0.72	65.0	65.0	0.0
4	1	0.83	1	1	1	1	96.7	96.7	0.0
									21.11

It can be seen that the regressed values have a very small difference as compared to the database outputs. Hence the regressed fuzzy outputs are used as fuzzy allocation for the operator questions.

4.7. Plant wide Application of Multi-objective decision-making

The above methodology can then be applied to the rest of the plant under five of the categories listed in 4.2 in this chapter. The appropriate fuzzy questions are developed to accommodate operator inputs under these categories, see Appendix B1 for the detailed fuzzy calculations for the other 7 categories listed in section 4.2. The preferences are appropriately inputted in accordance with each category. A comprehensive plant wide system is developed that outputs an environmental status of the company.

The outputs from each section are summarized on a scale of zero to 100, where a zero indicates no room for improvement and 100 indicates major potential savings.

The allocation of inputs and operator values together with the relevant questions are detailed in Appendix B1. A summary of the remaining categories is described together with a brief description of each application.

4.7.1. Chemicals for wastewater treatment plant.

The efficient treatment of waste at the wastewater treatment plant results in reduced environmental impact with minimal cost to company. The fuzzy logic evaluation system for the chemicals for wastewater treatment was completed as per the rinse system. The initial inputs resulted in a sum of squares difference of 360. The final regressed values are detailed in Table 4.4.

Table 4.4: Table of values for chemicals for waste water after regression

Using less excess of chemicals	Using spent process baths instead	Optimizing treatment of spent process baths	Better separation of waste streams	Automatic dosing and control	Fuzzy output	Database output	Sum of squares
0.24	0.23	0.48	0.22	0.2	26.30	25.00	1.69
0.50	0.55	0.62	0.22	0.38	46.20	50.00	14.44
0.73	0.80	0.78	1	0.69	78.40	75.00	11.56

1.0	0.98	0.99	1	1	99.46	100.00	0.30
						Sum	27.99

From Table 4.4 it can be seen that the post regressed fuzzy logic model outputs are similar to the Flemming CP tool output. The actual difference in the sum of squares is reduced from 360 to 28.

4.7.2. Waste Water Treatment Plant(WWTP) operations.

The aim in auditing the operations employed at the wastewater treatment facility was to determine the state of wastewater treatment at a particular company. This is specifically with regards to the equipment used at the wastewater treatment plant. This includes the various systems for the proper treatment of the different effluent types such as acid/alkali metals etc. The initial inputs resulted in a sum of squares difference of 225. The final regressed values are detailed in Table 4.5.

Table 4.5: Waste water treatment plant post regression

Neutralization equipment	Chrome monitoring equipment	Cyanide monitoring equipment	Metals monitoring equipment	COD monitoring equipment	Fuzzy logic	Database values	Sum of squares
0.29	0.30	0.10	0.38	0.29	26.25	25.00	1.56
0.53	0.48	0.48	0.50	0.53	50.00	50.00	0.00
0.76	0.74	0.74	0.75	0.76	75.00	75.00	0.00
1.00	1.00	1.00	1.00	1.00	100.00	100.00	0.00
						Sum	**1.56**

It was seen that the regression reduces the sum of square error from 225 to 1.56.

4.7.3. Health and safety and environment.

The occupational health and safety category results are reflected in Table 4.6. The regression was successful in reducing the error for the sum of square difference between the new fuzzy model and the initial estimates from 517 to 41.61. The largest errors were generated in the lower end of the scale as can be seen in Table 4.6.

Table 4.6: Occupational health and safety post-regression

Effect of chemistry	Effect of temperature	Effect of noise	Effect of heavy lifts	General risk	Fuzzy output	Database outputs	% Error
0.25	0.30	0.20	0.20	0.20	23.75	17.30	41.60
0.39	0.54	0.20	0.20	0.53	40.00	40.00	0.00
0.54	0.79	0.64	0.58	0.53	62.00	62.00	0.00
1.00	1.00	1.00	1.00	1.00	100.09	100.00	0.01
						Sum	**41.61**

4.7.4. Sludge tables

The aim of conducting an evaluation into the sludge generated at the electroplating facility was to evaluate the source of sludge and the management of the process of sludge generation with the aim of potentially reducing the sludge at source. The initial inputs results in a sum of squares difference of 707. The final regressed values are detailed in Table 4.7.

Table 4.7: Sludge generation post-regression

Reduction of drag-in/ drag-out	Optimum bath chemistry	Concentration of waste	Improved maint of process bath	Recovery from waste	Fuzzy model output	Database output	Sum of squares
0.15	0.70	0.50	0.30	0.20	34.25	40.00	33.06
0.70	0.30	0.50	0.30	0.30	47.00	40.00	49.00
0.30	0.30	0.50	0.70	0.20	37.50	35.00	6.25
1.0	0.78	0.99	0.98	0.99	95.00	95.00	0.00
						Sum	**88.31**

4.8. Testing of the rinse model

For the purpose of verification the fuzzy model developed for the above plant sections were verified using a random company data from the database. The Flemming CP tool output was compared to the output generated by the fuzzy model. The outputs for the Flemming and fuzzy models for the relevant categories are illustrated in Table 4.8.

Table 4.8: Comparative outputs of Flemming and proposed fuzzy model

	Flemming	Fuzzy model	Difference percentage
Rinse system	65	56	4
Occupational health and safety	29	25	4
Waste water treatment plant chemicals	65	71	6
Waste water treatment plant equipment	37	37.5	0.5
Sludge/waste	45	45.5	0.5

From Table 4.9 it can be seen that for the five categories with comparative Flemming tables the fuzzy model produces results with a maximum difference of 6 %. The mean overall difference is 3%. Thus the output from the fuzzy model can be considered to be comparative to Flemming's output.

4.9. Application of the fuzzy model

The aim of the fuzzy system has been to replace the rigid data requirements of the Flemming model. Data for the fuzzy model is obtained from the plant operator. The fuzzy questions and options, as illustrated in this chapter, were compiled into an operator-based questionnaire, see Appendix B2. For the purpose of simplifying data capturing and data manipulation the questionnaire together with the fuzzy manipulation, illustrated above, was programmed in Visual Basic, see Appendix B3.

4.10. Conclusion

This chapter has dealt with the evaluation of the different sections of the plant using fuzzy logic. The categories of water and chemical consumption are addressed separately in subsequent chapters.

The fuzzy logic model allows for the evaluation of the cleaner production status of an electroplating facility, which was always difficult to conduct. The model performs exceptionally well especially when the available production and environmental data is incomplete, imprecise, and uncertain. The model is able to use operator level inputs to establish a comprehensive cleaner production status. It is particularly applicable to small or medium-sized plants where environmental auditing expertise is always insufficient. The fuzzy-logic-based decision analysis approach described in this chapter demonstrates an effective way for fast and systematic assessment of plant practice. This approach is applicable to any type of plating lines with any capacity.

The cleaner production evaluation is by no means complete and subsequent chapters deals with the quantification of the various processes and their efficiencies. The next chapter deals with the development of the acid cleaning model.

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CHAPTER FIVE

ACID CLEANING MODEL DEVELOPMENT

This chapter details the development of the first of the mathematical models i.e. the acid cleaning model. The model focuses on using weekly operator acid dosing to determine the plant production, in meters square. The acid-cleaning model is developed using a factorial experimental design as detailed in section 5.3. The experimentation for the model is carried out on a pilot plant, detailed in section 5.4. The model is verified using data from the database of companies, section 5.7. A Monte Carlo simulation illustrating the effect of input variability is detailed in section 5.9. Section 5.10 details the application of the model for cleaner production evaluation.

5.1. Introduction

The fuzzy logic model developed in Chapter 4 does not quantify exact potential chemical/water savings. Quantification of the exact potential savings would strongly encourage plating companies to adopt cleaner production. This study now aims at providing models that support the quantification of potential savings by modeling individual processes and comparing current plant practices to ideal operations. The models developed focuses on the use of non-rigid data in the form of operator inputs for model development.

The models in this thesis were developed based on data obtained from a factorial experimental design. It can be argued that a more detailed experimental design would have improved accuracy. However, it must be stated that the purpose of this study is to develop a tool for CP evaluation. This tool has to have an engineering level of accuracy and be simplistic in its approach.

The development of the acid cleaning, degreaser and zinc models, developed in this thesis, were based on typical plant operating conditions. They were validated by inputting plant data from previous audits i.e. the database. The models, once validated, were applied to predict optimum operating conditions. These were used as the CP chemical consumption. The actual consumption entered by the operator is compared to these model outputs. The difference was considered to be the potential CP saving.

The purpose of this acid cleaning model is twofold; firstly the acid-cleaning model is required to predict optimum operation of the acid tank. This is essential for cleaner production. The second and more important use of the acid-cleaning model is its use to determine the plant production in terms of surface area of metal plated. It must be noted that in Chapter 3, determining the production surface area, was identified as the data requirement which was the greatest challenge obtaining.

Due to the nature of the process and input data variations there are large changes in the operating variables. Hence, the validity of the acid-cleaning model was reinforced by the application of the Monte Carlo technique. The Monte Carlo technique was used to integrate the variable variations into the acid-cleaning model.

5.2. Background

Preparation of the metal surface for electroplating consists of two processes. The first is the removal of oil (known as degreasing) and the second is the acid cleaning process. The aim of this chapter is to discuss the investigation into the acid cleaning process. This process is normally referred to as pickling. The method of cleaning metallic surfaces by immersion in acid[1] is termed pickling

The metal surface needs to be acid cleaned due to the formation of “rust”. If this rust is not properly removed the integrity of the plating is compromised. This results in poor adhesion of the plated metal onto its substrate.

The formation of rust occurs due to various machining processes that the metal has undergone. This is typical of all surfaces to be plated as they have been manufactured by heating/cooling and cutting processes. When steel or iron is heated and allowed to cool, unless this cooling takes place in an atmosphere free from oxygen, a scale layer of oxide is formed.[1]

With abundant oxygen supply and heat, the oxide layer is in the form of Fe_2O_3 or Fe_3O_4 and sometimes a little FeO[2]. Thus prior to being plated the metal is subject to corrosion. Corrosion results from the presence of water, air, moisture and perhaps some acids. It can be stated that a piece of steel supports various iron oxides. Hoerle[3] investigated some of the oxides of iron, see Table 5.1

Table 5.1: Some of the oxides of iron[3]

Composition	**Name**	**Crystal System**
Fe_3O_4	Magnetite	Cubic(Spinel)
γ-Fe_2O_3	Maghemite	Cubic(spinel)
α-FeOOH	Goethite	Orthorhombic
γ-FeOOH	Lepidocrocite	Orthorhombic
β-FeOOH	Akaganeite	Tetragonal
γ-Fe-OH-OH	Reduced lepidocrocite	Orthorhombic
$Fe(OH)_2$	Ferrous hydroxide	Hexagonal

There have been various studies on rust formation[4,5] on metal surfaces. These studies have led to the development of complex models on rust formation. It is not the aim of this study to reproduce detailed models with high levels of precision but to produce a model that is representative of typical plating conditions.

Hoerle[3] identified Fe_2O_3 as the major oxide formed on post-machined components. Based on this reaction, equation 5.3 was used as a basis for the reaction calculations for the purpose of this study.

The reactions for iron and sulfuric acid can be summarized as[6,7]:

$$Fe + H_2SO_4 \Rightarrow FeSO_4 + H_2 \quad (5.1)$$

$$FeO + H_2SO_4 \Rightarrow FeSO_4 + H_2O \quad (5.2)$$

$$Fe_2O_3 + 3H_2SO_4 \Rightarrow Fe_2(SO_4)_3 + 3H_2O \quad (5.3)$$

$$Fe_3O_2 + 4H_2SO_4 \Rightarrow Fe_2(SO_4)_3 + FeSO_4 + 4H_2O \quad (5.4)$$

5.2.1. Rust removal by sulfuric Acid

In the typical surface finishing company rust removal is achieved by using either sulfuric or hydrochloric acid. From the database of 25 companies reviewed, 15 used sulfuric acid for metal pickling. Hence for the purpose of model development, the pickling model was developed around the use of sulfuric acid.

5.3. The variables affecting the rate of cleaning

The rate at which the acid is able to remove the rust and surface clean the metal is dependent on various variables. For the purpose of the acid-cleaning model development the variables that were considered to effect the chemical reaction were; temperature, concentration of the contaminant, concentration of the acid, time and inhibitor concentration. The following justifications were used for the use of these variables:

5.3.1. Dissolved iron content of the solution

Iron is considered to be a contaminant in the pickling process. The amount of iron in solution is critical to the solution effectiveness. Current practice at electroplating facilities is to dump the acids with high iron content. In experiments conducted by Marcus e*t al*[7,8,9] it was found that initial reaction rate increases with low iron contamination. These experiments also indicated lower reaction rates as the iron content increased. Markus[9] carried out experiments with iron content in the range 0.1 to 0.3 mol/ℓ to reinforce these theories.

The acid tank, at plating facilities start with zero iron content and is usually dumped when the iron content renders the acid ineffective. Large amounts of metal sludge forms at the bottom of the tank, as the iron content increases.

5.3.2. Acid concentration

Experiments conducted by Quraishi[10] indicate that the acid concentration has a significant effect on the pickling reaction. Markus[9] also indicates that the acid concentration effects the ferrous reaction. Since it is common practice at plating facilities to increase or use higher acid concentrations for "dirtier parts", the concentration of the acid was considered to be a variable for experimentation.

5.3.3. Temperature

According to Quraishi *et al* [10,11,12] experiments with sulfuric acid and iron are highly dependent on the reaction temperature. This was confirmed by Markus and Rubisov as the results from trials at elevated temperature, 75 to 95 degrees Celsius, indicated that together with acid concentration, temperature had a significant effect on the reaction rate. Since most acid cleaning solutions are operated at elevated temperatures and concentration, it was appropriate to use temperature as a variable in experiments.

5.3.4. Inhibitor

The inhibitor is added to the acid solution to prevent the attack of the acid on the pure iron i.e. the acid would attack the iron oxides only. Due to cost, the acid used by plating companies is not always a specifically designed proprietary chemical. Some plating companies use pure acid without inhibitors whilst others add their own inhibitors to the acid. This results in variations in the acid/ metal reactions. The amount of inhibitor dictates the effectiveness of the acid in removing oxides/ metal and is hence crucial to the acid-cleaning model.

5.3.5. Time

Operational practices and the condition of the pre-cleaned metal surface vary significantly. This results in a variation in the time the metal spends in the acid tank. Ideally the reaction with the acid stops, once the metal oxide is removed. In the absence of an inhibitor the acid would continue to react with the metal as time is increased i.e. the amount of iron removed is dependent on the time spent by the metal in the acid solution. The metal contaminant concentration in the acid solution effects the reaction rates, prolonged acid pickling times are required as the contaminant increases. Thus the time spent in the acid solution was a variable in the experiment.

5.4. Experimental

The electroplating process involves various chemical reactions which could potentially be modeled using reaction kinetics etc. This would entail detailed investigations and experimentations on reactions and variable effects. This could have resulted in a rather drawn out exercise, which is not the main focus of this study. This study focuses on providing a model that would conduct a cleaner production assessment at a plating company with minimum data requirements, within minimum time, requiring minimum expertise. Due to these constraints, and the need to develop and test the potential of a reduced data approach to cleaner production evaluations, the factorial approach was used for model development.

5.4.1. Acid experimentation

Electroplating companies operate at various concentrations of acids, 60-120 g/ℓ and at various temperatures ranging from ambient to 80 deg C. The instantaneous concentration of iron in solution changes with every piece pickled. The acid concentration changes as the reaction proceeds. Topping up of chemicals usually occurs once per week. The impact of drag-out losses and topping up after drag-out is a significant factor to consider in the acid reaction as it impacts on the acid concentration.

This study aims at predicting the operation of the acid tank at any electroplating facility. Since these facilities operate within a large range of variability, the model must have the ability to accommodate all variable variations together with their interactive effects. Hence the fractional factorial[13] method was employed for the experiments. It would have been ideal to conduct a detailed study into the reactions but due to various limitations including, the need for a user-friendly model and time constraints, the factorial method was chosen as the most appropriate.

Appendix C1 details the factorial design that was used to determine the acid – cleaning model. The variables were acid concentration (variable 1), temperature (variable 2), contaminant (variable 3), inhibitor concentration (variable 4) and time (variable 5)

In accordance with the factorial methodology, variables were given a maximum and a minimum limit, see Table 5.2. This was determined from the data obtained from the companies via the review process[13]. The range that was used for the above reactions are listed in Table 5.2.

Table 5.2: Trial data values for factorial experiments

Variable	Minimum Value (-1)	Maximum Value(+1)
Acid	60 g/ℓ	120 g/ℓ
Temperature	25 °C	45 °C
Iron contaminant	0	1 g/ℓ
Inhibitor (Actipret BTS 40)	0	5 g/ℓ
Time	180 s	600 s

The acid experiments were conducted on a pilot plant as illustrated in Figure 5.1 and 5.2. The plant was designed and constructed for this research. The plant consists of a degreaser system and an acid system. The plates to be acid cleaned were precision cut to ensure size consistency. They were then individually weighed before each trial using a four-digit laboratory balance. The plates were pre-cleaned using the degreaser. They were then rinsed, dried and reweighed.

The pilot plant included a temperature control bath that was used to maintain the acid temperature. The metal pieces were cut to size (75mm by 50 mm). The solutions were prepared and placed in the acid tank for the specified times. The amount of iron reacted was determined by the mass difference of the metal piece before and after the experiment. A four decimal place mass balance was used to determine these mass changes. All pieces, once reacted, were dried to ensure no liquid remained on the metal as this would impact on the mass of metal reacted.

Figure 5.1: P &ID of pilot plant-Acid component

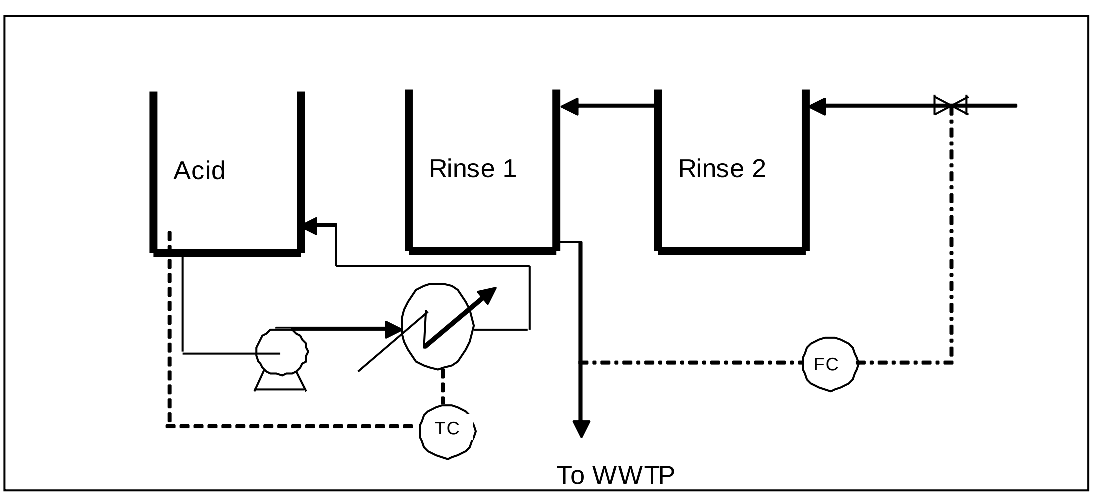
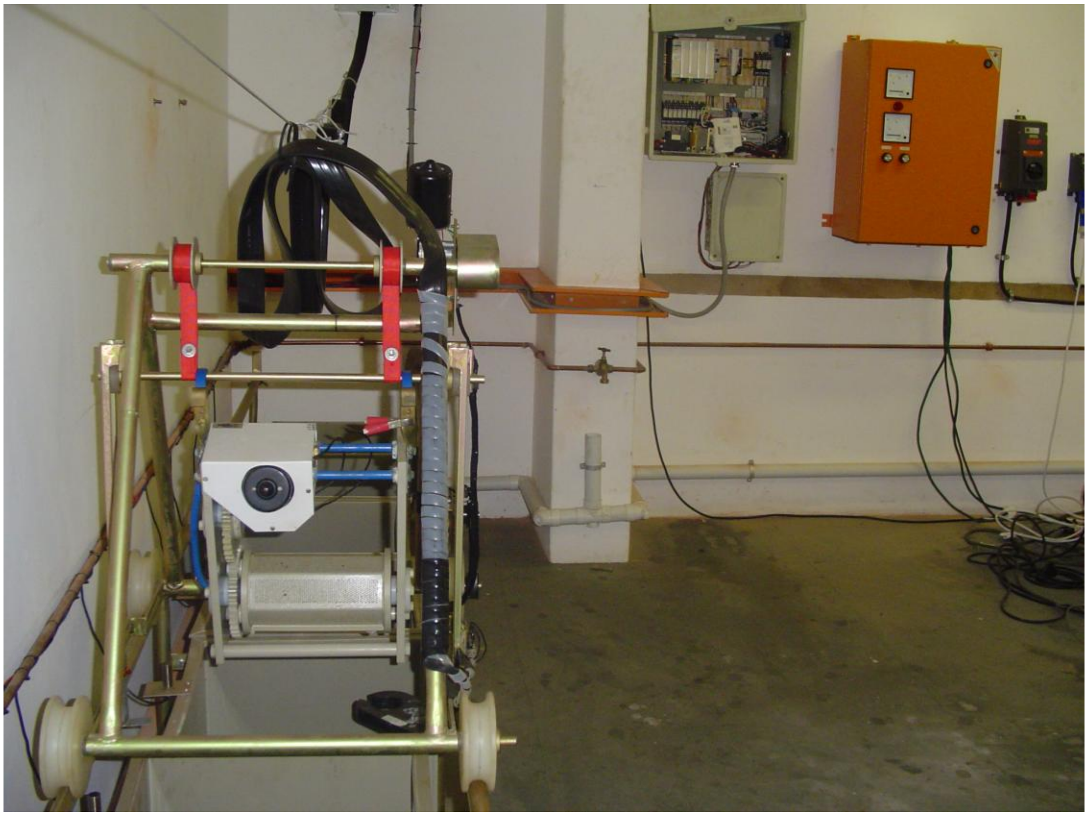


Figure 5.2: Photo of pilot plant



Experiments were conducted over a period of three weeks with repeatability's conducted with fresh solutions. The trials were conducted in triplicate to ensure accuracy.

5.5. Experimental Results

The results from the trials indicate the rate of mass loss. This is a direct indication of the mass of metal/ metal oxide reacted. The detailed results are attached in Appendix C2**.**

In order to ensure the integrity of the acid experiment, all trial results were statistically verified. The data points that fell within the statistical control limits were used for model development, see Appendix C2**.**

5.5.1. Interpretation of results

The experimental results were substituted in the factorial model and manipulated to determine the co-efficients for the effects and there interactions, see Appendix C3 for detailed calculations.

The factorial methodology is able to convert the impact of different variable changes into a representative equation. The statistical significance of the effects and interactions were evaluated. At 95% confidence, the interaction between, acid+contaminant, contaminant+time, temperature+inhibitor, time+temperature, acid+inhibitor, inhibitor+contaminant, contaminant+temperature, inhibitor+time were found to be statistically insignificant. Removing this from the overall factorial equation, representing the metal depletion, results in the following equation:

$$M_D = 136.27 + 9.02 * C^A_{H2SO4} + 17.44 * C^A_{Fe} - 10.4 * T^A - 18.97 * IN^A - 23.66 * t^A + (17.14 * C^A_{H2SO4} * C^A_{Fe}) - (16.85 * C^A_{H2SO4} * \mathrm{IN}^A) - (25.384 * T^A * \mathrm{IN}^A) \quad (5.5)$$

Where:

C^A_{H2SO4} =Concentration of acid(g/ℓ)

C^A_{Fe} =Concentration of Iron(g/ℓ)

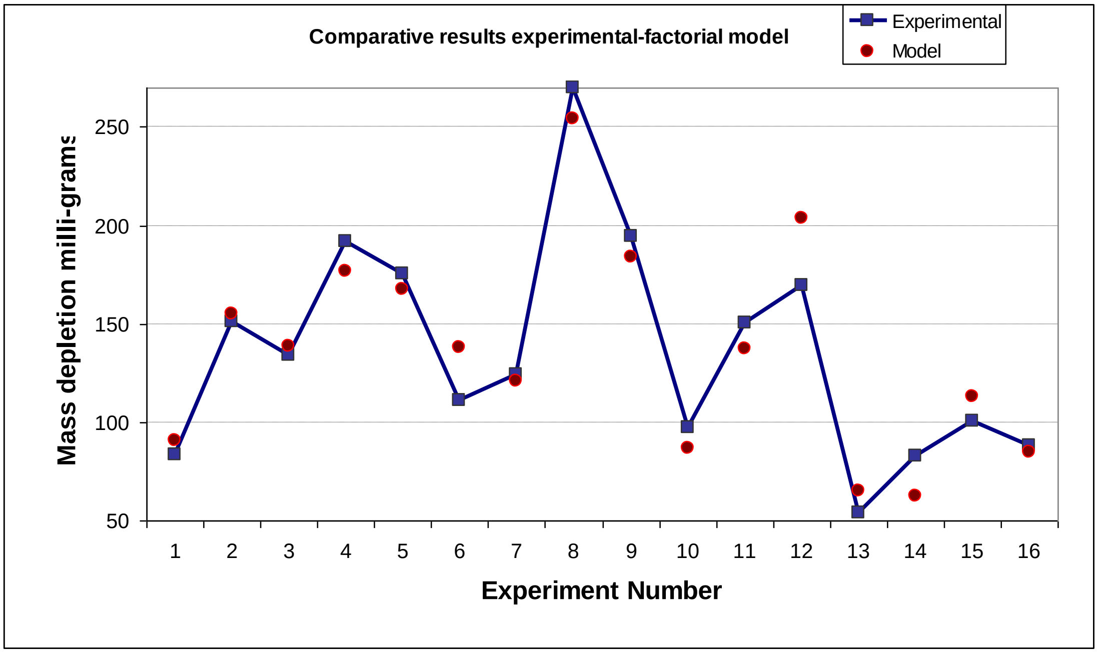
T^A =Temperature of bath(C^0)

IN^A =Inhibitor concentration (g/ℓ)

t^A =Time(s)

It can be seen that the resulting equation after statistical corrections, is a function of all the variables discussed previously, including the statistically significant interactive effects. The equation outputs the metal mass depleted under the specified conditions. The polynomial model, Equation 5.5, represents the experimental data. Figure 5.3 illustrates the comparison of results for each trial undertaken and results from the developed model. From Figure 5.3 it is clearly seen that the model is a reasonable representation of the experimental data. It can thus be stated that the equation is representative.

Figure 5.3: Comparison between model output and experimental results



5.6. Model development

If the operating conditions are known then it can be stated that Equation 5.5 can be used to predict the rate of metal depletion at plating facilities. Extracting operating data from the database of companies, the above model can be applied to compare model outputs to that of the database.

The operating conditions of the acid tank at the selected electroplating facility were entered into equation 5.5. These include; temperature, acid concentration, surface area/jig, contaminant concentration, inhibitor status and time in the acid tank. These variables were substituted into equation 5.5 and the mass of iron removed from the surface was determined.

M_d is mass of metal removed. The consumption of acid can be calculated by determining the mass change in metal i.e. the metal that has reacted is now in solution and hence this has consumed a specific amount of acid.

$$Fe_2O_3 + 3H_2SO_4 \Rightarrow Fe_2(SO_4)_3 + 3H_2O \qquad (5.3)$$

For the purpose of our calculations the average molecular weight of the iron oxide to be removed, would be taken as 179.6. This is determined from the reaction equation. (equation 5.3) i.e. three moles of acid is consumed as per mole of metal reacted. Since the mass of metal reacted is known the number of moles of acid consumed is calculated.

From a newly made up acid solution:

$$C^{t1}_{H2SO4} = C^{0}_{H2SO4} - C^{r}_{H2SO4} \qquad (5.6)$$

Where:

C^{0}_{H2SO4} = Initial acid Concentration of acid(g/ ℓ)

C^{r}_{H2SO4} = Acid reacted (g/ ℓ)

C^{t1}_{H2SO4} = New acid concentration (g/ ℓ)

The jig/barrel is then removed from the bath. The drag-out of acid and contaminant is calculated based on the volume dragged-out.

$$C^{t2}_{H2SO4} = C^{t1}_{H2SO4} - Do * C^{t1}_{H2SO4} \qquad (5.7)$$

Where:

Do=Drag-out(l)

C^{t2}_{H2SO4} = Acid concentration after drag-out (g/ ℓ)

The increase in iron concentration in the acid is calculated from the mass depletion equation. The state of the acid after the jig/barrel is removed is thus determined.

$$C^{t1}_{Fe} = C^{0}_{Fe} + C^{r}_{Fe} \qquad (5.8)$$

Where:

C^{0}_{Fe} = Initial iron Concentration in acid (g/ ℓ)

C_{Fe}^{r} = Iron reacted from metal surface (g)

C_{Fe}^{t1} = New iron concentration (g/ ℓ)

This new condition for the acid solution is substituted into equation 5.5 to determine the condition of the acid after the second jig/barrel. This is continued for the period indicated by the plant operator i.e. if top-up of acid occurs then the acid concentration has to be adjusted and the process continued. The acid concentration is adjusted after every jig together with the contaminant concentration i.e. iron content is continuously increasing as the acid is used and hence results in a lower reaction rate. Due to the repetitive and evolving nature of the process, it would be ideally represented in a simulation.

5.7. Model validation

The model developed needed to be evaluated using existing company data to determine its accuracy. Hence spreadsheets were developed to test data of individual companies against the model. A sample run is attached in Appendix C4.

5.7.1. Verification of model using database results

The model is verified based on a weekly dosing system. This is common practice at all electroplating facilities. The chemical supplier samples the acid tank once per week. The topping up of acid is based on this analysis.

The data requirements for Equation 5.5 were extracted from the database of companies reviewed. This includes the acid tank concentration, temperature, time in the acid tank and tank volume. The annual surface area of the company is divided by the number of production weeks to determine the weekly production in square meters. This surface area is used together with the number of jigs/week to calculate the individual jig surface area. All the tank conditions were inputted into the model. Assuming there are n barrels/week this calculation would be done n times to produce the acid tank condition at the end of the week i.e. the calculations illustrated in section 5.6 is carried out.

Thus determining the acid consumption, using the proposed model, is carried out for all the companies in the database. The following table indicates the data obtained from companies during the database reviewing process as compared to the model outputs.

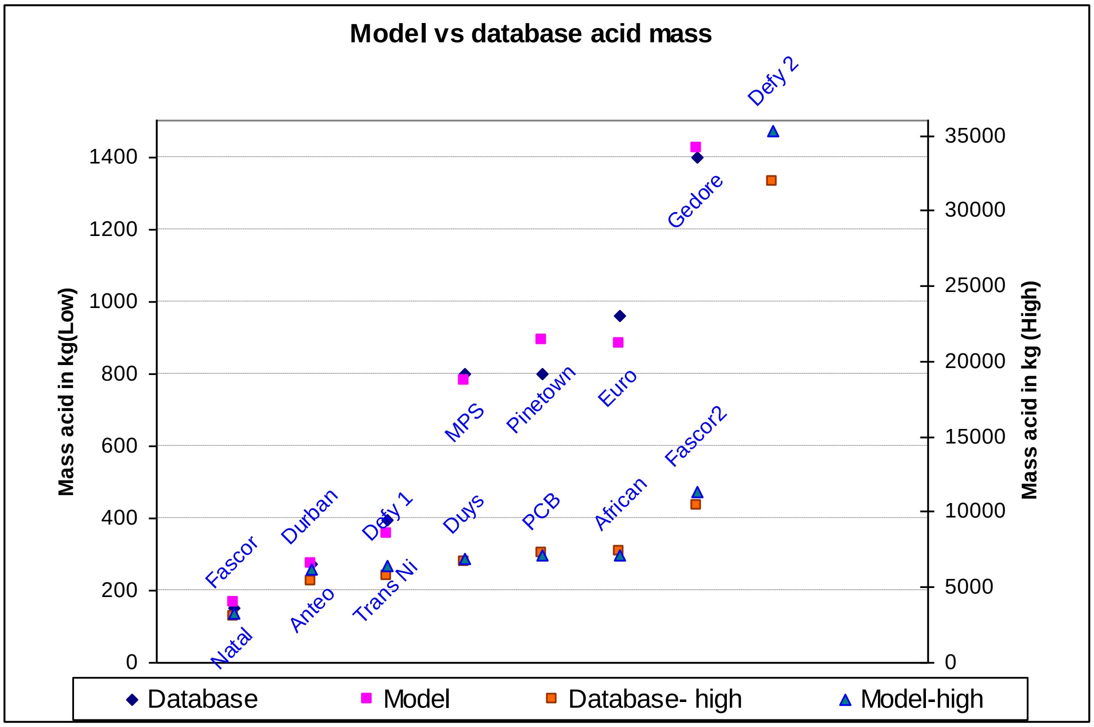
Table 5.3: Table of comparison, acid consumption model vs database

Company	Production	Acid consumption (Kg)		Percentage
	Sq meters	Database	Model output	Error
African	54001	7103	7359	-3.6
Anteo	2200	275	274	0.4
Defy 1	25344	6400	5797	9.4
Defy 2	1100000	35340	31955	9.6
Durban	20496	6160	5371	12.8
Duys	6522	6840	6653	2.7
Euro	4000	960	881	8.2
Fascor 1	30000	3302	3094	6.3
Fascor 2	157283	11280	10403	7.8
Gedore	33689	1400	1424	-1.7
MPS	12219	800	778	2.8
Natal	950	150	167	-11.3
PCB	20323	7103	7280	-2.5
Pinetown	6806	800	891	-11.4
Trans Ni	11222	395	356	9.9

From Table 5.3 above, it can be deduced that the model is able to predict accurately the acid consumption at an electroplating facility if the plant operating conditions are known. The mean difference between the model and the database values is calculated to be 2.9%. This error could be as a result of model input variability. This input variability is dealt with using the Monte Carlo technique later in this chapter.

Figure 5.4 is a graphical representation of the model results as compared to the actual database values for acid consumption. Due to the large range of values for the company acid consumption data is separated into the larger (>1400kg) and the smaller (<1400kg) acid consumption.

Figure 5.4: Illustration of the comparison between the database acid consumption and the model acid consumption.



5.7.2. Model application-Determining surface area

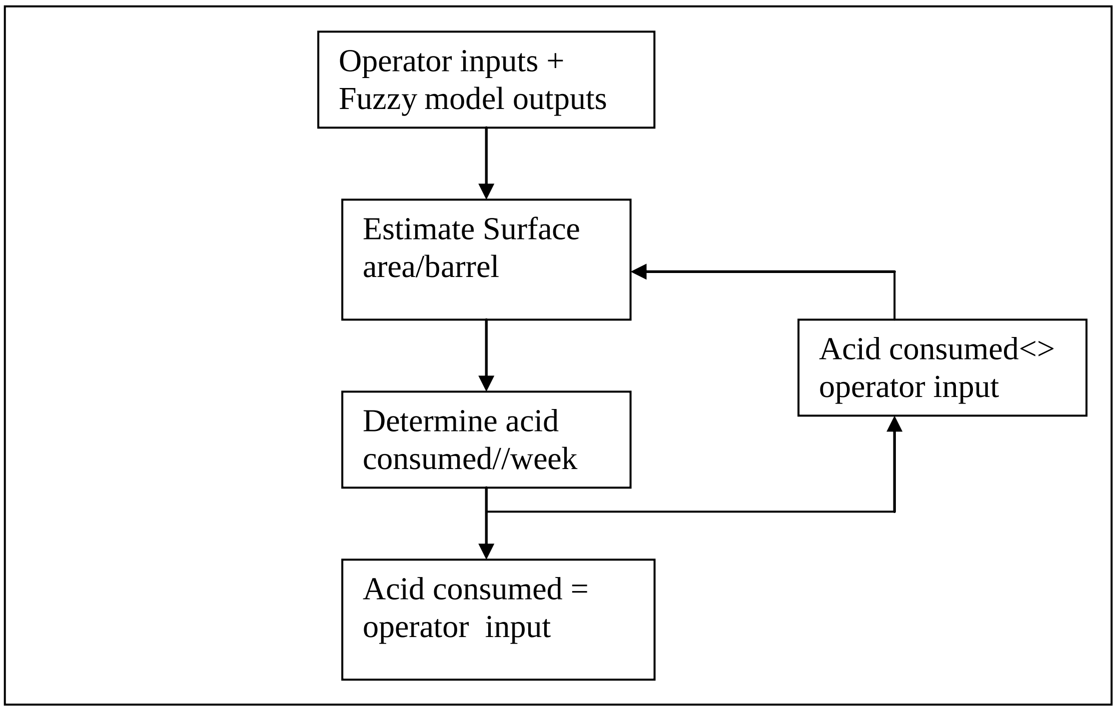
The model has been proven to be accurate to determine acid consumptions. The model developed has surface area as an input variable and is able to calculate the acid consumption. This can be used to develop the final system. In the final, proposed model, the surface area is not known. It is intended to determine the surface area from the acid-cleaning model. This can be done by rearranging Equation 5.5, with acid concentration as the subject of the formula.

The weekly acid dosed is known by the operator and hence would be ideally suited as an input for the system. Thus the requirement is to input the average weekly chemical consumption into the model. Since the operator conducts chemical dosing on a weekly basis, this input is harnessed and used for the model. This is also in line with the overall aim of the holistic model i.e. the use of operator level inputs. So a modified model is developed that accepts all input variables as previously done, but now, instead of the surface area as an input, the weekly acid consumption is entered.

The drag-out is dependent on plant operations (size, shape, and drip-time) and is obtained from the fuzzy model detailed in Chapter 4. The acid temperature and operations time is obtained as inputs from the operator and can be considered to be relatively constant. The acid, iron and inhibitor concentration is changing as the acid is used in the process

The modeling now commences by estimating the acid consumption for a single jig. From this the metal depletion can be determined. Equation 5.5 is rearranged to make the surface area the subject of the formula. These values are entered into a rearranged equation 5.5 to generate an estimated surface area/jig.

Figure 5.5: Surface area calculation flowchart



The model requires the number of jigs/week or per day. The model determines the acid consumption for the week using the estimated surface area. It then compares this acid consumption to the operator value. If it is incorrect it adjusts the estimated barrel surface area. This continues until the model generates the same amount of acid consumed as indicated by the operator, See Figure 5.5.

The model can hence produce the required surface area. The challenge however was to validate the model with realistic conditions i.e. there is various external influences on the variables modeled and it would be ideal to investigate the effects of these variable changes.

The model had to be presented in a user friendly and cost effective package, this was in keeping with the main aim of the research project. The system developed for a cleaner production assessment had to be easily applied to the local industry. This implies the packaging of the computational model into a user friendly, accessible interface. It was decided to use visual basic as the program base. Hence the acid-cleaning model was programmed into visual basic so as to effectively carry out the task of data gathering from the operators. See Appendix C5 for visual basic screens and program.

5.8. Mat Lab Model

A major consideration for the establishment of the model is the uncertainties of the input data. Plant data would be based on operator inputs and hence are subjective. The plant status may also change within a certain limit, hence this needs to be accommodated, within the model. Section 5.7.1 of this study determined the mean difference between the model and the database values as 2.9%, this can be considered to account for the variability. As an illustration of the models response to input variability the Monte Carlo simulation is used. For the purpose of the Monte Carlo the input variables were changed, randomly, within a range from 0 to a maximum of 2.9% of its original value.

The variables that were considered for the uncertainties were:

- Temperature
- Acid concentration
- Contaminant
- Pickling time
- Inhibitor concentration

5.8.1. Temperature

The temperature in the acid tank may vary due to various factors, among these factors are the environmental temperature, topping up rate, heater control, production rate and operation influences.

The tank temperature may increase or decrease based on the weather conditions, wind factors and convective losses. This means that minor changes in temperature can be encountered due to outside climate changes.

The acid tank is subjective to drag-out, drag-in and receives cold components from the previous tank. This would have a significant effect on the temperature of the acid tank. The acid tank may be heated after a weekend or night of non production.

The temperature in the acid tank is maintained by the use of electrical heaters. These heaters are controlled based on a control loop. Variations in temperature would occur depending on the ability of the control system to manage all the disturbances.

5.8.2. Concentration

The acid-cleaning model calculates the evolution of acid tank concentration. This indicates a change in tank concentration depending on measurement and dosing. Other factors such as drag-in and drag-out also influence the concentration in the acid tank.

5.8.3. Contaminant

The model indicates an evolution of contaminant in the acid tank. It is known that the contaminant builds up in the acid tank over a period of time until it is unacceptably high and has to be dumped. Metal pieces sometimes fall into the acid tank causing spikes in concentration of contaminant.

5.8.4. Time

Most plating plants work on a schedule system and this implies that operators/cranes would not be able to remove a jig/barrel from a plating bath at the precise allocated time. This may occur due to PLC schedules or due to operator availability to remove the barrel/jig from the acid tank.

5.8.5. Surface area

The program assumes an initial surface area/jig and then depending on the iteration, increases or decreases the surface area. The operator loading of the barrel/jig is also an important factor to consider as components vary, and hence individual barrel surface areas would change.

The Mat Lab program was developed for the acid-cleaning model. The Monte Carlo technique can be applied to the Mat Lab program with variable changes of up to 2.9%. The variable changes are obtained using Mat Lab random numbers.

5.8.6. Random numbers

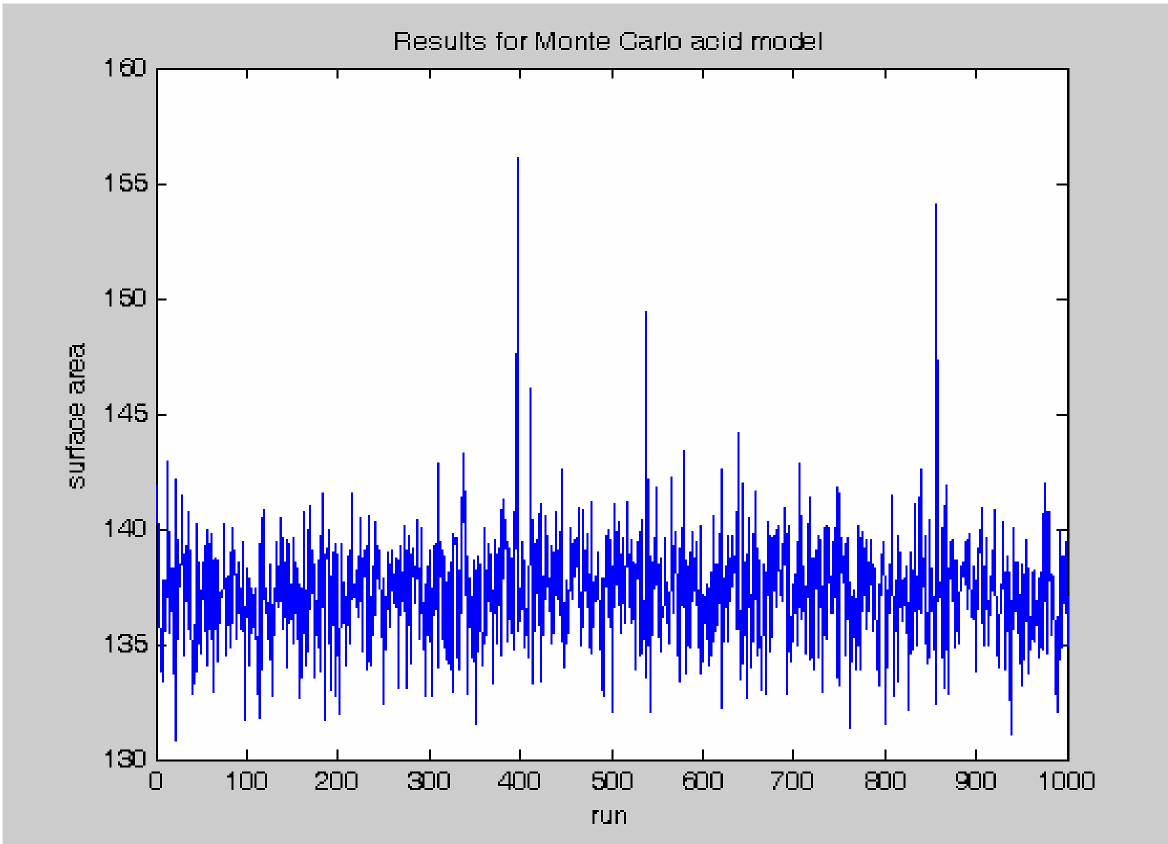
The aim is to run the model to determine the surface area but to randomly change input variables within the range described above. The "randn" function from Mat Lab generates random numbers, which are normally distributed with a mean of zero and a variance and standard deviation of one.

The initial estimate surface area/barrel is assumed. This initial estimate is used to generate the metal depletion, which is then used in the acid equation to generate the acid consumption/barrel. The consumption is calculated considering the number of barrels plated /week and the total acid consumed is calculated. This is then compared to the operator dosed acid and the surface area adjusted until they are equal i.e. as per Figure 5.5 but with random variations in variables.

5.9. Mat Lab results

Figure 5.6 is the results from the initial simulation. From the database, the actual weekly surface area for the company under consideration is 141.8 m^2. The results from Mat Lab indicate that the mean surface area after 1000 runs is 137.2 m^2 with a standard deviation of 2.3.

Figure 5.6: Mat Lab Monte Carlo results for surface area



From the above it can be seen that the acid-cleaning model developed is able to successfully predict the surface area plated at an electroplating facility with a high level of accuracy. The model is able to accommodate plant/operational variations. The model developed only requires basic operator inputs in order to complete the calculations for surface area. The surface area predicted in this chapter would be used as the production rate for the other models developed in this thesis.

As a comparison of relative accuracy, during the data collection phase of this study, it was found that the surface area determined by different auditors were significantly different.

The largest difference between the two auditors for surface area was 40% i.e. the second auditor calculated the surface area to be 40% greater than the first.

With the current model it can be seen that the standard deviation is low(2.3%). The model generates an error, which is lower than the previous methods of obtaining surface area. Thus the current model can be considered to be more reliable for surface area prediction.

5.10. Model application for cleaner production savings

The model developed can determine the plant production. This production can be used together with the acid-cleaning model, but with CP operations, to determine the minimum acid usage at the facility under consideration. The difference between the consumption indicated by the operator and the minimum consumption would be the potential cleaner production saving.

For the acid system typical areas for improvements for cleaner production would include; drag-out reduction, drip time improvements and premature dumping. The model can be used with to determine the effect of extended drip times and drag-out. The model can also determine the level of contamination, which aids in determining when disposal should occur.

As an illustration of a cleaner production acid system the above simulation is run but with a drag-out of 0.16 ℓ/m^2 the weekly liquid dragged out reduces by 34 liters. With an acid concentration of 100 g/ℓ the plant acid consumption would reduces by 3.4kg/week.

The model is also able to predict the build up of iron in the acid tank. For the above case the initial iron content of the acid is inputted as 1 g/ℓ. After running the acid tank for one week the acid contamination was 1.444 g/ℓ. These statistics assists with the prediction of disposal times for the acid.

5.11. Conclusion

The chapter on the acid-cleaning model is critical to the development of the comprehensive cleaner production tool. The usage of the outputs from the acid-cleaning model dictates the integrity of the rest of the model. It can be clearly seen from the model developed, that the acid-cleaning model is accurate when tested against database values. It can thus be concluded that the acid-cleaning model developed is successful in predicting the operations in the acid tank and more importantly, is able to predict the surface area passing through a production facility.

The acid-cleaning model is one of the three process models proposed in this study. The surface area determined in the acid-cleaning model would be used to determine the other process chemical consumptions.

The degreaser model, which is proposed in the next chapter, uses the surface area calculated by the acid-cleaning model.

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CHAPTER SIX

THE DEGREASER MODEL

Chapter six details the development of a degreaser model. The degreaser model focuses on determining the concentrations of components of the degreaser with an aim of predicting the instantaneous degreaser operation. The model was based on a factorial experimental design, as detailed in section 6.5. Section 6.8 details the verification of the model using data from the database of companies. Once verified, the model was used to predict ideal (cleaner production) degreaser consumption. Thus by applying the model, for cleaner production, the difference between current and the ideal can be calculated.

6.1. Introduction

The purpose of the degreaser tank is to remove oil from the surface of the metal to be plated. The degreaser chemical is usually dumped when, oil/grease, contamination becomes too high. Thus a degreaser model must predict the effectiveness of the degreaser solution based on the variables affecting its operation.

The aim of this chapter is to generate a model to predict the operations of the degreaser system. This includes chemical and contaminant concentrations, dumping times, drag out losses etc. The degreaser system can be described as chemically complex and hence a factorial experimental design was used for model development.

The model, once developed, was validated using actual plant data. This was done by comparing the model output to values from the database of companies. The model, once proven to be able to predict degreaser operation, can be used to generate the ideal degreaser chemical consumption i.e. predicts cleaner production. The difference between current consumptions and the cleaner production consumption can be described as the potential savings.

Similar to the acid, the degreaser tank is subject to various variations. The variations in operator and process input variables were accounted for using the Monte Carlo technique. This simulation was conducted in Mat Lab.

6.2. Background

This chapter now focuses on model development to determine the ideal degreaser tank chemical usage. This ideal consumption is based on cleaner production operating conditions, e.g. reduced drag-out/drag-in, optimum temperatures and concentration control. The difference between this ideal and actual plant chemical usage, as provided by the operator, is the potential cleaner production saving.

The electro cleaner is used to clean the oil from the surface of the metal to be plated. The oil has either been used as a corrosion prevention measure or has been left behind during the manufacturing process. Oil is used as a cutting fluid. The dirt and grease, otherwise known as the cutting lubricants results from machining, stamping, spinning, pressing or polishing.[1] The cutting lubricants can be further categorized into oils, emulsions and water based products.

Lubrication[2] is required during manufacturing to reduce excessive tool wear. Lubricants used during manufacturing and for corrosion prevention has a direct bearing on the anti corrosion effect of the metal[3]. The post-manufactured components are exposed to the elements for long periods of time before they are surface treated. These surfaces are preserved using oil as a temporary protective layer.

It is common for oil to be used for the purpose of corrosion inhibition as the oil has the property of repelling water. Some oils have the added protection of corrosion resistant additives.[2,4] Corrosion resistant coating are common in environments of high salts,[4,5] coastal areas, high acid medium etc. Due to the variation in manufacturers, all corrosion-inhibiting oils do not offer the same level of protection against rusting.[6]

The difficulty for surface treatment companies is the removal of the oil from the metal surface. This process is called cleaning or electro cleaning depending on the process adopted. The importance of perfect cleaning cannot be over emphasized, since effective plating occurs due to efficient cleaning.[1]

The lubricating oils and cutting oils that are used can be one of many thousands available from different manufacturers, each with their own unique properties. In order to determine the electro cleaning chemistry a working understanding of these oils is required. The coatings used are stated as being complex,[7] ranging from an n-paraffin, iso-parrafin, aromatic or a mixture of these structures. The molecular weight of these oils is varied.

6.3. The model

It is usually impossible for the plater to determine the cutting fluid type used or the rust preventative applied. This is due to the supply of pieces from various sources and the information supplied to platers is limited.

It was considered beyond the scope of this study to account for all the different types of oils used. For the purpose of this model it was assumed that an intermediate but representative oil type was used. The model was developed based on this assumption.

Since most cutting and lubricating fluids are mineral oils[2,8] with some additives it would be ideal to use the mineral oil category for our reaction. The composition of the oil, from literature was [2,8] $(C_{17}H_{35}COO)_3C_3H_5$

6.4. Oil removal-Electro cleaning

The types of electro-cleaners available vary[9] but the essential compositions are the same. The electro cleaner chemical is caustic based. The electro cleaner serves two functions i.e. chemical and mechanical removal of the surface oil. The gas bubbles that are formed, see reaction 6.1, 6.2, achieve mechanical cleaning. In this chapter chemical cleaning is considered in detail.

The reaction is essentially the electrolysis of water into oxygen and hydrogen. The reactions at the anode and cathode are:[10]

Cathode reaction

$$4H_2O + 4e^- \rightarrow 4OH^- + 2H_2 \qquad (6.1)$$

Anode reaction

$$4OH^{-} \rightarrow 2H_2O + O_2 + 4e^{-} \qquad (6.2)$$

From Equation 6.1 and 6.2 it can be seen that a large amount of oxygen and hydrogen gas evolved at the anode and cathode. This results in the lifting of the oil/ dirt from the surface of the piece being electro cleaned.

From Equation 6.1 and 6.2 it can be seen that the electrolysis reaction has no impact on the hydroxide ion concentration in the bath. The net result of reactions 6.1 and 6.2 is the depletion of water. Hence for the purpose of degreaser depletion, with regards to electrolysis, the degreaser caustic concentration is unaffected by the electrolysis reaction.

The main reaction for consumption of the degreaser caustic is the emulsification reaction:

$$(C_{17}H_{35}COO)_3C_3H_5 \;+\; 3NaOH_{(aq)} \;\rightarrow 3C_{17}H_{35}COO^{-}Na^{+} + C_3H_3(OH)_3 + H_{2O} \qquad (6.3)$$

Since the reaction requires 3 OH^- [11] molecules per single molecule, the ratio of oil removal to caustic consumption can be represented as.

$$A \;+\; 3B \;\rightarrow 3C$$

Where:

A=Oil

B = Caustic

This ratio was used for the purpose of calculations of consumption of degreaser chemicals i.e. caustic strength.

6.5. Experimental

The reactions above had to be considered in order to determine the operation of the electro cleaner. The model had to be developed, with due regard for all variables that would potentially effect the reactions. As for the acid model, the fractional factorial method, see Appendix D1, was used to determine the combined impact of all the variables on the reaction. The justifications for the variables investigated were:

6.5.1. Temperature

The saponification reaction is a chemical reaction and most chemical reactions depend on temperature. Most electro cleaning baths operate at elevated temperatures i.e. 65-85 degrees Celsius[12,13,14] however some operate at room temperature.[13,14] The aim of the higher temperatures is to aid in the reaction and also to ensure a more stable emulsion.[15,16] The fumes from the tanks are not a major issue as there are extractor systems to remove fumes. The evaporative losses of the liquid is made up as required. The operating ranges for the purpose of experiments were ambient to 65 degrees Celsius.

6.5.2. Oil content

From the above discussion it is obvious that the oil is the contaminant in the system. The degreaser contains chemical agents designed to ensure emulsification of this oil. As the oil concentration in the degreaser solution increases, the oil breaks out of solution resulting in an oil layer forming on the surface of the degreasing tank. This creates an operation problem i.e. although the parts are electro cleaned, in the bath, the oil attaches itself to the metal surface as it is withdrawn from the bath. Thus the oil concentration has to be considered for the purpose of experimentation on degreaser efficiency.

6.5.3. Current/voltage

The recommended amperage is 5-10 amps / square decimeter.[10,13] This by definition implies a dependency on surface area. It is known that the current is not adjusted for each jig although each jig may contain a different arrangement of pieces and hence a different surface area. This results in a varied current density. For the purpose of this model the current density was used as a variable due to the wide variation existing in industrial applications.

6.5.4. Time

As per Equation 6.1 and 6.2, it can be seen that a longer time in the bath would ensure more time for scrubbing of the metal surface by the gas evolved at the anode and cathode. The time spent in the electro cleaning tank can be between 1-5 minutes,[10,13] depending on the dirtiness of the parts. For the purpose of experimentation the shortest submerged time was 1 minute and the longest was 5 minutes.

6.5.5. Caustic concentration

Another major variable in chemical reactions is the chemical concentration. Since the caustic is the key chemical under consideration its concentration needs to be a variable. It is a well known fact that the degree of cleaning required determines the concentration of chemicals to be used. From company audits conducted for the database typical ranges are from 60 g/ℓ to 120 g/ℓ [10,13] This would be used for the experiments.

6.6. Experimentation

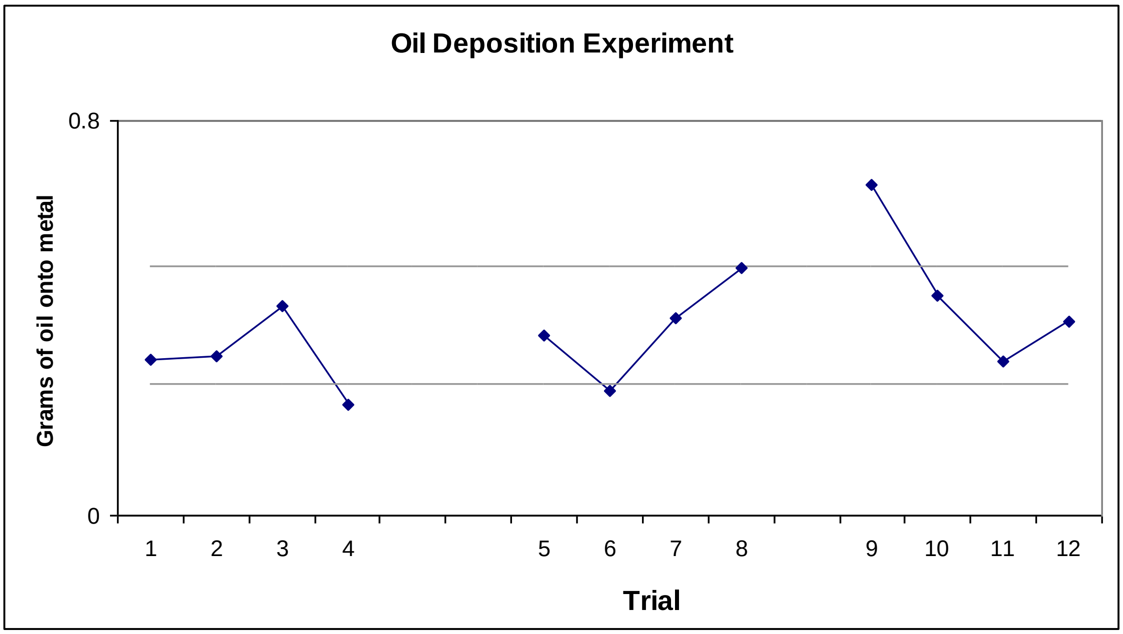
The above variables were used in the fractional factorial experimental protocol and experiments were carried out on the pilot plant in the laboratory. See Appendix D1 for factorial design for the degreaser experiments.

The greatest difficulty associated with the degreaser experiment was the determination of the exact amount of oil removed. The degreaser trials were conducted by artificially coating the metal surface with oil and then submerging the metal into the degreaser solution. Since the plates used for the experiments were of the same dimensions, it was assumed that the amount of oil deposited onto the plate had to be consistent. Due to this the experiments for the oil deposition onto the metal surface was carried out under very controlled conditions. The mass difference before and after was used to determine the oil removal efficiency. See Appendix D2 for detailed experimental procedure.

6.7. Experimental Results.

The amount of oil deposited and removed was monitored using quality control charts. This was to ensure experimental accuracy. The upper and lower limits for these charts were determined by using three standard deviations. See Appendix D3 for equation and control charts for all degreaser experiments. A typical run result is illustrated in Figure 6.1

Figure 6.1: Experimental control for oil deposition



The results for experiment 4, 6 and 9 fell out of the upper and lower control limit and were repeated. The results that fell within the band of three standard deviations were used as representing the results for that particular trial.

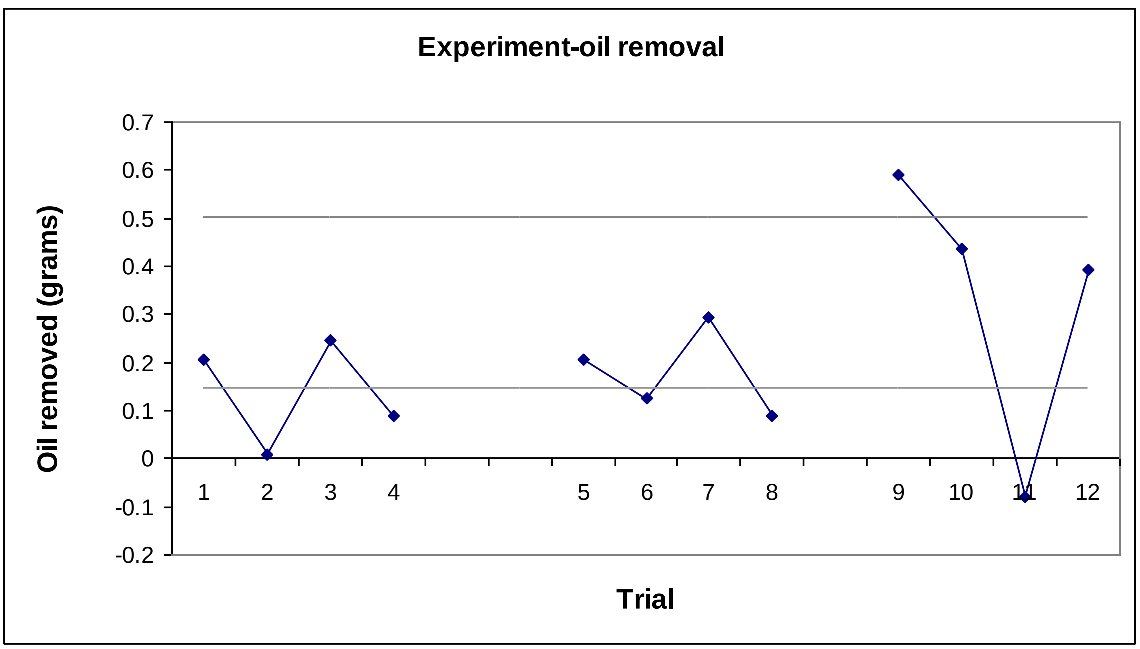
The oil removal results were also analyzed using quality charts with three standard deviations. Table 6.1 is a summary of results for experiment 1.

Table 6.1: Typical values for experimental results

Trial No.	Mass Metal	Oil (grams) Deposited	Oil degreased (grams)
1	23.6324	0.3147	0.2066
2	24.1723	0.3224	0.0081
3	24.0249	0.4233	0.2453
4	23.7419	0.2239	0.0879
5	24.5405	0.3664	0.2067
6	23.41113	0.254	0.1272
7	24.0862	0.3993	0.2924
8	24.3131	0.5032	0.0879
9	23.4855	0.6707	0.5934
10	23.5416	0.4445	0.4376
11	24.1435	0.3128	0.0091
12	24.5139	0.3942	0.3935
		UCL=0.505	**UCL=0.396**
		LCL=0.267	**LCL=0.039**
	Mean	0.386	0.217
	Range	0.445	0.672

Figure 6.2 illustrates the amount of oil removed from the individual test pieces during the electro-cleaning experiment. Test piece 2,4,6,8,9 and 10 were excluded due to these results falling out of the control limits.

Figure 6.2: Representation of the results from table 6.1 in the form of graphs



The results for the sixteen runs were entered into an excel spreadsheet; see Appendix D4 for detailed spreadsheet calculations. The factorial model equation was determined from the spreadsheet calculations. The results generate a linear model with 16 variables. The model was further refined by extracting only the significant variables. This was done using an analysis of variance at a 95 % confidence. The final equation representing the amount of oil removal is illustrated as Equation 6.4. It can be seen that the equation is dependent on all input variables.

$$O_R = S_A * (182.457 - (5.1612 * C_{Oil}^D) - (10.818 * O_{Oil}^D) - (24.505 * t^D) + 10.7581 * (C_{Oil}^D * T^D) \\ - (8.7055 * O_C^D * T^D) + 7.60675 * (C_{Oil}^D * A_M) + 29.5501 * (O_C * A_M) - 8.1726 * (T^D * A_M) \quad (6.4)$$

Where:

O_R=Oil removal(g)

C_{Oil}^D = Concentration of degreaser(g/ ℓ)

O_C^D = Concentration of oil in solution(g/ ℓ)

T^D =Degreaser temperature (^{0}C)

A_M^D =Power into bath(Amps)

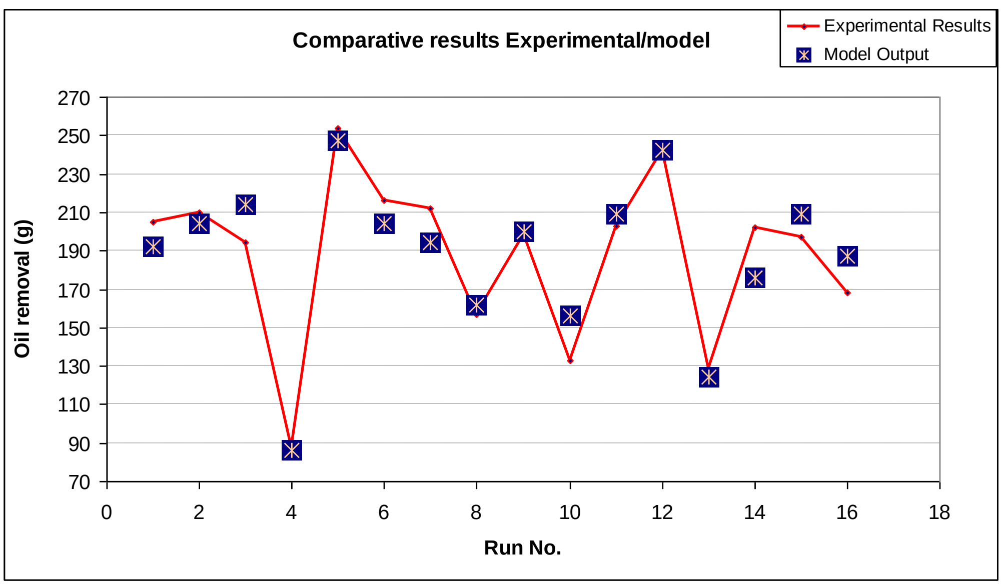
t^D =Time in bath(s)

The model results were compared to the experimental results to determine whether the model is representative. The result is illustrated in table 6.2 and in Figure 6.3.

Table 6.2: A summary of experimental conditions and the results

Trial Number	Experimental Results	Model outputs	Differnence
1	205.00	192.07	6.31
2	210.00	203.97	2.87
3	194.69	214.51	-10.18
4	87.81	86.06	2.00
5	253.45	247.47	2.36
6	216.60	204.21	5.72
7	212.00	194.67	8.18
8	156.80	161.54	-3.02
9	198.59	199.95	-0.68
10	132.83	156.26	-17.64
11	202.96	209.26	-3.10
12	242.53	242.42	0.04
13	128.80	124.47	3.37
14	202.00	176.10	12.82
15	196.90	209.02	-6.15
16	168.00	187.02	-11.32

Figure 6.3: Graph of comparative results model vs experimental



From Figure 6.3 it can be seen that the experimental and model results are similar. From Table 6.2 it is noted that the difference between the model and experimental ranges from 0 to 18 % with a mean difference of 5.9%.

6.8. Modeling the degreaser system

The degreaser system consists of a degreasing tank and one/two or three rinse tanks. Close circuiting the degreaser solution cannot be achieved due to accumulation of oils during the degreasing process. This implies that the degreaser consumption is only dependent on the degreaser tank operation.

The model requires operator input on degreaser tank concentration, tank volume and degreasing time. The model obtains the production in square meters and number of barrels/jigs per week from the acid model. The calculation for the degreaser system can be summarized as:

Equation 6.4 generates the mass of oil removed/ barrel. This is used together with Equation 6.3 to determine the amount of degreaser used in the reaction. Starting with a newly made up degreaser solution, the amount of degreaser depleted as a result of the first jig/barrel is calculated as:

$$C_{Oil}^{Dt1} = C_{Oil}^{Dt0} - C_{Oil}^{Dr} \qquad (6.5)$$

Where:

C_{Oil}^{D0} = Initial degreaser concentration (g/ ℓ)

C_{Oil}^{Dr} = Degreaser reacted (g/ ℓ)

C_{Oil}^{Dt1} = New degreaser concentration (g/ ℓ)

The jig/barrel is then removed from the bath. The drag-out of degreaser and oil contaminant is calculated based on the volume dragged-out.

$$C_{Oil}^{Dt2} = C_{Oil}^{Dt1} - Do * C_{Oil}^{Dt1} \qquad (6.6)$$

Where:

Do=Drag-out(l)

C_{Oil}^{Dt2} = Degreaser concentration after drag-out(g/ ℓ)

The increase in oil concentration in the degreaser (used to calculate degreaser usable life) is calculated from Equation 6.4. The state of the degreaser solution after the jig/barrel is removed is thus determined.

$$C_C^{D1} = C_{C1}^{D0} + C_C^{Dr} \qquad (6.7)$$

Where:

C_{Cl}^{D0} = Initial oil Concentration in degreaser (g/ ℓ)

C_C^{Dr} = Oil added to solution from metal surface (g)

C_C^{D1} = New oil concentration in degreaser (g/ ℓ)

Thus the condition after a single jig/barrel has passed through the degreaser tank is determined. These include the new concentration of degreaser, the concentration of oil (contaminant) and the amount of liquid dragged out. The new condition for the degreaser solution is substituted into Equation 6.4 to determine the condition of the degreaser after the second jig/barrel. This is continued for the stipulated period.

In order to determine the degreaser consumption, the model has to be applied to specific plant conditions. The model has to account for all the variables influencing the degreaser consumption.

6.8.1. Model comparison with database

In order to test the model output, the required data from the database of companies were extracted and used as model inputs. The individual company data was inputted into the model as described in section 6.8 above. The model was used to determine the degreaser consumption, for the plant under consideration, for a period of one year. This was done in order to compare the consumptions with the yearly consumption of the database.

This calculation was initially done using excel. The results indicate that the model is able to predict the degreaser consumption provided the surface area(Acid model), tank size, dumping rate, tank concentration(Operator inputs), etc is known. These are considered to be available user inputs obtained from the plant operator.

The excel equivalent was programmed in Mat Lab, see Appendix D5, and the excel sheet was used to confirm the results, see Table 6.3. The model is able to successfully predict the degreaser usage and consumption based on the above inputs. It is able to calculate degreaser consumption based on very basic operator inputs. This implies that the model does not require detailed chemical consumptions of the degreaser.

Table 6.3: Comparison of model to database outputs

Company	**Tank Size**	**Degreaser Database**	**Model Output Degreaser**	**Percentage Error**
Anteos	480	275	273	1
Euro	500	300	319	6
Gedore	2000	2200	2200	0
Fed Mougal	670	127	127	0
African 1	14000	2674	2900	8
African 2	3000	2900	2674	8
Fascor 1	1700	6772	7000	3
Fascor 2	1000	2000	1640	18
Transwerk	300	2800	2768	1
Defy 1	9200	12966	12703	2
Abberdare	600	7500	7061	6
Mps	1000	2492	2418	3
Pinetown	3000	500	573	15
Defy 2	2000	3000	3359	12
Natal	1000	150	189	26

The degreaser model was applied to the companies audited for the database. Only sixteen company data could be used as only these companies used an electro cleaner. The other companies used a non-electrolytic cleaner. From Table 6.3 it can be seen that the degreaser model is able to predict the actual degreaser consumption based on plant operations. However, there are exceptions. Fascor nickel has an 18 % error, the model underestimating the usage of degreaser. This is due to the use of the nickel line degreaser for the brass line cleaning. Pinetown electroplaters also have a large deviation from the model. If the data for Pinetown electroplaters is scrutinized it can be seen that the acid model also generated a large error. It can be concluded that the data obtained from Pinetown was not as accurate as desired. The same justification can be used for the error on the Defy plant results. The results from Natal electroplaters indicated the highest error. This can be due to the usage of the degreaser for more than one electro cleaning line, as in Fascor. The mean difference between the model and the database values is 6.8%.This would be used in the Monte Carlo simulation to account for the deviations.

The overall fit of the model seems sufficient to accept it as reasonable, since the standard error is seven percent.

6.9. Mat Lab Modeling

From the comparative results detailed above it can be seen that there exist differences between the model and the database values. A major consideration for the establishment of the model is the range of uncertainties of the input data. This is due to inaccuracy in data collection. The operator may not accurately know the data or the values provided may not be precise. The model is now subjected to variations up to a maximum of 6.8 %(Obtained from mean error in table 6.3) of input values. This input variation is done using the Monte Carlo technique.

The input variables that were considered to contain uncertainties were, temperature, time, contaminant content and caustic concentration.

6.9.1. Temperature

The temperature in the degreaser tank may vary due to various factors; among these factors are the environment temperature, power to the bath (based on jig load), topping up rate, heater control, production rate and operational influences.

The tank temperature may increase or degrease based on the weather conditions, wind factors and convective losses. This means that minor changes in temperature can be encountered due to outside climate changes.

The degreaser tank is subjective to dragout, dragin and receives cold components, as it is usually the first tank in the process sequence. This temperature shock would have a significant effect on the temperature of the degreaser tank. The degreaser tank may be heated after a weekend or night of no production.

The degreaser tank temperature is maintained by the use of electrical heaters. These heaters are controlled based on a control loop. Variations in temperature would occur depending on the ability of the control system to manage all the disturbances.

6.9.2. Concentration

The degreaser model calculates the evolution of degreaser tank concentration. This indicates a change in tank concentration depending on measurement and dosing. Other factors such as dragin and dragout also influence the concentration in the degreaser tank.

6.9.3. Contaminant-oil

The model indicates an evolution of contaminant in the degreaser tank. The oil from the metal is the main contaminant in the degreaser tank. The oil content changes, based on various variables including; drag-out losses, temperature, tank top up and plant operations.

6.9.4. Time

Most plating plants work on a schedule system and this implies that operators/cranes would not be able to remove a jig/barrel from a plating bath at the precise allocated time. This would be due to crane and operator production constraints. There would be variations depending on operator timing/jig scheduling.

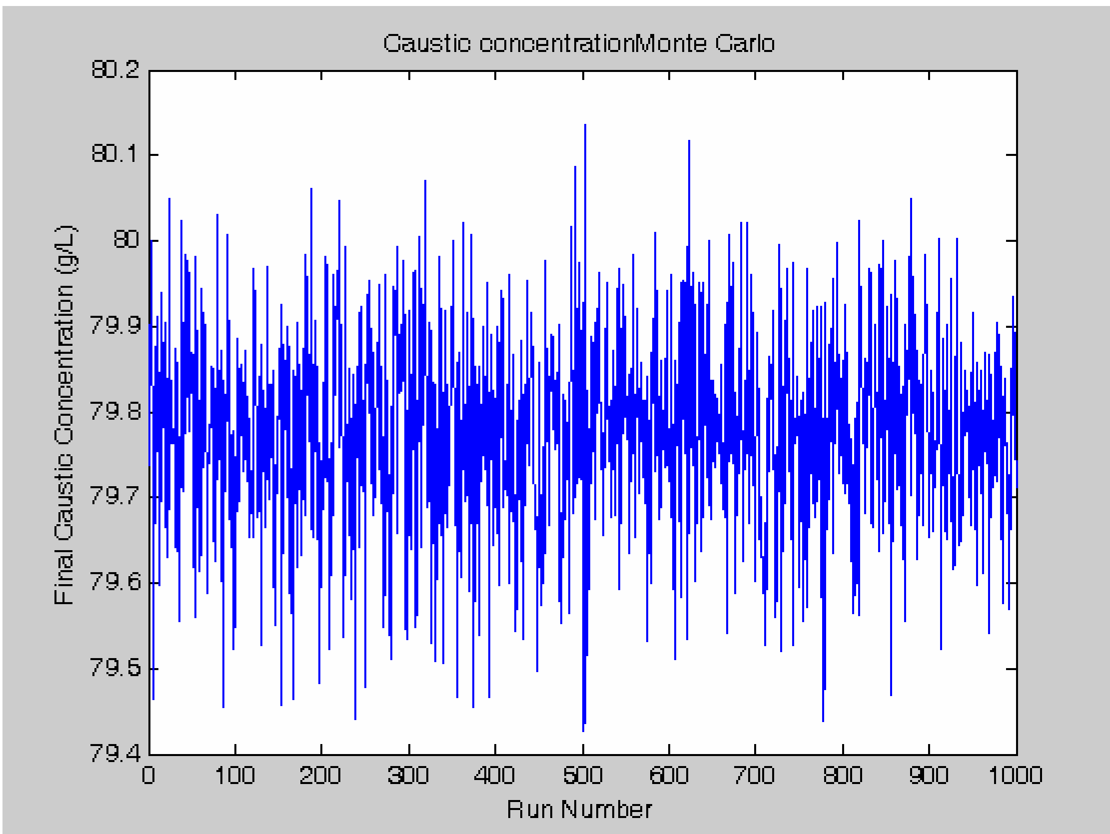
6.9.5. Surface area

The operator loading of the barrel/jig is also an important factor to consider as components vary and hence individual barrel/jig surface areas would change. This occurs due to variations in components being plated and jig limitations.

6.9.6. Mat Lab Program

The Mat Lab program developed is run with the variable changes described in section 6.9 above. Random numbers are generated for each run. Figure 6.4 illustrates the model run 1000 times with random changes in variables to a maximum of 6.8%

Figure 6.4: Mat Lab results for a typical electroplating company



The Mat Lab simulation was used to test the output from Pinetown electroplaters. The mean output from the Mat Lab Monte Carlo simulation is 79.766 g/ℓ as the final degreaser concentration after running for one week. The actual calculated value without the variable changes was 79.7736 g/ℓ. This is an error of 3.36% for the degreaser consumption. The Mat Lab model has a variance of 0.0162. Thus the model can be seen to be successful, even with data variations, in predicting the degreaser consumption at an electroplating facility.

6.10. Model application for cleaner production

It can be stated that the model developed has been validated and can be used for any degreaser application. This includes using the model to predict the ideal chemical consumption i.e. chemical consumption under cleaner production operations. The cleaner production degreaser system would include a two-stage rinse system. Ideal/cleaner production considerations for the degreaser system include:

- Optimum temperature
- Optimum chemical composition
- Reduced contamination (Oil)
- Reduced drag out
- Optimize rinse water flow rates
- Reduced drag-in
- Avoiding spills
- Optimum dumping of tank

For the purpose of setting up the ideal model the rest of the input data, as provided by the operator, would be unchanged i.e. the surface area, chemical concentration, temperature etc.

The cleaner production model outputs include:

- Individual degreaser chemical consumptions
- Contaminant concentration
- Degreaser liquid(tank) volume
- Instantaneous degreaser efficiency based on chemical and contaminant concentration

The degreaser model is thus able to assist with providing the company with an ideal theoretical degreaser consumption based on cleaner production operations. The difference between the actual operator dosing and the ideal consumption would be the potential cleaner production saving achievable by the company.

The model has to be also compared to the Flemming model in terms of inputs and outputs. To prevent repetition this is presented together with the acid and zinc systems in the case study in Chapter Eight.

6.11. Conclusion

The aim of developing a degreaser model was to predict the ideal degreaser consumption at any electroplating facility using basic operator level inputs. The inputs required for this calculation is simply the average weekly dosing and dumping of the degreaser, degreasing time and the degreaser concentration. Other information that is required for the model is obtained from the fuzzy logic section of this study.

The multiple benefits of the model include:

- The model requires weekly top up masses of degreaser and basic data to determine plant degreaser consumption
- The model outputs the chemical and contaminant concentration at any given time. From this the current tank operations and the ideal degreaser dosage can be determined and maintained to ensure optimum operations
- The model can be used to determine the ideal (degreasers dumped when oil content is excessive) degreaser consumption, which would be used for cleaner production evaluations.

The model is applied in Chapter 8 of this thesis where a comparative case study is conducted.

The model developed has been validated using existing plant data. The uncertainties in the model have been accounted for using the Mat Lab simulations. The model is able to successfully determine the degreaser chemical consumption.

The next process in the plating line is the zinc plating tank system. The zinc plating process is modeled in the next chapter as an illustration of a typical plating process.

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CHAPTER SEVEN

THE ZINC MODEL

Chapter seven details the development of the zinc plating model. Similar to the acid and degreaser model the zinc model is based on a factorial design. The background chemistry of the plating model is detailed in section 7.3.1. The zinc model is developed with considerations for closed circuit operations, section 7.4. The experimental methods and model development is detailed in sections 7.6 to 7.8. The final Mat Lab simulation and database comparison is detailed in section 7.10.

7.1. Introduction

Once the metal surface has been degreased and acid cleaned, the metal is ready to be electroplated. Electroplating is a process whereby a single metal or a multi-metal layer is deposited onto the base metal surface. Deposition metals include nickel, tin, copper, chrome etc. Each metal plating system can operate under a variety of operating conditions, e.g. acid/alkali, cyanide/non cyanide based. Development of comprehensive models for all these systems was considered to be beyond the scope of this study. This study aims to illustrate the principles of modeling for cleaner production using a single plating type. This chapter discusses the development of the alkali zinc-plating model. The principles used to develop the zinc model can be applied to any of the various plating systems available.

The model proposed in this chapter is used to determine the zinc plating tank's instantaneous individual chemical consumption. The aim is to develop a model that can be used to determine the ideal operations of the zinc plating tank i.e. under cleaner production conditions. This includes the use of minimum drip times, optimum chemical concentrations, three-stage counter current rinsing etc. Thus the model would generate the minimum chemical and water consumption. The actual consumption, as provided by the operator, can be compared to the model output to generate a potential cleaner production saving.

The chapter begins with an introduction to the alkali zinc plating process together with the reactions and mass balance equations. These equations are manipulated to complete the material balances across an entire zinc plating system and is then used as a basis for the model developed.

The model was developed from laboratory investigations. Factorial experimental protocol was used to establish the baseline model. This model was then further developed into a full plating model, which considered all the disturbances to the alkali zinc-plating tank. The model was applied to various cases.

The main aim of the model is to accurately predict, the chemical consumption, using operator level inputs. The effect of uncertainties in the model and inputs were estimated using Monte Carlo simulation.

7.2. Background-Zinc plating

Virtually all-manufacturing processes of metal products involve electroplating to preserve the base metal from environmental effects. There are over 500 electroplating plants in South Africa and in more established countries like the United States up to 8000 electroplating companies. These companies provide numerous types of plated parts to the electronics, automotive, aerospace, and other manufacturing industries.[1, 2] These plants have been generating huge amounts of metal waste in the forms of wastewater, sludge, and spent solutions.[3,4] The waste usually contains over 100 chemicals, metal, and non-metal contaminants.[5, 6] A continuous generation of these wastes has led the industry to be the second most regulated one in the USA.[7,8,9]

An electroplating line consists of different sections including; cleaning, rinsing, and the core operation, electroplating. In the electroplating tank, the metal is electrochemically deposited onto the surface of work pieces. The work pieces, which are either loaded in barrels or on racks, are immersed in the electrolyte solution. The metal deposition thickness is used as a key indicator of plating quality. The metal deposition is largely determined by the electrolyte composition, current density, and plating time.[10, 11] It is known that the work piece rejection rate due to coating thickness problems is frequently above 5%. The re-work of the rejected work pieces may involve costly stripping and re-plating. In addition to the quality issue, plating solution losses during operation is a very serious problem.

Industrial practice has shown that the loss through drag-out is commonly as high as 30% of overall chemical consumption.[12] In a case study on an acid zinc plating line with the production rate of 11 barrels per hour (100 kilograms of work pieces per barrel), the solution loss was about 400 000 liters per year, on a basis of 300 production days per year.[13] The lost solutions usually enter wastewater streams from relevant rinse units. The plating solution contains a number of valuable chemicals and metals, and the treatment of the wastewater stream containing those chemicals and metals is always very expensive. Thus, the prevention of solution loss into wastewater is of great economic and environmental significance.[14-16]

The reduction of chemical/metal loss through drag-out from plating units has drawn great attention over the past two decades.[2,17] Various drag-out reduction approaches have been practiced in plants, such as the use of a longer drainage time, a higher solution temperature, a lower surface tension, and an improvement of barrel design.[6,12] However, the exact relationships of these parameters with plating quality and solution reduction are unknown.[18-20] In addition to drag-out reduction, a reversed-drag-out technique was introduced a decade ago.[12] By this technique, the rinse unit, a series of low flow rinses is located immediately after the plating step. In operation, a barrel or rack of work pieces is rinsed in the low flow rinses immediately after plating. The solution-containing rinse water in the unit is then periodically pumped back to the plating unit. There are various technical difficulties yet to overcome, which are related to the effectiveness of solution loss reduction and the assurance of plating quality. As such, this technique has not been well adopted in plants.[21] If this method is adopted it would lead to zero or near zero losses of plating chemicals. This system was chosen as the ideal cleaner production option as it entailed close circuiting of the plating tank. This low flow rinse system results in zero waste. The low flow system is compared to the inputs obtained from the operator.

This chapter now presents a detailed model for predicting the cleaner production chemical consumption of a zinc plating process. This model consumption when compared to the current consumption would indicate the potential cleaner production savings. The current consumption is obtained from the weekly dosing by the operator. The model was designed for closed circuit operation i.e. where none of the chemicals from the plating tank are lost to the waste water system. The system is based on the chemistry of the plating process under consideration. The concentration of the post plating low flow rinses are integrated into the model.

7.3. Model development

7.3.1. Alkali Zinc plating chemistry

The zinc plating process is a typical electroplating system i.e. anode and cathode. The anode is pure zinc whilst the cathode is the metal component to be coated. The electrolyte consists of zinc metal in a caustic solution. The solution contains many supplier specific components such as brighteners etc. These components enhance the cosmetics of the final product.

The zinc plating tank reactions[22-25] can be separated into anode and cathode reactions. Reactions are complex but the main reactions can be represented as:

Anode reaction:

$$Zn + 4OH^- \rightarrow Zn(OH)_4^{2-} + 2e^- \tag{7.1}$$

$$2OH^- \rightarrow \frac{1}{2}O_2 + H_2O + 2e^- \tag{7.2}$$

Cathode reactions:

$$Zn(OH)_4^{2-} + 2e^- \rightarrow Zn + 4OH^- \tag{7.3}$$

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^- \tag{7.4}$$

It can be seen from the cathode and anode reactions (Equations 7.1-7.4) that there is dissolution of zinc at the anode and a deposition of zinc at the cathode. There is also an evolution of oxygen at the anode together with an evolution of hydrogen at the cathode. From the four reactions it can be seen that there is a net depletion of water. These equations can be used to determine the mass balance for the plating tank.

7.3.2. The mass balance in the plating tank

The change in concentration of zinc metal in the plating tank is dependent on the rate of dissolution at the anode and the rate of deposition at the cathode. The rate of deposition is dependent on various influences on the system. Chemical composition and temperature are the two main variables influencing anode dissolution and cathode deposition. The impact on each component has to be investigated. The impact of interaction of the different components is also essential.

The rate of change of dissolved zinc metal in solution can be related to the cathode and anode efficiency[26] i.e. R_c and R_a. The net change in dissolved zinc in the plating tank can be represented by:

$$V_P \frac{dC_{Zn_P}}{dQ} = \frac{R_a^{Zn} - R_c^{Zn}}{2F} \tag{7.5}$$

where:

V_p=Volume of plating tank (L)

R_c=Cathode efficiency

R_a=Anode efficiency

F=Current(Faradays)

C_{Zn}=Zinc concentration in plating tank(g/ℓ)

From the anode and cathode reactions (Eq 7.1-7.4) above it can be seen that the caustic is also consumed during the reaction. The rate of change of caustic is directly related to the anode and cathode efficiency since it can be considered to be the main side reaction.

$$V_P \frac{dC_{OH_P}}{dQ} = \frac{-2R_a^{Zn} - (100 - R_a^{Zn}) + (100 - R_c^{Zn}) + 2R_c^{Zn}}{F} \qquad (7.6)$$

C_{OH}=Caustic concentration in plating tank(g/ℓ)

For the plating tank it can be assumed that the current supplied remains constant and that the charge is dependent on the plating time, so:

dQ =Q dt

Where Q is the current

Substituting and simplifying Equation 7.5 and 7.6 we get:

$$\frac{dC_{Zn_P}}{dt} = \frac{(R_a^{Zn} - R_c^{Zn}) * Q}{2F * V_P} \qquad (7.7)$$

$$\frac{dC_{OH_P}}{dt} = -\frac{(R_a^{Zn} - R_c^{Zn}) * Q}{F * V_P} \qquad (7.8)$$

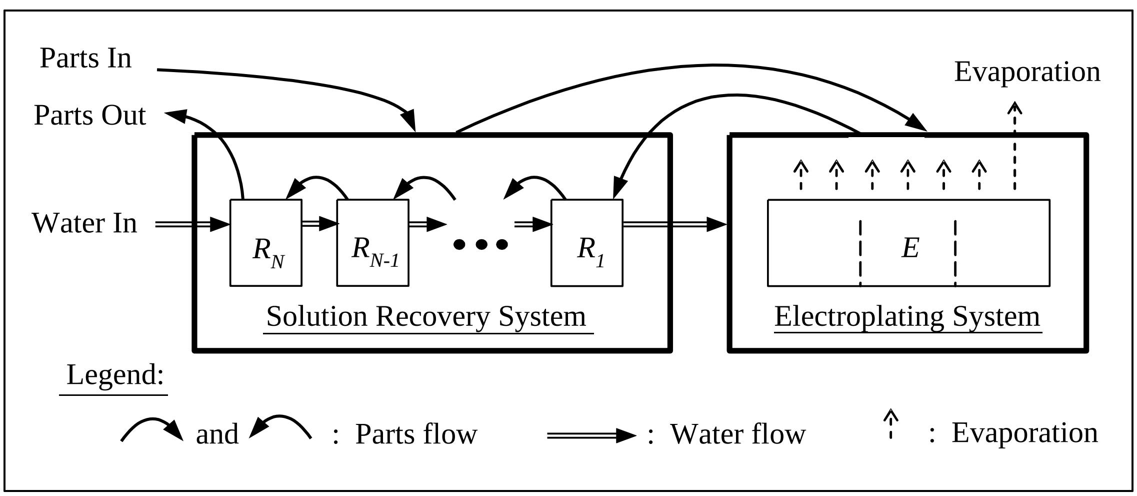
Equation 7.7 & 7.8 can be used to determine the two key chemical changes in a zinc-plating tank during zinc electroplating.

7.4. Closed circuit operation

This section on closed circuiting is not essential for the basic plating model. Closed circuit operation, of the plating tank, is essential for cleaner production. Since this model is to be applied for CP predictions, closed circuit operations are detailed.

The zinc-electroplating tank if operated on its own would result in a low efficiency due to the high rate of chemical dragout. The losses due to dragout can be as high as 30% of the chemical consumption.[27] The chemicals dragged out also have be treated at the wastewater treatment facility. This requires additional treatment equipment, treatment chemicals and labour. This is an unnecessary cost to the company. Further to this cost, the rinse water consumption is high. The problem can be solved by creating a closed loop system.[28-30] This ensures minimal metal losses and very low water consumption. There is almost zero metal discharge to the waste water treatment plant.[30,31] The proposed three-stage counter current rinse system is illustrated in Figure 7.1

Figure 7.1. Illustration of closed circuit operations



With this system the barrels are first dipped into rinse one as a pre-dip and then into the zinc tank. After plating the barrels are then rinsed in rinse 1,2 and3. The evaporative losses from the zinc tank are made up by de-ionized water in the last rinse tank. This volume of water is pumped through to the zinc tank via the second and first rinse tanks. De-ionized water is used to avoid accumulation of salts from municipal water.

With the plating and cleaning system as illustrated in Figure 7.1 the plating tank concentration is subject to a variety of external disturbances. For simplification the process can be separated into two sub-processes: the plating process (phase 1) and rinsing (phase two). Phase two includes the drag-out time and the time between plating.

Considering phase 1; The net change in concentration in the plating tank is as a result of the plating process plus the recovery from rinse tank 1.

Hence the equations for the zinc and caustic have to be modified

$$\frac{dC_{Zn_P}}{dt} = \frac{(R_a^{Zn} - R_c^{Zn}) * Q}{100 * 2F * V_P} + \frac{R^{R1} * C_{Zn}^{R1}}{V_P} \qquad (7.9)$$

R^{R1}=Recovery of rinse water (L)
C_{Zn}^{R1}=Concentration of zinc in rinse 1

The change in concentration is in moles /liter. Recovery rate is in liters and concentration is in moles/liter.

$$\frac{dC_{OH_P}}{dt} = -\frac{(R_a^{Zn} - R_c^{Zn}) * Q}{100 * F * V_P} + \frac{R^{R1} * C_{OH}^{R1}}{V_P} \qquad (7.10)$$

Equation 7.9 and 7.10 are used to predict the rate of change of the two major chemicals in the zinc-plating tank during phase one of the process.

From Equation 7.9 and 7.10 it can be seen that the concentration of chemicals in the first rinse tank are required in order to complete the model. Flemming[32] used a basic mass balance model to determine the concentrations in the rinse tanks based on dragout, concentrations in the plating tank and evaporation rates.

In order to complete the mass balance as the process proceeds the concentration of the individual chemicals in the rinse tanks needs to be determined. C^{R1} to C^{R3} represents the zinc concentration in the three tanks.

$$\frac{dC_i^{R1}}{dt} = -\frac{R(C_i^{R1} - C_i^{R2})}{V_{R1}} \tag{7.11}$$

$$\frac{dC_i^{R2}}{dt} = -\frac{R(C_i^{R2} - C_i^{R3})}{V_{R2}} \tag{7.12}$$

$$\frac{dC_i^{R3}}{dt} = -\frac{R(C_i^{R3})}{V_{R3}} \tag{7.13}$$

Where i represents the individual chemical species and R is the rinse water recovery rate.

Expanding the equations to include counter current rinses as in Figure 7.1.

$$\frac{dC_{Zn_P}}{dt} = \frac{(R_a^{Zn} - R_c^{Zn})*Q}{100*2F*V_P} + \frac{R^{R1}*C_{Zn}^{R1}}{V_P} + \frac{Dr*C_{Zn}^{R1}}{V_P} - \frac{Dr^E*C_{Zn}^E}{V_P} \tag{7.14}$$

Dr= Drag-out(L)

Similar equations can be established for the other components.

$$\frac{dC_i^{R1}}{dt} = \frac{R(C_i^{R1} - C_i^{R2})}{V_{R1}} - \frac{Dr*C_i^{R1}}{V_{R1}} + \frac{Dr*C_i^{zn}}{V_{R1}} \tag{7.15}$$

Where:

C_i = Concentration of component i

Equation 7.15 represents the material balance for component i in the first rinse tank. Similar equations were established for each component of each rinse tank. These were used to predict the evolution of concentration in each tank over time.

According to Wery[5] the anode efficiency is related to the cathode efficiency and the zinc concentration. This can be simplified to:

$$R_a^{Zn} = R_c^{Zn} + 2.8 * C_{Zn_P} \qquad (7.16)$$

From the equations above the instantaneous change throughout the system can be determined. The only unknown variables in the above equation are the cathode and anode efficiencies. In order to complete the model the cathode and anode efficiencies are required.

7.5. The determination of the cathode and anode efficiencies

Wery *et al*[5] developed a model for the prediction of cathode efficiency based on the impact of the five main chemicals in an alkali zinc solution. The chemicals that were considered by Wery together with their concentrations are illustrated in Table 7.1.

Table 7.1: Table of variable limits for the zinc experiment, Wery *et al*[5]

	Zinc/ mol/ l	Sodium hydroxide- mol/ l	Sodium carbonate: mol/ l	Leveling agent: ml/ l	Brightening agent: ml/ l
Factor for model equation	X_1	X_2	X_3	X_4	X_5
Lower level	0.15	2.5	0	10	0.5
Optimum	0.21	3.25	0.28	20	1
High level	0.27	4	0.57	30	1.5

For the alkali zinc plating process, the plating temperature[11] has a substantial effect on the plating efficiency; hence the investigating variables were modified. In Table 7.2 the leveling agent was replaced with temperature. The temperature range used was 22-32 degrees Celsius.

Table 7.2: Table of variable limits for the zinc experiment, Actual

	Min	**Max**	**Optimum**
Zinc(Moles/l)	0.15	0.27	0.21
Sodium carbonate (Moles/l)	0	0.65	0.32
NaOH (Moles/l)	2.5	4	3.25
Brightener	10 ml/l	20 ml/l	15 ml/l
Temp (^{0}C)	22	28	34

The above variables were investigated using the fractional factorial method. The method proposes that the maximum and minimum limits of the variables being investigated be investigated in a specified sequence. The detailed experimental methodology[5] is contained in Appendix E1.

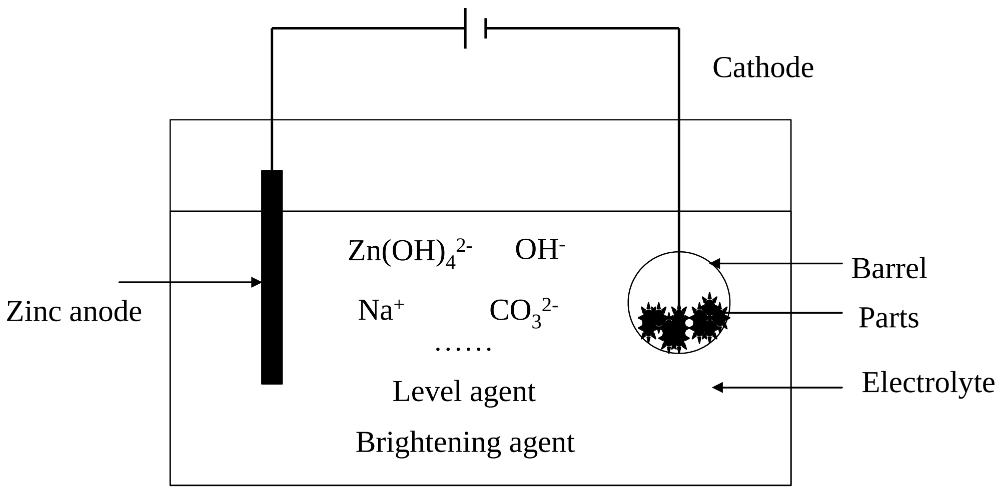
According to the factorial table for the zinc experiments attached in Appendix E1, there were 16 trials with the upper variable limit indicated as a 1 and the lower limit indicated as a –1. The five variables used for the investigation were:

- Zinc concentration
- Caustic concentration
- Sodium carbonate concentration
- Brightener concentration
- Temperature

7.6. Experimental

A plating line was constructed with a degreasing, acid cleaning and a plating section, see Chapter 5. The plating was conducted in a 1kg barrel. Samples of flat steel buttons were obtained from a local manufacturer. The surface area was determined by sampling and measurement[10]. Degreasing, acid cleaning and plating chemicals were obtained from Chemserve systems, a local supplier of plating chemicals. The basic plating system is illustrated in Figure 7.2.

Figure 7.2: Plating tank and barrel



7.6.1. Experimental methodology

The plating tank chemicals were made up as per Table 7.2. The plating tank was a 400mm*400mm polypropylene tank. The tank was equipped with a heater and a cooling system for temperature regulation. The plating barrel was a polypropylene barrel with double electrical contactors, for current flow to the barrel. The barrel has a single dangler, which makes electrical contact with the components in the barrel. The barrel was 300mm long and 120mm across the hexagonal. Local chemical supplier make-up specifications[33] were used. The local supplier combined the brightener and leveling agent so for this study this was referred to as the brightener. One kilogram of steel buttons was weighed, degreased and put into the acid strike. The buttons were then removed, dried with an air drier and accurately weighed. The weighing was carried out on a laboratory balance with a five-digit accuracy. The buttons were then placed into the barrel, degreased and acid cleaned. The barrel was then rinsed and dipped into a caustic pre-dip.

Thereafter the barrel was placed in the electroplating tank. The current and voltage was set and measured with a multi-meter. The anode was only placed into the plating tank just before switching on the current to minimize dissolution of the anode. The anode was cleaned in caustic before every trial, this was to ensure that the anode surface was kept consistently clean. The anode was cleaned and weighed between each trial. The temperature, voltage and current were recorded every five minutes during the sixty-minute time interval. Once the trial was completed, the metal buttons were removed from the plating tank, rinsed and taken out of the barrel. A magnet was used to remove the metal buttons so as to minimize the potential errors that could occur if the buttons were left in the barrel. The buttons were cleaned and dried and then re-weighed. The net increase in weight was used as an indication of cathode efficiency.

7.7. Experimental Results

The results from the factorial experiments were used in the factorial calculations, see Appendix E, for detailed factorial calculations. The factorial method manipulates the experimental results and a model representing the cathode efficiency is generated. The factorial results are illustrated in Table 7.3.

Table 7.3 also details a comparison between outputs from the experimental results and factorial model. Factorial manipulation results in a model that includes all variables and their interactive effects. The significant effects were obtained by conducting an analysis of variance similar to the acid and degreaser model. The significant variables and their effects is illustrated as Equation 7.17.

Table 7.3: Comparative results, model and experimentation zinc mass plated

Trial Number	Experimental results (g)	Model output (g)	Deviation Percentage
1	51.3	50.8	1.1
2	14.4	19.7	-36.6
3	19.4	20.4	-5.2
4	58.1	53.8	7.4

5	14.8	10.1	31.9
6	46.8	46.2	1.3
7	14.2	17.5	-23.1
8	71.2	70.9	0.5
9	56.4	58.3	-3.3
10	19.4	15.9	17.9
11	31.9	24.2	24.3
12	48.2	46.3	4.0
13	38.1	40.9	-7.4
14	48.2	47.4	1.7
15	13.2	16.3	-23.3
16	32.8	33.15	0.35
		Standard deviation	18.1

$$R_c = 81.15 + 6.36250.\ C_{Zn}^E + 10.2125\ C_{Zn}^E * C_{Na_2CO_3}^E + 8.6 * C_{Zn}^E * C_{OH}^E - 5.9 * T^E * C_{Bright}^E - 5.1125 * C_{Zn}^E - 4.475 * C_{Na_2CO_3}^E * T^E \quad (7.17)$$

Where:

C_{Zn}^E : Zinc concentration (mol/ ℓ)

C_{OH}^E : Caustic concentration(mol/ ℓ)

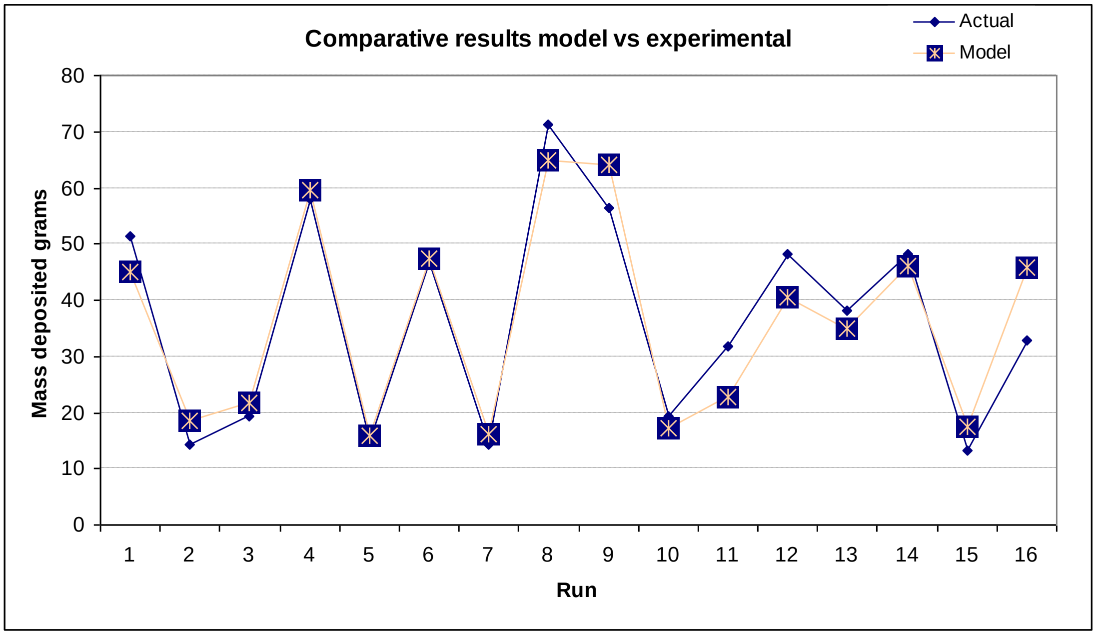
T^E : Temperature of Zinc tank(Degrees Celsius)

C_{Bright}^E : Brightener concentration(ml/l)

$C_{Na_2CO_3}^E$:Sodium carbonate concentration (mol/ ℓ)

The equation representing the significant variables, Equation 7.17, is to be used for the purpose of modeling. The factorial model outputs indicates that the zinc and caustic concentration together with the temperature are the most significant variables. The correlation between the outputs of Equation 7.17 and the experimental results are illustrated in Figure 7.3.

Figure 7.3: Comparative graph of model vs experimental results



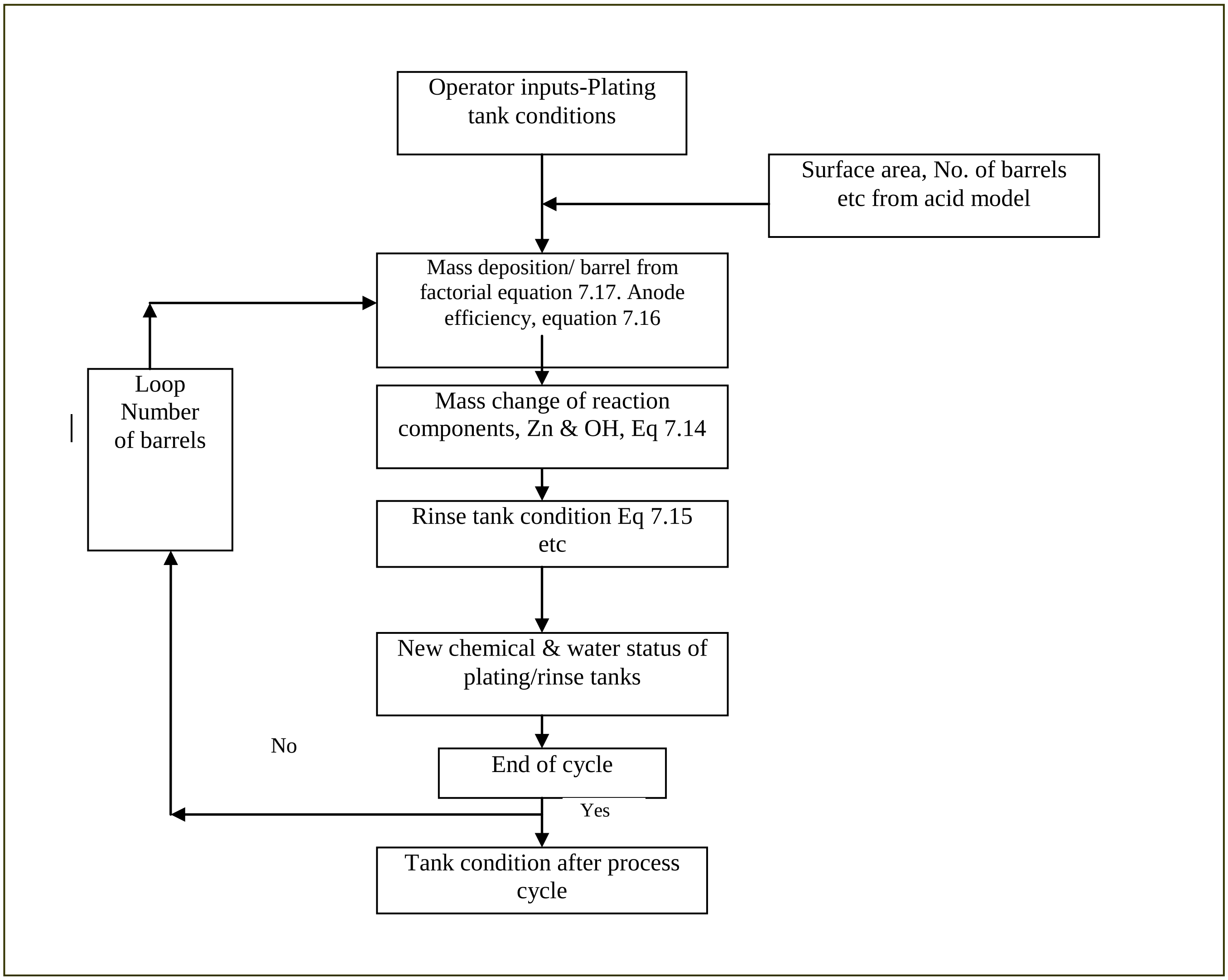
Equation 7.17 would now be used for further model development based on the closed circuit system.

7.8. Zinc Model Development

The holistic zinc model is merely a combination of the factorial model and the mass balance, across the zinc plating system. This includes closed circuit operation. The model developed would successfully predict chemical consumption at an electroplating facility, including ideal consumption. The difference between the ideal and current consumption can be used, as an indication of potential savings. For the purpose of illustration the ideal model would be detailed i.e. the cleaner production system with a three stage counter current rinse.

The mass balance equations, Equations 7.5-7.15, together with the factorial equation, Equation 7.17, were used to model the operations of the plating tank. The model layout is detailed in Figure 7.4.

Figure 7.4. Flow sheet illustrating zinc model calculations



The Mat Lab, see Appendix E2, results for the anode and cathode efficiency of the zinc tank is illustrated in Figure 7.5A. The simulation run is based on the flow sheet described above. The simulation represents a plant running 150 barrels/week with a plating time of 50 minutes/barrel. The drag out is inputted as 0.16 ℓ/m^2, with a recovery rate of 0.2 ℓ/min.

From Figure 7.5A, it can be seen that the cathode and anode efficiency initially increases; this can be attributed to the increase in zinc metal concentration. This illustrates that although the system is being run under supplier specifications it is not optimum.

Figure 7.5A: Anode and cathode efficiency evolution for zinc plating tank

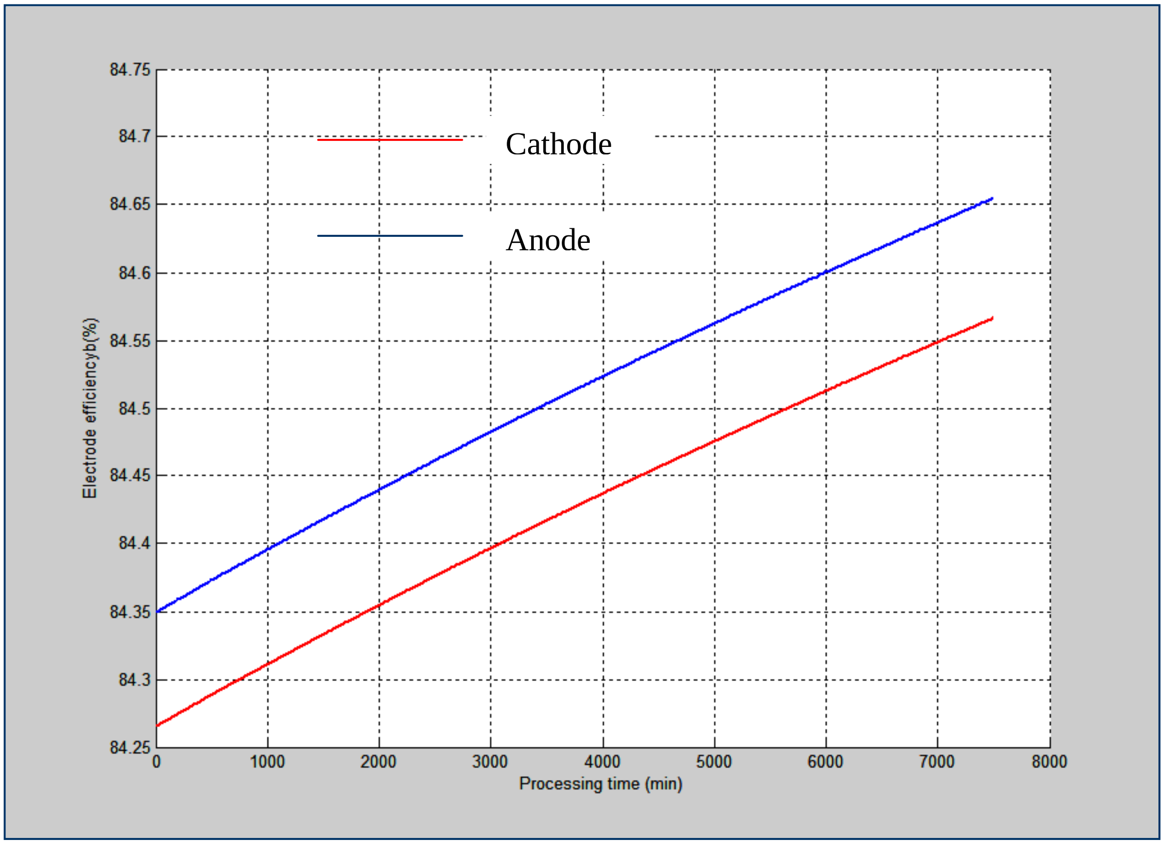
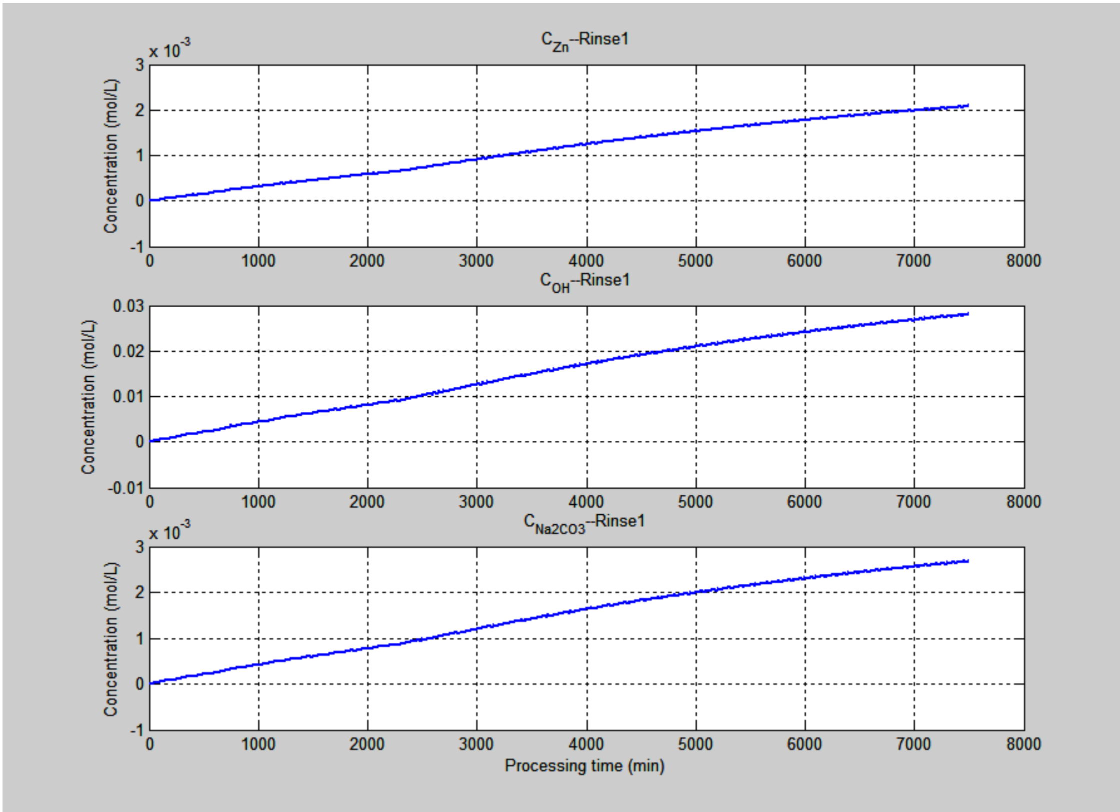


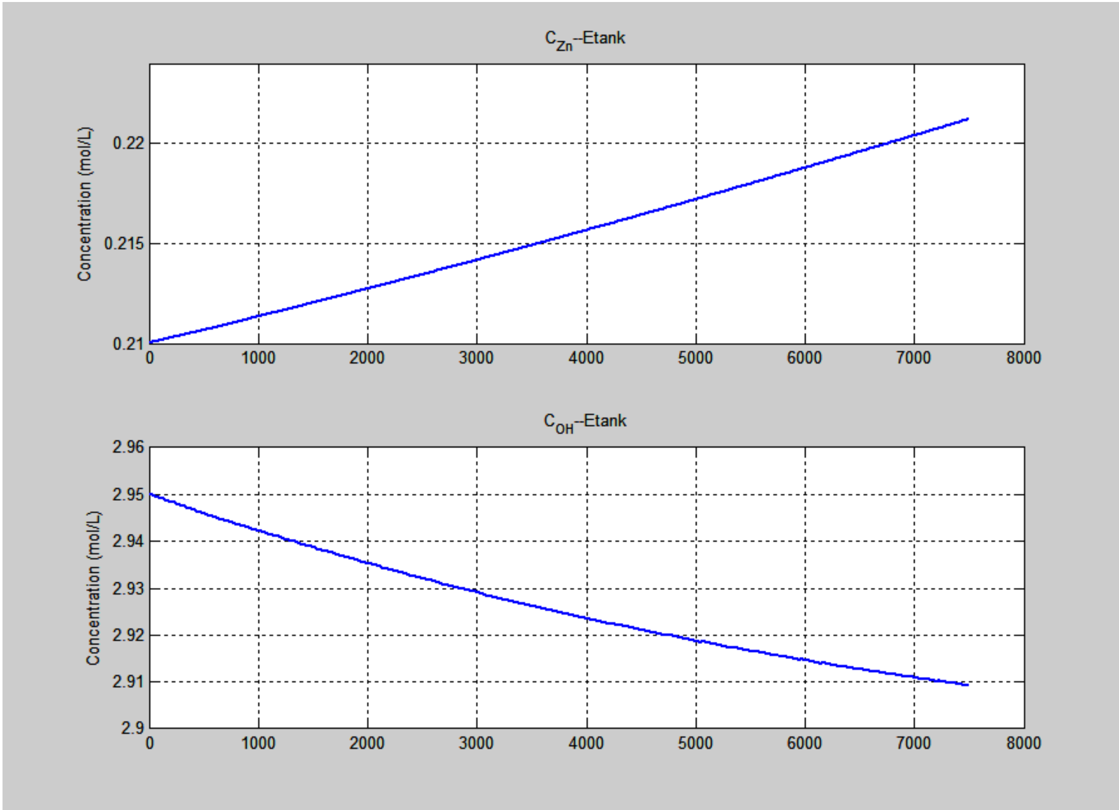
Figure 7.5B: Caustic and Zinc evolution for zinc plating tank



From Figure 7.5B it is noted that the caustic concentration in the plating tank is reduced from 2.95 to 2.91 mol/ℓ. This is the actual amount that needs to be topped up in order to operate at the suppliers specification. Figure 7.5B also illustrates the increase in zinc concentration. This results in the zinc concentration exceeding the supplier specification. The anode and cathode efficiency increases with this increase in zinc concentration. The effect on quality has to be decided upon by the company. Electroplaters have various techniques to reduce zinc concentration.

Figure 7.5C illustrates the evolution of the chemicals in the rinse tanks. It is noted that the start concentrations were taken as zero. The rinse tanks must achieve equilibrium as an indication that the water topped up as recovery water is sufficient. From Figure 7.5C it can be seen that steady state is being achieved i.e. the curves are leveling off.

Figure 7.5C: Evolution of chemical concentration for rinse tank 1



The model developed above generates the chemical modifications that need to be made in order to maintain the zinc tank at the specified operating conditions. Thus if the target operating conditions are known, then together with the model developed the optimum chemical dosing can be determined. This is illustrated in the case study of this thesis. Thus from the model the weekly dosing is extracted and compared to the consumptions given by the operator. The difference can be described as cleaner production savings.

Unlike the degreaser and acid model, the results from the zinc model could not be directly compared to the database of companies. The main constraint being, the availability of data on closed circuit zinc plating processes. The impact of variability, on the inputs variables, was not easy to determine. Using the acid and degreaser models as benchmarks the variability was in the region of 2%. The variability of these two models were based on plant operations. It can be assumed that similar plant operations occur through the plant. The Monte Carlo technique was once again applied in an attempt to indicate the model output with due consideration to input variability.

The variables that contribute to the uncertainty detailed above include:

Temperature: The plating tank temperature encounters a variety of disturbances, this includes, cold jigs/barrels, recovery of liquid, power into bath for electro-deposition, outside temperature etc. These factors imply a significant uncertainty in the plating tank temperature. For the purpose of the Mat Lab simulation, a maximum of 2% of the set-point temperature variation was used.

Chemical composition: Due to inconsistent operations, over/under-dosing, spills etc chemical compositions have a degree of variability.

7.9. Accounting for Model input variations

In order to conduct some verification of the model it would be ideal to test its output against plant data. This cannot be done with the model in its present form as during the case studies conducted none of the companies were found to operate under closed circuit. None of the companies audited conducted recovery of rinse water into their zinc tanks. The model was thus modified for the purpose of testing against plant data.

The model was set up to simulate the rinse tank operations without the recovery of drag out chemicals from the rinse tanks i.e. operating without closed circuit. This was as in data obtained from companies during the audits conducted for this study.

7.10. Comparative results

The first step in confirming the validity of the model was to compare the results with the results from the database. Searching through the database, the results from Coroma was chosen for comparison. The specific operating conditions, temperature, chemical composition, dragout, tank volumes etc were inputted into the model and the results compared.

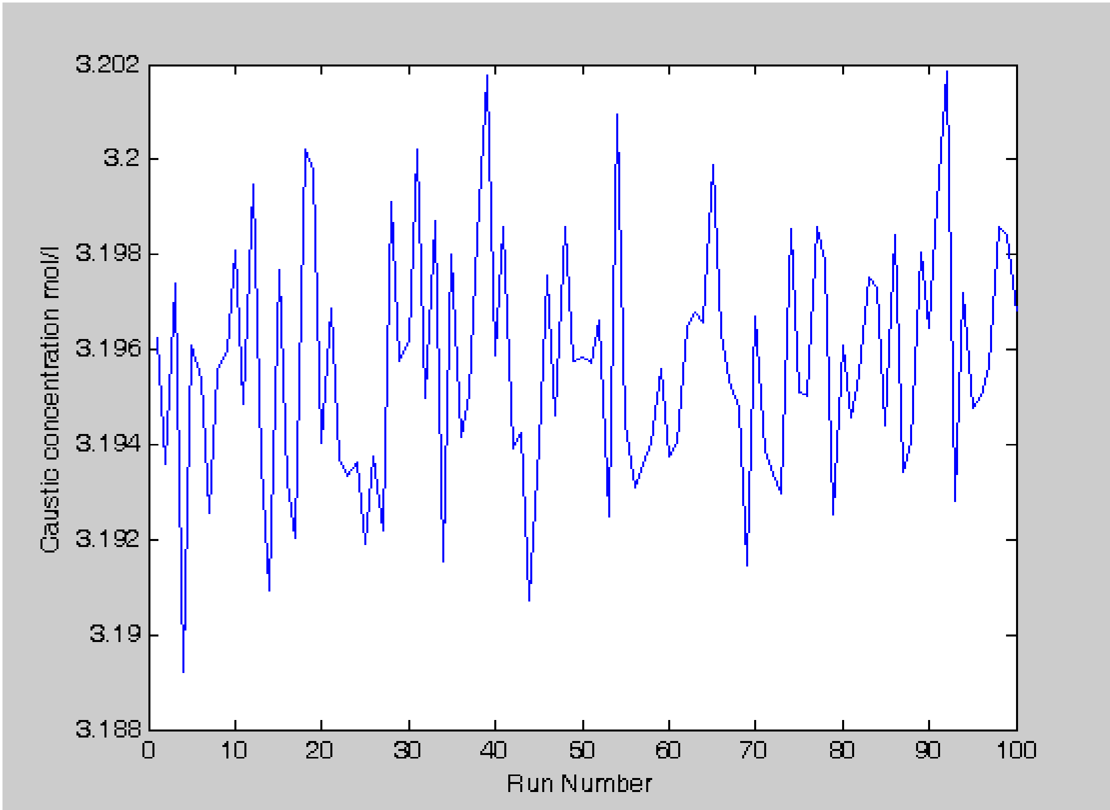
Based on the Mat Lab simulation, the actual chemical consumptions at Choroma was compared to the model outputs. For the caustic consumption the model generates a total consumption of 2167 kg/year whilst the database value for the company concerned is 2091 kg/year, a difference of 76 kg and an error of 3.7 %.

From the simulation it is noted that the accumulation of the contaminant, i.e. the carbonate, is seen to increase from an initial value of 0.065 moles over the period of the week. This translates to 0.71 g/ℓ increase in contamination. This can be considered new information, as the previous model did not provide contaminant level.

The Mat Lab results also indicates that the zinc concentration increased from 0.27 m/l to 0.2712 m/l. This is due to the anode efficiency being higher than the cathode efficiency. Details of model operation are presented in Chapter 8.

The simulation was then run 100 times using the Monte Carlo simulation technique. The mean final caustic consumption for these trials was 3.1968 mol/ℓ. On a tank of 2700l this translates to 275.8 kg/year. The actual value from the database is 300 kg/year.

Figure 7.6: Mat Lab (Caustic concentration) output for Monte Carlo trials.



7.11. Model requirements

The model requires basic information from the plant operator in order to complete the comparative cleaner production evaluation for the zinc plating tank system. The model has the current consumptions due to reactions, drag out etc and then compares this to ideal consumption, as illustrated above based on a three stage counter current rinse system.

The model draws on information from other sections, such as the surface area which is obtained from the acid model, and the number of rinse tanks, drip times, tank volume etc is obtained from the fuzzy evaluation. This together with the inputs specific to the zinc model are used to complete the comparative zinc model for cleaner production.

The above are all considered to be knowledge of the operator and are in keeping with the aim of this study. It would best to compare inputs and outputs between the Flemming model and the model developed in this chapter. For the purpose of illustrating the two systems holistically this is done in the case study of this thesis, Chapter 8.

7.12. Conclusions

From the model results it can be seen that the optimum zinc consumption was calculated from operator level inputs, as determined in the acid model. These results can then be compared to the current chemical consumption, as provided by the operator as weekly dosages, for the zinc system. The difference in consumption can be considered to be the potential cleaner production savings.

The aims of this chapter are thus met in that the model is able to compare the current plant operations to cleaner production operations. This system can be applied to other plating types in order to achieve the potential savings for the purpose of cleaner production.

This is the last of the mathematical equations. In the next chapter a case study is conducted using the holistic CP model proposed thus far.

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CHAPTER EIGHT

CASE STUDY

In this chapter a case study is presented to illustrate the comparative application between Flemming's model and the model proposed in this thesis. The case study was conducted on a local jobbing shop that conducts alkali zinc plating. The two systems are compared in terms of direct input, time requirements, skills requirements and outputs. Mat Lab simulations are used as illustrations of current and cleaner production operations.

8.1 Company Introduction

The case study was conducted at Saayman Danks Electroplaters. The company can be described as a jobbing shop plating nickel, zinc and chrome finishes for a wide range of application. Due to space constraints very little upgrading has been conducted on the facility. The chemicals for the alkali zinc plating plant are supplied by Chemserve systems.

The plant operates 24 hours per day, six days per week. There are a total of 11 operators, working a two-shift cycle, operating the plant. This includes jiggers, plant operators and foreman. The company is classified as an SMME.

A key factor for consideration for this case study is the fact that the owner of this facility has been involved in cleaner production initiatives over the past 10 years. He has had the privilege of being the provincial chairperson, national chairperson and South African representative on international funding agencies associated with cleaner production. It can thus be assumed that information was reasonably available at this company.

8.2 Model Inputs

The Flemming model and the model developed in this thesis were both applied to Saayman Danks Electroplaters. The data for the two models used, for the comparative study, was collected independently. The Flemming data sheets detailed in Chapter 3 was used for the Flemming model. The questionnaire detailed in chapter 4 was used for the purpose of data gathering, for the model proposed in this study.

8.2.1 Data gathering-Flemming

The data acquisition process for the application of Flemming's model, at Saayman Danks electroplaters, was conducted over a two-week period. The owner and the lab manager completed the pre-review questionnaire. At the end of the first week a plant visit was conducted to facilitate the data gathering. During this time, discussions were held on the requirements of the data sheets.

The owner indicated his challenges and methodology of determining the surface area for the purpose of the review, NB the surface area challenge was highlighted in Chapter 3 of this thesis.. The owner explained the difficulty in obtaining exact data; this included obtaining figures from the accounts department on exact chemical usage. At the end of this session it was agreed that the review information would be completed the following week.

On the day of the review, more explanations were required on the data sheets as the company had only completed three tables and found it difficult to complete the rest. The initial data capturing was done on site and various measurements were conducted together with the plant foreman.

A major discrepancy arose with the surface area value provided by the company. After discussions with the owner it was found that he had under estimated the surface area by fifty percent. Thus the surface area input was adjusted.

The plant operator using a measuring cylinder and stopwatch determined the water consumption. All the relevant inputs were gathered and the data entered into the spreadsheets. The entire day was spent on data collection and spreadsheets inputs.

8.2.2 Data gathering-Proposed model

The application of the artificial intelligence based model was also applied at Saayman Danks electroplaters. The questionnaire comprised of 56 questions as detailed in chapter 4 of this thesis.

In order to ensure an independent assessment, an independent reviewer completed the questionnaire. The reviewer had no prior knowledge of the plating process and no experience in conducting reviews.

The company had availed their plant foreman to answer the questions, as the plant operators did not communicate in English. The foreman was also responsible for day to day running of the plant, including dosing of chemicals.

The questionnaire was conducted on site and was completed in 34 minutes. The data gathered was then plugged into the various models and the results analyzed. No further contact was made with the company for further data.

8.3. Data handling

8.3.1. Flemming's spreadsheets

The Flemming's model required that the data gathered via the questionnaire be entered into the excel spreadsheets. The data was entered into eight spreadsheets relevant to zinc plating. Flemming's model required some 245 inputs into these spreadsheets. The following data was a major challenge to obtain:

- The surface area plated in the line under consideration
- The chemical consumptions for each tank on an annual basis
- The water consumption for each tank on an hourly basis

- The plated thickness

8.3.2. Model developed in Visual Basic and Mat Lab

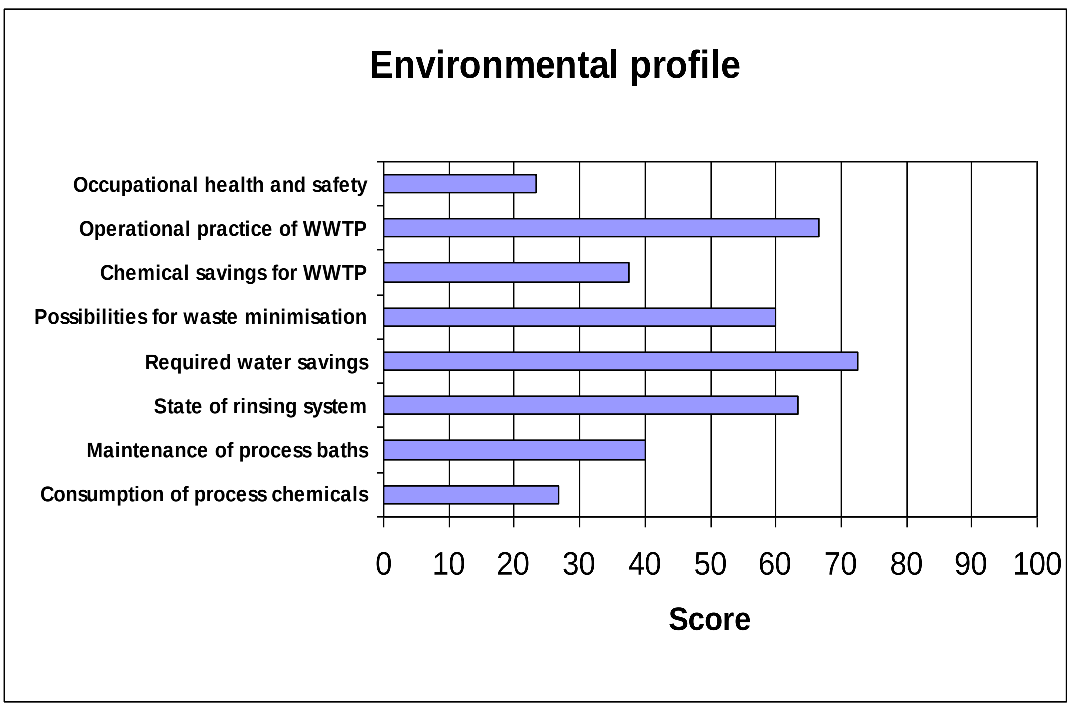
The 56 answers from the operator based questionnaire was captured in the Visual Basic/ Mat Lab software. The Visual Basic software entailed simple selections from choices as per the questionnaire. The Mat Lab model required basic operator inputs such as weekly tank dosing, drip times, number of barrels/ day etc. All data was extracted from the operator based questionnaire.

8.4. Comparative Outputs

8.4.1 Flemming model

The Flemming model output has been discussed at length in the introductory sections of this thesis. The key qualitative output from the Flemming model is the environmental profile of the company see, Figure 8.1.

Figure 8.1: Environmental status of company



This profile presents a qualitative indication of the potential for improvements in the eight key areas of the plant.

Further to this qualitative output the Flemming's model has to be interpreted by the reviewer to generate various scores. These scores is generated by Flemming's spreadsheets based on the data inputted. It is a comparison between actual consumptions and theoretical consumptions embedding in the spreadsheets. Typical results are illustrated in Appendix F.

The detailed review is attached in Appendix F. The key outputs are individual chemical consumption on a scale of 1-5 (5 indicating significant room for improvement). The basic outputs from each table are detailed in Table 8.1.

Table 8.1: Outputs from Flemming tables

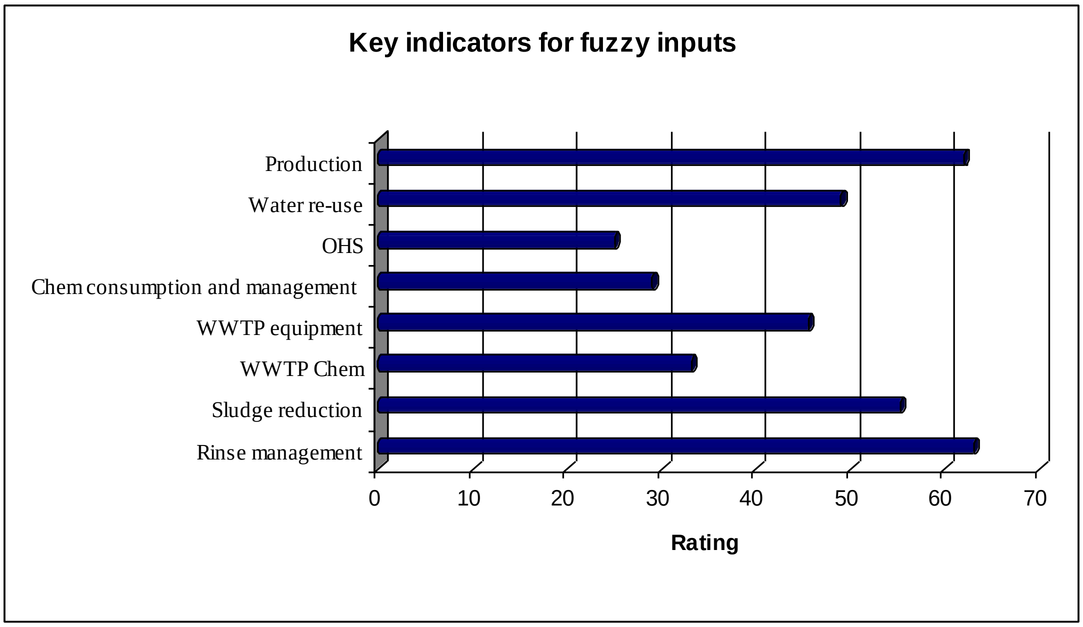
Table description	Output
Zinc tables	Estimated plated thickness
Chemical tables	Rating 1-5 as compared to goal figures on selected chemicals
Rinse Tables	Goal water consumption Theoretical water savings
Waste minimization table	Final rating on waste on a 0-100 % potential saving
WWTP Chemicals	Final rating on chemicals used on a 0-100 % potential saving
WWTP	Final rating on WWTP operations on 0-100 % potential saving
CP options	Indication of cleaner production options available to company

Based on the results of the review, the consultant makes the relevant deductions and interpretations as detailed in Appendix F. It can be seen that the review highlights the main problem areas where CP-options should be further assessed. A more detailed assessment on exact savings is conducted in a feasibility study.

8.4.2 Proposed model outputs

The model proposed has two separate outputs. The first being the fuzzy logic output that is similar to Fleming's qualitative output, see Figure 8.2. This model output is intended to help the company identify areas of potential improvement. The actual quantifiable savings are determined in the mathematical component of the proposed tool.

Figure 8.2: Key indicators of plant-Fuzzy



In summary the qualitative fuzzy model provided the equivalent of the Flemming model outputs. From the figure above it can be seen that the areas of the plant are rated on a scale of 1-100. This has been achieved with a significantly less intense data gathering process. In order for the company to determine the exact benefit of cleaner production a detailed feasibility had to be completed. The aim of the feasibility study was to quantify the cleaner production savings.

8.5. Mathematical model outputs

This case study now illustrates the second component of the research presented in this study i.e. the mathematical models. The aim of these models was to illustrate precise potential saving as traditionally illustrated in a feasibility study. The case study results is based on the models illustrated in chapters:

- Chapter 5 (Acid model)
- Chapter 6 (Degreaser model)
- Chapter 7 (Zinc model)

The models are programmed in Mat Lab as discussed in chapters 5-7. The models use the operator-based inputs to predict the current operation of the plant. The models then calculate the chemical and water usage for optimum operation.

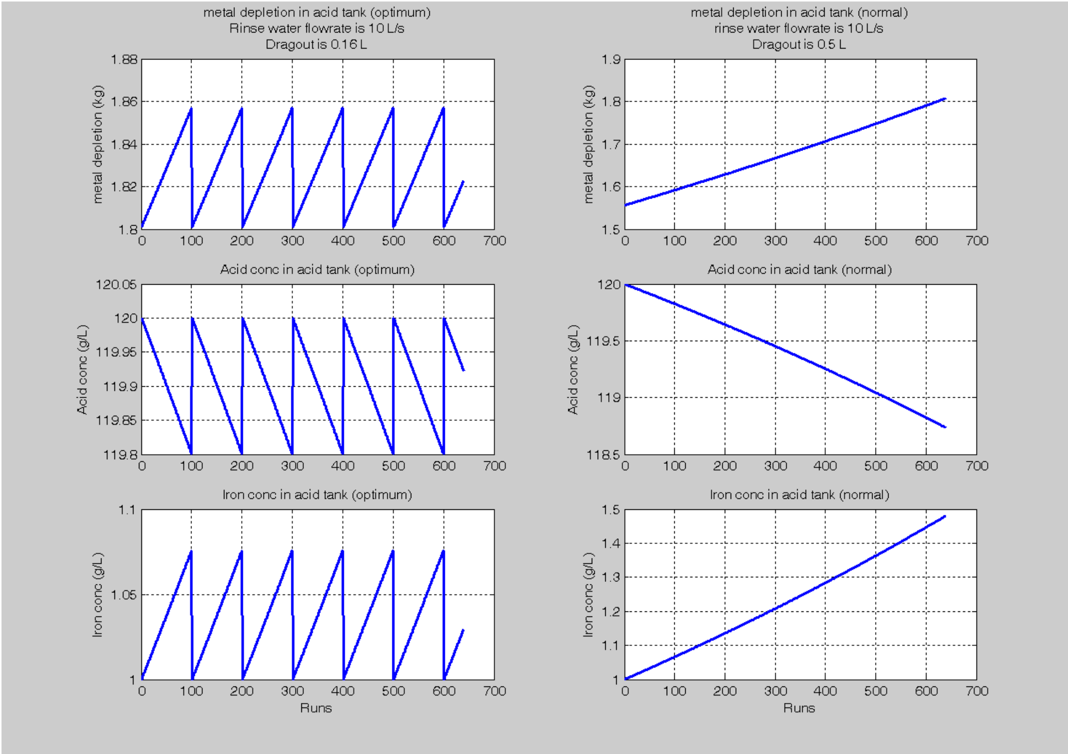
8.6. Application of mathematical models

The detailed simulations and results of the models are now illustration for each section of the plant. The simulations illustrate current operations and cleaner production operations. A summary comparison of inputs and outputs is detailed later in this chapter.

8.6.1 Acid model

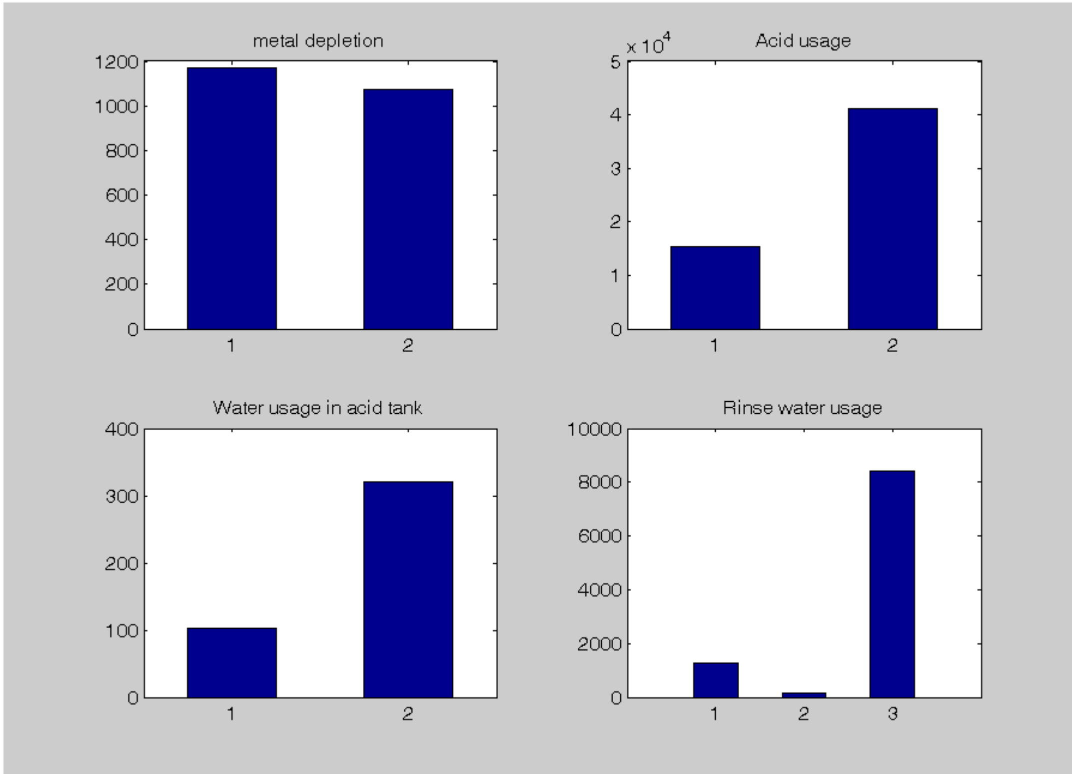
The first and foremost challenge of the model was determining the plant production in meters squared. Operator inputs were used to input data into the acid model. The acid model, illustrated in chapter 5, was applied to the Danks plant in order to determine the surface area production. This was achieved by extracting the relevant information from the operator-based questionnaire. The crucial information required by the acid model includes; current weekly acid top up, number of barrels/week, time etc. The model outputted a surface area as 66346 m^2 for the Danks plant.. This value was 4.3 % less than the value calculated for the Flemming model. This surface area is now used as input into the rest of the models.

Figure 8.3: Evolution of metal depletion, contamination and acid consumption



The model was then used to simulate current plant operations. The results are illustrated, on the right of Figure 8.3. The evolution of current typical acid consumption, metal depletion and contamination is illustrated. These are typical values that currently occur at Danks. The left side of Figure 8.3 illustrates the evolution of values if basic cleaner productions systems were implemented. The optimum operation is based on replenishing the solution after every 100 barrels have passed through. This implies top ups every day as compared to the current weekly top ups. It must be noted that the acid model was developed around the lower iron contamination in the acid tank, which results in improved acid cleaning efficiency. If the acid were allowed to become more contaminated the efficiency would decrease. From the Figure 8.3 it is clear that the acid efficiency can be maintained if the solution is topped up regularly. The model can be adjusted to allow for continuous bath maintenance by setting the top up to occur after every barrel.

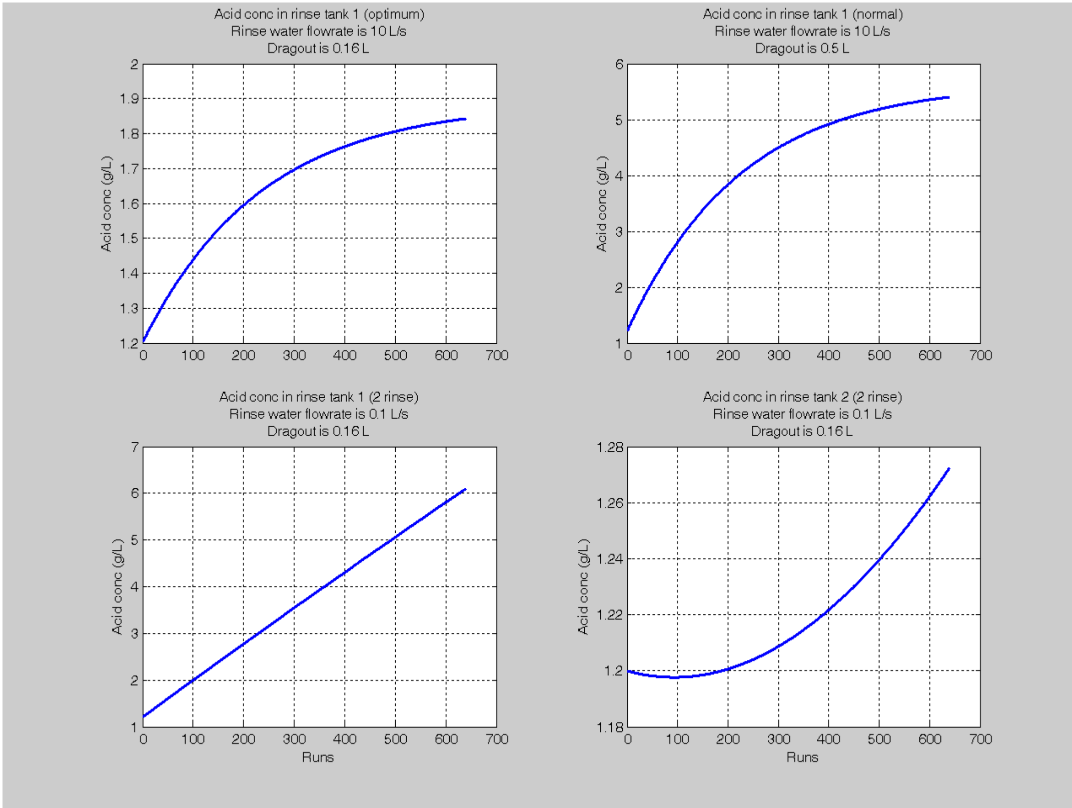
Figure 8.4: Illustration of metal depletion, acid usage and water usage



The model also generates a comparison of acid consumptions, water usage in the acid tank and metal depletion of the surface of the metal. These results are illustrated in Figure 8.4. From the simulation it is concluded that the current acid usage is significantly higher at 41 kg (bar 2) compared to 15.4 (bar 1) for the cleaner operations. A comparison of water used to top up the acid tank is also illustrated. The current operation results in a water usage of 320 **l** /week whilst cleaner operations result in a water consumption of 102 **l** /week. From Figure 8.4 it can be seen that the rinse water usage needs to be expanded. This is expanded upon below.

Figure 8.5 illustrates the water concentration in the rinse tank under different operating conditions. These conditions include a single rinse tank with a high drag-out(current operation), a single rinse tank with low drag-out and a two stage counter current rinse. The current operation with high drag out and a single rinse uses more than 100 times the water as compared to the 2-stage counter current rinse system. The option of redirecting the acid rinse to the degreaser would be discussed in the degreaser section.

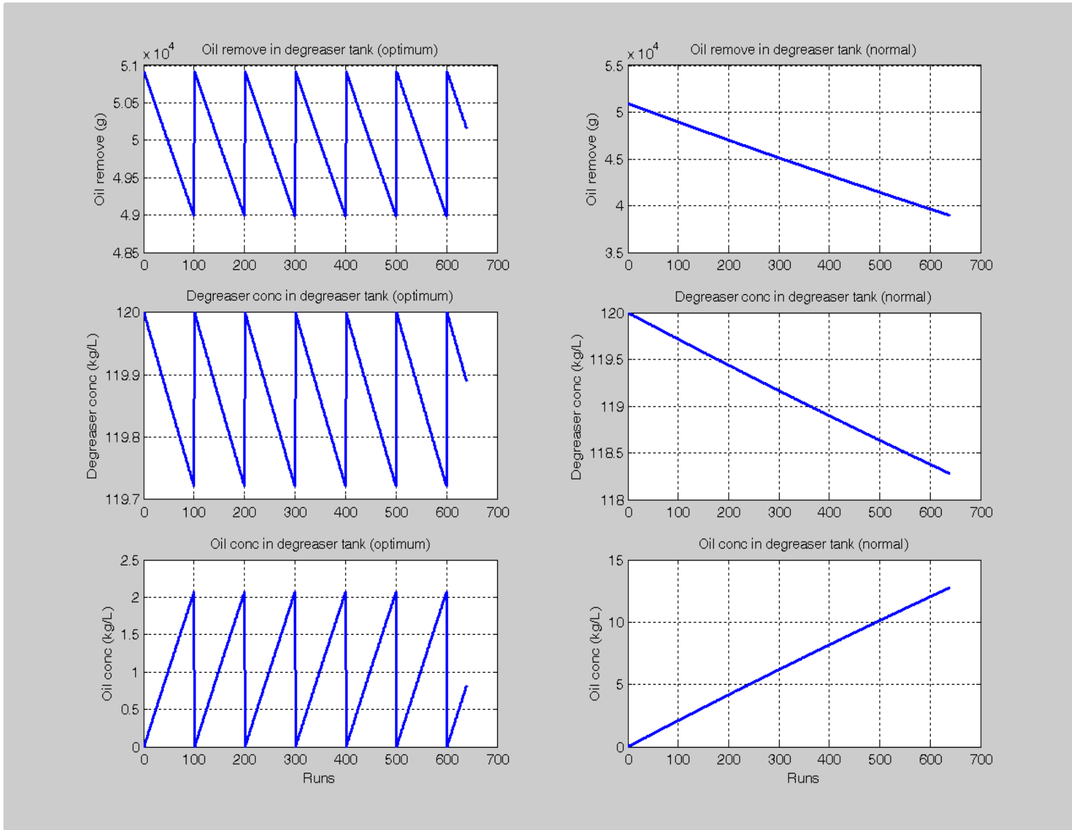
Figure 8.5: Mat Lab results: Water concentration in rinse tanks



8.6.2 Degreaser model

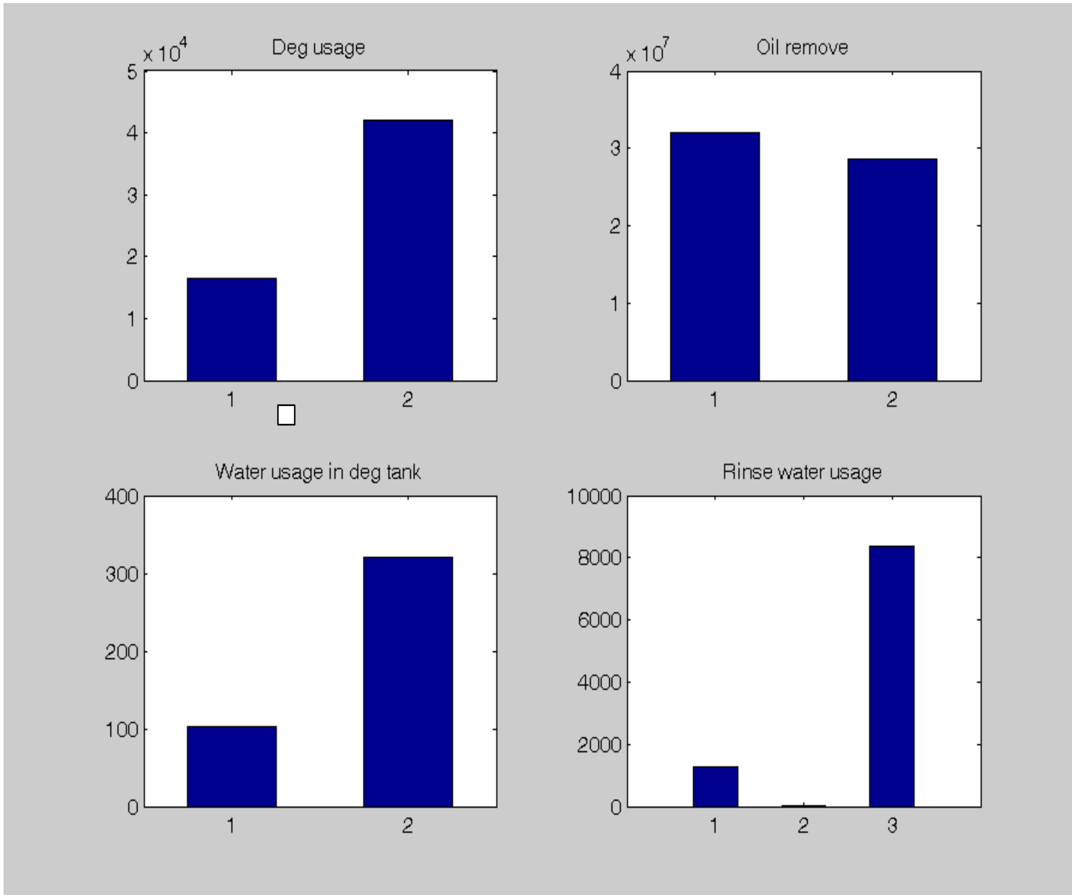
Similar to the acid model the degreaser model is now applied to the Danks process. The model is able to predict degreaser concentration, oil removal rate, oil contamination and bath volume changes at any given time. As per the acid, top up quantities, can also be determined for the degreaser system.

Figure 8.6: Comparative tank operation, degreaser system



In Figure 8.6 the current operation of the degreaser is compared to cleaner production operations. It can be seen that the rate of oil removal is significantly affected as the contamination increases and the degreaser strength decreases. Comparing the graphs on the left (CP operation) to the graphs on the right(current operations), it can be seen that over a period of one week the effectiveness of the degreaser is reduced due to oil accumulation and poor chemical maintenance. Further details on comparative operation are illustrated in Figure 8.7 below.

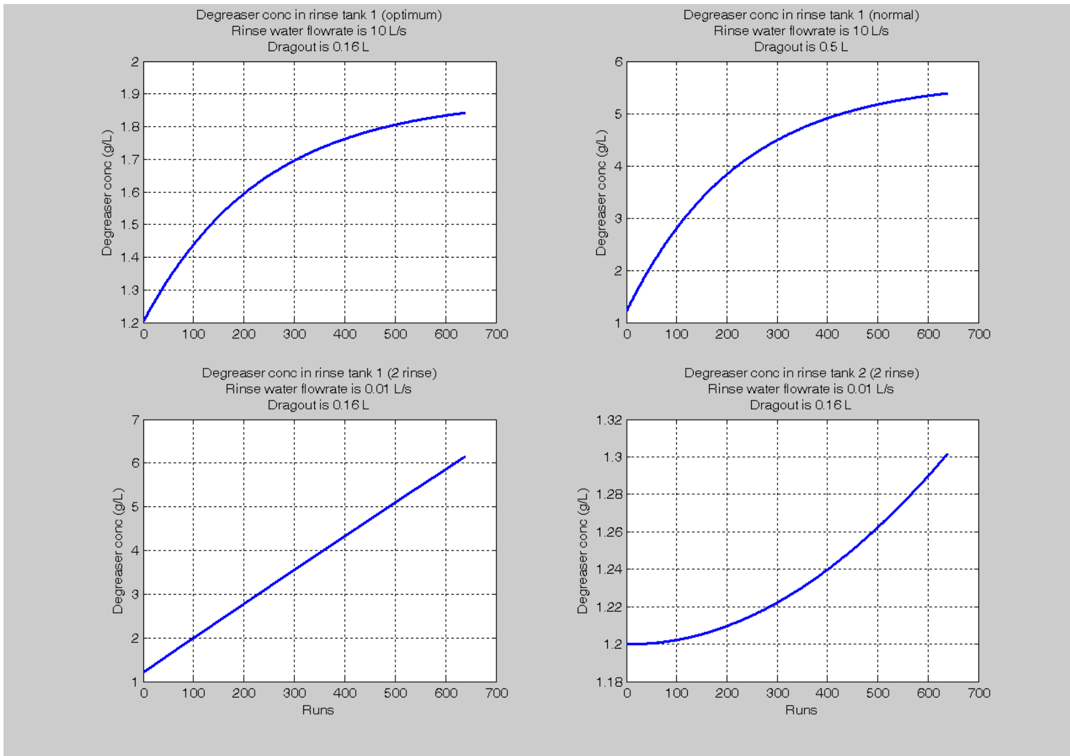
Figure 8.7: Mat Lab results: Comparative consumptions



From 8.7 the first graph (top left) illustrates the degreaser usage. It is clear that optimum operation (bar 1) results in a significantly reduced degreaser consumption, 16.6kg for optimum and 42 kg for non-optimum (current) operation. The second graph (oil remove) illustrates the effectiveness of the degreaser to remove oil from the metal surface. From bar 2 on this graph it is clear that CP operations results in more effective oil removal i.e. 3.2 kg/week as compared to 2.82 kg/week. The top up water consumed by the two operations is illustrated in the Water usage in deg tank (bottom left graph). The CP system uses 102 l/week (bar 1) as compared to the current 320 l /week (bar 2). The rinse water graph is further elaborated in the following figure.

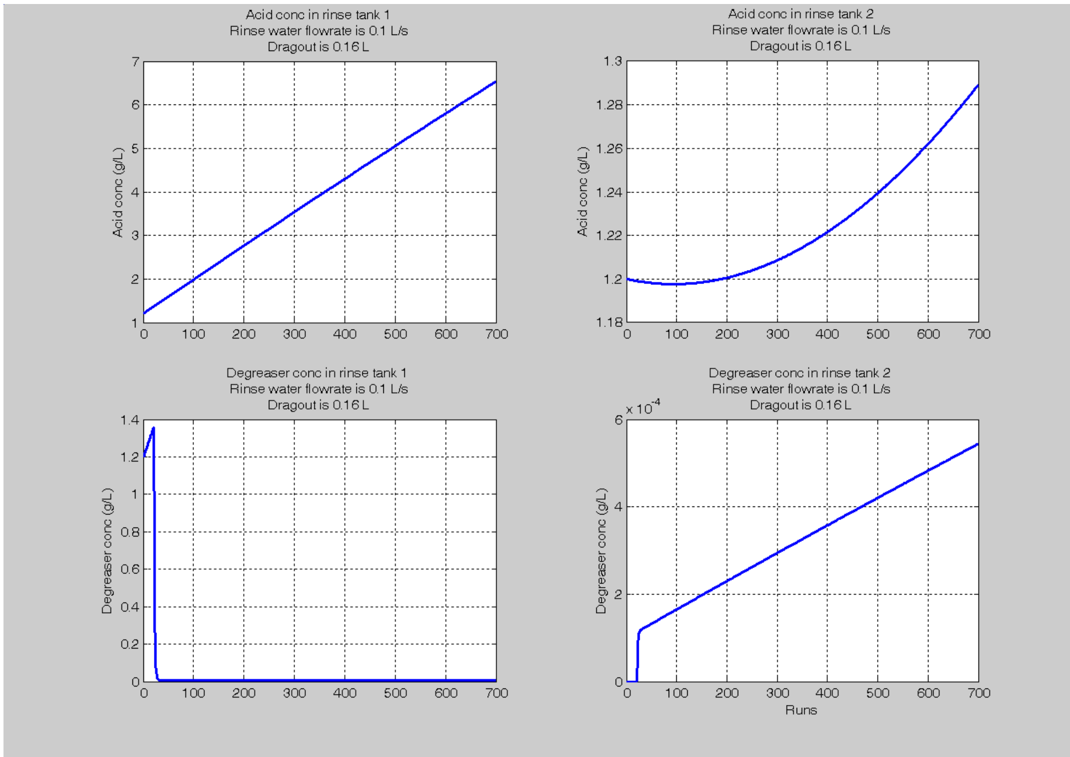
Figure 8.8 illustrates the effects of operating different rinse systems. The first (top right) illustrates current scenario at 10 l /s. The second (top left) illustrates CP operation. The concentration difference in the rinse water is clear. If the company applied CP and employed a two-rinse tank system the concentration evolution of the rinse tanks is detailed in the bottom two graphs. It is clear that with a water flow of 0.1 **l** /s the dilution can be achieved in the second rinse. This is 100 times less than the current consumption.

Figure 8.8: Rinse water usage 2 stage rinse



Before illustrating the zinc model, the benefit of redirecting the acid rinse to the degreaser is illustrated. The rinse water from the first acid rinse is sent to the second degreaser rinse and then to the first degreaser rinse. The reaction effects are illustrated in Figure 8.9. It can be seen (bottom right) that the final effluent leaving the degreaser rinse one is pH adjusted and thus reduces the loading on the wastewater treatment facility. The system reduces the rinse water to half of the independent 2-stage rinse system as the rinse water from the acid is reused. An added bonus is improved cleaning of the degreaser of the metal surface due to neutralization. The degreaser contamination into the zinc tank is also reduced.

Figure 8.9: Acid/degreaser rinse water redirecting



From Figure 8.9 the effect of redirecting the rinse is clear as the caustic is neutralized in the rinse water.

8.6.3 Zinc model

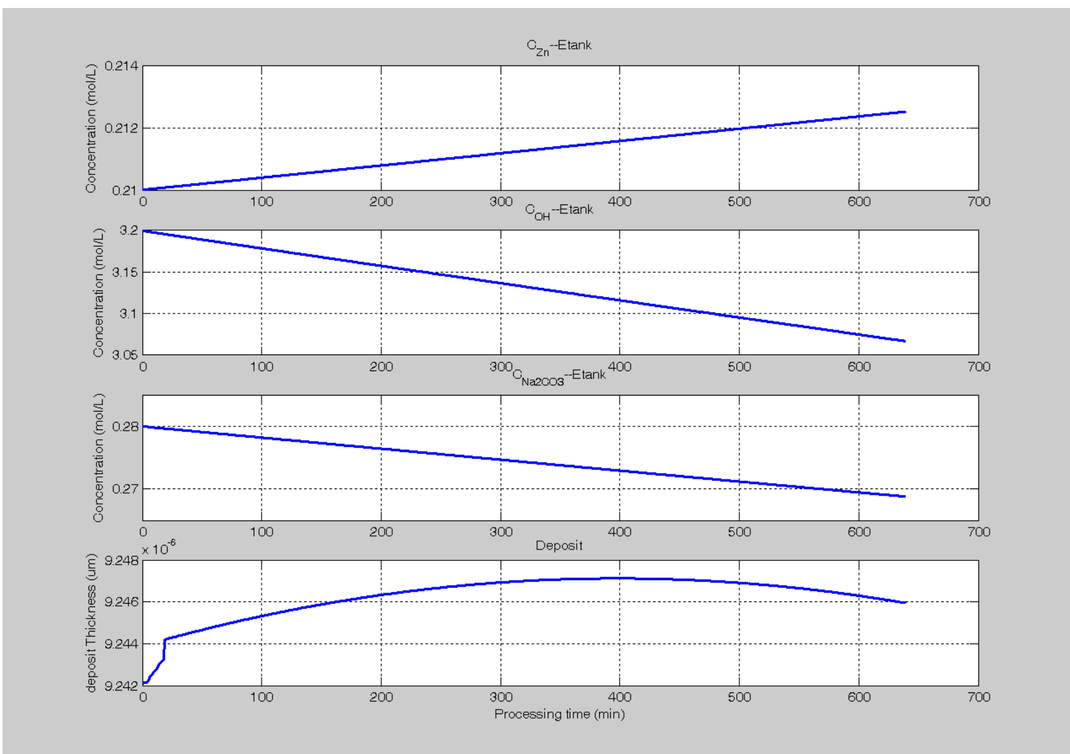
For the purpose of illustration, the model is applied to different scenarios of operations. These include; current operation, CP operation with weekly chemical maintenance and operation with daily chemical maintenance. The zinc model is able to predict the difference between the current and optimum operation based on a three-stage counter current rinse system. The cleaner production model is based on zero discharge and is able to predict:

- The zinc concentration in the zinc tank
- The caustic concentration
- The plated thickness
- The brightener concentration

- The optimum operating condition
- The evolution of the rinse tank concentrations for
  - Zinc
  - Caustic
  - Brightener
- Optimum recovery for tank water balance

The current status of operation is illustrated in Figure 8.10. The company currently operates with a two-stage rinse without recovery of rinse water. The most significant observation lies in the rate of zinc deposition. The start and end of the week's deposition rate is 9.24 microns whilst metal deposition during the middle of the week increases to 9.25 microns. This can be attributed to chemical evolution in the zinc tank.

Figure 8.10: Current operation



The current water consumption is illustrated in Figure 8.11. The water and effluent load can be determined from the rinse water concentrations. The individual component evolutions are illustrated.

Figure 8.11: Current chemical evolution in rinse tank

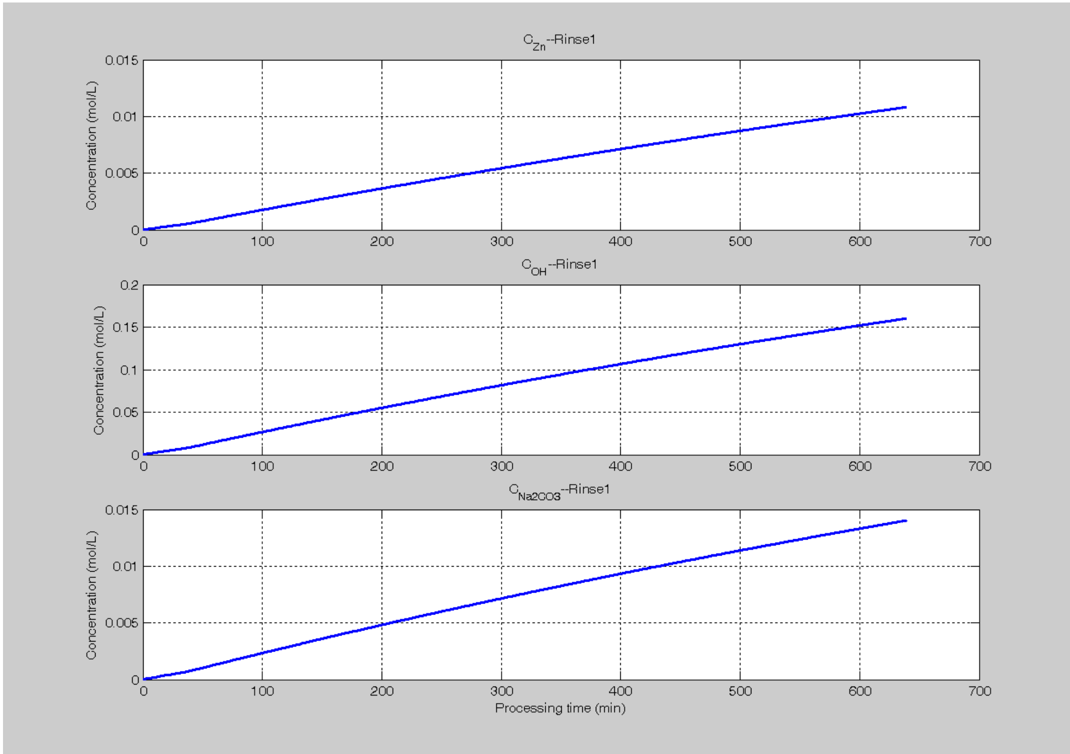
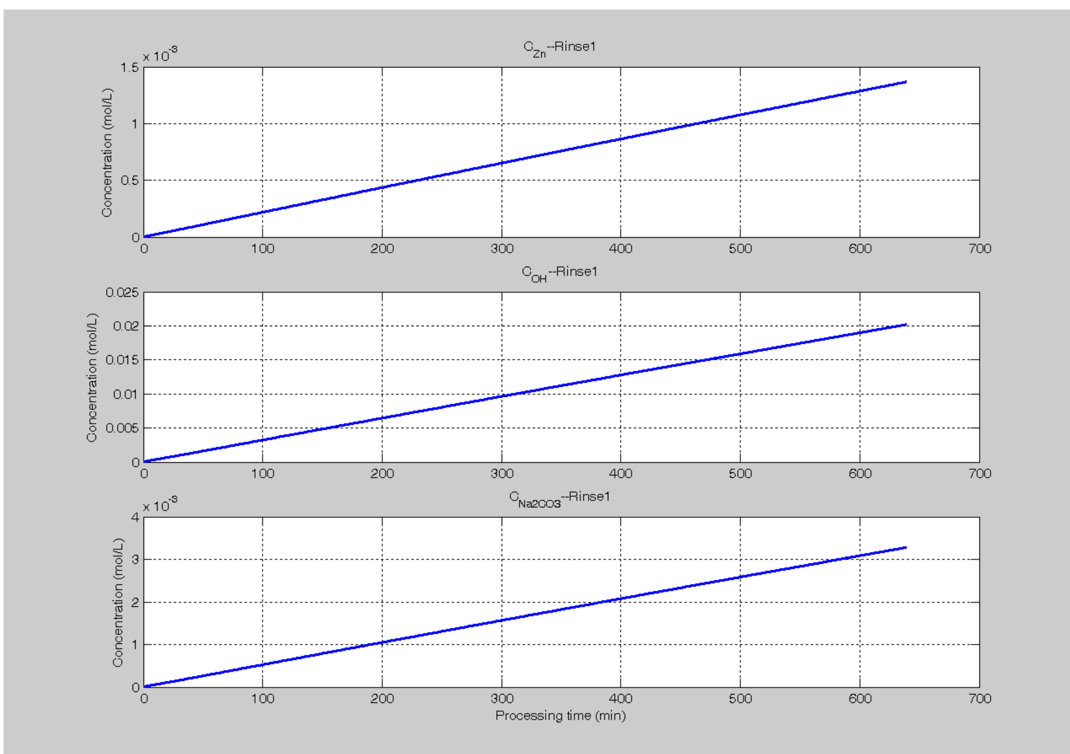


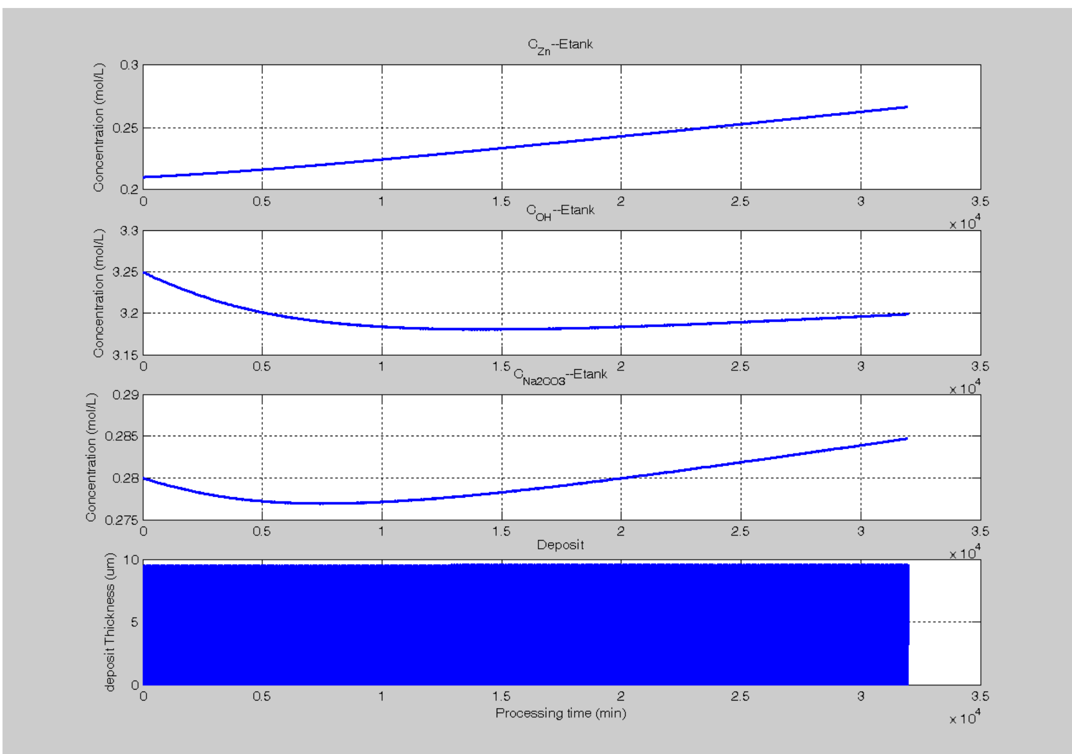
Figure 8.12: Chemical evolution at minimum dilution



The program allows for variations in water flow rates. The rinse water contamination can be modelled to determine the amount of water that is required to ensure minimum dilution factors are achieved. This is illustrated in Figure 8.12. The amount of water used is 1440 l /week.

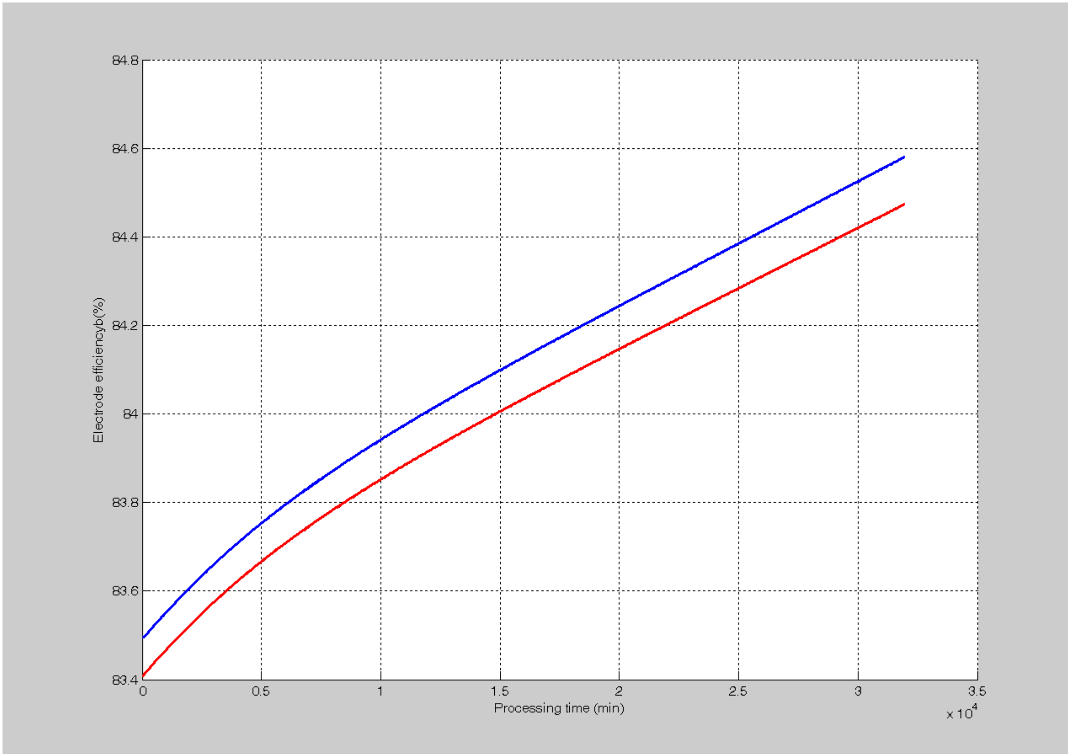
The model was then applied to illustrate the benefits of a basic cleaner production operation. Figure 8.13 illustrates the chemical evolution in the zinc tank for a period of one week, with a 3-stage counter current rinse. It can be seen that the zinc concentration increases significantly. This is due to the recovery of drag-out and due to the difference in cathode and anode efficiencies i.e. dissolution and deposition. This results in accumulation of zinc. The anode and cathode efficiencies are illustrated in Figure 8.14. It is clearly illustrated that as plating proceeds through the week the difference between anode and cathode efficiency increases resulting in the accumulation of zinc in the plating tank.

Figure 8.13: Zinc tank chemical evolution



From Figure 8.13 it can be seen that the caustic and carbonate concentrations can also be predicted in the plating solution. It is important to note that the plating thickness changes with time due to the concentration variation. This is expanded upon later.

Figure 8.14: Zinc cathode and anode efficiencies



The model incorporates the zinc rinse tanks and the model is able to predict the concentrations of all the plating tank chemical components, in the rinse tanks. It is also important to note that the models for these rinse tanks were started at zero concentration. The equilibrium concentration can be determined and helps the company to predict water consumptions. In Figure 8.15 0.2 **l**/min was used as water flow rate through the closed loop system.

If the company sought to enquire on the impact of operating the zinc tank with a closed circuit rinse but with a higher drag-out, this is illustrated in Figure 8.16. It is clearly seen that the concentrations of the individual plating chemicals increase drastically in the rinse water system with an increase in drag-out.

Figure 8.15: Rinse system achieving equilibrium concentration

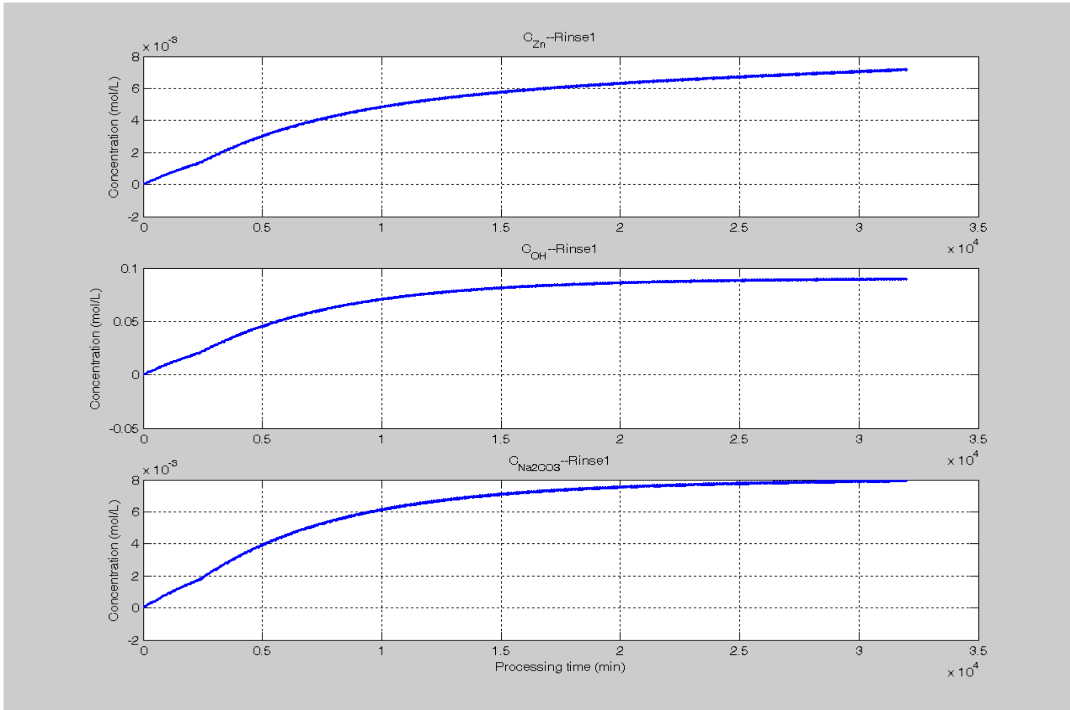
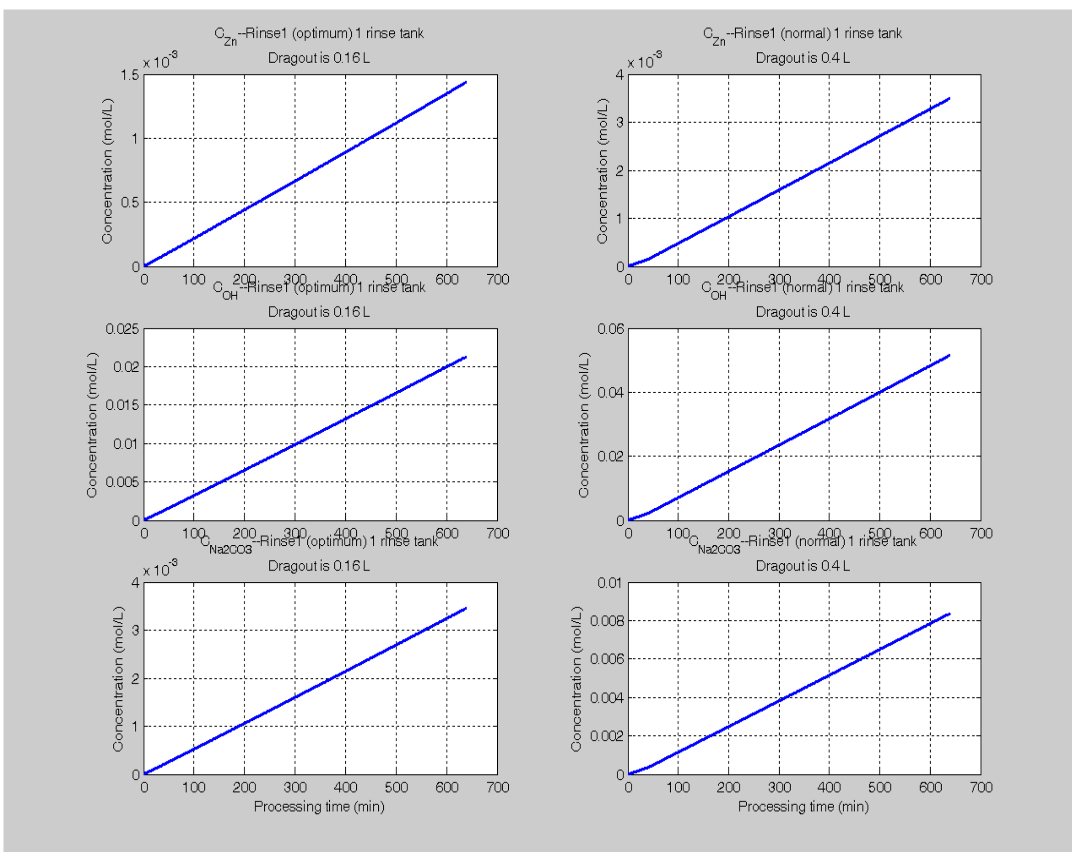
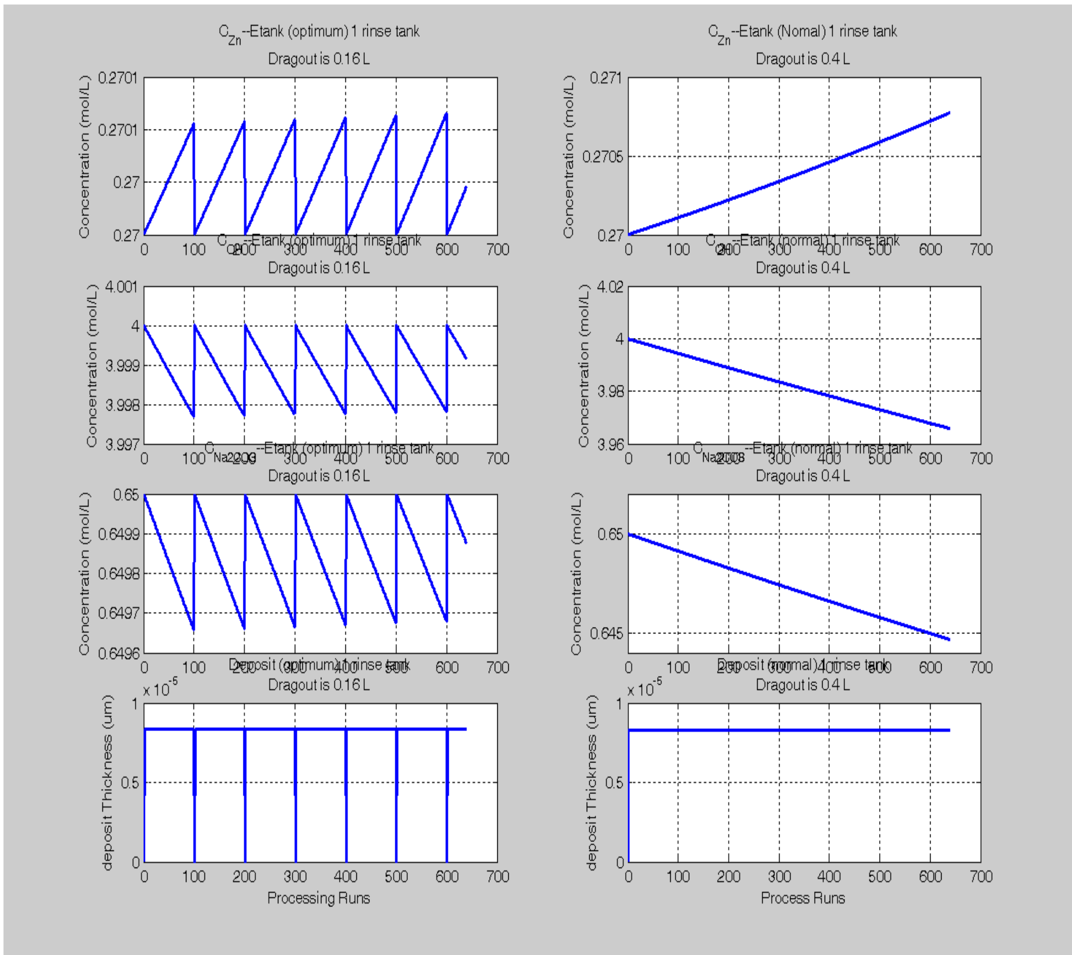


Figure 8.16: Tank chemical evolution with varying drag-out



The operational benefit of regular bath maintenance is illustrated in Figure 8.17 with a comparison with poor operation. The benefit of operating the plating tank close to supplier specification is illustrated. The key benefit was the plating thickness, which is maintained at 8.32 microns as compared to the weekly maintenance, which results in a thickness of 8.29 microns.

Figure 8.17: Plant operation with regular bath maintenance



A summary of the comparative outputs between current operations and cleaner production operations is illustrated in Table 8.2.

Table 8.2: Summing up the benefits of cleaner production on the zinc system.

	Current	**CP**
Zinc consumption (drag-out)	28.8 kg/week	0
Caustic consumption (drag-out)	34.6 kg/week	0
Thickness	8.29(inconsistent)	8.32(consistent)
Water consumption (plating tank)	288 l /week	0
Rinse water consumption	28000 l /week (100 times dilution)	1440 l/week (1000 times dilution)
Contamination to WWTP	1 g/ l of zinc	0

8.7 Comparative summary between proposed and existing CP evaluation tools

From the case study conducted above it would be ideal to summarize the benefits of the inputs and outputs in comparative tables. The model basic inputs are summarized in Table 8.3 below whilst the qualitative and quantitative outputs are compared in Table 8.4 and 8.5 respectively.

Table 8.3: Table of comparison -Case study data acquisition

Inputs-Flemming	Data/Time requirement	Proposed model	Data/Time requirement
Tank individual chemical make up	Data to be obtained from supplier specification-Days	Weekly operator chemical dosing	Operator prior knowledge- Data on hand
Tank yearly individual chemical consumption	Data to be obtained from company records-Days	Not required	
Calculation of Drag-out	This is determined by the auditor-Hours	Not required	Drag out is determined from fuzzy model
Dilution factors required	This is determined by the auditor-based on auditors experience	Not required	
Tank volume	Obtained from company-Minutes	Tank volume obtained	Obtained from operator-Minutes

Disposal volume	Obtained from company-Minutes	Number of disposals	Obtained from operator-Minutes
Plated thickness	Obtained from supplier-Days	Not required	Model generates values
Rinse water flow rate	Obtained from plant	Not required	Model generates case scenarios

Table 8.4: Table of comparison: Qualitative outputs

	Flemming	**Proposed**	**Percentage difference**	**Comments**
Qualitative output	**Yes**	**Yes**		
Rinse	Yes	Yes	2.9	
Chemicals	Yes	Yes	2	
OHS	Yes	Yes	2	
WWTP Chem	Yes	Yes	4.9	
WWTP	Yes	Yes	4.5	
Sludge	Yes	Yes	4.75	
Production	No	Yes	N/a	
Water	No	Yes	N/a	
Rinse system	Yes	No		Replaced by rinse system
Waste minimization	Yes	No		Found to be redundant

Table 8.5: Table of comparison: Quantitative outputs

Output	**Flemming**	**Proposed**
Rinse water concentration	No	Yes
Rinse water reaction-Acid/alkali	No	Yes
Chemical savings	Rating provided	Actual value generated
Water	Rating provided	Actual value generated
CP layout	No	Yes

Surface area calculate	Not determined, calculated manually	Model calculates SA from basic data
Time required	2-4 weeks	1 Day
Chemical concentration evolutions	No	Yes- all tanks plus rinse tanks
Data gathering	Management sourced	Operator sourced
Determines impact of process changes	No	Yes process changes can be modeled
Calculate exact impact of CP initiatives	No	Yes
Instantaneous zinc deposition rate	No	Yes
Individual chemical evolution-Acid/ degreaser/zinc	No	Yes
Individual chemical evolution-all rinses	No	Yes
Anode and cathode efficiency-monitoring	No	Yes
Illustrate benefit of continuous tank maintenance	No	Yes

8.8 Conclusions

From the comparative results listed it can be concluded that the artificial intelligence model outputs are similar if not equal to the Flemming model outputs. The comparative indices indicate a maximum difference in output of 4.75%. In some cases the model improves upon Flemming's model by providing further details.

The precise data requirements for determining the actual chemical consumptions have become obsolete. The output from the model is now used as an indication of the chemical consumption of the company. The model was used to determine the optimum consumption. Hence the potential savings can be quantified.

The greatest challenge in conducting the cleaner production assessment using the Flemming model was the determination of the surface area. As can be seen from the case study the model can predict the surface area within 4.5 % of the calculated value. This was conducted solely from operator inputs as compared to the traditional calculations requiring extensive data and time.

The model was used to determine the degreaser and other chemical consumptions based on the operator inputs. The values were traditionally considered difficult to obtain from companies.

The lifetime of the degreaser and acid can be predicted using the proposed model. The actual anode and cathode efficiencies and evolutions of individual chemicals were predicted using the proposed model. This information was not generated in any existing model.

The comparativeness and superiority of the proposed model is clear from the above case study. The demand for precise data becomes absolute using the proposed model.

CHAPTER NINE

CONCLUSION

The final chapter of this thesis aims at summarizing the case presented in this thesis. The focus of this chapter is to briefly outline the aims of this study and to describe how these aims were achieved. The conclusions of this study are detailed together with further work to be undertaken as an expansion of work undertaken in this study.

9.1 Background

The objective of this study was to develop an artificial intelligence based cleaner production audit model for the surface treatment industry.

International experts have conducted various environmental initiatives, such as waste minimization, source reduction and cleaner production with a focus on waste reduction in the metal finishing industry. These studies have resulted in significant improvements in the metal finishing industry. The various cleaner production initiatives that were undertaken, previously, resulted in significant savings. However, the success of these cleaner productions studies was found to be limited due to various constraints. These constraints included data availability, expertise requirements and time taken to conduct these studies. Cleaner production initiatives could have been significantly enhanced if these barriers were overcome.

This study was initiated based on the above limitations encountered during an attempt to conduct cleaner production audits in the metal finishing sector in South Africa. The key aim of the study was the development of a comprehensive cleaner production assessment tool that required minimum time, data and high level skills.

9.2 Overall approach

This thesis commences by detailing a background to the plating industry including some of the challenges traditionally encountered in conducting a cleaner production audit at a surface finishing facility. This thesis then details the development of expert knowledge on the plating industry. This includes the identification of the most comprehensive existing tool for cleaner production evaluations in the metal finishing sector. This tool was then applied to develop a database for the purpose of future model verification. A total of 25 companies were audited for this purpose.

This study then identifies the limitations and difficulties associated with the application of this cleaner production assessment tool. The tool was critically assessed to determine the potential of obtaining the equivalent result, but with alternate data and skills inputs. The aim was to produce equivalent or better quality outputs if compared to traditional models.

Based on this analysis the approach of this thesis has been to split the proposed cleaner production assessment tool into two key components. Hence, two models were developed, which when applied in parallel, produce a comprehensive cleaner production assessment. These two components of the study are best describes as the qualitative and quantitative components. The qualitative model was developed using fuzzy logic whilst the quantitative model was developed using mathematical models based on experimentation. The key factor to the models being its sole dependency on operator based inputs.

9.3. Development of the alternate CP evaluation system

The development of the first component of this study i.e. the qualitative evaluation components is achieved using fuzzy logic. For the fuzzy model the plant was categorised into different operational units. These included the wastewater treatment plant, the rinse system etc. Questions were developed to facilitate data acquisition on assessing the cleaner production status of these operational units. Together with these questions fuzzy alternates were generated as operator answers (alternates) to these questions. Fuzzy logic multi variable decision analysis was applied to the ratings of the operator alternates. This decision analyses generated fuzzy equations, which provided a qualitative status on each operational unit. A comparison was conduced with a previous CP tool, in order to ensure that these outputs were equivalent to the previous CP tool outputs. The fuzzy inputs were regressed, wherever necessary, in order to generate the equivalent outputs. The key output of the fuzzy model is a rating on a scale of 0 to 100 on the potential saving in each of the eight plant categories.

The quantitative component of this study entails the development of three mathematical models. These models comprise of the plating, degreaser and the acid cleaning models. The aim of developing these detailed model was that they be used to model current operation together with the potential cleaner production operation. The difference between the two would be the projected cleaner production savings.

The models were developed using basic experimentation in a pilot plant that was specifically constructed. The experimentation entailed detailed literature searches into the variables that impacted on the operation of these processes. Fractional factorial design was employed for the experimentation. This ensured that the influence of all the variables and their interactive effects were considered to determine the operation of each of the processes.

The first mathematical model that was developed was the acid cleaning model. The major variables affecting acid cleaning were, temperature, iron contamination and acid concentration. This basic model was then integrated into a holistic acid cleaning model which included drag-out, cleaning time and the rinse system. This model was then applied to determine the surface area passing through the acid tank. From previous models the production (surface area) was always difficult to determine. The surface area was now obtained by an iterative estimate-programming loop based on the operator weekly acid dosing. This proved to be the first major success of this study. Armed with this surface area the chemical consumptions of all the processes could now be modeled.

The basic degreaser model was developed using the major variables that influence the degreaser operation. The holistic degreaser model was developed using similar consideration to the acid model. These include reaction time, drag-out, temperature, oil contamination etc. The degreaser model included the degreaser rinse system.

The last of the mathematical models was the zinc model. The zinc model was perhaps the most complex as there were three main reactions to consider together with determining cathode and anode efficiency. The major variables that were considered for the zinc system included the zinc concentration, caustic concentration, power inputs and temperature. These were integrated with a comprehensive rinse system into a holistic zinc model.

The three mathematical models were programmed into Mat Lab so that they could be applied to the various case scenarios. The fact that the inputs to these models were to be obtained from plant operators implied that there was a possibility that some date would not be as accurate as expected. This uncertainty in inputs was accounted for by illustrating (simulation) the variations in inputs using the Monte Carlo technique. Here, inputs to the mathematic models were randomly changed to account for potential operator inaccuracy.

Using the operator based questionnaire the three mathematic models could thus be used to simulate the current operations of the plating facility. Typical cleaner production strategies can then be applied to the plant and the cleaner production operation determined. The differences in chemical and water consumptions can be predicted together with the potential impact on the wastewater load.

The application of the holistic tool was illustrated by conducting a case study at a local metal finishing company. In order to reinforce the comparative benefit of the proposed tool a cleaner production audit was conducted, in parallel, using a traditional cleaner production evaluation tool.

Comparing the two approaches, the model proposed in this study required less than an hour of time from a plant supervisor whilst the traditional model required a two-week period to be completed. The data inputs for the traditional CP tool were obtained from the plant manager in consultation with the laboratory manager. The auditor had to intervene on various occasions to clarify data issues. The auditor had to conduct various plant measurements as required by the audit data sheet. A total of 245 inputs were required for the traditional model as compared to the 56 inputs required for the model proposed in this study.

The outputs from the two CP tools were found to be very comparable. The fuzzy model generated the equivalent of the traditional model. This included a rating of potential saving in the major plant categories.

The key challenge of determining the plant surface area required more than a days work to determine in traditional model but is now obtained by a few simple inputs in a few minutes. Applying the operator input for dosing of the acid tank generates the surface area. For the purpose of the case study the initial surface area estimated by the plant manager was also found to be incorrect. The model generated a surface area that was 4.3% less that the plant managers estimate.

The CP tool was found to be superior to the traditional cleaner production evaluation systems as various details were generated that were never available using the traditional models. These include the instantaneous predictions of individual chemical and water consumption, tank efficiencies, wastewater load etc.

In summary the CP tool proposed in this study was found to produce a cleaner production evaluation that was better than rigid traditional models.

9.4 Recommendations and future work

It can be seen that the difference in outputs from CP tools developed and previous well-reputed models is rather insignificant. It can thus be stated that the aims of this study to provide a user-friendly CP tool based on operator level inputs were fully achieved. There is however certain details that needs to be addressed. These need to be part of a potential implementation phase of the above CP tool and can be considered as future work. This includes the application of the CP tool to various metal plating companies and conducting the necessary improvements so as to improve the confidence levels in such a CP tool.

The other consideration for future improvements includes the stand-alone use of the CP tool i.e. the use of the CP tool outside of the control of the developer. This would probably result in various improvements and fine-tuning of the CP tool.

More detailed kinetics based models, for process tank operations can be developed and compared to the current factorial models. The factorial models proved useful under the constraints of the limited time, complexity of the reactions due to various supplier chemical additives, availability of supplier data on chemicals and the need to obtain an operational model for the purpose of this study.

Cleaner production evaluations for various sectors have proven to be a significant challenge. The methodology described in this study can be used to justify research into the development of similar models for various other industrial sectors. It would thus be considered ideal to follow the methodology of this study for cleaner production evaluations in other industrial sectors.

Appendix A

Appendix A1: General instructions for completing questionnaires.

The questionnaire is prepared to fit with the PC-tool we are using for environmental reviews in electroplating companies. You should try to answer the questions as exactly as possible, and it is important that you fill in the information required and in the form specified.

Try to fill in as much data possible. If you are missing some information to make a complete answer, try to get the information before returning the questionnaire. You may add additional information if relevant. If it is not possible to answer all questions correct, try to give as much information you are able to do.

If you cannot fill in data, please make an estimate and explain in a footnote the criteria or conditions under which you made the estimate. We can then discuss it during the review. This will give us a more complete platform of information to work from

Please do not give us the answers in a separate letter or report. We need the answers to be filled into the questionnaire.

Please notice, that the review will cover:

- One electroplating line
- Total amount of hazardous waste from the electroplating shop or department
- Total wastewater treatment plant (WWTP) for electroplating wastewater
- Occupational health and safety (OHS) for the electroplating line

If you have no wastewater you can skip the table covering this topic.

Start to fill in the basic information of the company:

Name of the company		
No + Street		
Town and area		
Postal code		
Contact persons	1. Responsible persons for questionnaire:	
	2. General manager (CEO):	
	3. Electroplating manager:	
Phone		
Cell		
Fax		
E-mail		
Number of employees of the total company		
Number of employees working with electroplating		

Please include a flow-sheet of the process line and a flow-sheet of the wastewater treatment plant in your answer.

1. Information about production and process chemicals for the selected line.

General production figures:

You should use the most actual figure. If possible take figures from the last 12 months (or from the last 6 months and multiply by 2) or from last year (1999).

Name of the process and the line	
Production in m^2/year (if you cannot give the m^2/yr try to give kg/yr or something else)	
Layer thickness of coating in µ (if you don't know, try to estimate for all layes)	
Production time, h/day + h/week + h/year	

Consumption of chemicals:

For pre-treatment baths fill in both main component (always) and additives (if possible). For plating baths fill in all main components (always), anodes (always), brighteners (as a sum and use only total price in R/year) and other additives (if consumption is relatively high). For chromating baths fill in main components (always) + additives (if possible). Use one line in the table for each chemical. This means that an acid zinc bath need at least 5 lines (anodes, zinc chloride, ammonium chloride, brighteners, other additives). All columns must be filled in except the chemical formula if it is not available. We use the chemical formula to avoid mistakes about which chemicals are used.

Name of process bath	Name of chemical (always)	Chemical formula (if possible)	Consumption kg/year	Unit price R/kg	Total price R/year

2. Maintenance of process baths

The table must include all process bath including pre-treatment, plating and post-treatment as well as other chemical baths. If there are more baths of the same kind (e.g. 3 nickel tanks) you can collect them in one row (and add the volumes) of the table or you can separate them. All columns must be filled out for every bath, but if the bath is never dumped you write 0 in the frequency column.

<u>Bath analysis and chemistry:</u>

Use the following abbreviations: (you make use more figures for each bath)

1. Bath chemistry is adjusted at least once a week
2. Bath chemistry is adjusted at least once a month
3. Bath chemistry is only adjusted when we have problems
4. We make the analyses in our own lab
5. We analyse only some parameters in our own lab
6. The supplier analyse all the parameters
7. We have a record of added chemicals for the bath

Bath purification procedure:

1. Filtration, continuously
2. Filtration, occasionally
3. Treatment with active coal
4. Chemical treatment
5. Selective metal precipitation
6. Crystallisation
7. Membrane electrolysis
8. Other types of purification and regenerant

The dumping frequency you can describe as the following examples:

- Once every month
- Once every 2nd week
- Two time per year
- 50% dumped every week

The treatment method for dumped baths could be:

CT = Treatment on a central plant (external)
IT = Internal treatment in own wastewater plant
IR = Internal treatment and recycling
ER = External treatment and recycling
OD = Other disposal methods (please specify)

Name of bath	Tank volume litres	Bath analysis and chemistry	Bath purification procedure	Dumping frequency	Total dumping m^3/year	Treatment method for dumped baths

3. Rinsing processes.

In the first column you may write a number of each rinsing tank referring to your flow-sheet. You may skip this column if you don't have a number.

Name of rinse:

The name of the rinse must refer to the process bath you drag into the rinse. Use names as pickling rinse, cleaner rinse, chromating rinse, cyanide zinc rinse etc.

Type of rinsing system:

The type of rinse system could be (you can yourself add more to this list):

1 running rinse
2 running rinses
1 drag-out rinse (static rinse) with reuse
2 static rinses with counter current reuse
1 static rinse (dumping)
1 static + 1 running
2-step counter current rinse
3-step counter current rinse
1 static + 2-step counter current rinse, etc.

Raw water quality:

T-water =	tap water
I-water =	ion-exchanged water
C-water =	chemical treated water
R-water =	reuse water from another rinse tank
DI-water =	de-ionised water

Water flow:

If possible we will ask you to measure the water flow inlet in each rinsing system. If you already have installed a separate flow meter on each inlet it is easy for you to get these figures. If you don't have these figures it is normally easy to make a flow measurement using a small container and a stop watch. You can par example measure how many seconds it will take to collect 1, 2 or 5 litres water from the water inlet pipe or from the outlet, if it is easier. If you use a static rinse that is regularly dumped you can calculate the yearly water consumption by multiplication of tank volume by the number of dumps per year. If you finally divide by the number of working hours per year you get the flow in l/h. To assess your measurement it will be very useful to have other figures from total water consumption of the line. We have included two possibilities in the below table.

No.	Name of rinse	Type of rinse	Inlet water quality	Inlet flow litre/h
Sum for total line (calculated form individual measurements above)				
Sum for total line estimated (from account or total water meter)				
Sum for total line measures by separate water meter				

4. Hazardous waste.

This table shall only include hazardous waste disposed of for external treatment, dumping, processing or recovery. Use names as thin sludge from WWTP, filter cakes from WWTP, spent pickling bath, etc.

It is important that all columns are filled in. If there is no fee for disposal, then write zero in the price-column.

Name and type of waste	ton/year	Disposal and treatment methods (must always be specified)	Unit price for disposal R/ton	Total price for disposal R/year

Please write name and contact person at the waste collection company:____________________________________

5. Wastewater treatment plant (WWTP).

Consumption of chemicals for wastewater treatment:

All columns in the below table should be filled in as far as possible for all individual chemicals used for wastewater treatment. These could be caustic soda, soda lye, lime, sodium hypochlorite, hydrochloric acid, sodium metabisulphite, polymer, etc. For pure solids the concentration is 100%. For solutions we must know the exact concentration. Write the chemical formula if possible. Write the purpose for using the specific chemical (NaOH for neutralisation and precipitation, sodium hypochlorite for cyanide oxidation, polymer for flocculation, etc.).

Name of chemical	Chemical formula	Concentrate tion, % (w/w or w/v)	Used for	Consumptio n kg/yr or l/yr	Unit price R/kg or R/litre	Total price R/year

Operation of wastewater treatment plant:

Control procedures are collected in the next table. If you don't use the mentioned process you shall write "no" in 2nd column and no more information is filled in this row. For the frequency in column 4 and 5 write the time interval between two cleanings/calibrations or the number per time unit.

	Exist: yes/no	Control parameter	Probe cleaning frequency	Probe calibration frequency	Additional check used	Yes or no
Neutralisation		pH			Transportable pH-meter	
Cyanide oxidation		pH			Transportable pH-meter	
		mV			Monitor excess chlorine	
Cr-6 reduction		pH			Transportable pH-meter	
		mV			Monitor residue Cr-6	
					Monitor excess sulphite	
Outlet monitor		pH			Transportable pH-meter	
		Flow				

Wastewater analysis:

Fill in actual values from a period of 6-12 months from samples taken by the authorities or arranged by yourself

Parameter	Period:			Discharge limits
	Minimum	Maximum	Average	
Water, m^3/day				
Water, m^3/year				
pH				
Chromium, total, mg/l				
Chromium-6, mg/l				
Copper, mg/l				
Nickel, mg/l				
Zinc, mg/l				
Cadmium, mg/l				
Cyanide, mg/l				

Tool for Environmental Review of Electroplating Processes

Copenhagen, 02.10.2000
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Table of Content

Introduction

The review tool is an excel based tool specially developed to identify and highlight all important process figures and environmental data by electroplating production. The tool is developed to assist a consultant in making reviews. The tool can be used completely or partly in the review work what is most convenient in each case. The tool is especially suitable for electroplating lines and less suitable for manual processes where some tanks are used for more purposes.

The tool use a scoring system to rank the individual issues. The scores can be 1, 2, 3, 4 and 5. We use 1 when the situation is acceptable, and we cannot make any improvements. We use 5, when the situation is completely unacceptable and there are a lot of possibilities to improve by implementation of CP-methods. Even high scores are unacceptable they offer the company opportunities to improve and to save money by implementation of cleaner production.

As far as possible key figures are calculated based on consumption per 1000 m^2 surface area. This way you can compare figures from one company to another or to branch standards. You can even use the key figures only for one company to follow the improvements in a relevant and quantitative way.

The consultant must fill in the blank white cells of the tables. The yellow cells are used for calculations and fixed values and should only very seldom be changed. The yellow cells are locked and can therefore be protected, if the spread-sheet or workbook is protected by a password. We have found out that it is most adequate to fill in the tables on site based on pre-filled questionnaires. This way the calculated key-figures immediately and discuss them with the company and adjust the figures if necessary.

The scoring system is described in the support tables to each principal table. Furthermore we have below described comments for each table to assist the consultant in understanding the tool.

Table 2 - Consumption of Process Chemicals

This table describes the production rate as well as the chemical consumption. For pre-treatment baths fill in both main component (always) and additives (if possible). For plating baths fill in all main components (always), anodes (always), brighteners (as a sum and use only total price in R/year) and other additives (if consumption is relatively high). For chromating baths fill in main components (always) + additives (if possible). Use one line in the table for each chemical. This mean that an acid zinc bath need at least 5 rows (anodes, zinc chloride, ammonium chloride, brighteners, other additives).

1. Select the table aimed at the particular process line and fill in the name of the process line. Each process line must have its own table.

2. Fill in the estimated layer thickness. The treated surface area is automatically calculated on the basis of layer thickness and consumption of anodes, chromic acid, etc. The information is necessary, as all other calculations are related to treated surfaces area. By anodising, chromating, degreasing and pickling the surface must be either calculated or estimated.

3. Another possibility is to calculate or estimate the m^2 in another way. Fill in this figure in column H in the same row as anodes for the plating bath. Then the program will calculate a layer thickness you can compare with the estimated thickness. This will give an idea of which estimate is the most reliable.

4. Key figures are calculated on the basis of the correlation between consumption and surface area. The goal values, listed in the table, are realistic goals for companies using the technology of today. It should be noted that a very large variation occurs within the various processes. The goals therefore could be adjusted, if this can be justified. The goals should be defined from case to case.

5. The environmental assessment score for each individual bath is a measure for over-consumption of chemicals in each individual bath as well as the over-consumption in relation to the total over-consumption of chemicals of the entire process line. Thus, it would not be so critical to use 5 kg of chemicals too much for one single bath even though it equals a 50% over-consumption in this bath, if the total over-consumption of the entire line is 500 kg.

6. The score of the line is calculated in the support table. Here all over-consumption figures are summarised and for each bath the over-consumption of the bath is divided with the total over-consumption for the line. This figure is transformed to a score from 1 to 5.

7. When the table is completed you should hide rows with chemicals not being used and also columns (G and J) not being used to obtain a more clear presentation of the table. You must never delete lines or rows in a table, because this will damage the calculations

Table 3 - Maintenance of Process Bath

According to practical experience the dumping of process baths is often the biggest source of heavy metal waste from electroplating. Therefore the tool focus very much on how to reduce the dumping of process baths. If the baths are maintained proper it is often possible to keep the bath alive for a long time, but often you need to use some advanced purification technology to purify and regenerate the bath. The procedures for controlling bath chemistry are also important to prolong the life time.

In table 3 we calculate the total price for the baths.

Total costs = costs for new chemicals + costs for disposal of spent baths

If the dumped baths are treated in the company wastewater treatment plant the treatment costs should not be included in table 3. The total wastewater treatment costs you will find in table 6. Only if the treatment is done in a separate plant or by an external waste collection company the costs should be included in table 3. Notice, that the name of the baths and costs of new chemicals for the baths is automatically transferred from table 2 to table 3.

1. In column F you fill in the volume in litres of each process tank
2. In column G you fill in the maintenance procedure for each bath (use code number from maintenance table)
3. In column H you fill in the disposal method for each bath (use code number from disposal table)
4. In column I you fill in how many m^3 are dumped per year. Use information from the company about dumping frequency and multiply the number of dumps by the tank volume.
5. In column J you fill in the cost of dumping (fees for transport and external treatment at waste companies)
6. The total bath costs for the baths (buying of new chemicals + disposal of spent baths) is automatically calculated in column K.
7. Key figures are calculated on the basis of the correlation between rejected bath volumes and surface area of the production. Even there are some realistic goals for the branch the goals should be adjusted and specified from case to case according to the pre-conditions for the individual companies.
8. The score for each individual bath is a kind of measure for bath economy. It uncover if the company is dumping unnecessary big amounts of baths compared to the standard of today. The score is relative and weighted for the total line as for table 2.

Table 4 - State of Rinsing Water

This table is applied for description and assessment of the existing rinse water systems used in the electroplating line to be reviewed. In column F to K is focused on construction and lay-out of the particular rinse system. A good score in this table is not equivalent with an acceptable low water consumption. In column L to P is focused on the water consumption, where the actual water volumes are compared with key figures for the branch in general or with regulations.

The columns A, B, C, D and E are filled-in for each rinsing stage of each process line. By calculation of the score for each rinsing stage the 6 independent parameters, which effect the effectiveness of the rinsing stage, are considered. These 6 parameters are:

Dripping By dripping is understood the length of time where the items are placed above the process bath before being moved to the next bath. If the time of dripping is too short, the liquid will not reach to drip off completely before the item is moved on.

A score for dripping is, therefore, determined by the length of time where the items are dripping above the bath, before being send on to the next bath.

The scores in table A below are acceptable for racked goods but for barrel goods a more individual assessment can be necessary.

Table A: Scoring by dripping (Racks or jigs)

Score	Time
1	> 20s
2	15 - 19s
3	10 - 14s
4	5 - 9s
5	0 - 4s

Hanging By hanging (suspension) we understand the physical way in which the items are placed on the rack or jig. By tilting the items in order to avoid as many entrapments as possible, drag-out volume is minimised. For example must a cup-shaped item always be racked upside-down, hollow tubes should be racked vertically with a slight slope.

The score for hanging therefore depends on the efficiency of the liquid to drip off the item, before the items are lead to the next process. For barrel items the score should always be 1.

Table B: Scoring by hanging (Racks or jigs)

Score	Procedure
1	All water drips off immediately
2	All water drips off gradually
3	Moderate dripping
4	Slow dripping
5	Slow dripping + entrapments

Agitation By agitation we understand the physical motion of the liquid. If the liquid is not in motion or being agitated the replacement of the liquid film on the item surface will be very slow, and there is a risk to drag-out the chemicals before they have been exchanged from the surface layer. By heavy agitation and liquid motion the liquid film physically is replaced much faster. The agitation and liquid motion thus have high influence on the speed of the replacement of the liquid film.

Table C: Scoring of Agitation (Liquid Motion)

Score	Procedure
1	Agitation and liquid motion
2	Agitation and no liquid motion
3	Heavy liquid motion, no agitation
4	Light liquid motion, no agitation
5	No liquid motion, no agitation

Inlet/Outlet By inlet/outlet we understand the way in which the rinse water physically are let in and out of each rinse tank. The inlet/outlet has major influence on the physical passage of water in the rinse tank and on the utilisation as well. If the inlet and outlet physically are placed side by side there can be a high water consumption but a very low rinsing efficiency.

Table D: Scoring of Inlet/Outlet

Score	Procedure
1	Outlet (top) reverse inlet (bottom)
2	Outlet (top) reverse inlet (immersed)

3	Outlet reverse inlet (bottom)
4	Outlet reverse inlet (top)
5	Outlet reverse inlet (bottom)

Back-Mixing When two or more rinsing tanks are connected (eg. counter current rinse) it is important that the water will run from the tank with clean water to the tank with more dirty water. This is normally controlled by a simple gravity flow where there is a difference in water height. Under normal conditions the flow direction is correct, but if a big rack or even worse a big barrel is submersed in the dirty water, the water level in the dirty tank may increase above the water level of the clean water tank. In this case the water will flow in the wrong direction, and the clean water tank will get polluted with dirty water. In this case there is a very low efficiency of the rinsing process compared to normal conditions for this kind of rinse systems. The wrong construction should be repaired to improve rinsing quality and reduce water consumption.

Table E: Scoring of Back-mixing

Score	Procedure
1	No back-mixing
2	Minimum back-mixing
3	Moderate back-mixing
4	Some back-mixing
5	Heavy back-mixing

Flow-control Controlling the inlet flow of water to a rinse tank is maybe the most important factor influencing the water consumption. To control the flow you need a valve for adjustment and a flow meter to monitor the flow - but you also need to know how much water is needed. The demand of water is determined by the defined water quality (F = dilution factor) and the drag-out from the previous process tank.

The typical situation is a water-valve totally open, and nobody has considered if less water would be sufficient. Some companies implement some kind of water restrictors and this is highly recommended, but it is still very important that the restrictors are allowed to control the water flow. Too often we see the operation staff increasing the water flow by further opening the water-valve because they found the rinse water too dirty. This is an important part of the management task to set up correct instructions and ensure that these instructions are followed.

A high score assume, that you control rinse water quality and rinse water flow.

Table F: Scoring of Flow-control

Score	Control method and efficiency
1	Complete flow-control
2	Some flow-adjustment
3	Coarse flow-control
4	Very little flow-control
5	Total open valve

The overall shape and functioning of the each actual rinsing process of the line is scored as a weighted average, as the 6 parameters do no have equal impact. The score of the actual rinsing system will uncover if you can save rinse water by improving the existing system, but it don't tell you, if these savings are sufficient. The assessment is exclusively based on the functioning of the existing rinsing system.

<u>Water consumption:</u>

1. If the water flow of the various rinsing stages is unknown, we cannot compare the water consumption with goal-values. The water flow must therefore be measured or estimated.

2. The recommended water flow (goal value) is calculated for each rinsing stage as a 3-stage cascade rinsing is applied (BAT). To carry out the calculation the dilution factor F must be noted in column S and the drag-out in column V. Water consumption at 3-stage cascade rinsing is the goal according to the BAT-principle.

The dilution factor is the dilution of the process bath required in the last rinse water tank before the item is passed on to the next stage of process. Recommended F-values in the various baths are:

Table G: Recommended F-values for selected rinsing process

F	Rinsing Process
100-1.000	After degreasing and pickling
500-2.000	Before electroplating metal finishing baths
200-2.000	After miscellaneous chemical baths
5.000-10.000	Final rinsing after decorative chromium
1.000-5.000	Final rinsing after other galvanic baths

Drag-out is defined as concomitant liquid which is left on the item, and thus carried from one tank to the next as the liquid volume. Empirical figures for drag-out from various items:

Table H: Typical drag-out values for different items and different suspension

Drag-out, ml/m²	Item and Dripping
25-50	Vertical hanging, good dripping
160	Vertical hanging, bad dripping
50-100	Horizontal hanging, good dripping
200-400	Horizontal hanging, bad dripping
300-1.000	Cup-shaped items, bad dripping
100-200	Typical "normal average"
200-300	Barrels

When these values have been chosen and inserted in the columns S and V, the columns N, O, P and Q are calculated automatically.

The possibilities of savings now appears from column Q, if we assume that the companies follow the recommendations and implement 3-stage counter current rinses or other low water consuming rinse technique.

Table 5 - Chemical Waste

This table is applied for describing the present chemical waste produced by the company as well as for describing the potential possibilities of waste minimisation.

1. Fill in the quantities, disposal methods and disposal costs in the columns A-E for each type of chemical (hazardous) waste. The table shall only include waste that are treated or deposited external by a waste collection company.

2. Assessment of the possibilities for waste minimisation is very much depending on the type of waste. Below there is a brief description of the various methods for waste minimisation:

Column F **Reduction of Drag-Out**

Reduction of drag-out will normally reduce the chemical consumption in the process baths and reduce the rinse water volume and the generation of sludge in the WWTP. When we reduce the drag-out we will also reduce the drag-out of impurities from the process bath. Therefore it should often be combined with bath purification system

The net drag-out can also be reduced by implementing static rinse tanks, where the concentrated rinse water is used for topping up the plating bath to replace evaporation loss. The static rinse may also be used as a pre-dip before entering the plating tank, and by this procedure you can always return 50% of the direct drag-out from the plating bath. After nickel and chromium plating tanks it will often pay to use 2 or 3 static rinse tanks with reuse according to the counter current principle.

When you reduce drag-out you will also reduce the drag-in of impurities from the previous process.

Column G **Optimising bath chemistry**

By optimising bath chemistry it is often possible to reduce chemical waste. You can keep the concentration of active chemicals at a suitable low level (cleaning baths, chromating baths, plating baths) which will reduce the drag-out to rinse water and thereby reduce the generation of WWTP sludge.

Column H **Concentrating of waste**

Waste may be concentrated to reduce disposal costs. Liquid waste may be concentrated by an evaporation technique or by transferring it to solid waste by chemical methods. Thin sludge may be dewatered in filter bags or in a filter press. Dewatered sludge may be further concentrated in a sludge dryer.

Column I **Maintenance of process baths**

Spent process baths may be collected by a waste company (external treatment) or treated in the WWTP of the company (internal treatment) and thereby sludge is generated. If the baths are maintained better it is possible to prolong the lifetime and thereby reduce the amount of sludge. More purification methods are available for treatment of process baths (filtration, UF, MF, centrifuges, chemical purification etc.).

Column J **Internal Recovery of Waste**

Recovery of waste often requires a separate process. When waste has been recovered to usable products, it is sometimes a problem for the company to sell these products, as they often differentiate strongly from the "normal" range of products. Examples are: Metal recovery by electrolysis.

Scoring: When it is not possible to reduce the specific waste by the mentioned technique you should fill in a score 1. If there are some possibilities you fill in a higher score from 2-5. The bigger possibility for waste reduction, the higher value.

In column K the ranking of waste minimisation opportunities is calculated, and the sum of these rankings are 100. You can use the result for prioritisation of your effort. The ranking is a combination of potential for savings and the amount of waste. The highest priority will be given to the waste where you have the most obvious possibilities to save more money.

The total score calculated in cell K24 is a kind of total potential for savings as a figure between 0 and 100. The higher figure, the more money it should be possible to save by minimisation of chemical waste. Please study the support table to find the way we calculate K24.

Table 6 - Wastewater Treatment Plant (WWTP)

In table 6 is listed the various possibilities of optimising the present wastewater treatment plant concerning consumption of chemicals. A number of different chemicals are used for wastewater treatment. By examination of the treatment plant several optimising options become evident. Each parameter is briefly described below:

Reduce excess chemicals

It is often possible to reduce the consumption of chemicals by reducing the excess dosing. By chromate reduction we often use sodium metabisulphite at low pH (2.0-3.5). Here we can operate at 3.5 to save acid and also we should use as little excess of sulphite as possible (5-10 mg/l). Similarly by cyanide oxidation we operate at high pH (11-13). Here we can operate at 11 to save NaOH and also we should use as little excess of chlorine as possible (5-10 mg/l). Also dosing of flocculating chemicals ($FeCl_3$ and $Al_2(SO_4)_3$) and polymers should be minimised and optimised

Reuse of spent baths

If spent baths are to be used for neutralisation or chromate reduction in connection with wastewater treatment, it is important to examine the compositions carefully.

Spent pickling baths contain acid and may be used for pH-adjustment. Spent pickling baths from steel pickling may be used from chromate reduction instead of sodium metabisulphite. Alkaline degreasers and cleaners can in some cases substitute caustic soda but this should be done with caution as they often contains complexing agents, that may disturb the chemical precipitation. Instead of flocculating chemicals it is possible to use spent alkaline etching solutions from aluminium etching, but also spent anodising baths may be used for this purpose.

In general it is important to make a thorough evaluation of the consequences by using spent baths before implementing in full scale.

Optimising treatment of spent baths

By optimising the treatment process it is often possible to reduce the chemical consumption in the wastewater treatment plant. The baths which are treated in the internal treatment plant, must be appraised as regards volumes and dumping frequency. If a sulphuric acid bath is rejected every fortnight and an alkaline bath every week, these two types of baths can be used to neutralise each other. Storage tanks with dosing pumps are needed for the storage tanks, and the spent baths are pumped slowly into the general wastewater stream.

Improved separation waste streams	It is normally a good idea (and often necessary) to separate the **of** wastewater into a number of sub-streams for treatment in the WWTP. Chromate containing wastewater should be separated for the chromate reduction process. Don't mix any other wastewater with this water. A bigger amount of wastewater for chromate reduction will consume more chemicals. Similar procedure should be followed for cyanide containing wastewater. Wastewater with complexing agents should also be separated and treated in a separate process.

Procedure for completing table 6:

1. Fill in the columns A, B, C and D with information from the company.
2. For each chemical you shall score the possibilities for reducing chemical consumption specified in column E, F, G and H.
3. The program will now calculate the total score of each chemical in column I. This figure will indicate (from 0-100) the possibility for saving each specific chemical..
4. In column J the program will calculate the saving-index, which is the consumption multiplied by the 1/100 of the score in column I. In cell J22 we have the total score which is a sum of saving indices divided by the total chemical consumption (cell C22).

Table 7 - Wastewater Treatment Efficiency

Table 7 concerns operation control of the wastewater treatment. We are focusing on treatment efficiency and stability demonstrated by chemical analyses and maintenance procedures. The table is divided into three independent parameters: outlet monitoring, treatment and calibration procedures and checking methods.

In this model we have no score for outlet monitoring. These figures will give an overall impression of the quality of outlet water from the WWTP. The figures should be compared to the actual discharge limits.

The operational control is scored by observing treatment and calibration and control measurement, respectively. These parameters are scored as illustrated below:

Table **Error! Unknown switch argument.**: Scoring of operational control of a treatment plant

Score	Cleaning and Calibration	Checking measurements
1	Once every week or more	Once every day
2	Once every second week	Once or twice a week
3	Once every month	Once every month
4	Once or twice a year	Once or twice a year
5	Never	Never

Procedure for completing table 7:

1. For discharge control: Fill in analyses results from a suitable period (6 or 12 months) and the discharge limits.

2. For operation control: Fill in the frequencies and scores for "electrodes" and "checking measurements".

3. The program will now calculate average score for "electrodes" and "checking measurements". The total score is a weighted score with 1/3 for "electrodes" and 2/3 for "checking measurements".

Table 8 - Occupational Health and Safety (OHS)

Table 8 concerns the state of occupational health and safety issues of the electroplating process lines. In order to limit the number of parameters to be assessed, only the impact from chemistry and temperature of the "worst" baths (1-3 baths) is included together with the general impact from noise, heavy lift and risk for the whole line. An overall assessment for noise, heavy lifts and occupational risks are made for each process line.

For every parameter (except risk) we calculate the score from the equation:

Score = quantity * exposure time * effect

Quantity, time and effect may be 1, 2 or 3 - and the maximum score therefore 27. For each parameter we have special guidelines how to score. The higher impact, the higher score.

Chemistry The influence of the chemistry is scored concerning concentration, exposure time and effect. The concentration is compared to TLV (threshold limit value) and the effect has been categorised by impact on human beings. For the scoring the "worst" chemical compound should be selected for each bath.

Table **Error! Unknown switch argument.**: Scoring of chemical impact

Score	Concentration, mg/m^3	Exposure, h/day	Effect
1	< 0.5*TLV	< 0.5	Non toxic, but irritant
2	0.5-1,0*TLV	0.5-2	Corrosive, dangerous to health
3	> TLV	> 2.0	Carcinogenic and toxic compounds

Temperature The impact of the bath temperature is scored concerning level of temperature, time of exposure and effect. The volume is related to the temperature fluctuations, which the worker is imposed to at each bath. These temperature fluctuations are assessed in regard to the temperature of the surroundings. The effect is related to the degree of which it causes accidents or discomfort.

Table **Error! Unknown switch argument.**: Scoring of Temperature (T = room temperature)

Score	Temperature	Exposure h/day	Effect
1	< T+5	< 0.5	No discomfort
2	T+5 - T+10	0.5-2	Discomfort, tiredness, etc.
3	> T+10	> 2.0	Errors, accidents, etc.

Noise The impact of the noise is scored in regard to noise level, time of exposure and the effect. The volume is related to the limit values, which in Denmark is 85 dB(A). Experiences show that approximately 10% of all people which has been exposed to 90 dB(A) for 10 years will be hearing-impaired .

Table **Error! Unknown switch argument.**: Scoring of noise

Score	dB(A)	Exposure h/day	Effect
1	< 85	< 0.5	
2	85-90	0.5-2	Discomfort
3	> 90	> 2.0	Hearing-impairs

Heavy Lifts The impact of the heavy lifts is scored in regard to weight of each item lifted, time of exposure and the effect. The volume is related to the limit values, which in Denmark is 20 kg. The first symptoms of heavy lifts is tiredness of the body and errors are committed. Accidents and illness occur. The effect is correlated in relation to weight.

Table **Error! Unknown switch argument.**: Scoring of heavy lifts

Score	Kg	Exposure h/day	Effect
1	< 20	< 0.5	
2	20 - 30	0.5-2	Discomfort
3	> 30	> 2.0	Hearing-impairs

Risks: Occupational risks can not be assessed the same way as the other working parameters, as this parameter depends on the probability of an accident and it's effect. The areas to be examined are:

- the probability of contact with chemicals and the impact of these

- dangerous machinery (shielding, etc.)
- fires and explosions (order and preventive measures)
- other aspects (slippery floors, stairs, etc.)

Table **Error! Unknown switch argument.**: Scoring of occupational risks

Score	Chemistry	Machinery	Fire	Other Aspects
6	low	low	low	low
9	middle	middle	middle	middle
18	high	high	high	high
27	very high	very high	very high	very high

The support table is filled in by means of the above tables concerning occupational health parameters.

The programme automatically calculates the scores for each parameter and inserts all the results in table 8 (excel program). Furthermore, it calculates the score of the occupational health per process line as an average of each parameter and a total score of the entire occupational health.

In cell C30 and D30 we have the average score (0-100) of chemistry and temperature for the included lines. In cell E30, F30 and G30 the general score for noise, heavy lift and risk for the whole line. In cell H30 the program calculate the total score for the whole line combining the contribution from C30, D30, E30, F30 and G30. Here G30 have a weight of 50% in the total score and C30, D30, E30 and F30 each have a weight of 12.5%.

Table 9 - Cleaner Technology

Table 9 is an overview of the possibilities for implementation of cleaner technology (cleaner production). The consultant complete this table when all other tables have been completed and assessed. The table is a kind of long-list where we can check the possible CT-options. The list will present an overview, but it cannot be used for specifying CT-solutions.

The term *cleaner technology* (CT) is interpreted in regard of the technical possibilities of reducing the environmental impact of the processes, and not just as in table 5 in regard of methods for waste minimisation. Below the activities of cleaner technology have been divided into groups in compliance to the production and what measures can be taken. Before completing the table please notice:

- Tick "not relevant" if the chemical, bath or CT-method are not used or cannot be used in the future
- Tick "low" if the CT-option is possible but not really interesting (technically and economically)

- Tick "medium" if the CT-option is interesting (and should be considered) for this company
- Tick "high" if the CT-option is relevant and very interesting for this company

Purification of process baths There exist a number of different techniques for purification of process baths. To mention a few; Filtration of impurities, active carbon filtration, oil removal by skimming, crystallising and chemical methods. More sophisticated techniques are UF, MF and dialysis. Purification of process baths is an extremely important CT-activity and should always be considered very carefully.

Substitution of process baths Substitution of chemicals is very specifically addressed to each bath. By the technical evaluation of possible substitutions, it is very important to consider not only the environmental benefit but also the consequences on rinse water and other process baths. From an economical point of view, substituting one compound for another is not always profitable, but it should improve the environmental performance. Substitutions often have a great influence on what other CT-activities to be introduced in the company later on.

Concentration and recycling To concentrate drag-out chemicals several condition must be fulfilled before-hand. The rinse water may not contain impurities that will accumulate and destroy the bath. Furthermore, there must be a certain evaporation loss in order to give physical room for the concentrate. Without evaporation 50% reuse can still be obtained by pre-dipping the items in a drag-out rinse before entering the plating tank and again after the plating.

Numerous techniques can be applied for concentration of drag-out chemicals. For example: static rinse, low-flow rinse, multistage cascade rinsing, membrane filtration, evaporation and ion-exchanging. Rinsing methods are often more simple and cheaper while other solutions are complex and costly.

Metal recovery by electrolysis When assessing the options of metal recovery be electrolysis it is important to determine all present metals and anions in the liquid. If the content of other metals is too high an alloy will be produced, which might be either useless or unusable. If the chloride content is high, chlorine might be generated at the anode, which complicates the electrolysis process. If the liquid is either too acid or alkaline there is a risk that the metals are dissolved before they are precipitated.

There are numerous aspect to consider when assessing the technical side. The economical assessment is depending on several things:

- What is the metal concentration
- is the electrolysis performed in the bath or in a static rinse
- is a separate electrolysis cell available
- is it necessary to use membrane electrolysis instead of ordinary electrolysis

Rinsing processes In table 4 we have assessed the actual rinsing systems and the actual water consumption. We have assessed the options of water saving activities by water recycling or water reuse. Many of these solutions are technically cheap and simple. The linking of several rinsing processes in the same series in order to use the water several times requires piping and maybe also a pump, but it may provide a reduction of water consumption and therefore also financial savings.

A more costly solution is recycling of chemically treated wastewater. Among the expensive solutions there are techniques as ion-exchanging and reverse osmosis. Ion-exchangers may be a feasible solution where you don't have space for more rinsing tanks and where the ion load from the process bath is relatively low. Reverse osmosis have until now primary been used for concentrating drag-out chemicals for reuse. Ion-exchanging and reverse osmosis often prolong the lifetime of the subsequent baths due to a reduced drag-in of saline solutions.

WWTP The wastewater treatment plant is assessed concerning consumption of treatment chemicals.

Chemical waste Here we assess the possibilities of reducing waste by implementing various recovery techniques inside the company or by using an external company for recovery of waste.

Finally, it is assessed (by ticks) as to which extent the various techniques are already used in the production today (no, partly, fully).

Table 1 - Total environmental status

The table and graph highlight more than 90 % of all environmental impacts coming from the chemical and electrolytic metal finishing processes of a company. The shown profile is thus an expression of the actual environmental situation in the company, and an indication of where the measures should be taken in order to improve the environmental performance by implementation of cleaner technology.
To ensure a correct calculation of this table, it is important that all inputs in the support tables are concerning this specific company. If you use an old excel-file (from another company) you must remember to delete all figures that have not been overwritten.

The scores on process baths and production conditions, maintenance and disposal of process baths, rinse water and chemical waste are all calculated by a formula, where figures are weighted according to consumption and/or over-consumption. If a company have more lines where tables are completed the contribution from each line will be included in the total calculation of the profile. The weighing is directly proportional, meaning that process lines with large consumption and production will count more than other lines with a small consumption and production.

Table 2 and 3 are referring to separate lines and the score for each line are combined as mentioned above. The other tables covering the whole company and all production processes and therefore no combined score is necessary to calculate.

Appendix A2: Data Tables

Bath tables

Process bath	Chemicals: Type	Chemicals: kg/yr	Chemicals: R/yr	Production: m2/yr	Process baths: Volume, litre	Process baths: Maintenance	Replaced Process Baths: Disposal	Replaced Process Baths: m3/yr	Replaced Process Baths: R/yr	Cost of Baths: R/yr	Key figures: litre bath per 1000m2: Calculated	Key figures: Goal	Key figures: Score, 1-5
Zinc line													
Degreasing bath	Degreaser salt	0	0	0						0	0	75	
Sulfuric acid pickling	Sulfuric acid, 96%	0	0	0						0	0	45	
HCl pickling	HCl, 32%	0	0	0						0	0	30	
Pickling-degreaser	Sulfuric acid, 96%	0	0	0						0	0	45	
Electrolytic cleaner	Cleaner salt	0	0	0						0	0	50	
Acid dip	HCl, 32%	0	0	0						0	0	15	
(Pre-treatment)	(Other)	0	0	0						0	0		
Zinc bath	Zinc anodes	0	0	0						0	0	0	
Zinc bath	KCl, 100%	0	0	0						0	0		
Zinc bath	H3BO3, 100%	0	0	0						0	0		
Zinc bath	ZnCl2, 100%	0	0	0						0	0		
Zinc bath	Brightener	0	0	0						0	0		
Zinc bath	(Other)	0	0	0						0	0		
Deoxidizer	Nitric acid	0	0	0						0	0	50	
Chromating, blue	Concentrate	0	0	0						0	0	500	
Chromating, blue	Nitric acid	0	0	0						0	0		
Chromating, yellow	Concentrate	0	0	0						0	0	75	
(Other)	(Other)	0	0	0						0	0		
(Other)	(Other)	0	0	0						0	0		
Sum:		0	0		0			0	0	0	0		0

Score: 1 = good, 5 = unsatisfactory

Maintenance Procedures for Process Baths

1. Filtration, continuously
2. Filtration, occationally
3. Treatment with carbon
4. Chemical treatment
5. Selective metal precipitation
6. Crystallisation
7. Membrane electrolysis
8. Other types of purification and regeneration

Disposal methodes:

0 = No disposal
CT = Treatment on a central plant
IT = Internal treatment in own wastewater plant
IR = Internal treatment and recycling
ER = External treatment and recycling
OD = Other disposal methods

Chemicals tables

Process bath	Chemicals: Type	Chemicals: kg/yr	Chemicals: R/yr	Thickness in µm: Calculated	Thickness in µm: Estimated	Production: m2/yr	Production: m2/h	Key figures: kg chemicals/1000m2: Calculated	Key figures: Goal	Key figures: Score, 1-5
Zinc line:										
Degreasing bath	Degreaser salt					0	0	0.0	5	
Sulfuric acid pickling	Sulfuric acid, 96%					0	0	0.0	20	
HCl pickling	HCl, 32%					0	0	0.0	20	
Pickling-degreaser	Sulfuric acid, 96%					0	0	0.0	20	
Electrolytic cleaner	Cleaner salt					0	0	0.0	3	
Acid dip	HCl, 32%					0	0	0.0	5	
(Pre-treatment)	(Other)					0	0	0.0		
Zinc bath	Zinc anodes					0	0	0.0		
Zinc bath	KCl, 100%					0	0	0.0	10	
Zinc bath	H3BO3, 100%					0	0	0.0	2.0	
Zinc bath	ZnCl2, 100%					0	0	0.0	3.5	
Zinc bath	Brightener					0	0	0.0	0	
Zinc bath	(Other)					0	0	0.0		
Deoxidizer	Nitric acid					0	0	0.0	5	
Chromating, blue	Concentrate					0	0	0.0	2.0	
Chromating, blue	Nitric acid					0	0	0.0		
Chromating, yellow	Concentrate					0	0	0.0	5	
(Other)	(Other)					0	0	0.0		
(Other)	(Other)					0	0	0.0		
Sum:		0	0					0.0		0
Operation time: h/yr	1700									

Score: 1 = good, 5 = unsatisfactory

Support table	
I - J	(I-J)/J*(I-J)/sum(I-J)
0.0	000.0E+0
0.0	000.0E+0
0.0	000.0E+0
0.0	000.0E+0
0.0	000.0E+0
0.0	000.0E+0
0.0	000.0E+0
0.0	000.0E+0
0.0	000.0E+0
0.0	000.0E+0
0.0	000.0E+0
0.0	000.0E+0
0.0	000.0E+0
0.0	000.0E+0
0.0	000.0E+0
0.0	000.0E+0
0.0	000.0E+0
0.0	000.0E+0
0.0	000.0E+0
0	

Occupational health and safety tables

		Chemistry	Temperatur	Noise	Heavy Lifts	Occupational safety risks	
Zinc1	Alkaline degreaser						
	Zinc bath						
Zinc2	Alkaline degreaser						
	Zinc bath						
Zinc3 (CN)	Alkaline degreaser						
	Zinc bath						
Zinc4 (CN)	Alkaline degreaser						
	Zinc bath						
Cu-Ni-Cr-1	Nickel bath						
	Chromium bath						
Cu-Ni-Cr-2	Nickel bath						
	Chromium bath						
Cu-Ni-Sn-1	Alkaline degreaser						
	Nickel bath						
Cu-Ni-Sn-2	Alkaline degreaser						
	Nickel bath						
Aluminium1	Alkaline pickling						
	Anodising						
Aluminium2	Alkaline pickling						
	Anodising						
Phosphating 1	Alkaline pickling						
	Phosphating						
Phosphating 2	Alkaline pickling						
	Phospahting						
	Sum	0	0	0	0	0	Total
Occupational Health and Safety	Total score	0.0	0.0	0.0	0.0	0.0	0.0

Quantity	Time	Effect	Quantity	Time	Effect	Quantity	Time	Effect	Quantity	Time	Effect	Score	

Scores: 3=high, 2=medium, 1=low — Risk score: from 1 - 2

WWTP operations tables

Operation monitoring	Cleaning and calibration		Control Measurement			Total
	Frequency	Score	Frequency		Score	
pH, neutralisation						
pH, chromate reduction						
mV, chromate reduction						
pH, cyanide oxidation						
mV, cyanide oxidation						
pH, outlet						
Chlorine monitoring						
Cr+6 monitoring						
SO3 monitoring						
Metal monitoring						
Avarage score		0.0			0.0	
Total score-%		0.0			0.0	0.0

Score: 1=satisfactory, 5=unsatisfactory

Chemicals for WWTP tables

Chemicals	Concentration	Consumption	Costs	Possibilities of savings					
		kg/yr	R/year	5=big and 1=small possibilities					
				Using less excess of chemicals	Use spent process baths instead	Optimising the treat-ment of spent baths	Better separation of wastewater streams	Total score, 0-100%	Saving index = consumption * score
Sodium hydroxide	100%								
Sodium hydroxide	28%								
Hydrochloric acid	30%								
Sulfuric acid	96%								
Sodium disulfite	100%								
Sodium dithionite	100%								
Hydrogen peroxide	35%								
Polymer	100%								
Iron(III) chloride									
Sodium hypochlorite									
Sum		0	0						

Waste tables

Type of waste	Waste	Disposal methods	Costs		Possibilities for waste reduction: 5=big and 1=small					
Write the types below	ton/yr		R/ton	R/yr						
					Reduction of drag-out and drag-in	Optimising bath chemistry	Concentrating of waste	Improved maintenan-ce of process baths	Recovery from waste	Relative ranking of saving possibilities
Liquid sludge										
Filter cakes										
Sum	0			0						0
					Score: 1 = good, 5 = unsatisfactory					
								Total score		0,0

Support table

Number of score-cells >0	% potential savings	T * B
0		
0		
0		
0		
0		
0		
0		
0		
0		
0		
0		
0		
0		
0		
0		
0		
	0	0

Disposal methodes (codes):
CT = Treatment on a central plant
ER = External Recovery
ED = External Destruction
DL = Disposal at landfill

Rinse tables

Rinse tank no.	Rinse system	Process bath before rinse	Raw water	Tank litre	Rinse system data score (1=OK, 5=unsatisfactory) Drip-ping	Hang-ing	Agita-tion	Inlet-outlet	Back-mix	Flow-control	Total,% Max100	Waterflow, l/h Actual	Goal	Water consumption: l/m2 Calcu-lated	goal	Savings m3/yr
3	1		T	4425								2700		#DIV/0!	0.0	#DIV/0!
5	1		T	4425								2700		#DIV/0!	0.0	#DIV/0!
9	1		T	4425								2700		#DIV/0!	0.0	#DIV/0!
10	1		T	4425								2700		#DIV/0!	0.0	#DIV/0!
13	1		T	4425								2700		#DIV/0!	0.0	#DIV/0!
14	1		T	4425								2700		#DIV/0!	0.0	#DIV/0!
														0.0	0.0	0.0
														0.0	0.0	0.0
														0.0	0.0	0.0
														0.0	0.0	0.0
														0.0	0.0	0.0
														0.0	0.0	0.0
														0.0	0.0	0.0
														0.0	0.0	0.0
														0.0	0.0	0.0
														0.0	0.0	0.0
														0.0	0.0	0.0
														0.0	0.0	0.0
														0.0	0.0	0.0
														0.0	0.0	0.0
														0.0	0.0	0.0
														0.0	0.0	0.0
														0.0	0.0	0.0
														0.0	0.0	0.0
Sum:												16200	0	#DIV/0!	0.0	#DIV/0!

Abbreviations for rinse system:
1 = running rinse
2 = static rinse (spare rinse)
3 = Spray rinse
4 =static + running rinse
5 =static +2-running rinse
6 =static +3-running rinse
10=
11 = 2-step counter current rinse
12 = 3-step counter current rinse
13 = 4-step counter current rinse
14 = static + 2-step counter current rinse
15 = static + 3-step counter current rinse

Abbreviations for raw water types:
T-water = tap water
I-water = ion-exchanged water
C-water = chemical treated water
R-water = reuse water from another rinse tank
DI-water = de-ionised water

Agitation and Liquid Motion
1 = agitation and motion
2 = agitation and motion
3 = heavy motion, no agitation
4 = some motion, no agitation
5 = no motion, no agitation

Inlet/outlet in Rinsing Tanks
1 = Inlet (top) reverse outlet (bottom)
2 = Inlet (top) reverse outlet (dived)
3 = Inlet reverse outlet, bottom
4 = Inlet reverse outlet, top
5 = Inlet near outlet, top

Back-Mix in Rinsing Tank
1 = No back-flow
2 = Minimum back-flow
3 = Moderat back-flow
4 = Some back-flow

Score for Dripping
1 = 20- sek
2 = 15-19 sek
3 = 10-14 sek
4 = 5-9 sek
5 = 0-4 sek

Score for Hanging
1 = All water run off immediately
2= All water run off after some time
3 = Moderat run off
4 = Slow run off
5 = Slow run off + water pockets

Score for flow-control
1 = Complete flow-control
2 = Some flow adjustment
3 = Coarse flow-control
4 = Very little flow-control
5 = Totally open valve

Appendix A3: A Typical Review Report and Feasibility Document

Cleaner Production In the Metal Finishing Industry

Republic of South Africa

Environmental Review
Company Cables

Conducted by
Arnesh Telukdarie
July 2002

Summary of conclusions and recommendations

This report is a representation of the current status of a company as compared to best available practice. The report covers a detailed analysis of water and chemical consumption together with operational practices at Company Cables.

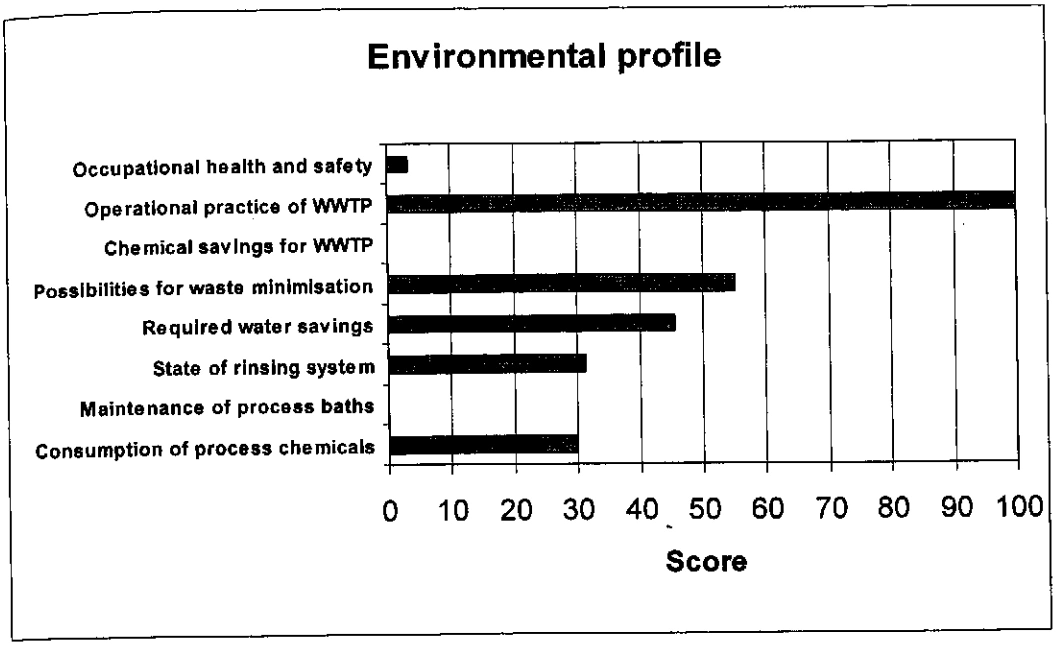
From Figure 1 (A graph representing a summary of the review data) it can be concluded that the following areas can be improved:

- Operational practice at wastewater treatment plant, No current waste water treatment exists
- Reduction in chemical waste
- Water consumption
- Improvements to the rinsing system
- Better maintenance/operation of process baths to prolong their lifetime
- Reduction of consumption of process chemical

No scores were recorded for chemical savings at the waste water treatment plant and the maintenance of the process baths. This is due to the company not currently treat its waste water leaving the surge tank, so no treatment chemicals are used. The tool does not consider the use of tin separately and hence does not churn out a key figure for metal consumption. Calculations and comparisons were made based on plated thickness.

The score for occupational health and safety is low, this is due to the structure of the plant. All process tanks are contained and none of the processes are at elevated temperatures. Due to the nature of the material being plated, no heavy lifts etc are required.

Figure 1: Summary graph of environment review



The conclusions listed above can be addressed by installing and modifying processes to facilitate improvements. These modifications would result in a more cost effective and environmentally friendly facility. The following recommendations can be considered:

- The rinsing system can be improved by introducing three stage counter current rinses on all process tanks and/or by redirecting rinse waters. This system ensures minimum water usage and chemical consumption.
- Increasing dripping time(Time for water/ process chemicals to drip/wipe off wire), this would ensure a reduction in dragout of process chemicals to rinse tanks and ultimately to the waste water treatment plant. This would also ensure minimal water usage for rinsing.
- Improving the operational practice and management of the waste water treatment plant. One of the major considerations is the broad band of pH measurements taken and the non compliance's.
- Measurement and dosage of process chemicals be done with greater accuracy. The company samples the tanks and adjusts process chemicals once / week this needs to be properly investigated and optimized.
- Control and optimization of the use of rinse water
- Recycle polished waste water back to process so as to minimize water usage and waste production
- Introduction of de-ionised water as process feed water

Implementation of the above recommendations would result in a cleaner, more cost effective production facility. The actual layout and details on equipment required together with chemical consumption's and water usage would be done in a comprehensive feasibility study.

Table of contents

Introduction

Cleaner production in the metal finishing industry in South Africa is currently being assisted by a Danish government initiative called The Cleaner Production in the Metal Finishing industry project (CPMFI). The project is conducted in three steps in order to achieve companies cleaner production objectives.

The first step is a walk through which entails an overview of the company and information on problems identified together with some easily achievable solutions. The second step is a review of the current status of the company. The company's consumption's etc are compared to internationally generated key figures. The last stage is a feasibility, which entails a comprehensive design and layout together with water and chemical consumption's on a cleaner production line. The feasibility also contains detailed costing with a payback period on investment. The Cleaner Production in the Metal Finishing Industry project pays twenty percent of the cleaner production investment up to a maximum of R 75 000, contributions in kind are also considered.

Other cleaner production projects completed have achieved a ninety percent reduction in water and almost fifty percent reduction in chemical consumption with final rinses, before waste water treatment plant, meeting Metro metal effluent specifications.

The CPMFI project is in close collaboration with local Metro's with regards co-regulation. These Metro's currently considers recommendations from the project and makes allowances based on these recommendations.

Company

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1. Company Introduction

Company Cables is a manufacturer specializing in manufacturing and plating of various sizes(diameter) wire. The company tin plates the wire 4 microns thick. Some wire products are further drawn after being plated. This review will focus on the activities of the three wire plating lines and the waste water treatment plant.

The company is in a process of upgrading its production to twice its current capacity. The company aims at designing this new facility to be more environmentally friendly with due considerations to production.

1.1 Review Introduction

This Environmental review is the first to be conducted at Company Cables. It is also intended that this review be used as a base to justify savings in a feasibility study for a new line with a production rate of two times the combined current production rate.

The review conducted at Company Cables is meant to indicate key figures for their wire electro-plating process. The figures are related to international best available practice and accordingly bench marks the environmental performance of the company. These figures are to assist with waste minimization initiatives for the company. The following report is a discussion on the different categories investigated and some results obtained.

The review is based on tables, extracted from the excel spreadsheet developed for the environmental review. The tables cover production and environmental issues for the production line. The wastewater treatment plant was also evaluated and is reported.

During the course of this report the tables described below will be referred to:

Flow-sheet:	Process sequence, tank lay-out and water flows pre-treatment line
Table 1:	Summary table with environmental profile for the company including graph
Table 2:	Data for production and consumption of chemical for chrome line
Table 3:	Data for maintenance and disposal of spent process baths
Table 4:	Data for rinsing processes and water consumption
Table 5:	Data for hazardous waste and potential for waste minimisation
Table 6:	Consumption of chemicals for wastewater treatment
Table 7:	NA Wastewater treatment: Performance and operational practice
Table 8:	Assessment of occupational health and-safety
Table 9:	Preliminary checklist including potential for implementation of cleaner production

2. Discussion of spreadsheets

2.1 Environmental profile: Table 1 and Graph 1

The graph and table are a summary of the key areas evaluated. The graphs rate the company on eight key indicators on a scale of 0 to 100.

On this graph a value of:

- Between 0-20 would imply a very low potential for saving
- Between 21-50 would imply a medium potential for saving
- Greater than 50 would imply a high potential for saving

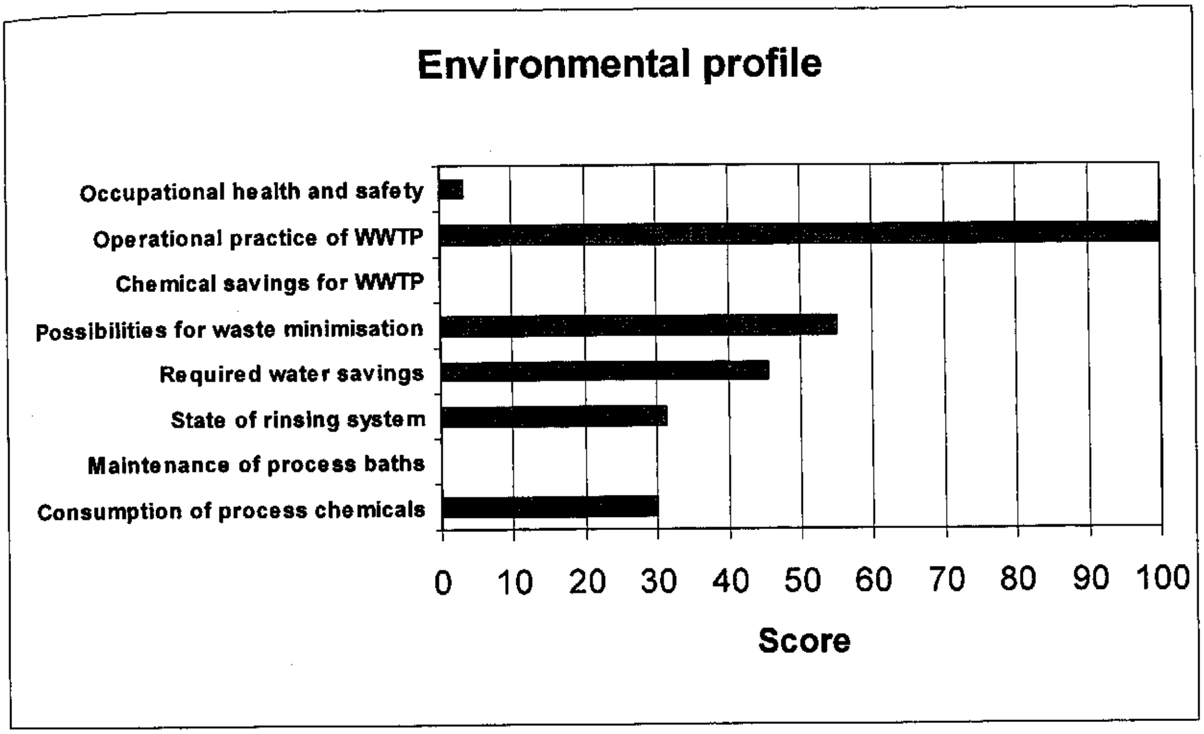
From the graphs it can be clearly seen that the following areas have a medium to high potential for improvements and for implementation of cleaner production strategies to improve the environmental performance and obtain further waste and cost reductions:

- Operational practice at wastewater treatment plant, No current waste wastewater treatment
- Reduction in chemical waste
- Water consumption
- Improvements to the rinsing system
- Better maintenance/operation of process baths to prolong their lifetime

- Reduction of consumption of process chemical

This report continues to discusses, in detail and with reference to the relevant tables, the above conclusions.

Graph 1: Environmental status of company



Environmental parameters	Score
Consumption of process chemicals	30
Maintenance of process baths	0
State of rinsing system	31
Required water savings	46
Possibilities for waste minimisation	55
Chemical savings for WWTP	
Operational practice of WWTP	100
Occupational health and safety	3

2.2 Production, chemicals and process baths: Table 2 + 3

The tables 2 and 3 are used as indicators for the use of process chemicals. The consumption and production in square meters is used to establish the process chemical requirements. The consumption is compared to figures of international best available practice.

The consumption's are rated on a scale of 1 to 5, a rating of 5 implies greatest room for improvement and a rating of 1 would imply minimum room for improvements.

The surface area for this report has been an estimate based on the average rate of production. The average wire thickness was taken as 1.8 mm at a production rate of 100 m /min/line working 21 hours /day, 6.5 days /week.

Diameter:	0.0018 m
Length/min:	100 m
Area /m:	0.018m*(22/7)*1m
	= 0.00565 m^2
Area/ min:	=100* 0.00565
	= 0.565 m^2
Area/day:	= 0.565*60*21(Effective 21 hours)
	= 679 m^2
Area/year	= 529509 m^2

This is total for the entire three lines.

Consumption of tin is rated as 4, this is high and a minimum of 10 % of the current consumption can be saved. This would imply cost savings both for production and a reduction in cost for sludge generated as this excess of metal has to be treated at the WWTP and its sludge disposed off. Although the caustic consumption is not flagged as high in the spreadsheet it is assumed that major cost savings can be achieved if the caustic is managed properly. With the low oils content of the metal it would be feasible to install a counter current rinse and close the caustic circuit. This can be properly justified in a feasibility study.

The high consumption of can be attributed to:

- Too large Drag-out from all process bath
- Too short drip times, improper dripping
- The ineffective use of Drag-in of the Drag out
- Dosing accuracy, Large variances in day to day tank concentrations, Too large a dosing tolerance band
- Irregular dumping of baths
- Spillage's due to overfilling of tanks

The other chemical consumption's are also high. This over usage can also be attributed to the above reasons.

The coating thickness is specified and measured (twice per week), the company samples and determines the coated thickness in house. The spreadsheet determined a thickness based on chemical consumption and a plated area of 4 microns for tin. It is estimated that the actual plated thickness is lower than these values due to chemical losses.

The wipes located on the ends of the tanks are not effective as only a part of the wire is being wiped. This results in dragout of valuable chemicals. It is envisaged that this problem would be overcome with air wipes.

An example of dragout losses from the process bath:

A bath with a concentration of 100 g/l and a production rate of 85 m^2/ hour

Poor dragout(Short hanging time)	**Good dragout(Long hanging time)**
Poor dragout would imply loss of 400 ml/ m^2	Good dragout would imply loss of 200 ml/ m^2 or less
0.400 l/ m^2* 85 m^2/hr*100g/l	0.200 l/ m^2*85 m^2/hr*100g/l
= 3400 g//hr	= 1700 g//hr
= 3927 kg/ year	= 1964 kg /year

The calculated difference in loss of metal is 1785 kg /year or R 97 431/ year. Since no drag out tanks are currently being used this is the actual amount of metal lost to the WWTP. Financially the losses are : Chemicals* No. of baths /year. This is chemicals lost just by poor operational practice. These chemicals now have to be treated at the waste water treatment plant, which consumes even more chemicals which result in a larger loss to the company. All small improvements add up and have a considerable impact.

Table 2: Production and chemicals

Procesbad	Type	kg/yr	R/yr	Calculated	Estimated	m2/yr	m2/h	Calculated	Goal	Score, 1-5
Cu-Ni-Sn linie:										
Degreasing bath	Degreaser salt	7,500	17,400			529,509	85	14	25	1
Tin bath	Tin anodes	16,800	917,280	4.3581774	4	529,509	85	32	20	4
Tin bath	Sulfuric acid	3,380	5,983			529,509	85	6		
Tin bath	Diphone V	242	35,250			529,509	85	0		
Tin bath	PhenaolSulphonic acid	3,404	43,231			529,509	85	6		
Tin bath	Stannous Sulphate	3,132	275,773			529,509	85	6		
Tin bath	(Other)					0	0	0		
Sum:		0	1,294,916					65		2.5
Operation time: h/yr	6240									

Score: 1 = good, 5 = unsatisfactory

Table 3: Process baths

	Chemicals			Production	Process baths		Replaced Process Baths			Cost of Baths	Key figures: litre bath per 1000m2		
Process bath	Type	kg/yr	R/yr	m2/yr	Volume, litre	Mainte-nance	Disposal	m3/yr	R/yr	R/yr	Calculated	Goal	Score, 1-5
Cu-Ni-Sn linie:													
Degreasing bath	Degreaser salt	7,500	17,400	529,509	600	0	OD	6	0	17,400	11.3	75	1
Tin bath	Tin anodes	16,800	917,280	529,509	600	0	OD	6	0	917,280	11.3	60	1
Tin bath	Sulfuric acid	3,380	5,983	529,509						5,983	0.0		
Tin bath	Diphone V	242	35,250	529,509						35,250	0.0		
Tin bath	PhenaolSulphonic	3,404	43,231	529,509						43,231	0.0		
Tin bath	Stannous Sulphat	3,132	275,773	529,509						275,773	0.0		
Tin bath	(Other)	0	0	0						0	0.0		
Sum:		0	1,294,916		1,200			12	0	1,294,916	22.7		1

Score: 1 = good, 5 = unsatisfactory

Maintanance Procedures for Process Baths
1. Filtration, continuously
2. Filtration, occationally
3. Treatment with carbon
4. Chemical treatment
5. Selective metal precipitation
6. Crystallisation
7. Membrane electrolysis
8. Other types of purification and regeneration

Disposal methodes:
0 = No disposal
CT = Treatment on a central plant
IT = Internal treatment in own wastewater plant
IR = Internal treatment and recycling
ER = External treatment and recycling
OD = Other disposal methods

2.3 Rinsing and water consumption: Table 4

In table 4 the goal-values for water consumption's are based on a theoretical calculation for 3-stage counter current rinse for each rinsing process. Compared to this goal-value the consumption of water is high and in excess of 45 % of the current water usage can be saved. Note must be taken of the fact that the water consumption's are average figures from measurement conducted on water outlets.

The wire actually misses the spray in the actual rinse vessel, hence rinsing is not properly carried out. This results in carry over of chemicals which would cause neutralisation of the plating solution or would be carried over to the waste water treatment plant. Effective rinsing needs to be carried out.

The existing rinse system is less than ideally laid out and with scope for improvement. No flowmeters are in place to measure inlet water. Taps are just opened. Some water lines were partially blocked. The company does not record the water consumption for the plating plant separately.

The following improvements can be carried out to optimise the present system.

- Dripping should be improved
- Effective rinsing needs to be carried out
- Counter current rinsing needs to be implemented to save water and chemicals
- Introduction of drag-in from the drag–out tank.
- Recycling of rinse waters
- Arrange tanks to minimise dripping losses
- Improved removal of liquid from wire surface after process tank, Wiping, air blades

Minimal liquid must be lost from process tanks so as to prevent losses of chemicals which have to be treated at the waste water treatment facility.

Some recommendations for consideration for this line are:

- Introduction of a low flow counter current rinse system after all tanks
- Reduce the dragout by improving "wire dripping"
- Arranging the tanks so as to minimise losses of water and chemicals

All the above mentioned proposals may be further assessed individually or collectively in a comprehensive feasibility study.

Table 4: Rinsing and water consumption

Rinse tank no.	Rinse system	Process bath before rinse	Raw water	Tank litre	Rinse system data score (1=OK, 5=unsatisfactory) Drip-ping	Hang-ing	Agita-tion	Inlet-outlet	Back-mix	Flow-control	Total,% Max100	Water flow, t/h Actual	Goal	Water consumption: l/m2 Calcu-lated	goal	Savings m3/yr
2	1\3	Caustic	T		3	1	2	1	1	4	31	300	136	4	2	1025
4	1\3	Tin	T		3	1	2	1	1	4	31	300	136	4	2	1025
2a	1\3	Caustic	T		3	1	2	1	1	4	31	300	136	4	2	1025
4a	1\3	Tin	T		3	1	2	1	1	4	31	300	136	4	2	1025
2b	1\3	Caustic	T		3	1	2	1	1	4	31	300	136	4	2	1025
4b	1\3	Tin	T		3	1	2	1	1	4	31	300	136	4	2	1025
Sum:												1800	815	21	10	6149

Abbreviations for rinse system:
1 = running rinse
2 = static rinse (drag-out rinse)
3 = Spray rinse
4 =static + running rinse
5 =static +2-running rinse
6 =static +3-running rinse
10=
11 = 2-step counter current rinse
12 = 3-step counter current rinse
13 = 4-step counter current rinse
14 = static + 2-step counter current rinse
15 = static + 3-step counter current rinse

Abbreviations for raw water types:
T-water = tap water
I-water = ion-exchanged water
C-water = chemical treated water
R-water = reuse water from another rinse tank
DI-water = de-ionised water

Agitation and Liquid Motion
1 = agitation and motion
2 = agitation and motion
3 = heavy motion, no agitation
4 = some motion, no agitation
5 = no motion, no agitation

Inlet/outlet in Rinsing Tanks
1 = Inlet (top) reverse outlet (bottom)
2 = Inlet (top) reverse outlet (dived)
3 = Inlet reverse outlet, bottom
4 = Inlet reverse outlet, top
5 = Inlet near outlet, top

Back-Mix in Rinsing Tank
1 = No back-flow
2 = Minimum back-flow
3 = Moderat back-flow
4 = Some back-flow

Score for Dripping
1 = 20- sek
2 = 15-19 sek
3 = 10-14 sek
4 = 5-9 sek
5 = 0-4 sek

Score for Hanging
1 = All water run off immediately
2= All water run off after some time
3 = Moderat run off
4 = Slow run off
5 = Slow run off + water pockets

Score for flow-control
1 = Complete flow-control
2 = Some flow adjustment
3 = Coarse flow-control
4 = Very little flow-control
5 = Totally open valve

2.4 Waste minimisation: Table 5

The company has only disposed of sludge from its surge tank once in the last three years. The operator also scoops sludge from the sides and bottom of the tanks and disposes of it informally. This is a problem as the sludge is high in chemicals and metals. The companies sludge disposal cost is not a true indication of the amount of sludge generated. This is an area of potential improvement.

The amount of sludge may be minimised by reducing the drag-out/overspills from process baths. A filter press may need to be used to ensure effective de-watering of sludge. The need and operating conditions of the filter press needs to be investigated and optimised in a feasibility study.

A reduction in chemical losses to the rinse system can reduce the usage of treatment chemicals in the wastewater treatment plant.

The volume to the waste water treatment plant can be reduced by optimising the rinse system.

Table 5 : Waste minimisation

Type of waste	Waste	Disposal methods	Costs		Possibilities for waste reduction: 5=big and 1=small					
Write the types below	ton/yr		R/ton	R/yr	Reduction of drag-out and drag-in	Optimising bath chemistry	Concentrating of waste	Improved maintenan-ce of process baths	Recovery from waste	Relative ranking of saving possibilities
Liquid sludge	15	Bin	0	0	5	3	4	3	1	100
Filter cakes										
Sum	15			0						100
					Score: 1 = good, 5 = unsatisfactory					
								Total score		55.0

Disposal methodes (codes):
CT = Treatment on a central plant
ER = External Recovery
ED = External Destruction
DL = Disposal at landfill

2.5 Wastewater treatment: Table 6 + 7

The company is sampled once a month by Umgeni water for effluent management.

However the wastewater treatment plant is an area for great improvement. The entire plant needs to be optimised. Measurement and control is required to prevent the company exceeding effluent limits set by the local·municipality.

The test equipment used for testing at the waste water treatment plant is effective, pH probe. The probe is calibrated once/year this needs to be done more regularly(weekly).

The last 20 weeks pH readings were investigated, only 5 pH compliances were on record with the lowest value being 3.8 and the highest 12.4. For a continuous process this non compliance and the fact that the operating band is so wide is cause for concern. The low pH indicates an excess of acids to the waste water treatment facility, while an excess of caustic would reflect a high pH. It reflects the need for proper process optimisation and control especially at the waste water treatment plant. These high values indicate inconsistent losses of acids and alkali to the waste water treatment plant. If this facility were run correctly no spikes in pH should be noted.

NB The CPMFI project affords a 30 % discount on Hanna instruments upon purchase and a further 20 % upon usage. This is to facilitate proper measurement and control of waste water.

Table 6: Consumption of chemicals for waste water treatment (WWTP)

Since no treatment of wastewater is currently done there are no figures available.

Table 7: Operational practice for waste water treatment (WWTP)

Operation monitoring	Cleaning and calibration		Control Measurement			Total
	Frequency	Score	Frequency		Score	
pH, neutralisation	1/year	5				
pH, outlet	None	5				
Metal monitoring			None		5	
Avarage score		5.0			5.0	
Total score-%		100.0			100.0	100.0

2.6 Occupational health and safety (OHS) Table 8:

The total OHS-score is a sum of impact from chemistry, temperature, noise, heavy lifts and risks. The OHS conditions are in need of drastic changes.

The floors are wet due to waste water run off and spills, the waste water run of area is bunted. Slippery floors are a problem. The run off onto the floor is also not good operational practice, waste water needs to be piped to the waste water treatment facility. Chemicals spills result in wear on floors. If spills are kept to a minimum and if the floor is not used as a run off then normal concrete floors would be more than adequate.

No fumes are generated from the process , hence no risk associated with fume extraction.

Table 8: Occupational health and safety

		Chemistry	Temperatur	Noise	Heavy Lifts	Occupational safety risks	
Tin	Caustic	0	0	27	0	0	
	Tin Bath	0	0				
	Sum	0	0	27	0	0	Total
Occupational Health and Safety	Total score	0.0	0.0	26.9	0.0	0.0	3.4

Chemistry			Temperature			Noise			Heavy lift			Risk	
Quantity	Time	Effect	Quantity	Time	Effect	Quantity	Time	Effect	Quantity	Time	Effect	Score	
1	1	1	1	1	1	2	2	2	1	1	1	1	
1	1	1	1	1	1								
Scores: 3=high, 2=medium, 1=low									Risk score: from 1 - 27				

2.7 Cleaner production options Table 9:

The existing rinse system should be improved by improving dripping time. This will reduce consumption of rinse water, but further reduction may be obtained by implementation of low flow counter current rinsing with drag-in and drag-out. Better control of rinse water needs to be introduced such as flow meters on inlet lines.

Effective rinsing, water to wire contact, and overall management of the entire rinsing process needs to be investigated. The current rinsing system uses too much of water and is not effective.

It is obvious that sludge can to be reduced and managed properly, current disposal methods are unacceptable. This entire circuit would be investigated in a feasibility study.

Waste water can be recycled to reduce water consumption's and reduce running costs. Once the entire process is optimised the possibility of recycling waste water needs to be investigated.

Table 9: Cleaner production Options

CP methods	Potential for introduction of cleaner production (CP) Not relevant	Low	Medium	High	Is the technique applied today?
Treatment and purification of process baths:					
Oil skimming and sludge removal from cleaners		x			
Purification of cleaners by UF or centrifuges		x			
Substitution of process chemicals:					
Replacing cyanide	x				
Replacing EDTA	x				
Replacing complexing chemicals	x				
Replacing ammonia	x				
From high to low metal concentration	x				
Reuse of collected process chemicals from rinse water:					
Alkaline cleaners				x	
Zinc bath	x				
Chromating bath	x				
Copper bath	x				
Nickel bath	x				
Bright chrome bath	x				
Tin bath		x			Not cost effective
Silver bath	x				
Recovery of metals by electrolysis:					
Zinc	x				
Copper	x				
Nickel	x				
Chromium	x				
Tin		x			
Silver	x				
Rinsing processes:					
Optimising existing rinse system				x	
Counter current rinse				x	
Static rinse tanks with reuse (drag-out rinse)		x			Counter current rinsing
Spray rinse				x	
Water recycling by ion-exchangers				x	
Recycling of purified wastewater				x	
Control of rinse water flow				x	
Wastewater treatment plant (WWTP):					
Saving of chemicals					No current treatment
Chemical or hazardous waste					
Internal processsing and recovery			x		
External processing and recovery	x				

3. Recommendations

The review details many areas for improvement. Stemming from this the following recommendations can be considered for further investigations. These recommendations if implemented would result in improvements in the key areas reported in this report.

3.1 The rinsing system

The key to minimize water usage and reducing process chemicals in any plant is the rinsing system. By introducing a three stage counter current rinse both these objectives can be achieved. Process chemicals can also be reduced by dragging in the drag out solution before a process tank.

The following is recommended:

- Introduction of a low flow counter current rinse system after one or more tanks

Depending on drag out losses this system can be used to top up the process tank and if insufficient evaporation occurs from the process tank evaporation can then be induced. It is recommended that this system be used for the plating tank.

- Explore the possibility of redirecting the rinse water

This might be possible depending on the compatibility of the chemicals. This would result in a large saving on water and more effective neutralisation of acid and alkali.

Spray rinses are very efficient if used properly. The water can be recycled and the water needs to be in the form of a fine spray. The implementation of this system would depend on the company's production requirements.

3.2 Increasing dripping time

Low dripping times results in wastage of valuable chemicals. These chemicals have to be treated in the waste water treatment plant and is thus a double wastage. By increasing the drip time dragout can be drastically reduced. Proper wiping of the wire and air blades would facilitate proper dripping.

3.3 Separation of waste streams

Different waste streams require different treatment chemicals, by treating the entire volume of waste at once all chemicals are been treated at the same time.

Acids and alkali can be used to neutralize each other but the process consumption of these two chemicals are not at the same rate, resulting high and low pH peaks. This can be overcome by using a storage tank for one of the chemicals and dumping it when the other is ready to be dumped.

The separation of waste streams is going to depend on the companies choice of chemicals for the new production facility.

3.4 Measurement and dosage of process chemicals

Process chemicals are supplied in bulk but the process requirements are normally in small quantities. Use of smaller dosing equipment (e.g. Measuring cylinders and dosing pumps) would ensure accurate dosing and minimize wastage. Continuous dosing narrows the operating band, for tank concentration, and would facilitate improved product quality and lower chemical consumption.

3.5 Health and safety

Health and safety is imperative in ensuring good productivity and the use of personal protective equipment is essential, especially when dealing with dangerous chemicals. Operator training needs to be done to ensure protective equipment is worn at all times and that the hazards of chemicals are known.

The floors needs to be revamped, the current floor is slippery and wet. The waste water needs to be piped rather than run off onto the floor, as is the current practice.

3.6 Wastewater treatment

Better measurement and control be carried out at the wastewater treatment plant with regards all treatment ie

- Variables(pH and Concentration) are measured before and after treatment
- Improved dosing accuracy by proper measurement and control
- Possibility of automation
- Improved agitation after dosing

3.6 Further recommendations

De-ionised water needs to be introduced on the plant to reduce build-up of impurities if a counter current rinse system is going to be used.

The present process can be rearranged to optimise water flow and process operations.

The above recommendations would result in a cleaner, more cost effective production facility. The actual layout and details on equipment required together with chemical consumption's and water usage can be done in a comprehensive feasibility study.

Action sheet

	Recommendation	Action	Resource
1.	Low flow counter current rinses	Installation of additional tanks and piping. Arrange cascade from tanks Introduce water at last rinse tank	To be determined comprehensively in a feasibility study
2.	Redirecting of rinse waters	Redirect water between rinse tanks so as to optimise water consumption	To be determined comprehensively in a feasibility study
3.	Increased dripping time/ air wipes	Increase drip times/ use air wipes. This would ensure proper liquid drainage	To be determined comprehensively in a feasibility study
4.	Spray rinse system improvements	Spray rinse water be recycled and reused	To be determined comprehensively in a feasibility study
5.	Separation of waste streams	The presence of acid/alkali with metals in waste water dictates that this waste stream be treated accordingly	To be determined comprehensively in a feasibility study
6.	Improved dripping techniques	Spills into adjacent baths can be prevented by proper design	To be determined comprehensively in a feasibility study
7.	Use of process chemicals for neutralisation	Spent process chemicals can be storage and used for neutralisation	To be determined comprehensively in a feasibility study
8.	Measurement and dosing of process chemicals	Proper dosage of chemicals ensure optimal use of chemicals	To be determined comprehensively in a feasibility study
9.	Health and safety	Floors be revamped and proper piping be introduced for waste water run off	To be determined comprehensively in a feasibility study
10.	Waste water treatment plant	Proper control and management with regards, pH control and dosing-Automation	To be determined comprehensively in a feasibility study
11.	Management of sludge	Sludge generated needs to be removed and disposed.	To be determined comprehensively in a feasibility study

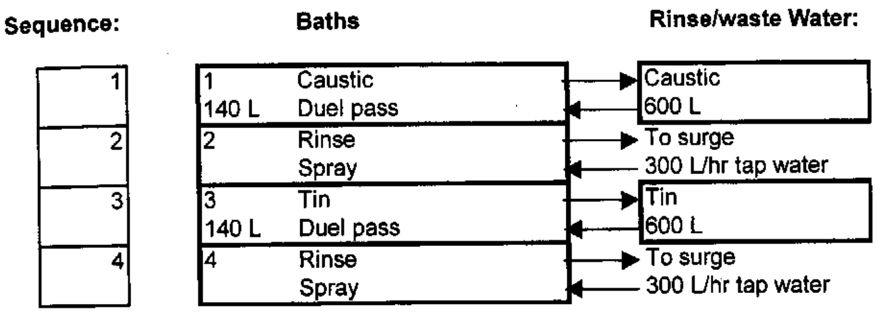
4. Conclusion:

This review highlights the main problem areas where CP-options should be further assessed. In this report some obvious possibilities are identified and presented very briefly. It is recommended that a more detailed study be done on the possibilities for reduction of chemical consumption and work practice.

A more detailed assessment and feasibility study on the plant is necessary to specify proposals for actual and detailed solutions for implementation to the process line.

The assessment and cleaner production options are both subsidized by the Cleaner Production in the Metal Finishing Industry Project. (CPMFI Project)

Appendix1: Figure 1: Flow sheet for process line



Cleaner Production In the Metal Finishing Industry

Republic of South Africa

Feasibility Study
Company Power Cables

Conducted by
Arnesh Telukdarie
August 2002

EXECUTIVE SUMMARY

An environmental review was carried out by the Cleaner Production in the Metal Finishing Industry project (CPMFI) reviewing team at Company in July 2002. Based on this report this feasibility concludes that the suggested changes would result in water savings of 99 % (R 120 514 /year) a chemical saving of approximately 14 % (R 346 440 /year, based on projected production) including a reduction of water and chemical for treatment at the wastewater treatment plant. The projected water consumption would be 0.2 L/ m^2 as compared to the current 25 L/ m^2. The additional capital investment (tanks, filter and air blades etc) would be R 617 880 with a payback period of 16 months.

The company has not been fined by the local metro based on any noncompliance of effluent limits although according to internal log sheets the company has had many non compliance's. The new plant is to be designed so as to exceed the company's present environmental requirements. The company's aim is to make this facility as environmentally friendly as possible and hence the request to the Cleaner Production in the Metal Finishing Industry Project.

A major consideration for the above investment is the potential 20% contribution from The Cleaner Production in the Metal Finishing Industry Project (CPMFI) on capital cost incurred. This would significantly impact on capital expenditure of the company, provided the conditions laid down by the CPMFI project are met. The payback period is reduced to 14 months if the CPMFI funding is considered.

The environmental review conducted generated several potential cleaner production options. The most relevant considerations are:

- Operational practice at wastewater treatment plant, No current treatment at the waste water treatment exists
- Reduction in chemical waste
- Water savings on rinse water by optimizing rinse water system
- Improvements to the rinsing system
- Better maintenance/operation of process baths to prolong their lifetime
- Reduction in waste-water volume to waste-water treatment plant

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- Reduction in chemical consumption in process line by optimizing chemical dosing to process tanks.

Stemming from this, the feasibility study takes into consideration methods of achieving the above in the most cost effective way. The following considerations are evaluated:

- The use of low flow rinse tanks after both process tanks to reduce chemical consumption.
- The optimal usage of rinse water to reduce water consumption
- The use of de-ionized water to reduce accumulation of ions in the process tank.
- Optimize the "dripping" process to limit carry over of expensive process chemical.
- Improve efficiency of the wastewater treatment plant, by reducing the load
- Optimize the sludge recovery from process tank
- Water recycling

This feasibility report aims at justifying the above recommendations by compiling the technical and environmental benefits of the modified plant relative to the existing plant.

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1. Introduction

Company Cables is a producer of tin plated copper wire. The current production facility is to be upgraded and the company aims to make this facility as cost effective and environmentally friendly as possible. An environmental review was carried out at Company Cables wire line at their factory in Mkondeni, Pietermaritzburg in July 2002.

The company plans to upgrade the current wire line in order to increase production together with improve cost effectiveness by reducing water and chemical usage. This upgrade would double the current plant capacity from 300 m/min to 600 m/min.

The company has had no major problems with Umgeni Water with regards effluent. The new plant is to be designed so as to exceed the company's present environmental requirements. The company's aim is to make this facility as environmentally friendly as possible and hence the request to the Cleaner Production in the Metal Finishing Industry (CPMFI) Project.

The scope of this report is to evaluate and recommend cleaner production options from a technical, economic and environmental perspective. This report does not consider the capital costs of the entire line recommended but only the options for cleaner production. The cleaner production options under consideration would significantly reduce chemical consumption and wastage, resulting in a reduction on the load to the wastewater treatment facility.

The calculations in this report assume a production rate of twenty one hours / day and does not consider fluctuations in product markets. The recommendations are based on detailed calculations and from engineering practice, however non compliance's to the figures in this report cannot be justified as the variables for control is beyond the scope of this study. The implementation and commissioning risk therefore lies with the company.

2. Current status

The present tin plating facility at Company Cables consists of 3 plating lines, each producing 100 m/min, with a total current production of 529 509 m^2/year. The current plant has two water inlet points consuming a total of 13 478 m^3 of water per year (approximately 43 m^3 / day). None of the rinses are redirected or reused. All rinses have separate inlets and all rinses exit to the waste water treatment plant surge tank. The line is compact with wire drawn in and out automatically. The plant compact with the chemical holding tank at the bottom. There is an air extraction system in place for fume removal on the entire three lines. No filter press is currently used to dewater sludge. The sludge is currently disposed off informally by the plant operator.

2.1. Waste water treatment

Wastewater from all tanks are sent to a common holding tank(surge), located next to the lines, outside the building. No treatment or of waste water is currently carried out. Weekly analysis of wastewater is done, pH measurements only. Sludge has only been removed once in the last three years from the surge tank. The plant is sampled once per month by Umgeni Water.

The company has had no fines or non compliance to effluent specifications.

3. Possible cleaner production technologies

The basis for cleaner production application is the environmental review tool used by the Cleaner Production in the Metal Finishing Industry (CPMFI) project to highlight potential process improvements. A number of possibly applicable cleaner production options were generated from this tool and is reported in the environmental review, (see environmental review, July 2002). These options are listed below together with recommendations.

NB: Recommended would imply the option been considered in this feasibility study but not necessarily finally selected.

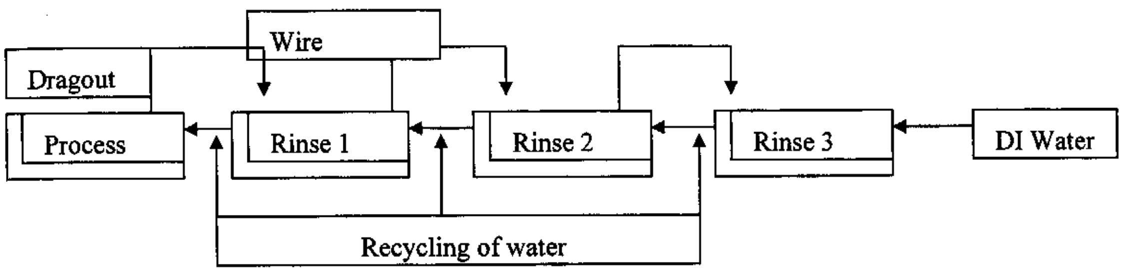
Table 1: Cleaner production options

[illegible]	Recommendation
Purification of cleaners by membranes.	Not recommended
Optimize rinse system.	*Recommended.*
Counter current rinse.	*Recommended.*
Improved chemical dosing	*Recommended.*
Control of rinse water flow.	*Recommended.*
DI feed water	*Recommended.*
"Pre dipping"	*Recommended.*
Introduction of multiple air blades	*Recommended*
Purification of process baths	*Recommended.*

3.1 Description of recommended operations

3.1.1 Three stage counter current rinse

The three stage countercurrent rinses, also known as the low flow rinse, located after the process tanks reduce the loss of expensive process chemicals and reduce the amount of rinse water used whilst saving on treatment at the waste water treatment plant. The three tanks are arranged in a three stage counter current cascade. The losses due to evaporation from the process tank is made up by fresh water (de-ionized water) on the last rinse tank and is pumped through to the first rinse tank. The first rinse tank is used to top up the process tank.



3.1.2. Pre dipping(Spraying)

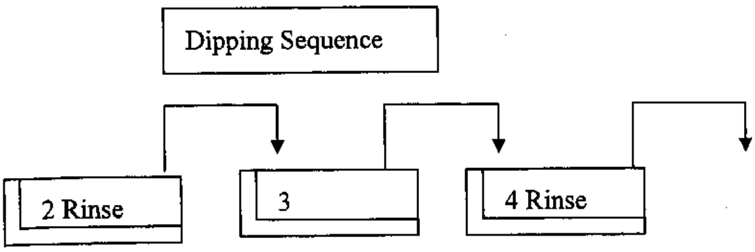
The dipping(spraying) sequence for material passing through the rinse section will be changed to provide pre-dipping. Pre dipping reduces the loss of high value chemicals to the WWTP. The dipping sequence for the plant is changed as follows:

Pre spray from tank	Process tank	Post spray	Tank spray sequence
2	1	2	2,1,2
6	5	6	4,6,5,6

Current dipping sequence:

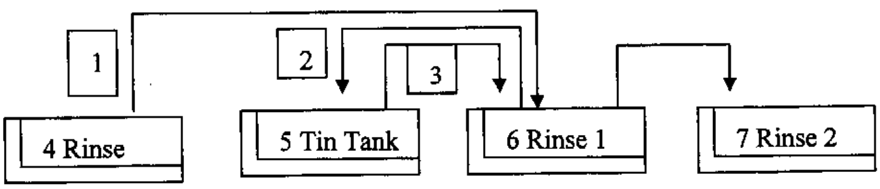
From Tank

2	Rinse
3	Tin
4	Rinse



Proposed dripping sequence:

Tank	
4	Rinse
6	Low flow rinse 1
5	Tin
6	Low flow rinse 1
7	Low flow rinse 2



Typical saving by the above system is 50% of the chemicals dragged out from the process tank.

3.1.4 Water reuse

It is envisaged that the amount of chemicals lost to evaporation would be high due to the use of air blades. This vapor would be removed by the air extractor system and would be scrubbed in a scrubber. If the chemicals are to be recovered, the extractor for the cleaner and plating solution has to be kept separate. An investigation would have to be carried out on recovering of this solution.

4. Description of proposed cleaner production options

It is proposed to increase the number of rinse tanks, install new equipment and change certain operating procedures to reduce raw material waste and environmental impact.

The option presented (Appendix 1, Figure 2- Proposed flow sheet) this is based on an evaporation rate on the process tanks specified in the flowsheets, this would occur by normal evaporative losses from the process tanks (online evaporators are installed). The evaporation required is low and would be achieved due to the heating of the tanks. The chemical supplier specifies up to 50 deg C on the tin and up to 70 deg C on the cleaner. The rates of evaporation would have to be optimized based on operational practice,

4.1 Suggested changes:

- Rinses for the tin and cleaner process tank be arranged in a closed countercurrent cascade, see appended flowsheet, otherwise known as a low flow rinse. This implies that the process liquid carried as a result of dragout out is used to top up the process tank thus minimizing losses while ensuring no metals are wasted to the waste water treatment plant.
- The evaporation required from the process tank would be made up by introducing de-ionized water into the last low flow tank. The final rinse has a calculated content depending on the dragout and evaporation rate. (This is calculated at varying dragout rates, see appendix 1) . All calculations are tabulated in Appendix 1, Tables 2 to 5.
- Rinse water is to enter the bottom of one end of the tank and leave at the top of the other end, this would ensure optimum mixing.
- Measurement and control of all water inlets, introduction of flowmeters
- Introduction of de-ionized water
- Multiple air blades on all wire exit from process liquid

4.1.1 Bath and process management

In the options proposed an important criterion for consideration is the rate of evaporation from the process tanks. A rate of 250 L/day , tin, and 200 L/day, cleaner, is imperative to ensure the material balance is correct and the dragged out chemicals is recovered (process tank evaporation rate is specified in Appendix 1).

This feasibility allows for options of different evaporation rates (Table of values attached in Appendix 1, Tables 2-5). Evaporation rates were obtained can be adjusted to optimize process, this would be done by the online evaporator.

A concern over the possibility of heating losses form the process tanks can be addressed by keeping the temperature constant and optimizing the dragout. The energy consumption associated with this heating would be negligible as heating would be carried out during plating. The low flow rinse would be pumped via pumps from tank to tank. This would ensure minimum tin content in the final rinse and the dilution factors in these rinse tanks are met, ensuring effective rinsing. The inlet water flow rate must be kept at a constant rate to ensure the calculated specification in the final rinse are met.

A key factor in determining water consumption and rinsing is dragout, good dragout would imply a carry over of 160 mL/m^2. However, this is wire and it is envisaged that the dragout is currently 4 mL/m^2, this is from using an analysis of a sample taken (20 mg/L caustic). Based on this together with the use of air blades the projected dragout is assumed to be 16 ml/m^2. This assumption is justified in terms of the use of a double air wipe to ensure minimum losses from the process baths. If this dragout figure is not achieved the plant has been designed so as to increase the evaporation rate so as to achieve the dilution factors required.

The chemical content at the waste water treatment facility would be zero as no rinse water would be sent to this treatment plant. This plant would now become redundant except for spills and emergencies. The equipment used for this facility is satisfactory to deal with this loading.

4.1.2 Sludge reduction

The sludge currently generated has not been quantified . Due to the change in chemicals used it would be difficult to predict the sludge volume generated, specification sheet only discusses organic contamination. This would be dealt with by the use of an online filter from the chemical supplier.

5. Environmental evaluation

5.1 Raw Water Usage

From the suggested process layout it can be seen that the number of water inlets to the system has been unchanged, but the total volume of water leaving the system is now zero.

The raw water usage is reduced by more than 99% from 13 478 m^3/yr to 88 m^3/yr. The contribution of each of the water saving systems is compared in Table 1, Appendix 1. This is a significant reduction in water consumption and would imply, subject to good management, significant reduction in waste water volume. The total cost associated with the water saving is R 60 257 R/year.

The feed water to all the low flow rinses is first de-ionized to prevent salt buildup in the process tanks. The use of de-ionized water is critical to the low flow rinse system. The introduction of an Reverse Osmosis/ de-ionized unit would improve the quality of water.

Table 2-5, Appendix 1 has detailed calculation for water flows to the process rinse tanks. Different options are generated. The table displays different flow rates together with the different dilution factors. The flowsheet given (Appendix 1, Figure 2) uses the optimum water flow rates.

The flow of water to the rinse after the degreaser is 300 L/hr with a dilution factor of 60. The flow of water to the rinse after the tin plating tank is 250 L/hr with a dilution factor of almost 110.

5.2. Chemical usage

The present chemical usage is high and proper management of this raw material would result in cost savings both in process chemicals and wastewater treatment chemicals. Dosing systems need to be considered allowing for accurate chemical dosing. Overdosing and underdosing of valuable chemicals must be prevented. Daily sampling and control needs to be done to optimize the dosing of chemicals.

A major consideration for the chemical bill is the changes in chemicals and equipment to be used. The flourborate system has an efficiency, subject to operating conditions, of 100 %. This is an important factor in terms of chemical usage.

A detailed costing based on consumption's is done in Appendix 1, Table 1.

There is currently no treatment of waste water at the surge tank. The new facility would consist of closed loop counter current rinses which would result in no effluent to the surge tank. Thus no chemicals would be required for the waste water treatment plant.

Zero chemical losses would be achieved by the introduction of counter current rinsing, improved dosing and by improving drip times ie the effectiveness of the air blades.

Chemical consumption would be reduced in all tanks based on improved dripping times.

An example of dragout using the degreaser bath:

A bath with a concentration of 60 g/l and a production rate of 300 m^2/ hour

Poor dragout(Short hanging time)	**Good dragout(Long hanging time)**
Poor dragout would imply loss of 160 ml/ m^2	Good dragout would imply loss of 16 ml/ m^2 or less
0.160 l/ m^2* 300 m^2/hr* 60g/l	0.016 l/ m^2*300 m^2/hr*60g/l
= 2880 g/hr	= 288 g/hr
= 18869 kg/ year	= 1887 kg /year

For the tin bath the losses would be reduced significantly. This was established from the review tool by using the surface area treated. The tool calculates a consumption of 32 kg Tin/1000m^2 plated and rates this consumption as a 5 which is very high. The figure generated by the tool is 20 kg/1000m^2 . This would imply a reduction in chemicals of 62 %. With the counter current rinsing process in place this is highly achievable. For the purpose of this study a conservative saving of 20 % by mass of tin would be assumed. It is justified in terms of the management of the rinses, reduced contamination and low flow rinsing . A further consideration is the excess use of stannous sulfate. This has been used as a substitute for anodes. This is a very expensive source of Tin as it cost twice the price as compared to anodes. With proper anode ratios and bath management this loss would be reduced. A figure of 30% of the previous consumption is considered, this is a very conservative value.

All other chemical additions to the baths have been reduced by 20 %. This would be savings achieved due to reduced dragout. This is also a conservative estimate.

5.3. Environment

In upgrading any production facility the most important consideration, next to cost effectiveness and productivity is the environmental impact. This combined with the trend from local metro's in reducing the heavy metals limits in wastewater sent to drain is reason enough to ensure that any modern plant is as environmentally friendly as possible. An additional reason is the cost of both purchasing and disposing of the most important raw material for metal finishing , water, which is rapidly becoming expensive and scarce.

Thus the plant designed is aimed at zero losses of heavy metals together with a very low water consumption. The final rinse for tin would have a concentration of 1.4 g/l. All process chemicals, circuit would now be a closed loop and thus no metals would be going to the waste water treatment plant. It is envisaged that the metal content at the waste water treatment plant would be zero.

Comment [illegible]

5.3.1. Health and safety

An air extraction system has to be introduced to extract the fumes from the process tank, this would be to remove the toxic air from the environment of the employees thus reducing potential health risks. It is envisaged that with good air circulation and proper ventilation, combined with the extraction system the air quality would be sufficient.

5.3.2 . Company image

Company cables has had no problems with Umgeni water and a green image would stand the company in good stead for the future. If the company is to operate as recommended in this report it would have no problems Umgeni water. The company could also market itself as a green company and this would position the company well in terms of the export markets as all products could be considered greener and environmentally friendly.

6. Capital costs

The construction of the new line allows for the implementation of the cleaner production options as discussed in this report. The capital cost for the entire new line is not considered. Only capital based on the cleaner production options suggested will be considered.

The cost of capital equipment are considered as follows:

- De-ionized water can be supplied with a reverse osmosis plant. If the company chooses to go for a reverse osmosis unit it would cost R 12 880.
- In line carbon filter R 26 000
- Operator training at R 1000 a day, total R 3000
- Further consultation R 3000
- Additional 2 stage rinse Degreaser, with air blade R 73 000
- Spray system for dragin of dragout R 37 000
- Carbon filter R 26 000
- A budget price from VJL for the scrubber system: R90 000
- A budget price for caustic and Florbourate recovery R140 000

All prices provided are from company quotes attached in appendix 1

Table 3: Cleaner production equipment cost

Description	Number of units	Unit Cost (Costs Rands)	Total cost
R O unit	1	12 880	12 880
Additional 2 stage rinse Degreaser, with air blade	1	73 000	73 000
Additional 2 stage rinse Plating, with air blade	1	92 000	92 000
Measuring and control	1	42 000	42 000
Spray system for dragin of dragout	1	37 000	37 000
Carbon filter	1	26 000	26 000
Evaporator: Degreaser	1	42 000	42 000

Evaporator: Plating	1	57 000	57 000
Scrubber system	1	90 000	90 000
Caustic and flouroborate recovery	1	140 000	140 000
Operator training + Operating Procedures	1	3 000	3 000
Consulting	1	3 000	3 000
Total Capital Cost			617 880

From Table 3 it can bee seen that the total capital cost would be R 617 880.

6.1 Equipment cost

Prices for the RO/ De-ionization unit were obtained from two companies the following tables provide the specification and further information.

Table 4: Suppliers for RO / DI units

Supplier	Unit cost	Specification	Contact person	Contact No.
True water Solutions	R 9 500	500 l/day	S Moss	033 3424000
Water Purification equipment	R 12 800	950 l/day	A Du Toit	031 564 4403

Price exclude piping and installation. The unit has to be sourced based on water requirements.

Table 5: Suppliers for flow meters

Supplier	Unit cost	Specification	Contact person	Contact No.
East Coast	R 998	10-100 l/hr 5-50 l/hr 3-24 l/hr	Shaun	031 3054918
City plastics	R 696	10-100 l/hr 5-50 l/hr 3-24 l/hr	D Hammond	031 2061512

Flow meter prices are independent of throughput. Flow meters must be properly sourced to ensure operation within flow range.

Since the equipment being built is specialized the prices supplied is from the manufacturer.

7. Economical evaluation

A detailed costing of the various options are detailed in Table 1, appendix 1. The consumption of chemicals are based on goal values from Table 2, environmental review report, and on dragout calculations. Table 1, Appendix 1 contains details on the water and chemical usage together with costs for each of the options. Table 1 can be summarized as follows.

Table 9: Water savings

	Current	New Line
Cost in Rands	60 653	396

Thus the total savings in water amounts to R 60 257, or 99 % of the current usage.

The chemical consumption's can be summarized as follows.

Table 10: Chemical consumption

Consumption	Unit	Today	New plant with current production
Water	R/yr.	[redacted]	[redacted]
Process Chemicals	R/yr	[redacted]	[redacted]
Chemicals WWTP	R/yr	[redacted]	[redacted]
Total Costs in Rands	**R/yr**	**1 355 569**	**1 113 082**

Process chemicals can be reduced by 14 % if managed properly.

The overall savings in chemicals and water etc adds up to R 242 487. Considering that the total capital investment required would be R 617 880 the payback period would be 19 months. The new plant would be designed to double production so the total savings can be doubled to

R 484 974 giving a pay back period of 16 months. Considering the 20 % from the CPMFI the payback is reduced to 14 months. This excludes labor savings and other indirect costs.

8. Conclusion and recommendations

The above discusses the details involved in the option proposed and lays the foundation for construction of a cleaner facility. The option presented has to be considered for implementation as an integral part of the proposal prepared for improvements to the production line being constructed.

The feasibility concludes that the company should invest in the additional cleaner production equipment together with the recommended plant modifications. This would ensure the current facility is optimized in the most cost effective way. This upgrade would ensure Umgeni Water's limits are met for now and for the foreseeable future.

It is recommended that a detailed design be carried out based on this feasibility report. It is also suggested that the waste water treatment facility be designed based on the flow rates recommended in this report, forecast as zero.

It is further recommended that the design of the new line be a consultative one and expertise from CPMFI consulted for any further changes.

Appendix 1

Figure 1: Flow sheet: Present plant

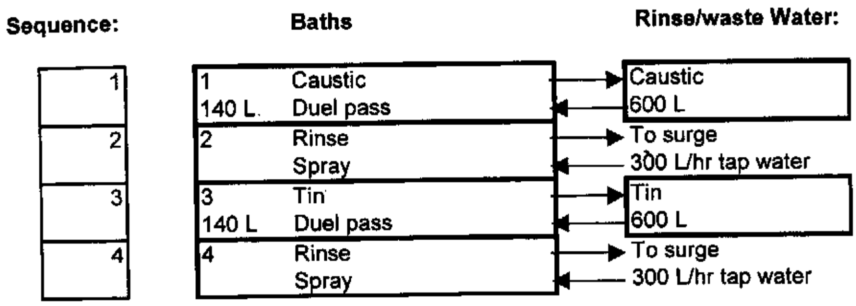


Figure 2: Flow sheet: New plant

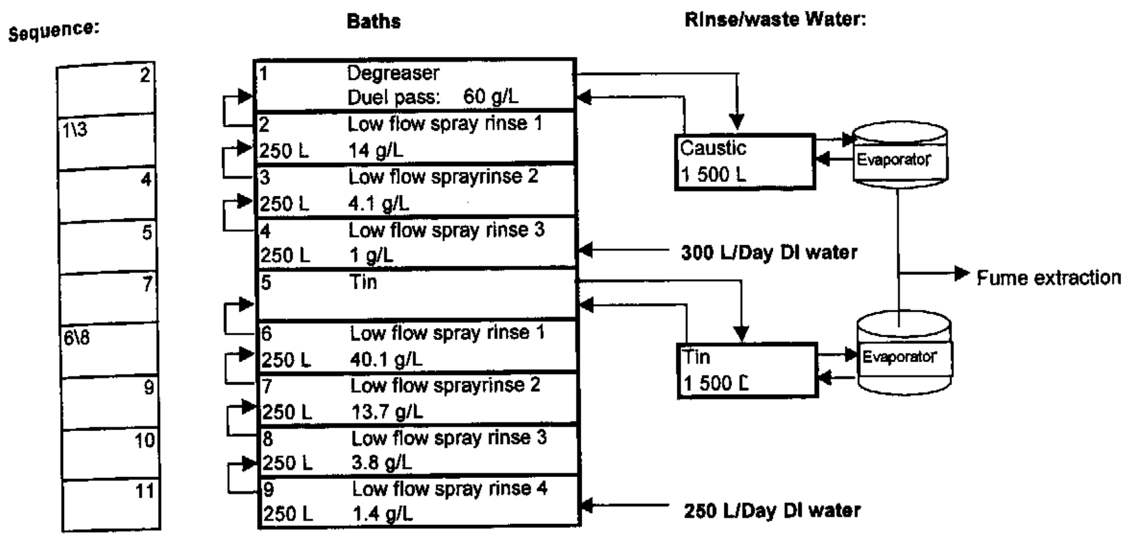


Table 1: Total costing

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Consumption	Unit	Present	New line		
Water	l/h	1800	25		
Water	m3/yr	13478.4	88		
Water	l/m2	25.45452485	0.166191698		
Water	R/yr	60652.8	396		
Savings			**60256.8**		
Tin Bath					
					Chemical cost / kg
Degreaser salt	kg/yr	7500			
	R/yr	17400			
HP 16	kg/yr		6000		13.40
	R/yr		80400		
Tin anodes	kg/yr	16800	13440	Tin anodes	
	R/yr	917280	733824		
Sulfuric acid	kg/yr	3380	2704	Flouroboric Acid	45.30
	R/yr	5982.6	122491.2		
Diphone V	kg/yr	242	**750**	M&T-Additive 221 A	49.70
		35250	**37500**		
			750	M&T Additive 221 B	48.30
			36750		
PhenaolSulphonic acid	R/yr	3404	2723.2	Boric acid	10.13
		43230.8	27586.016		
Stannous Sulphate		3132	939.6	Stannous flouroborate	78.90
		275772.6	74134.44		
Sub Total		**1294916**	**1112686**		
Savings			**182230**		
Total		1355569	1113082		
Total Saving			**242487**		

Table 2: Tin rinse Table: Table of values for rinse water flow 250/300 L/day with varying dragout volumes

275m hr at 0.016 l/m2

Florborate rinsing system with pre-dip in 1 st rinse

Case 1		
Evaporation:	250.0	litre/day
Drag-out:	4.5	litre/h
Drag-out:	94.5	litre/day
Production:	21.0	h/day
Florborate in bath:	150.0	g/l
Florborate in 1st rinse	40.1	g/l
Florborate in 2nd rinse	13.7	g/l
Florborate in 3rd rinse	3.8	g/l
Florborate in 4th rinse	1.4	g/l
Loss of Florborate to wastewater	134.7	g/day
Recovery of Florborate	97.5	%

Case 2		
Evaporation:	300.0	litre/day
Drag-out:	4.5	litre/h
Drag-out:	94.5	litre/day
Production:	21.0	h/day
Florborate in bath:	150.0	g/l
Florborate in 1st rinse	35.3	g/l
Florborate in 2nd rinse	10.4	g/l
Florborate in 3rd rinse	2.5	g/l
Florborate in 4th rinse	0.8	g/l
Loss of Florborate to wastewater	73.8	g/day
Recovery of Florborate	98.3	%

Case 3		
Evaporation:	250.0	litre/day
Drag-out:	4.0	litre/h
Drag-out:	84.0	litre/day
Production:	21.0	h/day
Florborate in bath:	150.0	g/l
Florborate in 1st rinse	37.0	g/l
Florborate in 2nd rinse	11.5	g/l
Florborate in 3rd rinse	2.9	g/l
Florborate in 4th rinse	1.0	g/l
Loss of Florborate to wastewater	81.4	g/day
Recovery of Florborate	98.1	%

Case 4		
Evaporation:	300.0	litre/day
Drag-out:	4.0	litre/h
Drag-out:	84.0	litre/day
Production:	21.0	h/day
Florborate in bath:	150.0	g/l
Florborate in 1st rinse	32.4	g/l
Florborate in 2nd rinse	8.6	g/l
Florborate in 3rd rinse	1.9	g/l
Florborate in 4th rinse	0.5	g/l
Loss of Florborate to wastewater	44.0	g/day
Recovery of Florborate	98.8	%

Florborate rinsing system without pre-dip in 1 st rinse

Case 1		
Evaporation:	250.0	litre/day
Drag-out:	4.5	litre/h
Drag-out:	94.5	litre/day
Production:	21.0	h/day
Florborate in bath:	150.0	g/l
Florborate in 1st rinse	54.7	g/l
Florborate in 2nd rinse	18.7	g/l
Florborate in 3rd rinse	5.1	g/l
Florborate in 4th rinse	1.9	g/l
Loss of Florborate to wastewater	183.6	g/day
Recovery of Florborate	96.6	%

Case 2		
Evaporation:	300.0	litre/day
Drag-out:	4.5	litre/h
Drag-out:	94.5	litre/day
Production:	21.0	h/day
Florborate in bath:	150.0	g/l
Florborate in 1st rinse	46.2	g/l
Florborate in 2nd rinse	13.5	g/l
Florborate in 3rd rinse	3.2	g/l
Florborate in 4th rinse	1.0	g/l
Loss of Florborate to wastewater	96.5	g/day
Recovery of Florborate	97.8	%

Case 3		
Evaporation:	250.0	litre/day
Drag-out:	4.0	litre/h
Drag-out:	84.0	litre/day
Production:	21.0	h/day
Florborate in bath:	150.0	g/l
Florborate in 1st rinse	49.1	g/l
Florborate in 2nd rinse	15.2	g/l
Florborate in 3rd rinse	3.8	g/l
Florborate in 4th rinse	1.3	g/l
Loss of Florborate to wastewater	108.0	g/day
Recovery of Florborate	97.4	%

Case 4		
Evaporation:	300.0	litre/day
Drag-out:	4.0	litre/h
Drag-out:	84.0	litre/day
Production:	21.0	h/day
Florborate in bath:	150.0	g/l
Florborate in 1st rinse	41.3	g/l
Florborate in 2nd rinse	10.9	g/l
Florborate in 3rd rinse	2.4	g/l
Florborate in 4th rinse	0.7	g/l
Loss of Florborate to wastewater	56.1	g/day
Recovery of Florborate	98.4	%

Table 3: Tin rinse: Table of values for rinse water flow at 300-400L/hr with varying dragout volumes

275m hr at 0.016 l/m2

Florborate rinsing system with pre-dip in 1 st rinse

Case 1		
Evaporation:	300.0	litre/day
Drag-out:	6.0	litre/h
Drag-out:	126.0	litre/day
Production:	21.0	h/day
Florborate in bath:	150.0	g/l
Florborate in 1st rinse	43.0	g/l
Florborate in 2nd rinse	16.1	g/l
Florborate in 3rd rinse	4.7	g/l
Florborate in 4th rinse	2.0	g/l
Loss of Florborate to wastewater	251.3	g/day
Recovery of Florborate	96.8	%

Case 2		
Evaporation:	350.0	litre/day
Drag-out:	6.0	litre/h
Drag-out:	126.0	litre/day
Production:	21.0	h/day
Florborate in bath:	150.0	g/l
Florborate in 1st rinse	38.8	g/l
Florborate in 2nd rinse	12.8	g/l
Florborate in 3rd rinse	3.4	g/l
Florborate in 4th rinse	1.2	g/l
Loss of Florborate to wastewater	153.2	g/day
Recovery of Florborate	97.7	%

Case 3		
Evaporation:	400.0	litre/day
Drag-out:	7.0	litre/h
Drag-out:	147.0	litre/day
Production:	21.0	h/day
Florborate in bath:	150.0	g/l
Florborate in 1st rinse	39.4	g/l
Florborate in 2nd rinse	13.2	g/l
Florborate in 3rd rinse	3.5	g/l
Florborate in 4th rinse	1.3	g/l
Loss of Florborate to wastewater	191.2	g/day
Recovery of Florborate	97.6	%

Case 4		
Evaporation:	400.0	litre/day
Drag-out:	6.0	litre/h
Drag-out:	126.0	litre/day
Production:	21.0	h/day
Florborate in bath:	150.0	g/l
Florborate in 1st rinse	35.3	g/l
Florborate in 2nd rinse	10.4	g/l
Florborate in 3rd rinse	2.5	g/l
Florborate in 4th rinse	0.8	g/l
Loss of Florborate to wastewater	98.4	g/day
Recovery of Florborate	98.3	%

Florborate rinsing system without pre-dip in 1 st rinse

Case 1		
Evaporation:	300.0	litre/day
Drag-out:	6.0	litre/h
Drag-out:	126.0	litre/day
Production:	21.0	h/day
Florborate in bath:	150.0	g/l
Florborate in 1st rinse	60.2	g/l
Florborate in 2nd rinse	22.5	g/l
Florborate in 3rd rinse	6.6	g/l
Florborate in 4th rinse	2.8	g/l
Loss of Florborate to wastewater	351.8	g/day
Recovery of Florborate	95.6	%

Case 2		
Evaporation:	350.0	litre/day
Drag-out:	6.0	litre/h
Drag-out:	126.0	litre/day
Production:	21.0	h/day
Florborate in bath:	150.0	g/l
Florborate in 1st rinse	52.3	g/l
Florborate in 2nd rinse	17.2	g/l
Florborate in 3rd rinse	4.6	g/l
Florborate in 4th rinse	1.6	g/l
Loss of Florborate to wastewater	206.5	g/day
Recovery of Florborate	97.0	%

Case 3		
Evaporation:	400.0	litre/day
Drag-out:	7.0	litre/h
Drag-out:	147.0	litre/day
Production:	21.0	h/day
Florborate in bath:	150.0	g/l
Florborate in 1st rinse	53.3	g/l
Florborate in 2nd rinse	17.8	g/l
Florborate in 3rd rinse	4.8	g/l
Florborate in 4th rinse	1.8	g/l
Loss of Florborate to wastewater	259.0	g/day
Recovery of Florborate	96.8	%

Case 4		
Evaporation:	400.0	litre/day
Drag-out:	6.0	litre/h
Drag-out:	126.0	litre/day
Production:	21.0	h/day
Florborate in bath:	150.0	g/l
Florborate in 1st rinse	46.2	g/l
Florborate in 2nd rinse	13.5	g/l
Florborate in 3rd rinse	3.2	g/l
Florborate in 4th rinse	1.0	g/l
Loss of Florborate to wastewater	128.7	g/day
Recovery of Florborate	97.8	%

Table 4: Degreaser rinse: Table of values for rinse water flow at 300/250 L/day with varying dragout volumes

Plating 275 m2/hr with a dragout of 0.016 L/m2

Degreaser rinsing system with pre-dip in 1 st rinse

Case 1		
Evaporation:	300.0	litre/day
Drag-out:	4.5	litre/h
Drag-out:	94.5	litre/day
Production:	21.0	h/day
Degreaser in bath:	60.0	g/l
Degreaser in 1st rinse	14.1	g/l
Degreaser in 2nd rinse	4.1	g/l
Degreaser in 3rd rinse	1.0	g/l
Loss of Degreaser to wastewater	93.7	g/day
Recovery of Degreaser	98.3	%

Case 2		
Evaporation:	300.0	litre/day
Drag-out:	10.0	litre/h
Drag-out:	210.0	litre/day
Production:	21.0	h/day
Degreaser in bath:	60.0	g/l
Degreaser in 1st rinse	22.6	g/l
Degreaser in 2nd rinse	12.3	g/l
Degreaser in 3rd rinse	5.1	g/l
Loss of Degreaser to wastewater	1064.5	g/day
Recovery of Degreaser	91.6	%

Case 3		
Evaporation:	300.0	litre/day
Drag-out:	12.0	litre/h
Drag-out:	252.0	litre/day
Production:	21.0	h/day
Degreaser in bath:	60.0	g/l
Degreaser in 1st rinse	24.3	g/l
Degreaser in 2nd rinse	14.8	g/l
Degreaser in 3rd rinse	6.8	g/l
Loss of Degreaser to wastewater	1701.5	g/day
Recovery of Degreaser	88.7	%

Case 4		
Evaporation:	250.0	litre/day
Drag-out:	10.0	litre/h
Drag-out:	210.0	litre/day
Production:	21.0	h/day
Degreaser in bath:	60.0	g/l
Degreaser in 1st rinse	24.3	g/l
Degreaser in 2nd rinse	14.8	g/l
Degreaser in 3rd rinse	6.8	g/l
Loss of Degreaser to wastewater	1418.0	g/day
Recovery of Degreaser	88.7	%

Degreaser rinsing system without pre-dip in 1 st rinse

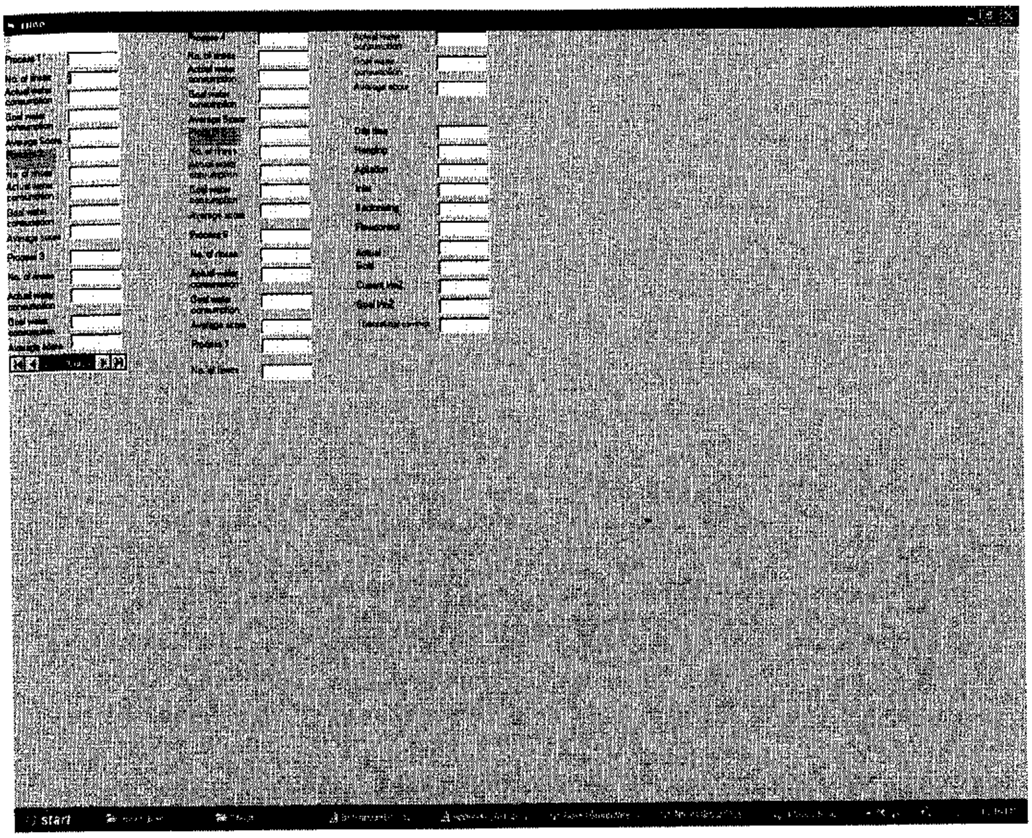
Case 1		
Evaporation:	300.0	litre/day
Drag-out:	4.5	litre/h
Drag-out:	94.5	litre/day
Production:	21.0	h/day
Degreaser in bath:	60.0	g/l
Degreaser in 1st rinse	18.5	g/l
Degreaser in 2nd rinse	5.4	g/l
Degreaser in 3rd rinse	1.3	g/l
Loss of Degreaser to wastewater	122.6	g/day
Recovery of Degreaser	97.8	%

Case 2		
Evaporation:	300.0	litre/day
Drag-out:	10.0	litre/h
Drag-out:	210.0	litre/day
Production:	21.0	h/day
Degreaser in bath:	60.0	g/l
Degreaser in 1st rinse	36.2	g/l
Degreaser in 2nd rinse	19.7	g/l
Degreaser in 3rd rinse	8.1	g/l
Loss of Degreaser to wastewater	1701.5	g/day
Recovery of Degreaser	86.5	%

Case 3		
Evaporation:	300.0	litre/day
Drag-out:	12.0	litre/h
Drag-out:	252.0	litre/day
Production:	21.0	h/day
Degreaser in bath:	60.0	g/l
Degreaser in 1st rinse	40.8	g/l
Degreaser in 2nd rinse	24.7	g/l
Degreaser in 3rd rinse	11.3	g/l
Loss of Degreaser to wastewater	2846.2	g/day
Recovery of Degreaser	81.2	%

Case 4		
Evaporation:	250.0	litre/day
Drag-out:	10.0	litre/h
Drag-out:	210.0	litre/day
Production:	21.0	h/day
Degreaser in bath:	60.0	g/l
Degreaser in 1st rinse	40.8	g/l
Degreaser in 2nd rinse	24.7	g/l
Degreaser in 3rd rinse	11.3	g/l
Loss of Degreaser to wastewater	2371.9	g/day
Recovery of Degreaser	81.2	%

Appendix A4: Visual Basic Screens



Detailed database on Disc

See Attached disc for programs, Folder "VB Database"

D:/Database

Appendix A5: VB Program Monte Carlo for categories

See Attached disc for programs, Folder "Mat Lab Monte Inputs"

Appendix B: Fuzzy Logic

Appendix B1: Approach

Development of a single fuzzy logic system for the entire plant would be an almost impossible task hence the plant can be categorized into subsections. For the purpose of this system the plant was categorized into the following sections:

- Sludge-Sludge generated plant-wide and handled at the wastewater treatment facility. The amount of sludge is proportional to plating chemical losses.
- Waste water treatment plant chemicals-Chemicals used for treatment of wastewater at the wastewater treatment facility. This is an indication of the chemical losses from the plant.
- Wastewater treatment plant equipment- The equipment used at the wastewater treatment plant must be effective in measurement and control. Calibration is also a key factor.
- Process Chemical-Process chemicals must be used for the plating process and not contribute to waste generation. Optimum management is required.
- Occupational health and safety-The employee's health is a major concern especially since such hazardous chemicals are being used.
- State of the rinsing system- The configuration of the rinsing system at a surface finishing plant could result in low or very high water consumption.
- Water consumption- The actual water flow is an important factor in an audit of a plating plant. Excessive water could result in an oversized treatment process.
- Production-The way things are done. Good operational practices imply a reduction in rejects and waste thus ensuring optimal use of resources.

The final output from the model would represent these categories of the company as key focus areas.

Multiobjective decision-making

The scope of this paper would include all of the above categories but the rinse tables would be used to illustrate fuzzy logic multi-objective decision function procedure. The objective of the rinse tables being, determining the water consumption rating of the company.

The key objectives for the effective rinsing and water consumption at a surface finishing facility would be those factors that impact on water consumption and effective rinsing off, of chemicals. The output has to be a function representing all the objectives with consideration to their levels of importance. The fuzzy logic multi-objective decision function would assist in determining the weighing of each objective. This shall be used to determine the water consumption rating for the company.

The key variables (A), which contribute to water consumption, are:

- Drip times (DT)- The time the components are allowed to drip above the tank before being moved to the next tank
- Hanging (HG)- The orientation of the components on a jig.
- Agitation (AG)-The liquid movement created in a tank by air or jig movement.
- Inlet (IN)- The water flow inlet and outlet of a rinse tank
- Back mix (BM)- The mixing of process rinses due to connections of the tanks

- Flow control (FC)- The regulation of water to a rinse tank

Hence defining set A:

$$A = \{DT, HG, AG, IN, BM, FC\}$$

The fuzzy logic multi-objective decision function is tasked with determining the weighted importance of each variable in $\{A\}$. This would be done using a set of criteria, say $\{O\}$ that is important in the decision-making. The decision function essentially represents a mapping of the alternates in A to a set of ranks. This process would require subjective information from the decision authority concerning the importance of each objective $\{O\}$.

The objectives for the rinse water problem are:

- Production (P)- The impact of rinsing on the rate of production, e.g. a longer drip time would result in increased production time.
- Cost(C)- The cost implications of the variables e.g. a longer drip time would result in a reduction in dragout chemicals and hence reduced chemical cost.
- Chemical Consumption (CC)- The impact the variables would have on the consumption of chemicals. The reduction in dragout would result in a reduction of chemical consumption.
- Water consumption (WC)- The water consumption is directly dependent on the rinsing required.

The set for the objective function can be defined as:

$O = \{P, C, CC, WC)$

Let the degree of membership of DT in {O} be denoted as μ_{oi} (DT) and is the degree to which DT satisfies the criteria specified for this objective. The decision function D must satisfy all the decision objectives. The decision function is hence the intersection off all the objective sets.

$$D = P \cap C \cap CC \cap WC$$

And hence the grade of membership that the decision function, D, has for each alternate in {A}, is given by:

$$\mu_D(a) = \min [\mu_P(DT), \mu_C(DT), \mu_{CC}(DT), \mu_{WC}(DT)]$$

The optimum decision, a^*, will then be the alternate that satisfies:

$$\mu_D(a^*) = \max (\mu_D(a))$$

Where $a \in A$

The set of preferences {P}, which are values, which can be described as linguistic or intuitive with values in the interval [0,1]. These preferences are attached to each of the objectives to quantify the decision maker's feelings about the influence that each objective should have on the chose alternate. Let the parameter, b_i, be contained on the set of preferences, {P}, where i =1,2,3,4. Hence we have the level of importance of each objective to the decision maker for each decision.

The form of the decision function, D, now changes to represent a combination of the weight and the objective function.

$$D = M(P,b_1) \cap M(C,b_1) \cap M(CC,b_1) \cap M(WC,b_1)$$

The decision measure for a particular alternative, a, can be replaced with:

$$M(P_i(a),b_i) = b_i \rightarrow P_i(a) = \bar{b}_i \vee P_i(a)$$

The statement "b_i implies P_i," indicates a unique relationship between a preference and its associated objective function. Hence a reasonable decision model will be the joint interaction of r decision measures:

$$D = \bigcap_{i=1}^{r} (\bar{b}_i \cup O_i)$$

And the optimum solution, a^*, is the alternate that maximizes D. If we define:

$$C_i = \bar{b}_i \cup O_i$$

Hence

$$\mu_{ci}(a) = \max\,[\mu_{bi}-(a), \mu_O(a)]$$

This implies that the optimium solution, expressed in membership form, is:

$$\mu_d(a^*) = \max[\min\{\mu_{ci}(a), \mu_{c2}(a) \ldots\ldots\ldots \mu_r(a)\}]$$

The model is intuitive in that as the *ith* object becomes more important in the final decision, b_i increases, causing $\bar{b}_i$ to decrease which in turn causes C_i (a) to decrease, thereby increasing the likelihood that C_i (a) =O_i (a), where O_i (a) will be the value of the decision function, D, representing alternate a. This process is repeated and a choice optimum a* is found.

Appendix B1.1: Application of Multiobjective decision making to the rinse tables

The rinse tables determine the state of the rinsing system. The variables that would be considered would be:

First the alternatives had to be defined. For rinsing the alternatives are:

A = {Drip times (DT), Hanging (HG), Agitation (AG), Inlet (IN), Back mix (BM), Flow control (FC)}

Then the main objectives in evaluating and controlling the rinses were determined:

O = {Production, Cost, Chemical consumption, Water consumption}

The ranking for each of the above objectives will be rated as preferences:

$$P = \{b_1, b_2, b_3, b_4\} \longrightarrow [0,1]$$

So inputting the relationship between each one of the alternatives and the objectives.

$$\underset{\leftrightarrow}{Q}_1 = \frac{0.25}{DT} + \frac{0.2}{HG} + \frac{0.15}{AG} + \frac{0.15}{IN} + \frac{0.1}{BM} + \frac{0.2}{FC}$$

$$\underset{\leftrightarrow}{Q}_1 = \frac{0.3}{DT} + \frac{0.15}{HG} + \frac{0.2}{AG} + \frac{0.15}{IN} + \frac{0.1}{BM} + \frac{0.1}{FC}$$

$$\underset{\leftrightarrow}{Q}_1 = \frac{0.25}{DT} + \frac{0.2}{HG} + \frac{0.1}{AG} + \frac{0.15}{IN} + \frac{0.1}{BM} + \frac{0.2}{FC}$$

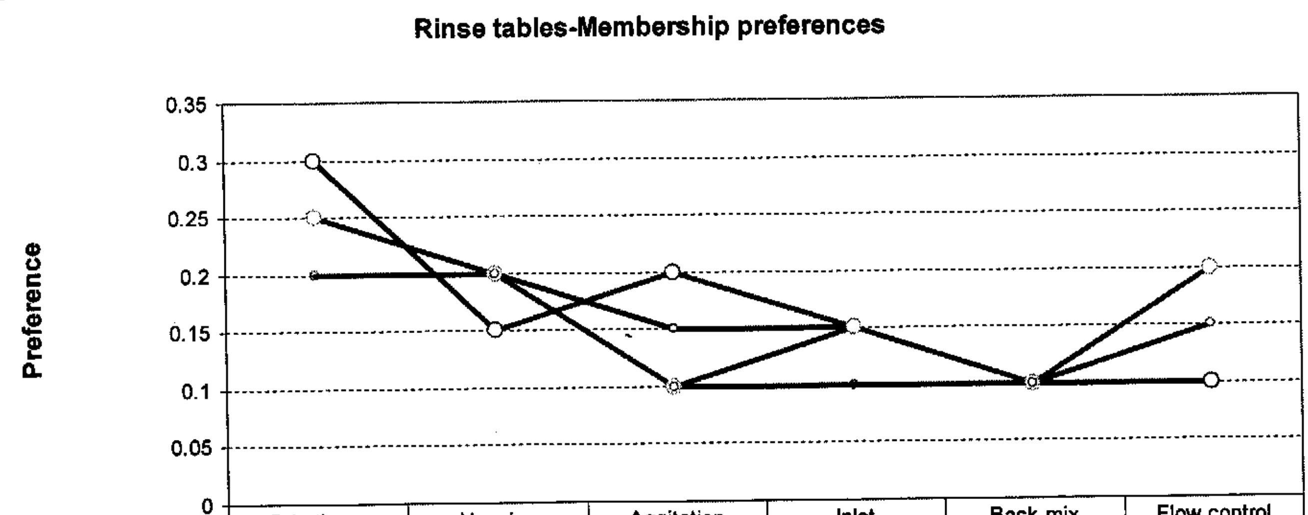
$$\underset{\leftrightarrow}{Q}_1 = \frac{0.2}{DT} + \frac{0.2}{HG} + \frac{0.1}{AG} + \frac{0.1}{IN} + \frac{0.1}{BM} + \frac{0.15}{FC}$$

Now each of the preferences has to be rated on a scale of 0-1.

- b_1= 0.75 : The production rate is among the most important preference as this is the main objective of the business. But in the rinsing system it would not be as important as water consumption.
- b_2= 1 Water consumption is the key for the rinse tables. The objective being to achieve effective rinsing with minimum water consumption.
- b_3= 0.7 Cost is always a key variable and enjoys a medium to high rating.
- b_4= 0.6 Chemical consumption is a key objectives as losses implies greater water consumption

A graph can be plotted of each membership with respect to the preferences.

Fig B1: Graph of membership and preferences



	Drip times	Hanging	Aggitation	Inlet	Back mix	Flow control
Chemical	0.25	0.2	0.15	0.15	0.1	0.15
Production	0.3	0.15	0.2	0.15	0.1	0.1
Water	0.25	0.2	0.1	0.15	0.1	0.2
cost	0.2	0.2	0.1	0.1	0.1	0.15

Membership

The complement of the preferences is required for the calculations so they are determined and substituted into the Decision making equation:

The decision-making equations:

$$D(a_1) = D(DT) = (\overline{b_1} V O_1)\Lambda(\overline{b_2} V O_2)\Lambda(\overline{b_3} V O_3)\Lambda(\overline{b_4} V O_4)$$

Now substituting into the above for each alternative:

$$D(a_1) = D(DT) = (0.25 V 0.7)\Lambda(0.3 V 0.75)\Lambda(0.25 V 1)\Lambda(0.2 V 0.7)$$

$$D(a_2) = D(HG) = (0.2 V 0.7)\Lambda(0.5 V 0.75)\Lambda(0.2 V 1)\Lambda(0.2 V 0.7)$$

$$D(a_3) = D(AG) = (0.3V0.7)\Lambda(0.25V0.75)\Lambda(0.1V1)\Lambda(0.3V0.7)$$
$$D(a_4) = D(IN) = (0.3V0.7)\Lambda(0.25V0.75)\Lambda(0.15V1)\Lambda(0.3V0.7)$$
$$D(a_5) = D(BM) = (0.3V0.7)\Lambda(0.25V0.75)\Lambda(0.1V1)\Lambda(0.3V0.7)$$
$$D(a_6) = D(FC) = (0.3V0.7)\Lambda(0.25V0.75)\Lambda(0.2V1)\Lambda(0.3V0.7)$$

Solving:

$D(a_1)= 0.25$

$D(a_2)= 0.2$

$D(a_3)= 0.1$

$D(a_4)= 0.15$

$D(a_5)= 0.1$

$D(a_6)=0.2$

With a maximum $D(a_1)= 0.25$. These values can now be used to determine the rinsing system environmental status. The final outcome indicates dripping times to be the highest priority. So to configure the output.

We consider the weighing in proportion to the output from the decision making process.

So:
State of the rinsing system
=100*(0.25*DT+0.2*HG+0.1*AG+0.15*IN+0.1*BM+0.2*FC)...... Equation 1

Thus a rating on the scale of 0-100 would be generated this can be used to determine the potential water savings that can be achieved with changes to the rinsing system. The alternates for the fuzzy model need to be inputted by the operator and fuzzy questions needs to be generated for this purpose.

Fuzzy Alternates

The alternates need to be presented in a user friendly and easily identifiable format for the operator. This implies determining the appropriate questions and options for the operator under each of the alternates.

Dripping

Dripping is understood to be the length of time where the items are placed above the process bath before being moved to the next bath. If the time of dripping is too short, the liquid will not drip off completely before the item is moved on to the next tank.

A score for dripping is, therefore determined by the length of time for which the items are dripping above the bath, before being send on to the next bath.

The scores in Table B1.1 below are acceptable for racked goods but for barrel goods a more individual assessment can be necessary.

Table B1.1: Scoring by dripping (Racks or jigs)

Initial Fuzzy association	Operator options
0.2	Jigs hangs for 0-4 seconds above tank before moving to next tank
0.4	Jigs hangs for 5-9 seconds above tank before moving to next tank
0.6	Jigs hangs for 10-14 seconds above tank before moving to next tank
0.8	Jigs hangs for 15-19 seconds above tank before moving to next tank
1	Jigs hangs for >20 seconds above tank before moving to next tank

Hanging

By hanging (suspension) we understand the physical way in, which the items are placed on the rack or jig. By tilting the items in order to avoid as many entrapments as possible, drag-out volume is minimised. For example, a cup-shaped item must always is racked upside-down; hollow tubes should be racked vertically with a slight slope.

The score for hanging therefore depends on the efficiency of the liquid to drip off the item, before the items are lead to the next process. For barrel items the score should always be 1.

Table B1.2: Scoring by hanging (Racks or jigs)

Initial Fuzzy association	Operator options
0.2	Pieces are hung so that there is no cup shaped sections entraining liquid. All flat sheets are hung with one corner facing down. Most liquid drains off in less than 3 seconds.
0.4	Pieces are hung so that there is some entrapment of liquid by cup shaped sections. All sheets are hung with one of the shortest end facing downwards. Most liquid drains off in less than 8 seconds.
0.6	Pieces are hung so that there is a large entrapment of liquid by cup shaped sections. All sheets are hung with one the shortest end facing downwards. Most liquid drains off in less than 12 seconds.
0.8	Pieces are hung so that cup shaped sections entraining liquid. All flat sheets are hung with the longer side facing down. Most liquid drains off once the jig is tilted and takes less than 15 seconds.
1	Pieces are hung so that cup shaped sections entraining liquid. All flat sheets are hung with the longer side facing down. Most liquid drains off in once the jig is tilted and takes greater than 15 seconds.

Agitation

By agitation we understand the physical motion of the liquid. If the liquid is not in motion or being agitated the replacement of the liquid film on the item surface will be very slow, and there is a risk to drag-out the chemicals before they have been exchanged from the surface layer. By heavy agitation and liquid motion the liquid film physically is replaced much faster. The agitation and liquid motion thus have high influence on the speed of the replacement of the liquid film.

Table B1.3: Scoring of Agitation (Liquid Motion)

Fuzzy association	Operator options
0.2	There is no agitation or liquid motion on any tanks.
0.4	There exists visible agitation or jig motion on some tanks. Either by air or jig motion.
0.6	There exists visible agitation or jig motion on all tanks. Either by air or jig motion.
0.8	There exists visible agitation and liquid motion on all process tanks. Either by air or jig motion.
1	There exists heavy agitation and liquid motion on all process tanks. Either by air or jig motion.

Inlet/Outlet

By inlet/outlet we understand the way in which the rinse water is physically let in and out of each rinse tank. The inlet/outlet has major influence on the physical passage of water in the rinse tank and on the utilisation as well. If the inlet and outlet physically are placed side by side there can be high water consumption but a very low rinsing efficiency.

Table B1.4: Scoring of Inlet/Outlet

Initial Fuzzy association	Operator options
0.2	Rinse tank inlet is located at the top of the tank and the outlet is located next to it on the top of the tank.
0.4	Rinse tank inlet is located at the top of the tank and the outlet is located on the top of the tank, on the opposite end.
0.6	Rinse tank inlet is located at the top of the tank and the outlet is located on the bottom of the tank, on the opposite end.
0.8	Rinse tank inlet is located at the bottom of the tank and the outlet is located at the top of the tank on the opposite end. Tank is not agitated.
1	Rinse tank inlet is located at the bottom of the tank and the outlet is located at the top of the tank on the opposite end. Tank is agitated.

Back-Mixing

When two or more rinsing tanks are connected (e.g. counter current rinse), it is important that the water will run from the tank with clean water to the tank with more dirty water. This is normally controlled by a simple gravity flow where there is a difference in water height. Under normal conditions the flow direction is correct, but if a big rack or even worse a big barrel is submersed in the dirty water, the water level in the dirty tank may increase above the water level of the clean water tank. In this case the water will flow in the wrong direction, and the clean water tank will get polluted with dirty water. In this case there is a very low efficiency of the rinsing process compared to normal conditions for this kind of rinse systems. The wrong construction should be repaired to improve rinsing quality and reduce water consumption.

Table B1.5: Scoring of Back-mixing

Initial Fuzzy association	Operator options
0.2	Rinse tanks are linked across the bottom and /or top allowing continuous flow of water.
0.4	Small pipes link rinse tanks resulting in continuous back mixing. Spills between rinse tanks are high during jig submersion.
0.6	Rinse tanks are linked across the bottom and /or top allowing moderate flow of water during jig submersion or Rinse tank overflows very small amounts of water to the next rinse tank during jig submersion.
0.8	Rinse tanks are linked across the bottom and /or top allowing very little flow of water during jig submersion or Rinse tank overflows some water to the next rinse tank during jig submersion.
1	No back mixing. Tanks are not linked.

Flow-control

Controlling the inlet flow of water to a rinse tank is maybe the most important factor influencing the water consumption. To control the flow you need a valve for adjustment and a flow meter to monitor the flow - but you also need to know how much water is needed. The demand of water is determined by the defined water quality (F = dilution factor) and the drag-out from the previous process tank.

The typical situation is a water-valve totally open, and nobody has considered if less water would be sufficient. Some companies implement some kind of water restrictors and this is highly recommended, but it is still very important that the restrictors are allowed to control the water flow. Too often we see the operation staff increasing the water flow by further opening the water-valve because they found the rinse water too dirty. This is an important part of the management task to set up correct instructions and ensure that these instructions are followed.

A high score assume, that you control rinse water quality and rinse water flow.

Table B1.6: Scoring of Flow-control

Initial Fuzzy association	Operator options
0.2	Rinse water supplied by non-restricted pipe. Each rinse tank has a separate inlet.
0.4	Rinse water supplied by valve on the end of a pipe with some control.
0.6	Static tanks, dumped regularly or moderate flow control with no rinse recovery system. No redirecting of rinse water occurs.
0.8	Static tanks, dumped regularly or moderate flow control with no rinse recovery system. Redirecting of rinse water occurs.
1	Flow control to rinse tank via predetermined rinse water requirements. Flow is continuously controlled and stops when no tank operations occur. All water is recovered via low flow rinse back into plating tank.

The overall shape and functioning of the each actual rinsing process of the line is scored as a weighted average, as the 6 parameters do no have equal impact. The score of the actual rinsing system will uncover if you can save rinse water by improving the existing system. The assessment is exclusively based on the functioning of the existing rinsing system.

Rinse tables

The application of regression can now be systematically applied to the Rinse tables

The fuzzy allocations under each sub category in the rinse tables B1.1-B1.6) can be summarized in a single table.

Table B1.7

General segregation	Drip times	Hanging	Aggitation	Inlet	Back mix	Flow control
Low	0.2	0.2	0.2	0.2	0.2	0.2
	0.4	0.4	0.4	0.4	0.4	0.4
[redacted]						

These values are then used as inputs into the fuzzy model. Example if the operator selects a low rating under Drip times, lets say 0.2, then the drip times (DT) value in equation 1 is multiplied by this value. This would be done for each of the categories in the rinse section. Table B1.7 contains a set of input values for the five different categories in the rinse section.

Table B1.8

Drip times	Hanging	Aggitation	Inlet	Back mix	Flow control	New Model	Summ of sqares
0.2	0.2	0.4	0.4	0.2	0.2	25.0	336.1
0.8	0.4	0.6	0.4	0.4	0.4	52.0	106.8
0.6	0.8	0.6	0.8	0.6	0.8	71.0	36.0
1	0.8	1	1	1	1	96.0	0.4
							479.3

As can be seen from table B1.8 above the fuzzy model needs to be streamlined so as to generate equivalent results as the |Flemming model. The fuzzy allocation values, Table B1.8, can be assumed to be raw estimate values. These values are partially crude and are aimed at being initial estimated of the potential fuzzy allocation. These values enjoy a low confidence level due to the nature in which they are obtained i.e. they are purely subjective. It would be ideal to regress these values so as to try and replicate vales from the database.

Using the excel solver and defining the sum of squares as the main objective to minimize the estimates of the fuzzy allocations can be streamlined. The limits for each of the ranges has to be defining i.e. the regression have to be conducted within the limits of low, medium and high as defined in table B1.8. Table B1.9 contains the limits for each category.

Table B1.9

Fuzzy allocation estimate	Regression range
0.2	0.1-0.3
0.4	0.3-0.5
0.6	0.5-0.7
0.8	0.7-0.9
1	0.8-1

The solver is then run with the above ranges and the output would minimize the difference between the database results and the fuzzy outputs.

The regression results are in table B1.10.

Table B1.10: Regression results

Regressed segregation	Drip times	Hanging	Aggitation	Inlet	Back mix	Flow control
Low	0.05	0.05	0.18	0.20	0.05	0.05
	0.30	0.30	0.30	0.30	0.30	0.30
[redacted]						

From table B1.11 it can be seen that the regression has resulted in some changes to the fuzzy allocations. These values are all within the initial estimated range. It can also be seen that if the database values are used that the sum of square differences is considerable reduced.

Table B1.11

Drip times	Hanging	Aggitation	Inlet	Back mix	Flow control	New values	Database	Sum of squares
0.05	0.05	0.30	0.30	0.05	0.05	11.25	6.67	21.01
0.70	0.30	0.50	0.30	0.30	0.30	42.00	41.67	0.11
0.51	0.83	0.50	0.70	0.56	0.72	65.00	65.00	0.00
1.00	0.83	1.00	1.00	1.00	1.00	96.67	96.67	0.00

It can be seen that the regressed values have a very small difference as compared to the database outputs. Hence the regressed fuzzy outputs are used as fuzzy allocation in the tables B1.1-B1.6.

The regressed values for the fuzzy association are now inputted into the fuzzy operator input tables and these values are used in the visual basic program. The tables are listed together with the fuzzy inputs

Table B1.1: Scoring by dripping (Racks or jigs)

	Initial Fuzzy association	Operator options
0.05	0.2	Jigs hangs for 0-4 seconds above tank before moving to next tank
0.3	0.4	Jigs hangs for 5-9 seconds above tank before moving to next tank
0.51	0.6	Jigs hangs for 10-14 seconds above tank before moving to next tank
0.7	0.8	Jigs hangs for 15-19 seconds above tank before moving to next tank
1	1	Jigs hangs for >20 seconds above tank before moving to next tank

Table B1.2: Scoring by hanging (Racks or jigs)

	Initial Fuzzy association	Operator options
0.05	0.2	Pieces are hung so that there is no cup shaped sections entraining liquid. All flat sheets are hung with one corner facing down. Most liquid drains off in less than 3 seconds.
0.3	0.4	Pieces are hung so that there is some entrapment of liquid by cup shaped sections. All sheets are hung with one of the shortest end facing downwards. Most liquid drains off in less than 8 seconds.
0.5	0.6	Pieces are hung so that there is a large entrapment of liquid by cup shaped sections. All sheets are hung

		with one the shortest end facing downwards. Most liquid drains off in less than 12 seconds.
0.83	0.8	Pieces are hung so that cup shaped sections entraining liquid. All flat sheets are hung with the longer side facing down. Most liquid drains off once the jig is tilted and takes less than 15 seconds.
1	1	Pieces are hung so that cup shaped sections entraining liquid. All flat sheets are hung with the longer side facing down. Most liquid drains off in once the jig is tilted and takes greater than 15 seconds.

Table B1.3: Scoring of Agitation (Liquid Motion)

	Fuzzy association	Operator options
0.18	0.2	There is no agitation or liquid motion on any tanks.
0.3	0.4	There exists visible agitation or jig motion on some tanks. Either by air or jig motion.
0.5	0.6	There exists visible agitation or jig motion on all tanks. Either by air or jig motion.
0.81	0.8	There exists visible agitation and liquid motion on all process tanks. Either by air or jig motion.
1	1	There exists heavy agitation and liquid motion on all process tanks. Either by air or jig motion.

Table B1.4: Scoring of Inlet/Outlet

	Initial Fuzzy association	Operator options
0.2	0.2	Rinse tank inlet is located at the top of the tank and the outlet is located next to it on the top of the tank.
0.3	0.4	Rinse tank inlet is located at the top of the tank and the outlet is located on the top of the tank, on the opposite end.
0.6	0.6	Rinse tank inlet is located at the top of the tank and the outlet is located on the bottom of the tank, on the opposite end.
0.7	0.8	Rinse tank inlet is located at the bottom of the tank and the outlet is located at the top of the tank on the opposite end. Tank is not agitated.
1	1	Rinse tank inlet is located at the bottom of the tank and the outlet is located at the top of the tank on the opposite end. Tank is agitated.

Table B1.5: Scoring of Back-mixing

	Initial Fuzzy association	Operator options
0.05	0.2	Rinse tanks are linked across the bottom and /or top allowing continuous flow of water.
0.3	0.4	Small pipes link rinse tanks resulting in continuous back mixing. Spills between rinse tanks are high during jig submersion.

0.56	0.6	Rinse tanks are linked across the bottom and /or top allowing moderate flow of water during jig submersion or Rinse tank overflows very small amounts of water to the next rinse tank during jig submersion.
0.8	0.8	Rinse tanks are linked across the bottom and /or top allowing very little flow of water during jig submersion or Rinse tank overflows some water to the next rinse tank during jig submersion.
1	1	No back mixing. Tanks are not linked.

Table B1.6: Scoring of Flow-control

	Initial Fuzzy association	Operator options
0.05	0.2	Rinse water supplied by non-restricted pipe. Each rinse tank has a separate inlet.
0.3	0.4	Rinse water supplied by valve on the end of a pipe with some control.
0.6	0.6	Static tanks, dumped regularly or moderate flow control with no rinse recovery system. No redirecting of rinse water occurs.
0.72	0.8	Static tanks, dumped regularly or moderate flow control with no rinse recovery system. Redirecting of rinse water occurs.
1	1	Flow control to rinse tank via predetermined rinse water requirements. Flow is continuously controlled and stops when no tank operations

		occur. All water is recovered via low flow rinse back into plating tank.

Dripping is understood to be the length of time where the items are placed above the process bath before being moved to the next bath. If the time of dripping is too short, the liquid will not drip off completely before the item is moved on to the next tank.

A score for dripping is, therefore determined by the length of time for which the items are dripping above the bath, before being send on to the next bath.

Plant wide Application of Multi-objective decision-making

The inputs from Table 1-6 are then used in equation 1. The output is a rating of the rinse system of the company under review. The output is on a scale of 0-100. Where 0 would indicate no scope for improvement whilst 100 would indicate a very poorly operated plant.

The above methodology can then be applied to the rest of the plant under the categories:

Appendix B1.2: The Sludge Tables

The procedure the rinse table was followed for the sludge tables.

The regression analysis of the tables is critical for the credibility of the models. The approach taken is that the tables would be looked at individually so as to minimize the differences between the two models.

The sludge tables

The fuzzy allocations under each sub category for the sludge system can be summarized in table B2.6.

Table B2.6

General segregation	Reduction of dragin/dragout	Optimum bath chemistry	Concentration of waste	Improved maint of process bath	Recovery from waste
Low	0.2	0.2	0.2	0.2	0.2
	0.4	0.4	0.4	0.4	0.4
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

These values are then used as inputs into the fuzzy model. Example if the operator selects a low rating under Dragin/Dragout of chemicals, lets say 0.2, then the dragin (DR) value in equation 2 is multiplied by this value. This would be done for each of the categories in the sludge section. Table B2.6 contains a set of input values for the five different categories in the sludge section.

Table B2.7

Reduction of dragin/dragout	Optimum bath chemistry	Concentration of waste	Improved maint of process bath	Recovery from waste	Database Output	Fuzzy model output	Sum of squares
0.75	0.6	0.6	0.4	0.2	40	56.25	264.0625
0.75	0.4	0.6	0.4	0.4	40	55.25	232.5625
0.5	0.4	0.6	0.8	0.2	35	49.5	210.25
1	0.8	1	1	1	95	96	1
						Sum	707.875

As can be seen from Table B2.7 above the fuzzy model needs to be streamlined so as to generate equivalent results as the |Flemming model. The fuzzy allocation values, Table B2.7, can be assumed to be raw estimate values. These values are partially crude and are aimed at being initial estimated of the potential fuzzy allocation. These values enjoy a low confidence level due to the nature in which they are obtained i.e. they are purely subjective. It would be ideal to regress these values so as to try and replicate vales from the database.

Using the excel solver and defining the sum of squares as the main objective to minimize the estimates of the fuzzy allocations can be streamlined. The limits for each of the ranges has to be define i.e. the regression has to be conducted within the limits of low, medium and high. Table B2.8 contains the limits for each category.

Table B2.8: Regression range

Fuzzy allocation estimate	Regression range
0.2	0.1-0.3
0.4	0.3-0.5
0.6	0.5-0.7
0.8	0.7-0.9
1	0.8-1

The solver is then run with the above ranges and the output would minimize the difference between the database results and the fuzzy outputs.

The regression results are in Table B2.9.

Table B2.9: Regression results

Reduction of dragin/dragout	Optimum bath chemistry	Concentration of waste	Improved maint of process bath	Recovery from waste
0.05	0.20	0.20	0.20	0.10
0.10	0.30	0.41	0.30	0.30
0.08	0.50	0.50	0.60	0.60
0.45	0.77	0.81	0.70	0.80
0.15	1.00	1.00	1.00	1.00
0.15				
0.05				
0.1				
0.15				

From Table B2.10 it can be seen that the regression has resulted in some changes to the fuzzy allocations. These values are all within the initial estimated range. It can also be seen that if the database values are used that the sum of square differences is considerable reduced.

Table B2.10

Reduction of dragin/dragout	Optimum bath chemistry	Concentration of waste	Improved maint of process bath	Recovery from waste	Fuzzy model output	Database Output	Sum of squares
0.15	0.70	0.50	0.30	0.20	34.25	40.00	33.06
0.70	0.30	0.50	0.30	0.30	47.00	40.00	49.00
0.30	0.30	0.50	0.70	0.20	37.50	35.00	6.25
1.00	0.78	0.99	0.98	0.99	95.00	95.00	0.00
							88.31

It can be seen that the regressed values have a very small difference as compared to the database outputs. Hence the regressed fuzzy outputs are used as fuzzy allocation in the tables B2.1- B2.5.

Table B2.1: Scoring of sludge with regards optimum dragin/dragout

	Initial Fuzzy association	Operator options
0.05	0.05	All plating tanks consist of single rinses with outlet to waste water treatment plant.
0.1	0.1	All plating tanks consist of two rinses with outlet to waste water treatment plant.
0.08	0.15	All plating tanks consist of two rinses with outlet to waste water treatment plant.
0.45	0.4	All plating tanks are closed circuit i.e. there is a

		minimum of three rinses. All top up liquid is redirected to the plating tank. De-ionised water is used as top up on last rinse tank.
0.15	0.2	Removing contaminants regenerates the acid tank. Acid tank lifespan is a minimum of one year
0.15	0.15	Removing contaminants regenerates the degreaser tank. Degreaser tank lifespan is a minimum of one year
0.05	0.05	Passivates have a single rinse
0.1	0.1	Passivate has a double rinse
0.15	0.15	De-ionised water is used on all rinses

Table B2.2: Bath chemistry

	Initial Fuzzy association	Operator options
1	1	Bath analysis and testing conducted online or twice/day. Continuous chemical dosing to plating tank
0.77	0.8	Bath analysis and testing conducted once in two days. Chemical dosing to plating tank done accordingly.
0.5	0.6	Bath analysis and testing conducted once per week. Chemical dosing to plating tank done accordingly.
0.3	0.4	Bath analysis and testing conducted once in two weeks. Chemical dosing to plating tank done

		accordingly.
0.2	0.2	Bath analysis and testing conducted once in per month. Chemical dosing to plating tank done accordingly.

Table B2.3: Waste concentration

	Initial Fuzzy association	Operator options
1	1	Filter press is used after sludge settling together with bed/solar drying.
0.81	0.8	Filter press is used after sludge settling or bed/solar dewatering.
0.5	0.6	Wastewater is pH adjusted, flocculated and settled before sludge removal.
0.41	0.4	Sludge is allowed to settle in settling tanks and is disposed of.
0.2	0.2	No systems exist to concentrate waste

Table B2.4: Maintenance of process baths

	Initial Fuzzy association	Operator options
1	1	Online filters continuously clean process baths.
0.7	0.8	Tanks are desludgeded once/ week. Process baths are purified every two days.
0.6	0.6	Tanks are desludgeded once/ month. Process baths are purified once in two days.

0.3	0.4	Tanks are desludgeded once/ year. Process baths are purified once per week.
0.2	0.2	No systems exist to purify process baths

Table B2.5: Internal waste recovery

	Initial Fuzzy association	Operator options
1	1	Process bath metal losses are recovered by onsite metal recovery systems and recycled into process.
0.8	0.8	Process bath recovery is done offsite and returned to site for reuse.
0.6	0.6	Process bath metal losses are recovered by metal recovery systems and not reused.
0.3	0.4	Process bath recovery is done of site and not returned to site
0.1	0.2	Process bath waste is disposed to outside contractor as a raw material.
0	0	No systems exist to recover waste process baths

The regression analysis of the tables is critical for the credibility of the models. The approach taken is that the tables would be looked at individually so as to minimize the differences between the two models.

The limits of low, medium and high as defined in table B2.11. Table B2.8 contains the limits for each category.

Table B2.11: Limits

Fuzzy allocation estimate	Regression range
0	0
0.2	0.1-0.3
0.4	0.3-0.5
0.6	0.5-0.7
0.8	0.7-0.9
1	0.8-1

The solver is then run with the above ranges and the output would minimize the difference between the database results and the fuzzy outputs.

The regression results are in table B2.12.

Table B2.12: Regression results

Regressed segregation	Reduction of dragin/dragout	Optimum bath chemistry	Concentration of waste	Improved maint of process bath	Recovery from waste
Low	0.15	0.20	0.20	0.20	0.20
	0.30	0.30	0.41	0.30	0.30
[redacted]					

From table B2.12 it can be seen that the regression has resulted in some changes to the fuzzy allocations. These values are all within the initial estimated range. It can also be seen that if the database values are used that the sum of square differences is considerable reduced Table B2.13

Table B2.13

Reduction of dragin/dragout	Optimum bath chemistry	Concentration of waste	Improved maint of process bath	Recovery from waste	Fuzzy model output	Database Output	Sum of squares
0.15	0.70	0.50	0.30	0.20	34.25	40.00	33.06
0.70	0.30	0.50	0.30	0.30	47.00	40.00	49.00
0.30	0.30	0.50	0.70	0.20	37.50	35.00	6.25
1.00	0.78	0.99	0.98	0.99	95.00	95.00	0.00
							88.31

It can be seen that the regressed values have a very small difference as compared to the database outputs. Hence the regressed fuzzy outputs are used as fuzzy allocation in the tables B2.1- B2.5.

Appendix B1.3: Wastewater treatment plant chemicals

The procedure the rinse table was followed for the waste water treatment plant chemicals tables. The application of regression can now be systematically applied to the wastewater treatment plant chemicals tables

The fuzzy allocations under each sub category in the rinse tables can be summarized in a single table.

Table B3.6

Using Less excess of chem	Using spent process baths instead	optimizing treatment of spent process baths	Better seperation of waste streams	Automatic dosing and control
0.05	0.05	0.2	0.05	0.05
0.05	0.25	0.4	0.25	0.2
0.25	0.3	0.6	0.25	0.35
0.05	0.3	0.8	0.2	0.2
0.05	0.15	1	0.15	0.3
0.25			0.15	0.2
0.05				0.3
0.25				
0.25				

Note the allocation of values do not increase from 0.2 to 1 but rather the summation of maximum allocations sum up to one.

These values are then used as inputs into the fuzzy model. Example if the operator selects a low rating under less excess of chemicals, lets say 0.05, then the less excess (LE) value in equation 3 is multiplied by this value. This would be done for each of the categories in the wastewater treatment plant section. Table B3.7 contains a set of input values for the five different categories in the wastewater treatment plant section.

Table B3.7

Using less excess of chem	Using spent process baths instead	Optimizing treatment of spent process baths	Better seperation of waste streams	Automatic dosing and control	Fuzzy Output	Database output	Sum of squares
0.40	0.40	0.40	0.40	0.40	40.00	25.00	225.00
0.60	0.60	0.60	0.60	0.60	60.00	50.00	100.00
0.80	0.80	0.80	0.80	0.80	80.00	75.00	25.00
1.00	1.00	1.00	1.00	1.00	100.00	100.00	0.00
							350.00

Using the excel solver and defining the sum of squares as the main objective to minimize the estimates of the fuzzy allocations can be streamlined. The limits for each of the ranges has to be define i.e. the regression has to be conducted within the limits of low, medium and high. Table B3.8 contains the limits for each category.

TableB3.8: Regression range

Fuzzy allocation estimate	Regression range
0.05	0.02-0.08
0.15	0.05-0.25
0.2	0.1-0.3
0.25	0.15-0.35
0.3	0.2-0.4

0.35	0.25-0.45
0.4	0.3-0.5
0.6	0.5-0.7
0.8	0.7-0.9
1	0.8-1

The solver is then run with the above ranges and the output would minimize the difference between the datbase results and the fuzzy outputs.

The regression results are in table B3.9.

Table B3.9: Regression results

Using Less excess of chemicals	Using spent process baths instead of fresh chemicals	optimizing treatment of spent process baths	Better seperation of waste streams	Automatic dosing and control
0.05	0.05	0.18	0.04	0.05
0.05	0.23	0.48	0.23	0.2
0.24	0.32	0.62	0.27	0.38
0.04	0.25	0.78	0.22	0.2
0.05	0.18	0.99	0.14	0.31
0.26			0.18	0.2
0.05				0.32
0.23				
0.22				

From table B3.9 it can be seen that the regression has resulted in some changes to the fuzzy allocations. These values are all within the initial estimated range. It can also be seen that if the database values are used that the sum of square differences is considerable reduced.

Table B3.10

Using Less excess of chemicals	Using spent process baths Instead of fresh chemicals	optimizing treatment of spent process baths	Better separation of waste streams	Automatic dosing and control	Fuzzy Output	Database output	Sum of squares
0.24	0.23	0.48	0.22	0.2	26.30	25.00	1.69
0.50	0.55	0.62	0.22	0.38	46.20	50.00	14.44
0.73	0.80	0.78	1	0.69	78.40	75.00	11.56
1.00	0.98	0.99	1	1	99.45	100.00	0.30
							27.99

It can be seen that the regressed values have a very small difference as compared to the database outputs. Hence the regressed fuzzy outputs are used as fuzzy allocation in the tables B3.1-B3.5.

The regressed values for the fuzzy association are now inputted into the fuzzy operator input tables and these values are used in the visual basic program. The tables are listed together with the fuzzy inputs

Table B3.1: Less excess of chemicals

	Initial Fuzzy association	Operator options
0.05	0.05	Plant operator does wastewater treatment when time is available. An excess of chemicals is used to ensure proper treatment of pH, chrome and/or cyanide.
0.05	0.05	Flocculants is added in excess to ensure treatment
0.24	0.25	Flocculants is only added as per predetermined requirement. Dosing is done after analysis of wastewater.
0.04	0.05	Chrome and cyanide is treated without measurement of chrome and cyanide concentration
0.05	0.05	Chrome is treated with more than 5mg/l of metabisulphite when the chrome containing waste water is at a pH of less than 3.5
0.26	0.25	Chrome is treated with 5mg/l of metabisulphite when the chrome containing waste water is at a pH of 3.5

0.05	0.05	Cyanide is treated with more than 5mg/l of hypocloride when the cyanide containing waste water is at a pH of greater than 11.
0.23	0.25	Cyanide is treated with 5mg/l of hypocloride when the cyanide containing waste water is at a pH of 11.
0.22	0.25	PH, Metals concentration and cyanide concentration is continuously monitored before dosing.

Table B3.2: Reuse of spent process baths

	Initial Fuzzy association	Operator options
0.05	0.05	Spent acid and degreaser is not stored for waste water treatment
0.23	0.25	Spent acid is stored for use for pH regulation
0.32	0.3	Spent degreaser is stored for use for pH regulation
0.25	0.3	Chrome and cyanide is stored and treated when spent acid ore degreaser is available for pH adjustment.
0.18	0.15	Spent acid is used as a flocculants

Table B3.3: Treatment of waste baths

	Initial Fuzzy association	Operator options
0.18	0.2	All wastewater is released to WWTP without any storage and optimum neutralization

0.48	0.4	Acids and alkali is dumped together
0.62	0.6	Streams containing acids and alkali are stored and treated separately.
0.78	0.8	Streams containing acids and alkali are stored and treated separately. All other treatment of chemicals is conducted in a co-ordinated fashion
1	1	The treatment of waste streams is carried out using stored spent chemicals. Storage facilities exist for acids/alkali/oily/cyanide rich and all metal waste separately.

Table B3.4: Separation of waste streams

	Initial Fuzzy association	Operator options
0.04	0.05	All waste streams are mixed and treated together
0.23	0.25	Cyanide is stored and treated separately
0.27	0.25	Chrome is stored and treated separately
0.22	0.2	Streams containing acids and alkali are stored and treated separately
0.14	0.15	Streams containing metals are separated
0.18	0.15	Streams containing complexing agents are stored and treated separately

Table B3.5: Dosing and control

	Initial Fuzzy association	Operator options
0.05	0.05	All treatment processes are done manually

0.2	0.2	pH regulation is done using continuous measurement, Dosing is done manually
0.38	0.35	pH regulation is done using continuous measurement, Dosing is done automatically
0.2	0.2	Chrome/Cyanide monitoring is done using continuous measurement, Dosing is done manually
0.31	0.35	Chrome/Cyanide monitoring is done using continuous measurement, Dosing is done automatically
0.2	0.2	Metals monitoring is done using continuous measurement, Dosing is done manually
0.32	0.3	Metals monitoring is done using continuous measurement, Dosing is done automatically

Appendix B1.4: Wastewater treatment plant equipment

The procedure the rinse table was followed for the wastewater treatment plant equipment tables. The application of regression can now be systematically applied to the Wastewater treatment plant equipment

The fuzzy allocations under each sub category in the rinse tables can be summarized in a single table.

Table B4.6

Neutralization equipment	Chrome monitoring equipment	Cyanide monitoring equipment	Metals monitoring equipment	Cod monitoring equipment
0.2	0.2	0.2	0.2	0.2
0.4	0.4	0.4	0.4	0.4
0.6	0.6	0.6	0.6	0.6
0.8	0.8	0.8	0.8	0.8
1	1	1	1	1

These values are then used as inputs into the fuzzy model. Example if the operator selects a low rating under neutralization equipment, lets say 0.2, then the drip times (NE) value in equation 4 is multiplied by this value. This would be done for each of the categories in the wastewater treatment plant section. Table B4.7 contains a set of input values for the five different categories in the wastewater treatment plant section.

Table B4.7

Neutralization equipment	Chrome monitoring equipment	Cyanide monitoring equipment	Metals monitoring equipment	Cod monitoring equipment	Fuzzy logic	Database values	Sum difference
0.4	0.4	0.2	0.4	0.4	35	25	100
0.6	0.6	0.6	0.6	0.6	60	50	100
0.8	0.8	0.8	0.8	0.8	80	75	25
1	1	1	1	1	100	100	0
							225

As can be seen from table ss above the fuzzy model needs to be streamlined so as to generate equivalent results as the |Flemming model. The fuzzy allocation values, Table B4.7, can be assumed to be raw estimate values. These values are partially crude and are aimed at being initial estimated of the potential fuzzy allocation. These values enjoy a low confidence level due to the nature in which they are obtained i.e. they are purely subjective. It would be ideal to regress these values so as to try and replicate vales from the database.

Using the excel solver and defining the sum of squares as the main objective to minimize the estimates of the fuzzy allocations can be streamlined. The limits for each of the ranges has to be define i.e. the regression has to be conducted within the limits of low, medium and high. Table B4.8 contains the limits for each category.

TableB4.8: Regression range

Fuzzy allocation estimate	Regression range
0.2	0.1-0.3
0.4	0.3-0.5
0.6	0.5-0.7
0.8	0.7-0.9
1	0.8-1

The solver is then run with the above ranges and the output would minimize the difference between the database results and the fuzzy outputs.

The regression results are in table B4.9.

Table B4.9: Regression results

Neutralization equipment	Chrome monitoring equipment	Cyanide monitoring equipment	Metals monitoring equipment	Cod monitoring equipment
0.20	0.20	0.10	0.20	0.20
0.29	0.30	0.40	0.38	0.29
0.53	0.48	0.48	0.50	0.53
0.76	0.74	0.74	0.75	0.76
1.00	1.00	1.00	1.00	1.00

From table B4.9 it can be seen that the regression has resulted in some changes to the fuzzy allocations. These values are all within the initial estimated range. It can also be seen that if the database values are used that the sum of square differences is considerable reduced.

Table B4.10

Neutralization equipment	Chrome monitoring equipment	Cyanide monitoring equipment	Metals monitoring equipment	Cod monitoring equipment	Fuzzy logic	Database values	Sum difference
0.29	0.30	0.10	0.38	0.29	26.25	25.00	1.56
0.53	0.48	0.48	0.50	0.53	50.00	50.00	0.00
0.76	0.74	0.74	0.75	0.76	75.00	75.00	0.00
1.00	1.00	1.00	1.00	1.00	100.00	100.00	0.00
							1.56

It can be seen that the regressed values have a very small difference as compared to the database outputs. Hence the regressed fuzzy outputs are used as fuzzy allocation in the tables B4.1-B4.5.

The regressed values for the fuzzy association are now inputted into the fuzzy operator input tables and these values are used in the visual basic program. The tables are listed together with the fuzzy inputs

Table B4.1: pH control

	Initial Fuzzy association	Operator options
0.2	0.2	The pH probe is never calibrated.
0.33	0.4	The pH probe is calibrated once or twice / year
0.53	0.6	The pH probe is calibrated once / month
0.76	0.8	The pH probe is calibrated once every second week
1	1	The pH probe is calibrated once / week

Table B4.2 :Chrome monitoring equipment

	Initial Fuzzy association	Operator options
0.2	0.2	The equipment is never calibrated.

0.3	0.4	The equipment is calibrated once or twice / year
0.48	0.6	The equipment is calibrated once / month
0.74	0.8	The equipment is calibrated once every second week
1	1	The equipment is calibrated once / week

Table B4.3: cyanide measurement

	Initial Fuzzy association	Operator options
0.1	0.2	The equipment is never calibrated.
0.4	0.4	The equipment is calibrated once or twice / year
0.48	0.6	The equipment is calibrated once / month
0.74	0.8	The equipment is calibrated once every second week
1	1	The equipment is calibrated once / week

Table B4.4: metal monitoring

	Initial Fuzzy association	Operator options
0.2	0.2	The equipment is never calibrated.
0.43	0.4	The equipment is calibrated once or twice / year
0.	0.6	The equipment is calibrated once / month
0.75	0.8	The equipment is calibrated once every second week
1	1	The equipment is calibrated once / week

TableB4.5: Chemical oxygen demand

	Initial Fuzzy association	Operator options
0.2	0.2	The equipment is never calibrated.
0.33	0.4	The equipment is calibrated once or twice / year
0.53	0.6	The equipment is calibrated once / month
0.76	0.8	The equipment is calibrated once every second week
1	1	The equipment is calibrated once / week

Appendix B1.5: Chemical-consumption and monitoring

It is a well-known fact that the main source of heavy metals in wastewater is as a result of dumping of plating tanks. Similarly the acid tank, if dumped, is known to have a high impact on the pH as well as the metals content at the wastewater treatment facility. The dumping of the degreaser would result on a high COD load to the wastewater treatment facility. The organics and other complexing agents would cause havoc with the effective treatment of chemicals.

The best way to prevent the unnecessary losses of these chemicals would be the optimum management of these tanks i.e. ensure their life is extended so as to minimize dumping. Hence, the plating tank, degreasing and acid cleaning tank require continuous monitoring and control to ensure optimum operation and contamination is reduced.

Control and measurement

The control and measurement of chemical concentration and contamination levels in a process tank is critical to effective plating and bath lifetime management.

Weekly chemical supplier analysis is typical but results are only available a week later, which implies a turn around time of two weeks before a bath composition is corrected. This has been the norm in most small to medium size facilities. This is cost effective in the short term but the long-term objectives needs to be determined. The ideal would be continuous monitoring and modifications. This is the ideal and may result in significant costs. The company has to evaluate the playoff between overall consumptions and long-term maintenance to the cost implications.

Table B5.1: Scoring of control and measurement

Initial Fuzzy association	Operator options
0	All process tanks are monitored by the chemical supplier once per month. Results are available within a week or two of analysis. Bath corrections are done based on these results.
0.2	All process tanks are monitored by the chemical supplier once per week. Results are available within a week of analysis. Bath corrections are done based on these results.
0.4	All process tanks are monitored by the chemical supplier twice per week. Results are available within the week. Bath corrections are done based on these results.
0.6	All process tanks are monitored by the chemical supplier/ plant operator, twice per week. Results are available the next day. Bath corrections are done based on these results.
0.8	All process tanks are monitored by the chemical supplier/ plant operator, daily. Results are available the daily. Bath corrections are done based on these results.
1	All process tanks are monitored continuously by automatic

	measurement devices. Bath corrections are done automatically.

Purification

It is common at most plating facilities to purify the plating tanks with 10-micron filters combined with carbon filtration. This system, if properly maintained would result in optimum maintenance of plating tanks with regards contaminants. It is uncommon to filter or treat the degreaser and acid tanks. This practices could, if properly conducted, extend the life of these tanks. The maintenance of the filtration system is also essential to ensure the integrity of the filtration process.

Table B5.2: Bath chemistry

Initial Fuzzy association	Operator options
0	No systems exist for bath purification.
0.2	Purification system on plating tank is used when problems arise, usually once per month.
0.4	Purification system on plating tank is used as required, usually once per week.
0.6	Plating tank is continuously filtered. No Acid recovery /Degreaser oil removal filtration system.
0.8	Plating tank is continuously filtered. Degreaser oil removal filtration system is operational. Acid recovery system is currently used.
1	Plating tank is continuously filtered. Degreaser oil removal filtration system is operational. Acid recovery system is currently used. All systems are continuously maintained and monitored.

Chemical Dosing

The dosing of chemical is a key parameter in the control of electroplating. The optimum chemical concentration is essential in order to achieve optimum operation. E.g. A too high or too low acid concentration would result in inefficient surface cleaning or a greater than required metal dissolution. The optimum chemical concentration is even more critical on a plating tank. This is especially true since there is usually more than one chemical in each bath. It has been proven elsewhere in this these the critical impact the chemical concentration would have on plating optimisation.

Table B5.3: Chemical dosing

Initial Fuzzy association	Operator options
1	There exists an online measurement system and chemical dosing is done online and continuously.
0.8	Chemical dosing is done online and continuously based on predetermined chemical consumption calculations.
0.6	Chemical dosing is done weekly after sampling and measurement.
0.4	Chemical dosing is done monthly after sampling and measurement.
0.2	No systems exist to measure chemical concentrations. Chemicals are dosed randomly.

Bath chemistry

The chemistry of all process baths has to be maintained at its optimum levels. This can only be done if plant personnel are aware of these optimal operating compositions for the different baths e.g. the contamination of chrome in a nickel tank is critical to the throwing power of the electrolyte hence it is essential that the contamination of the nickel tank be monitored over time and contaminants removed if possible. The impact of these different chemicals has traditionally been assumed to be negligible but with modern modelling techniques it has been proven that optimum bath chemistry is essential to ensure optimum efficiency. An efficiency change of a few percent may seem small but with a large production of a few thousand square meters this could have a significant impact.

Table B5.4: Process bath chemicals

Initial Fuzzy association	Operator options
1	Process bath chemistry is known a designated technical person monitors the process baths continuously. Contaminants as well as top up consumptions are monitored.
0.8	Process bath chemistry is known a designated person monitors the process baths one/ month. Contaminants as well as top up consumptions are monitored. Contaminants as well as top up consumptions are monitored.
0.6	Detailed Process bath chemistry is known to the chemical supplier. A technical representative monitors the process baths occasionally (once/month). Contaminants as well as top up consumptions are monitored.
0.4	Basic Process bath chemistry is known to the chemical

	supplier. A technical representative monitors the process baths regularly (once/week).
0.2	Basic Process bath chemistry is known to the chemical supplier. A technical representative monitors the process baths occasionally (once/month). Only top up consumptions are monitored.
0	No knowledge on the process bath chemistry.

Operations

Operations covers the operating practice at a surface finishing facility. The operating practices that are covered include the actions by the operator with regards variables that effect the process tanks as well as the actions of management to ensure proper staff training so that the impact of operators is minimal on the process.

Operator work practices can compromise the integrity of the plating process. E.g. the operator ignores the normal jigging procedure resulting can contamination of a plating tank or the operator overfills the tank, which results in losses.

The operational practice of the operator is only as good as there training and hence the operational practice at a surface finishing facility is the direct responsibility of management. Management has to ensure systems are in place so as to ensure work is carried out properly.

The main reason for focusing on these inputs is that they have an impact on the quality of production and on the plating tanks. Poor operational practice can cause problems on a plating line whilst good operational practice can ensure minimum problems.

Table B5.5: Operational practice

Initial Fuzzy association	Operator options
1	Operator training is ongoing. Standard operating procedures are in place and updated. No poor operational practices are observed from operators.
0.8	Some formal operator training exists with operating procedures. Management ensures regular courses are presented.
0.6	Operators undergo a formal training program managed by management.
0.4	Operators undergo an informal training program managed by management. Most training is on a needs basis.
0.2	Operators undergo an informal training program managed by other operators.
0	No systems for operator training or improvements exists. Operators work and learn.

The proper management of the chemicals for electroplating would imply significant cost savings directly as chemical savings and indirectly as quality savings. The impact of chemicals is significant to the sustainability of the company as well as to the environment.

The chemical tables determine the wastage of chemicals. The variables that would be considered would be:

First the alternatives had to be defined. For rinsing the alternatives are:

A = {Measurement/control (MC), Bath purification (PR), Chemical dosing (CD), Chemistry (CH), Operations (OT)}

Then the main objectives in evaluating and controlling the rinses were determined:

O = {Chemical consumption, Environment/ Water consumption, production, Cost}

The ranking for each of the above objectives will be rated as preferences:

$$P = \{b_1, b_2, b_3, b_4\} \longrightarrow [0,1]$$

So inputting the relationship between each one of the alternatives and the objectives.

$$\underset{\leftarrow}{Q}_1 = \frac{0.25}{CM} + \frac{0.15}{PR} + \frac{0.25}{DO} + \frac{0.15}{CH} + \frac{0.25}{OT}$$

$$\underset{\leftarrow}{Q}_2 = \frac{0.2}{CM} + \frac{0.15}{PR} + \frac{0.15}{DO} + \frac{0.15}{CH} + \frac{0.25}{OT}$$

$$\underset{\leftarrow}{Q}_3 = \frac{0.25}{CM} + \frac{0.15}{PR} + \frac{0.2}{DO} + \frac{0.25}{CH} + \frac{0.25}{OT}$$

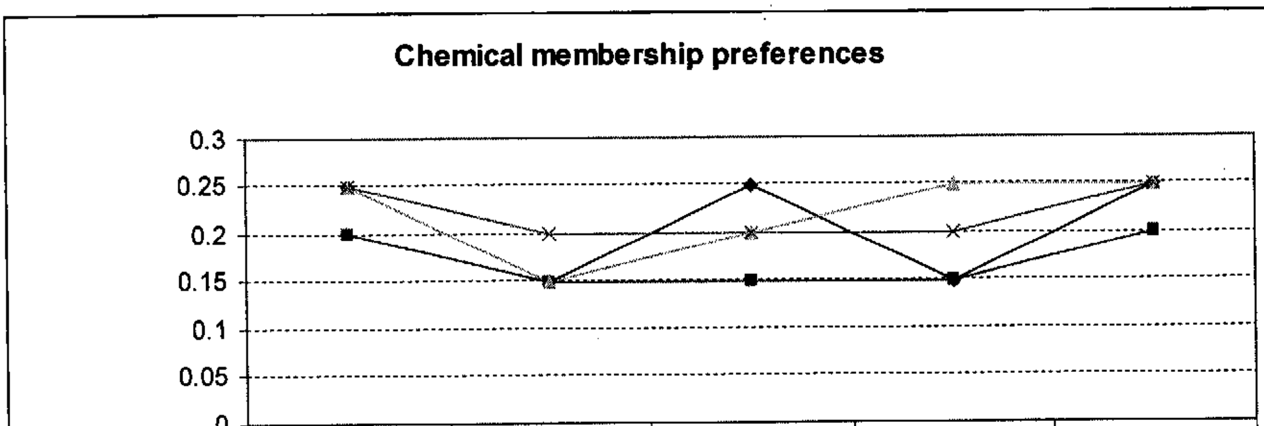
$$\underset{\leftarrow}{Q}_4 = \frac{0.25}{CM} + \frac{0.2}{PR} + \frac{0.2}{DO} + \frac{0.2}{CH} + \frac{0.25}{OT}$$

Now each of the preferences has to be rated on a scale of 0-1.

- b_1= 0.95 : Chemical consumption is a key objectives as losses implies greater cost and reductions in efficiencies
- b_2= 0.75 The main impact of heavy metal sludge is on the environment hence it is an important preference. It also requires more water for rinsing.
- b_3 = 0.9 Production is a function of efficiency. If the chemistry impacts on efficiency the indirectly production depends on the chemical composition.
- b_3= 0.75 Cost is always a key variable and enjoys a medium to high rating. Cost increase with efficiency losses.

A graph can be plotted of each membership with respect to the preferences.

Fig B5: Graph of membership and preferences



	control/measure	Purification	Dosing	Chemistry	operations
Chemical	0.25	0.15	0.25	0.15	0.25
Environment	0.2	0.15	0.15	0.15	0.2
production	0.25	0.15	0.2	0.25	0.25
cost	0.25	0.2	0.2	0.2	0.25

Association

$$D(a_1) = D(DR) = (\overline{b_1}VO_1)\Lambda(\overline{b_2}VO_2)\Lambda(\overline{b_3}VO_3)\Lambda(\overline{b_4}VO_4)$$

Now substituting into the above for each alternative:

$$D(a_1) = D(CM) = (0.05V0.25)\Lambda(0.25V0.2)\Lambda(0.1V0.25)\Lambda(0.25V0.25)$$

$$D(a_2) = D(PR) = (0.05V0.15)\Lambda(0.25V0.15)\Lambda(0.1V0.15)\Lambda(0.25V0.2)$$

$$D(a_3) = D(DO) = (0.05V0.25)\Lambda(0.25V0.15)\Lambda(0.1V0.2)\Lambda(0.25V0.2)$$

$$D(a_{14}) = D(CH) = (0.05V0.15)\Lambda(0.25V0.15)\Lambda(0.1V0.25)\Lambda(0.25V0.2)$$

$$D(a_5) = D(OT) = (0.05V0.25)\Lambda(0.25V0.2)\Lambda(0.1V0.25)\Lambda(0.25V0.25)$$

Solving:

$D(a_1)$= 0.25

$D(a_2)$= 0.15

$D(a_3)$= 0.2

$D(a_4)$= 0.15

$D(a_5)$= 0.25

With a maximum D $(a_{1,5})$= 0.25. These values can now be used to determine the chemical system environmental status. The final outcome indicates control and measurement/ operations to be the highest priority. So to configure the output.

We consider the weighing in proportion to the output from the decision making process.

So: Chemical consumption and monitoring

=100*(0.25*CM+0.15*PR+0.2*DO+0.15*CH+0.25*OT)……….Equation 5

Thus a rating on the scale of 0-100 would be generated this can be used to determine the potential sludge reduction that can be achieved with changes to the sludge system. The alternates for the fuzzy model need to be inputted by the operator and fuzzy questions needs to be generated for this purpose.

Appendix B1.6: Occupational health and safety

The application of regression can now be systematically applied to the occupational health and safety tables

The fuzzy allocations under each sub category in the OHS tables can be summarized in a single table B6.11.

Table B6.11

[redacted]		[redacted]	Lifts		[redacted]
	Effect of bath Temperature		Weight	Time of lifts	
	0.2		0.1667	0.1667	
	0.4		0.333	0.333	
	0.6		0.5	0.5	
	0.8				
	1				

Since these tables involve consolidating three inputs into one variable i.e. the effect of chemistry is determined by the summation of the impact of time, bath type and bath chemistry. This implies that the branches under each category have to be considered as the inputs and the regression done using these values. Hence the main inputs for the fuzzy model are:

Table B6.12: Inputs for fuzzy model

Effect of Chemistry	Effect of Temperature	Effect of noise	Effect of heavy lifts	General risk	Fuzzy Output	Database outputs	Sum Difference
0.33	0.40	0.33	0.33	0.33	34.92	17.30	310.46
0.55	0.60	0.33	0.33	0.67	52.07	40.00	145.73
0.66	0.80	0.67	0.67	0.67	69.80	62.00	60.84
0.99	1.00	1.00	1.00	1.00	99.75	100.00	0.06
							517.100084

These values are then used as inputs into the fuzzy model. Example if the operator selects a low rating under Effect of chemistry, lets say 0.33, then the Effect of chemistry (EC) value in equation 6 is multiplied by this value. This would be done for each of the categories in the wastewater treatment plant section. Table B6.12 contains a set of input values for the five different categories in the wastewater treatment plant section.

As can be seen from table ss above the fuzzy model needs to be streamlined so as to generate equivalent results as the |Flemming model. The fuzzy allocation values, Table B6.12, can be assumed to be raw estimate values. These values are partially crude and are aimed at being initial estimated of the potential fuzzy allocation. These values enjoy a low confidence level due to the nature in which they are obtained i.e. they are purely subjective. It would be ideal to regress these values so as to try and replicate vales from the database.

Using the excel solver and defining the sum of squares as the main objective to minimize the estimates of the fuzzy allocations can be streamlined. The limits for each of the ranges has to be defining i.e. the regression have to be conducted within the limits of low, medium and high as defined in table B6.12. Table B6.13 contains the limits for each category.

Table B6.13: Regression range

Fuzzy allocation estimate	Regression range
0.11	0.05-0.18
0.1677	0.07-0.27
0.2	0.1-0.3
0.22	0.12-0.32
0.3	0.2-0.4
0.33	0.23-0.43
0.4	0.3-0.5
0.5	0.4-0.6
0.6	0.5-0.7
0.8	0.7-0.9
1	0.8-1

The solver is then run with the above ranges and the output would minimize the difference between the database results and the fuzzy outputs.

The regression results are in table B6.14.

Table B6.14: Regression results

Effect of time	Effect of chemicals	Effect of bath type	Effect of bath Temperature	Exposure levels	Exposure time		Weight	Time if lifts	Chemicals	Machinery
0.05	0.11	0.11	0.20	0.10	0.10	0.00	0.10	0.17	0.10	0.10
0.20	0.14	0.20	0.30	0.32	0.32	0.00	0.32	0.33	0.26	0.27
0.33	0.33	0.33	0.54	0.50	0.50	0.00	0.50	0.50	0.50	0.50
			0.79							
			1.00							

From table B6.15 it can be seen that the regression has resulted in some changes to the fuzzy allocations. These values are all within the initial estimated range. It can also be seen that if the database values are used that the sum of square differences is considerable reduced.

Table B6.15

Effect of Chemistry	Effect of Temperature	Effect of noise	Effect of heavy lifts	General risk	Fuzzy Output	Database outputs	% error
0.25	0.30	0.20	0.20	0.20	23.75	17.30	41.60
0.39	0.54	0.20	0.20	0.53	40.00	40.00	0.00
0.54	0.79	0.64	0.58	0.53	62.00	62.00	0.00
1.00	1.00	1.00	1.00	1.00	100.09	100.00	0.01
							41.61

It can be seen that the regressed values have a very small difference as compared to the database outputs. Hence the regressed fuzzy outputs are used as fuzzy allocation in the tables B6.1- B6.5.

The regressed values for the fuzzy association is now inputted into the fuzzy operator input tables and these values are used in the visual basic program. The tables are listed together with the fuzzy inputs

Table B6.1: Exposure time

	Initial Fuzzy association	Operator options
0	0	Operators are not exposed to fumes from chemicals
0.05	0.1	Operators are exposed to fumes for less than 30 minutes per day
0.2	0.15	Operators are exposed to fumes for between 30

		minutes and two hours/day
0.33	0.33	Operators are exposed to fumes for more then two hours/day

Table B6.2: Chemistry concentration

	Initial Fuzzy association	Operator options
0	0	There exists no smell or fumes throughout the plant
0.11	0.1	Very mild fumes exist around the process tanks. Fumes are only notices when working close to the tank
0.14	0.15	The tank fumes are strong and can be felt a few meters from the tank
0.33	0.33	The tank fumes are very strong and can be felt anywhere in the plating shop

Table B6.3: Types of fumes

	Initial Fuzzy association	Operator options
0	0	No toxic fumes exists anywhere on the plant
0.33	0.33	The cyanide tanks fumes heavily and is a major hindrance.
0.2	0.22	The cyanide tank fumes is a partial hindrance
0.11	0.11	The cyanide tank fumes are seldom noticeable
0.33	0.33	The chrome tank fumes

0.2	0.22	The chrome tank fumes is a partial hindrance
0.11	0.11	The chrome tank fumes are seldom noticeable
0.33	0.33	The nickel tank fumes
0.2	0.22	The nickel tank fumes is a partial hindrance
0.11	0.11	The nickel tank fumes are seldom noticeable
0.33	0.33	The degreaser tank fumes
0.33	0.33	The acid tank fumes

Table B6.4: Scoring of Temperature (T = room temperature)

	Initial Fuzzy association	Operator options
1	1	No elevated tank temperatures exist throughout the plant
0.79	0.8	There exist tanks on the plant where there is a maximum temperature elevation of less than 5 degree Celsius above room temperature.
0.54	0.6	There exist tanks on the plant where there is a temperature elevation of greater than 5 degree Celsius above room temperature.
0.3	0.4	There exist tanks on the plant where there is a temperature elevation of greater than 5 degree Celsius above room temperature resulting in minor worker discomfort.
0.2	0.2	There exist tanks on the plant where there is a temperature elevation of greater than 5 degree Celsius above room temperature resulting in

		major worker discomfort.
0	0	There exist tanks on the plant where there is a temperature elevation of greater than 5 degree Celsius above room temperature resulting in an environment which is impossible to work in.

Table B6.5: Noise levels

	Initial Fuzzy association	Operator options
0	0	There exists no noise throughout the plant
0.1	0.16	Very manageable noises exist around the plant. Noise is not a disturbance
0.32	0.33	Loud noises exist on the plant and/or surroundings.
0.5	0.5	Noise levels are very load.

Table B6.6: Noise levels operators exposed to

	Initial Fuzzy association	Operator options
0	0	Operators are not exposed to any major noise
0.1	0.16	Operators are exposed to high noise levels for less than 30 minutes per day
0.32	0.33	Operators are exposed to high noise levels for between 30 minutes and two hours/day
0.5	0.5	Operators are exposed to high noise levels for more then two hours/day

Table B6.7: Heavy lifts

	Initial Fuzzy association	Operator options
0	0	There exists no heavy lifts throughout the plant
0.1	0.16	All lifts involve light equipment and are not a strain. All weights are less than 10 kg
0.32	0.33	All weights to be moved around the plant are between 10 and 20 kg.
0.5	0.5	All weights to be moved around the plant are greater than 20 kg.

Table B6.8: Heavy lifts operators exposed to

	Initial Fuzzy association	Operator options
0	0	Operators are not exposed to any major lifts
0.17	0.1	Operators are exposed to lifting objects more than 20 kg' s for less than 30 minutes per day
0.33	0.15	Operators are exposed to lifting objects more than 20 kg' s for between 30 minutes and two hours/day
0.5	0.5	Operators are exposed to lifting objects more than 20 kg' s for more then two hours/day

Chemicals Risks:

Table B6.9: Chemical Risks

	Initial Fuzzy association	Operator options
0.5	0.5	There are no potential accidents with chemicals. Precautions have been taken if there are any accidents.
0.26	0.33	There is a low risk of accidents with chemicals. There may have been an accident with chemicals in the last five years and no corrective measures have been taken.
0.1	0.16	There is a medium risk of accidents with chemicals. There has been some near accidents with chemicals in the last two years.
0	0	There is a very high risk of accidents with chemicals. There are regular near misses.

Machinery

Table B6.10: Machinery risks

	Initial Fuzzy association	Operator options
0.5	0.5	There are no potential accidents with machinery. Precautions have been taken.
0.27	0.33	There is a low risk of accidents with machinery. There may have been an accident with machinery in the last five years and no corrective measures have been taken.
0.1	0.16	There is a medium risk of accidents with

		machinery. There has been some near accidents with machinery in the last two years.
0	0	There is a very high risk of accidents with machinery. There are regular near misses.

Appendix B1.7: Water use and reuse systems

The water usage on a surface finishing facility is dependent on a variety of factors among these are the dripping, hanging etc which is described in this chapter under the state of the rinsing system. The other determining factors are the actual path of the water on an electroplating facility i.e. the use and reuse of water on an electroplating facility. This lends to the question of Can water be reused? Yes, within limits. Some water if redirected would result in contamination problems.

The redirecting of water is a separate issue to the recycle of water. The question that arises is why spend so much of money to treat waste water and then release to drain? Can this wastewater not be recycled? The answer is yes the water can be reused and recycled, here again within limits. Its obvious that water still rich in oil cannot be used for rinsing or metal contaminated rinse water cannot be used for post plating rinsing.

With these considerations it would possible to evaluate a surface finishing facility on the effectiveness of its water use and re/use system.

Degreaser acid reuse

Most companies use fresh water for rinsing on the acid tanks and a separate fresh water for rinsing of the degreaser. This is not optimum as the rinse water can be reused. The redirected rinse water is actually more effective in rinsing as a slightly acidic rinse water can clean off an alkali solution more effectively. Some challenges may occur with regards Phosphating but this can be easily solved by reducing the pH shock by cross directing. Cross directing is the directing of the second post acid rinse to the first acid rinse. The water is then directed to the first degreaser rinse and then back to the first acid rinse. This system ensure minimum pH shock. It is usual to redirect the second degreaser rinse to the second acid rinse and then to the first rinse.

Table B7.1: Fuzzy membership definition for sludge with regards to optimum dragin/dragout.

Fuzzy Association	Operator Options
0.2	The acid and degreaser consists of single rinses each with individual fresh water feed.
0.4	The acid and degreaser consists of double rinses each with individual fresh water feed.
0.6	The acid and degreaser consists of double rinses each with fresh water feed to rinse tank one which is then redirected to the other. There is still separate inlets for the degreaser and acid system.
0.8	The acid and degreaser consists of static tanks which are dumped on a regular basis.
1	The acid and degreaser consists of double rinses each with a single fresh water feed to the degreaser tanks which is redirected to the acid system.

Closed circuit plating rinsing

It has been a traditional belief that more is better for dilution and rinsing purposes. This theory has been successfully followed at most facilities. It has been successful in achieving one of the primary functions of the rinse systems ie the effective rinsing off of the plating solution.

This is the main function of the rinse but it is not the optimum in that the plating chemicals that are dragged out of the plating tank is lost to the waste water treatment plant.

The ideal would be to achieve effective rinsing and at the same time achieve recovery of plating chemicals. The reduction of water consumed would be an added bonus.

With the use of a low flow counter current rinse system this can be easily achieved ie the rinse water is fed into the last rinse tank and is cascaded into the first rinse tank. Some calculations are required for optimum operation.

Table B7.2: Fuzzy membership definition for closed circuit plating rinsing

Fuzzy Association	Operator Options
0.2	There exists a single rinse tank after the plating tank. The tank is fed with a single water inlet and the outlet is to drain.
0.4	There exists a double rinse tank after the plating tank. The tank is fed with individual water inlets and the outlets are to drain.
0.6	There exists a double rinse tank after the plating tank. The tank is fed with a single water inlet and the outlet is to drain. Water is redirected between the two tanks.

0.8	There exists a double rinse tank after the plating tank. The tank is fed with a single water inlet and the outlet is to drain. Water is redirected between the two tanks. Top up of the plating tank is done from the rinse tanks.
1	A minimum of a three stage rinse exists. The water is fed countercurrent back to the plating tank.

Flowmeters

A very popular saying is what you cannot measure you cannot save. The continuous flow of waste water without any form of measurement is a problem as the quantification of the water usage is unknown.

This problem needs to be solved at two levels. Holistically the plant needs sufficient water meters to be able to determine the water consumption at the different sections of the plant and the flowmeters need to be used to continuously monitor the individual tank/ inlet consumptions.

Table B7.3: Fuzzy membership definition for flowmeters

Fuzzy Association	Operator Options
1	Flow meters exists on all inlets to tanks. A water meter exists in each plant section. Water consumptions are monitored and regulated.
0.8	Flow meters exists on some inlets to tanks. A water meter exists. Water consumptions are sometimes monitored.
0.6	A water meter exists. Water consumptions are sometimes monitored.

0.4	Water readings are done via municipal mains. No control of plant water exists.
0.2	No systems exist to measure or monitor water usage

Waste water treatment plant reuse

Water, once treated has traditionally been disposed off. This is a wastage of resources. If this water could be used on the plant where high purity water can be used this could be ideal. This would imply using the water in an area such as degreaser or acid rinse.

Table B7.4: Fuzzy membership definition for waste water treatment plant reuse

Fuzzy Association	Operator Options
1	All rinse water once treated is reused on the plant. Only evaporative losses are required as inlet water.
0.8	Rinse water is segregated and some rinse tater is reused after treatment. Approximately 50 % reuse occurs.
0.6	Some of the rinse water is reused after treatment. Approximately 30 % reuse occurs.
0.4	Some of the rinse water is reused after treatment. Approximately 10 % reuse occurs.
0.2	No reuse of water occurs. Once treated the water is dumped.

De-ionised water use.

The use of municipal water at electroplating facilities is part of the contribution to waste problems. The salts found in municipal water contributes to the problems.

The ideal would be to remove these salts before they get into the system. This can be achieved by using De-ionised water. The cost of these systems have traditionally been a problem but with the onset of small scale units a the ion exchange unit and the reverse osmosis units have proven cost effective.

Table B7.5: Fuzzy membership definition for de-ionised water use

Fuzzy Association	Operator Options
1	De-ionized water is used on all rinse tanks
0.8	Plating tank rinses use de-ionised water
0.6	Plating tank rinses use de-ionised water when available
0.4	Make up of plating tanks were done with DI water. All top ups are done with tap water
0.2	All systems are fed with tap water.

Proper water supply quality would imply improved plating efficiency and long term cost saving.

The proper use of water as a very expensive resource can imply considerable savings. The variables that would be considered would be:

First the alternatives had to be defined. For rinsing the alternatives are:

A = $\{a_1, a_2, \ldots, a_5\}$ = {DA, CCT, FM, WW, DE}

where

DA: redirecting degreaser/acid

CCT: closed circuit

FM: flow meters

WW: waste water treatment recycle

DE: de-ionised

Then the main objectives in evaluating and controlling the rinses were determined:

$$O = \{o_1, o_2, \ldots, o_4\} = \{CC, E, WC, C\}$$

where

CC: the chemical consumption

E: the environment

WC: the water consumption

C: the cost for waste water treatment and due to production loss

The ranking for each of the above objectives will be rated as preferences:

$$P = \{b_1, b_2, b_3, b_4\} \longrightarrow [0,1]$$

So inputting the relationship between each one of the alternatives and the objectives.

$$\underset{\rightarrow}{Q}_1 = \frac{0.25}{DA} + \frac{0.25}{CC} + \frac{0.2}{FM} + \frac{0.2}{WW} + \frac{0.2}{DI}$$

$$\underset{\rightarrow}{Q}_2 = \frac{0.2}{DA} + \frac{0.3}{CC} + \frac{0.15}{FM} + \frac{0.25}{WW} + \frac{0.2}{DI}$$

$$\underset{\rightarrow}{Q}_3 = \frac{0.2}{DA} + \frac{0.2}{CC} + \frac{0.1}{FM} + \frac{0.15}{WW} + \frac{0.15}{DI}$$

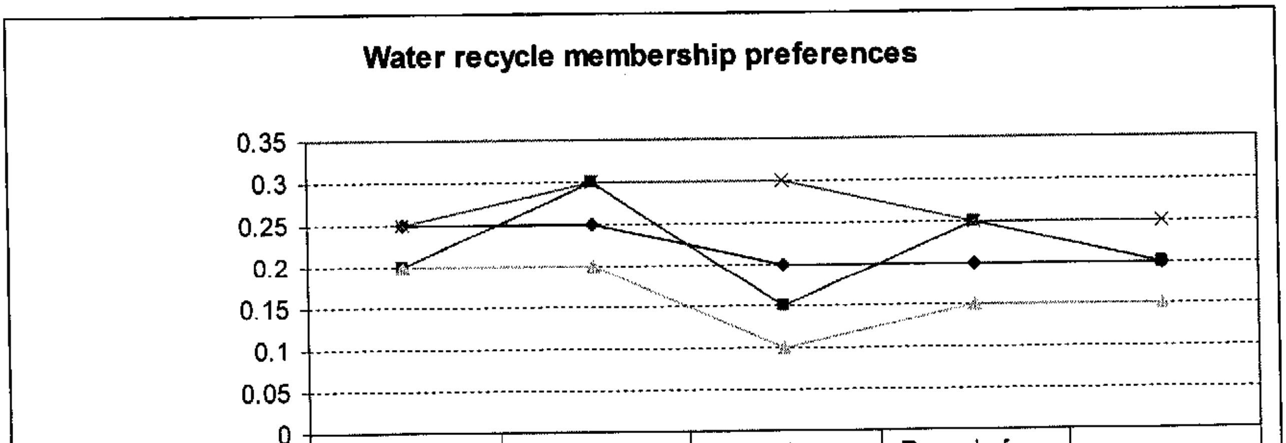
$$\underset{\leftrightarrow}{Q}_4 = \frac{0.25}{DA} + \frac{0.3}{CC} + \frac{0.3}{FM} + \frac{0.25}{WW} + \frac{0.25}{DI}$$

Now each of the preferences has to be rated on a scale of 0-1.

- $b_1 = 0.9$: Water consumption is the objective of this section hence it takes highest priority.
- $b_2 = 0.7$: The main impact of overuse of water is on natural resources which bears on the environment hence it is an important preference
- $b_3 = 0.7$ Production is important, if poor water quality reduces cleaning efficiencies this could impact on production.
- $b_3 = 0.8$ Cost is always a key variable, water saving could imply potential savings.

A graph can be plotted of each membership with respect to the preferences.

Fig B7: Graph of membership and preferences



	degras acid	closed plating rinses	water meters/flow	Recycle from wwtp	DI water
Water	0.25	0.25	0.2	0.2	0.2
Environment /chem	0.2	0.3	0.15	0.25	0.2
production	0.2	0.2	0.1	0.15	0.15
cost	0.25	0.3	0.3	0.25	0.25

The complement of the preferences is required for the calculations so they are determined and substituted into the Decision making equation:

The decision-making equations:

$$D(a_1) = D(DA) = (\overline{b_1} \vee O_1) \wedge (\overline{b_2} \vee O_2) \wedge (\overline{b_3} \vee O_3) \wedge (\overline{b_4} \vee O_4)$$

Now substituting into the above for each alternative:

$$D(a_1) = D(DA) = (0.25 \vee 0.1) \wedge (0.2 \vee 0.3) \wedge (0.2 \vee 0.3) \wedge (0.25 \vee 0.2)$$

$$D(a_2) = D(CC) = (0.25 \vee 0.1) \wedge (0.3 \vee 0.3) \wedge (0.2 \vee 0.3) \wedge (0.3 \vee 0.2)$$

$$D(a_3) = D(FM) = (0.2 \vee 0.1) \wedge (0.15 \vee 0.3) \wedge (0.1 \vee 0.3) \wedge (0.3 \vee 0.2)$$

$$D(a_4) = D(WW) = (0.2 \vee 0.1) \wedge (0.25 \vee 0.3) \wedge (0.15 \vee 0.3) \wedge (0.25 \vee 0.2)$$

$$D(a_5) = D(DI) = (0.2 \vee 0.1) \wedge (0.2 \vee 0.3) \wedge (0.15 \vee 0.3) \wedge (0.25 \vee 0.2)$$

Solving:

$D(a_1)$= 0.35

$D(a_2)$= 0.25

$D(a_3)$= 0.2

$D(a_4)$= 0.2

$D(a_5)$= 0.2

With a maximum D ($a_{1/2}$)= 0.25. These values can now be used to determine the water reuse/recycle system environmental status. The final outcome indicates acid/degreaser and closed circuit rinses to be the highest priority. So to configure the output.

We consider the weighing in proportion to the output from the decision making process.

So:
State of the rinsing system =100*(0.25*DA + 0.25*CCT + 0.2*FM + 0.2*WW + 0.2*DE ....Equation 7

Thus a rating on the scale of 0-100 would be generated this can be used to determine the potential sludge reduction that can be achieved with changes to the sludge system. The alternates for the fuzzy model need to be inputted by the operator and fuzzy questions needs to be generated for this purpose.

Appendix B1.8: Production

The production rate on a surface finishing facility can be considered to be the surface area treated over a period of time, which may be anything from a day to a year. Most production figures are either not monitored or is measured in mass. This is essentially flawed as it is not the true representation of the surface treated. An accurate measure of production would be the surface area treated or plated.

The plated thickness has a major impact on production time and production cost ie If a required thickness is 10 microns and 11 microns is plated that would imply a loss of production time of 10 percent and a loss of chemical usage of 10 percent. This could imply a potential annual saving of more than 20 percent if production were to increase by 10 percent whilst saving 10 percent of the chemicals.

The optimum voltage is also a critical factor in electrochemistry. An over voltage would imply a loss of efficiency which has a snowball effect. Contamination increases and production decreases. This can also occur with poor jig/barrel loading.

Surface area measurement

The accurate measurement of surface area is critical to production. Bath chemistry changes with production and in order to optimize the bath chemistry the production rate has to b known. Inline plater usually do not have a problem with determining their production rates but jobbing shops find this a challenge. One of the strengths of this thesis is the indirect determination of the rate of production.

Table B8.1: Fuzzy membership definition for surface area measurement

Fuzzy Association	Operator Options
0.1	No determination of production rate is considered.
0.2	Occasional determination of masses is conducted. This is used as an indicator of production. Less than 10 % of production is measured.
0.4	Mass is used as an indication of the rate of production. More than 50% of incoming material is weighted
0.6	Mass is used as an indication of the rate of production. 100% of incoming material is weighted
0.8	Surface areas of some components are measured. The rest is estimated by mass.
1	Surface area is measured accurately and used as an indication of production.

Weight measurement

If the surface area is not being measured the next best thing would be the determination of the mass of the articles to be plated. This would generate some kind of indication of the production rate at the facility.

Table B8.2: Fuzzy membership definition for weight measurement

Fuzzy Association	Operator Options
0.2	Mass of components to be plated is not determined
0.4	Approximately 10% of all components passing through the line is weighted.
0.6	Approximately 30% of all components passing through the line is weighted.
0.8	Approximately 50% of all components passing through the line is weighted.
1	Every component passing through the line is accurately weighted

Thickness measurement

The determination of the plated thickness is essential to ensure quality. The surface thickness plated has a direct bearing on the production cost. An optimum surface thickness coated would imply optimum production cost. It should be the aim of all surface finishing production facilities to ensure optimum surface thickness in order to optimise production.

Table B8.3: Fuzzy membership definition for thickness measurement

Fuzzy Association	Operator Options
1	Surface thickness is regulated hourly and adjustments made.
0.8	Surface thickness is monitored daily and adjustments made
0.6	Chemical supplier monitors surface thickness once/week
0.4	Chemical supplier monitors surface thickness once/month
0.2	No systems exist to conduct surface thickness tests.

Voltage and amperage measurement

The determination of the amperage per meter squared is not normally conducted on a plating tank. The optimum value is predetermined by the chemical supplier and it is taken for granted that optimum loading is done so as to achieve this during plating. The reality is that the operations team overload jigs and barrels resulting in a distortion of the current ie the amps per square meter is reduced. Monitoring of this critical variable is essential for optimisation.

Table B8.4: Fuzzy membership definition for voltage and amperage measurement

Fuzzy Association	Operator Options
1	Systems for determining Amperage/voltage is on every jig exists and adjustments made.
0.8	Amperage/voltage is regulated whenever there is a change in components plated.
0.6	Chemical supplier monitors Amperage/voltage Amperage/voltage once/week
0.4	Chemical supplier monitors Amperage/voltage once/month
0.2	No systems exist to conduct Amperage/voltage tests.

Jig/ barrel loading

The loading of the jig/ barrel is critical for production. Under loading could result in overplating whilst overloading would result in quality problems. Optimum loading is essential to ensure long term sustainability of the process and equipment.

Table B8.5: Fuzzy membership definition for jig/barrel loading

Fuzzy Association	Operator Options
1	Jigs/ barrel loads are monitored regularly and regulated to ensure optimum production
0.8	Operators monitor jig/barrel loading less than 80 % of the time.
0.6	Operators monitor jig/barrel loading less than 50 % of the time.
0.4	Operators monitor jig/barrel loading less than 20 % of the time.
0.2	Jigs/ barrel loading is never a factor. Weights vary considerably on each load.

Production is essential in order to be sustainable but optimum production can improve sustainability. The monitoring of the key input variables would result in optimum use of resources.

The production tables determine the wastage of raw materials due to poor process management. The variables that would be considered would be:

First the alternatives had to be defined. For rinsing the alternatives are:

A = $\{a_1, a_2, ..., a_5\}$ = {SM, WM, TM, VA, J/B}

where

SM: surface measurement

WM: weight measurement

TM: thickness measurement

VA: voltage and amperage

J/B: jig/barrel load

Then the main objectives in evaluating and controlling the rinses were determined:

$$O = \{o_1, o_2, \ldots, o_4\} = \{W/E, EFF, P, C\}$$

where

W/E: the water/environment

EFF: the efficiency

P: the production

C: the cost

The ranking for each of the above objectives will be rated as preferences:

$$P = \{b_1, b_2, b_3, b_4\} \longrightarrow [0,1]$$

So inputting the relationship between each one of the alternatives and the objectives.

$$\underset{\leftrightarrow}{Q}_1 = \frac{0.15}{SM} + \frac{0.15}{WM} + \frac{0.2}{TM} + \frac{0.15}{VA} + \frac{0.2}{JB}$$

$$\underset{\leftrightarrow}{Q}_2 = \frac{0.3}{SM} + \frac{0.25}{WM} + \frac{0.25}{TM} + \frac{0.25}{VA} + \frac{0.2}{JB}$$

$$\underset{\leftrightarrow}{Q}_3 = \frac{0.25}{SM} + \frac{0.2}{WM} + \frac{0.2}{TM} + \frac{0.15}{VA} + \frac{0.2}{JB}$$

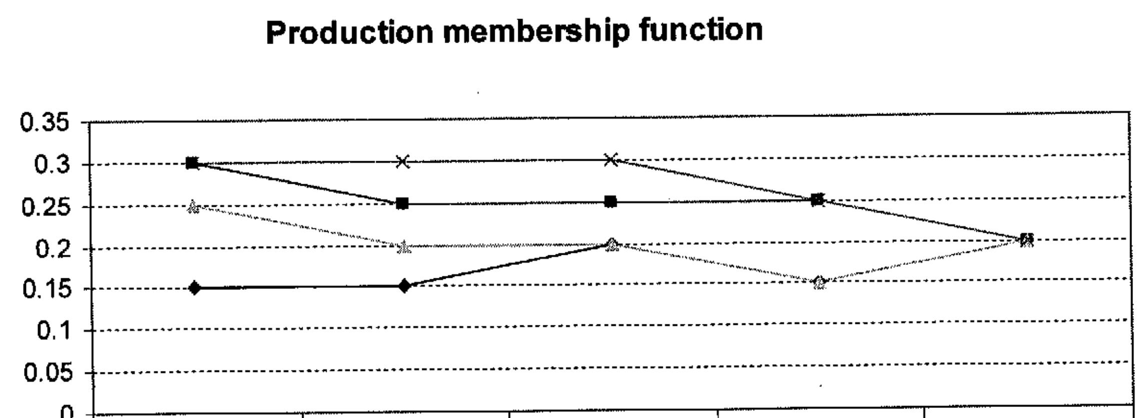
$$\underset{\leftrightarrow}{Q}_4 = \frac{0.3}{SM} + \frac{0.3}{WM} + \frac{0.3}{TM} + \frac{0.25}{VA} + \frac{0.2}{JB}$$

Now each of the preferences has to be rated on a scale of 0-1.

- b_1= 0.5 : Water consumption is a key objectives as losses in production implies water consumption increases ie overproduction
- b_2= 0.8 :The efficiencies of plating/cleaning if not optimum results in wastage which can be prevented.
- b_3 = 0.9 Production is the key as inefficiencies could imply a loss in production. The objective being to achieve minimum wastage.
- b_3= 0.5 Cost is always a key variable as inefficiencies cause losses which could have been prevented.

A graph can be plotted of each membership with respect to the preferences.

Fig B8.1: Graph of membership and preferences



	SA measured	Weight measured	Thickness	V&A	Jig/barrel load
Water/envir	0.15	0.15	0.2	0.15	0.2
efficiency	0.3	0.25	0.25	0.25	0.2
production	0.25	0.2	0.2	0.15	0.2
cost	0.3	0.3	0.3	0.25	0.2

The complement of the preferences is required for the calculations so they are determined and substituted into the Decision making equation:

The decision-making equations:

$$D(a_1) = D(SM) = (\overline{b_1} \vee O_1) \wedge (\overline{b_2} \vee O_2) \wedge (\overline{b_3} \vee O_3) \wedge (\overline{b_4} \vee O_4)$$

Now substituting into the above for each alternative:

$$D(a_1) = D(SM) = (0.15 \vee 0.5) \wedge (0.3 \vee 0.2) \wedge (0.25 \vee 0.1) \wedge (0.3 \vee 0.2)$$

$$D(a_2) = D(WM) = (0.15 \vee 0.5) \wedge (0.25 \vee 0.2) \wedge (0.2 \vee 0.1) \wedge (0.30.2)$$

$$D(a_3) = D(TM) = (0.2 \vee 0.5) \wedge (0.25 \vee 0.2) \wedge (0.2 \vee 0.1) \wedge (0.3 \vee 0.2)$$

$$D(a_4) = D(VA) = (0.15 \vee 0.5) \wedge (0.25 \vee 0.2) \wedge (0.15 \vee 0.1) \wedge (0.25 \vee 0.2)$$

$$D(a_5) = D(JB) = (0.2 \vee 0.5) \wedge (0.2 \vee 0.2) \wedge (0.2 \vee 0.1) \wedge (0.2 \vee 0.2)$$

Solving:

$D(a_1)$= 0.25

$D(a_2)$= 0.2

$D(a_3)$= 0.2

$D(a_4)$= 0.15

$D(a_5)$= 0.2

With a maximum D (a_1)= 0.25. These values can now be used to determine the production system environmental status. The final outcome indicates Surface area measurement to be the highest priority. So to configure the output.

We consider the weighing in proportion to the output from the decision making process.

So:

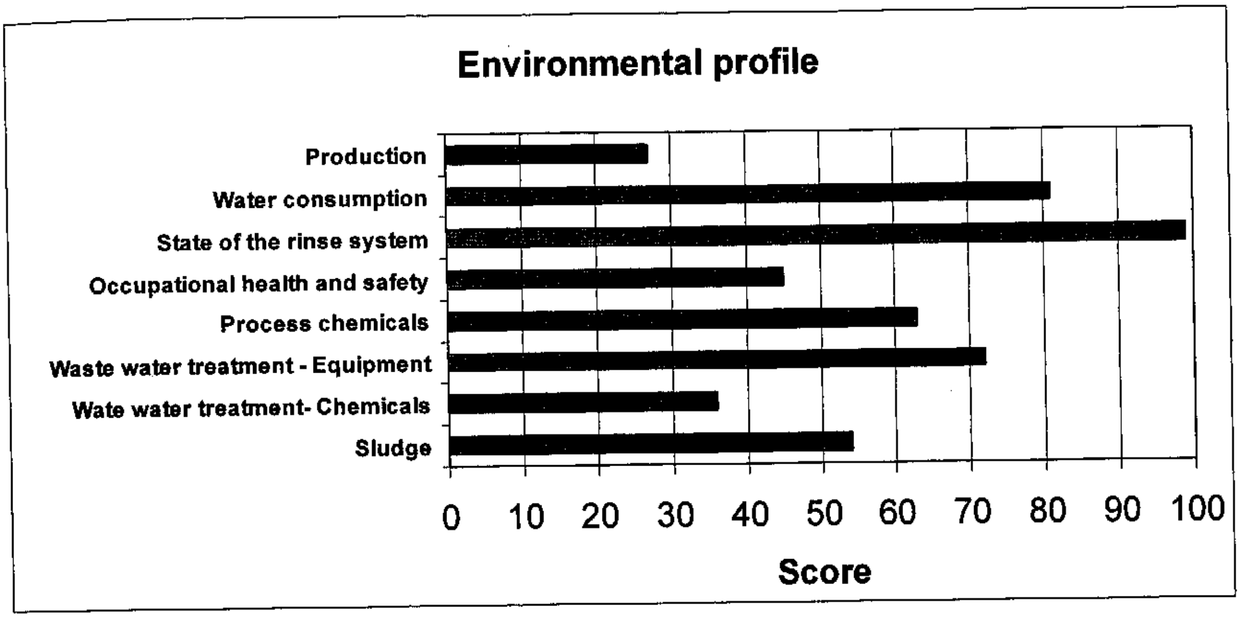
State of the rinsing system =100*(0.25*SM + 0.2*WM + 0.2*TM + 0.15*VA + 0.2*J/B ....Equation 8

Thus a rating on the scale of 0-100 would be generated this can be used to determine the potential sludge reduction that can be achieved with changes to the sludge system. The alternates for the fuzzy model need to be inputted by the operator and fuzzy questions need to be generated for this purpose.

The appropriate fuzzy questions are developed to accommodate operator inputs under these categories. The preferences are appropriately inputted in accordance with each category. A comprehensive plant wide system is developed that outputs an environmental status of the company.

The outputs from each section are summarized on a scale of zero to 100. Where a zero would indicate no room for improvement and a 100 would indicate major potential savings with system improvements.

Figure B8.2: Graph of plant environmental profile



Appendix B2: New operator based questionnaire

Cleaner Production Audit

Appendix B2.1: Rinse Tables

1. For how long does the jig stand above the bath for dripping before moving to the next bath ?

Answer	Operator Options
	Jigs hangs for 0-4 seconds above tank before moving to next tank
	Jigs hangs for 5-9 seconds above tank before moving to next tank
	Jigs hangs for 10-14 seconds above tank before moving to next tank
	Jigs hangs for 15-19 seconds above tank before moving to next tank
	Jigs hangs for >20 seconds above tank before moving to next tank

2. In what manner (physical way) are the items placed on the jig/barrel ?

Answer	Operator Options
	Pieces are hung so that there is no cup shaped sections entraining liquid. All flat sheets are hung with one corner facing down. Most liquid drains off in less than 3 seconds.
	Pieces are hung so that there is some entrapment of liquid by cup shaped sections. All sheets are hung with one of the shortest end facing downwards. Most liquid drains off in less than 8 seconds.
	Pieces are hung so that there is a large entrapment of liquid by cup shaped sections. All sheets are hung with one the shortest end facing downwards. Most liquid drains off in less than 12 seconds.
	Pieces are hung so that cup shaped sections entraining liquid. All flat sheets are hung with the longer side facing down. Most liquid drains off

	once the jig is tilted and takes less than 15 seconds.
	Pieces are hung so that cup shaped sections entraining liquid. All flat sheets are hung with the longer side facing down. Most liquid drains off in once the jig is tilted and takes greater than 15 seconds.

3. Is there agitation ?

Answer	Operator Options
	There is no agitation or liquid motion on any tanks.
	There exists visible agitation or jig motion on some tanks. Either by air or jig motion.
	There exists visible agitation or jig motion on all tanks. Either by air or jig motion.
	There exists visible agitation and liquid motion on all process tanks. Either by air or jig motion.
	There exists heavy agitation and liquid motion on all process tanks. Either by air or jig motion.

4. How is the rinse water let in and out of each rinse tank ?

Answer	Operator Options
	Rinse tank inlet is located at the top of the tank and the outlet is located next to it on the top of the tank.
	Rinse tank inlet is located at the top of the tank and the outlet is located on the top of the tank, on the opposite end.
	Rinse tank inlet is located at the top of the tank and the outlet is located on the bottom of the tank, on the opposite end.
	Rinse tank inlet is located at the bottom of the tank and the outlet is located at the top of the tank on the opposite end. Tank is not agitated.

	Rinse tank inlet is located at the bottom of the tank and the outlet is located at the top of the tank on the opposite end. Tank is agitated.

5. How does the back mixing work ?

Answer	Operator Options
	Rinse tanks are linked across the bottom and /or top allowing continuous flow of water.
	Small pipes link rinse tanks resulting in continuous back mixing. Spills between rinse tanks are high during jig submersion.
	Rinse tanks are linked across the bottom and /or top allowing moderate flow of water during jig submersion or Rinse tank overflows very small amounts of water to the next rinse tank during jig submersion.
	Rinse tanks are linked across the bottom and /or top allowing very little flow of water during jig submersion or Rinse tank overflows some water to the next rinse tank during jig submersion.
	No back mixing. Tanks are not linked.

6. How is the inlet flow of water into the rinse tanks controlled ?

Answer	Operator Options
	Rinse water supplied by non-restricted pipe. Each rinse tank has a separate inlet.
	Rinse water supplied by valve on the end of a pipe with some control.
	Static tanks, dumped regularly or moderate flow control with no rinse recovery system. No redirecting of rinse water occurs.
	Static tanks, dumped regularly or moderate flow control with no rinse recovery system. Redirecting of rinse water occurs.
	Flow control to rinse tank via predetermined rinse water requirements.

	Flow is continuously controlled and stops when no tank operations occur. All water is recovered via low flow rinse back into plating tank.

Appendix B2.2: Sludge Tables

7. How is drag out reduced ?

Answer	Operator Options
	All plating tanks consist of single rinses with outlet to waste water treatment plant.
	All plating tanks consist of two rinses with outlet to waste water treatment plant.
	All plating tanks consist of two rinses with outlet to waste water treatment plant.
	All plating tanks are closed circuit i.e. there is a minimum of three rinses. All top up liquid is redirected to the plating tank. De-ionised water is used as top up on last rinse tank.
	The acid tank is regenerated by removing contaminants. Acid tank lifespan is a minimum of one year
	The degreaser tank is regenerated by removing contaminants. Degreaser tank lifespan is a minimum of one year
	Passivates have a single rinse
	Passivate has a double rinse
	De-ionised water is used on all rinses

8. How is the bath chemistry optimised ?

Answer	Operator Options
	Bath analysis and testing conducted online or twice/day. Continuous chemical dosing to plating tank
	Bath analysis and testing conducted once in two days. Chemical dosing to plating tank done accordingly.
	Bath analysis and testing conducted once per week. Chemical dosing to plating tank done accordingly.
	Bath analysis and testing conducted once in two weeks. Chemical dosing to plating tank done accordingly.
	Bath analysis and testing conducted once in per month. Chemical dosing to plating tank done accordingly.

9. How is waste concentrated ?

Answer	Operator Options
	Filter press is used after sludge settling together with bed/solar drying.
	Filter press is used after sludge settling or bed/solar dewatering.
	Wastewater is pH adjusted, flocculated and settled before sludge removal.
	Sludge is allowed to settle in settling tanks and is disposed of.
	No systems exist to concentrate waste

10. How are the process baths maintained ?

Answer	Operator Options
	Online filters continuously clean process baths.
	Tanks are desludged once/ week. Process baths are purified every two days.
	Tanks are desludged once/ month. Process baths are purified once in two days.
	Tanks are desludged once/ year. Process baths are purified once per week.
	No systems exist to purify process baths

11. How is the waste recovered internally ?

Answer	Operator Options
	Process bath metal losses are recovered by onsite metal recovery systems and recycled into process.
	Process bath recovery is done offsite and returned to site for reuse.
	Process bath metal losses are recovered by metal recovery systems and not reused.
	Process bath recovery is done of site and not returned to site
	Process bath waste is disposed to outside contractor as a raw material.
	No systems exist to recover waste process baths

Appendix B2.3: Waste Water Treatment Plant Chemicals

12. How is excess dosing of chemicals reduced ?

Answer	Operator Options
	Plant operator does wastewater treatment when time is available. An excess of chemicals is used to ensure proper treatment of pH, chrome and/or cyanide.
	Flocculants is added in excess to ensure treatment
	Flocculants is only added as per predetermined requirement. Dosing is done after analysis of wastewater.
	Chrome and cyanide is treated without measurement of chrome and cyanide concentration
	Chrome is treated with more than 5mg/l of metabisulphite when the chrome containing waste water is at a pH of less than 3.5
	Chrome is treated with 5mg/l of metabisulphite when the chrome containing waste water is at a pH of 3.5
	Cyanide is treated with more than 5mg/l of hypochloride when the cyanide containing wastewater is at a pH of greater than 11.
	Cyanide is treated with 5mg/l of hypocloride when the cyanide containing waste water is at a pH of 11.
	PH, Metals concentration and cyanide concentration is continuously monitored before dosing.

13. Are spent baths reused ?

Answer	Operator Options
	Spent acid and degreaser is not stored for waste water treatment
	Spent acid is stored for use for pH regulation
	Spent degreaser is stored for use for pH regulation
	Chrome and cyanide is stored and treated when spent acid ore degreaser is available for pH adjustment.
	Spent acid is used as a flocculants

14. How are spent baths treated ?

Answer	Operator Options
	All wastewater is released to WWTP without any storage and optimum neutralization
	Acids and alkali is dumped together
	Streams containing acids and alkali are stored and treated separately.
	Streams containing acids and alkali are stored and treated separately. All other treatment of chemicals is conducted in a co-ordinated fashion
	The treatment of waste streams is carried out using stored spent chemicals. Storage facilities exist for acids/alkali/oily/cyanide rich and all metal waste separately.

15. How are the waste stream separated ?

Answer	Operator Options
	All waste streams are mixed and treated together
	Cyanide is stored and treated separately
	Chrome is stored and treated separately
	Streams containing acids and alkali are stored and treated separately
	Streams containing metals are separated
	Streams containing complexing agents are stored and treated separately

16. How are the chemicals dosed and controlled ?

Answer	Operator Options
	All treatment processes are done manually
	pH regulation is done using continuous measurement, Dosing is done manually
	pH regulation is done using continuous measurement, Dosing is done automatically
	Chrome/Cyanide monitoring is done using continuous measurement, Dosing is done manually
	Chrome/Cyanide monitoring is done using continuous measurement, Dosing is done automatically
	Metals monitoring is done using continuous measurement, Dosing is done manually
	Metals monitoring is done using continuous measurement, Dosing is done automatically

Appendix B2.4: Wastewater treatment plant equipment

17. How is pH controlled ?

Answer	Operator Option
	The pH probe is never calibrated.
	The pH probe is calibrated once or twice / year
	The pH probe is calibrated once / month
	The pH probe is calibrated once every second week
	The pH probe is calibrated once / week

18. How is chrome monitored ?

Answer	Operator Options
	The equipment is never calibrated.
	The equipment is calibrated once or twice / year
	The equipment is calibrated once / month
	The equipment is calibrated once every second week
	The equipment is calibrated once / week

19. How is cyanide monitored ?

Answer	Operator Options
	The equipment is never calibrated.
	The equipment is calibrated once or twice / year
	The equipment is calibrated once / month
	The equipment is calibrated once every second week
	The equipment is calibrated once / week

20. How are the metals monitored ?

Answer	Operator Options
	The equipment is never calibrated.
	The equipment is calibrated once or twice / year
	The equipment is calibrated once / month
	The equipment is calibrated once every second week
	The equipment is calibrated once / week

21. How is chemical oxygen demand monitored ?

Answer	Operator Options
	The equipment is never calibrated.
	The equipment is calibrated once or twice / year
	The equipment is calibrated once / month
	The equipment is calibrated once every second week
	The equipment is calibrated once / week

Appendix B2.5: Chemical-consumption and monitoring

22. How the chemical concentration levels and contamination levels in a tank measured and controlled ?

Answer	Operator Options
	All process tanks are monitored by the chemical supplier once per month. Results are available within a week or two of analysis. Bath corrections are done based on these results.
	All process tanks are monitored by the chemical supplier once per week. Results are available within a week of analysis. Bath corrections are done based on these results.

	All process tanks are monitored by the chemical supplier twice per week. Results are available within the week. Bath corrections are done based on these results.
	All process tanks are monitored by the chemical supplier/ plant operator, twice per week. Results are available the next day. Bath corrections are done based on these results.
	All process tanks are monitored by the chemical supplier/ plant operator, daily. Results are available the daily. Bath corrections are done based on these results.
	All process tanks are monitored continuously by automatic measurement devices. Bath corrections are done automatically.

23. How are the plating tanks purified ?

Answer	Operator Options
	No systems exist for bath purification.
	Purification system on plating tank is used when problems arise, usually once per month.
	Purification system on plating tank is used as required, usually once per week.
	Plating tank is continuously filtered. No Acid recovery /Degreaser oil removal filtration system.
	Plating tank is continuously filtered. Degreaser oil removal filtration system is operational. Acid recovery system is currently used.
	Plating tank is continuously filtered. Degreaser oil removal filtration system is operational. Acid recovery system is currently used. All systems are continuously maintained and monitored.

24. How is chemical dosing controlled ?

Answer	Operator Options
	There exists an online measurement system and chemical dosing is done online and continuously.
	Chemical dosing is done online and continuously based on predetermined chemical consumption calculations.
	Chemical dosing is done weekly after sampling and measurement.
	Chemical dosing is done monthly after sampling and measurement.
	No systems exist to measure chemical concentrations. Chemicals are dosed randomly.

25. How is the bath chemistry of the process baths maintained ?

Answer	Operator Options
	Process bath chemistry is known a designated technical person monitors the process baths continuously. Contaminants as well as top up consumptions are monitored.
	Process bath chemistry is known a designated person monitors the process baths one/ month. Contaminants as well as top up consumptions are monitored. Contaminants as well as top up consumptions are monitored.
	Detailed Process bath chemistry is known to the chemical supplier. A technical representative monitors the process baths occasionally (once/month). Contaminants as well as top up consumptions are monitored.
	Basic Process bath chemistry is known to the chemical supplier. A technical representative monitors the process baths regularly

	(once/week).
	Basic Process bath chemistry is known to the chemical supplier. A technical representative monitors the process baths occasionally (once/month). Only top up consumptions are monitored.
	No knowledge on the process bath chemistry.

26. What kind of training does the operator undergo ?

Answer	Operator Options
	Operator training is ongoing. Standard operating procedures are in place and updated. No poor operational practices are observed from operators.
	Some formal operator training exists with operating procedures. Management ensures regular courses are presented.
	Operators undergo a formal training program managed by management.
	Operators undergo an informal training program managed by management. Most training is on a needs basis.
	Operators undergo an informal training program managed by other operators.
	No systems for operator training or improvements exists. Operators work and learn.

Appendix B2.6: Occupational health and safety

27. For what time period are operators exposed to fumes ?

Answer	Operator Options
	Operators are not exposed to fumes from chemicals
	Operators are exposed to fumes for less than 30 minutes per day
	Operators are exposed to fumes for between 30 minutes and two hours/day
	Operators are exposed to fumes for more then two hours/day

28. What levels of fumes are the operators exposed to ?

Answer	Operator Options
	There exists no smell or fumes throughout the plant
	Very mild fumes exist around the process tanks. Fumes are only notices when working close to the tank
	The tank fumes are strong and can be felt a few meters from the tank
	The tank fumes are very strong and can be felt anywhere in the plating shop

29. What type of fumes are the operators exposed to ?

Answer	Operator Options
	No toxic fumes exists anywhere on the plant
	The cyanide tanks fumes
	The chrome tank fumes
	The nickel tank fumes
	The degreaser tank fumes
	The acid tank fumes

30. What temperature levels are the operators exposed to ?

Answer	Operator Options
	No elevated tank temperatures exist throughout the plant
	There exist tanks on the plant where there is a maximum temperature elevation of less than 5 degree Celsius above room temperature.
	There exist tanks on the plant where there is a temperature elevation of greater than 5 degree Celsius above room temperature.
	There exist tanks on the plant where there is a temperature elevation of greater than 5 degree Celsius above room temperature resulting in minor worker discomfort.
	There exist tanks on the plant where there is a temperature elevation of greater than 5 degree Celsius above room temperature resulting in major worker discomfort.
	There exist tanks on the plant where there is a temperature elevation of greater than 5 degree Celsius above room temperature resulting in an environment which is impossible to work in.

31. What noise levels are the operators exposed to ?

Answer	Operator Options
	There exists no noise throughout the plant
	Very manageable noises exist around the plant. Noise is not a disturbance
	Loud noises exist on the plant and/or surroundings.
	Noise levels are very load.

32. For what time period are the operators exposed to these noise levels ?

Answer	Operator Options
	Operators are not exposed to any major noise
	Operators are exposed to high noise levels for less than 30 minutes per day
	Operators are exposed to high noise levels for between 30 minutes and two hours/day
	Operators are exposed to high noise levels for more then two hours/day

33. Are the operators exposed to heavy lifts

Answer	Operator Options
	There exists no heavy lifts throughout the plant
	All lifts involve light equipment and are not a strain. All weights are less than 10 kg
	All weights to be moved around the plant are between 10 and 20 kg.
	All weights to be moved around the plant are greater than 20 kg.

34. For what time period are the operators exposed to these heavy lifts ?

Answer	Operator Options
	Operators are not exposed to any major lifts
	Operators are exposed to lifting objects more than 20 kg' s for less than 30 minutes per day
	Operators are exposed to lifting objects more than 20 kg' s for between 30 minutes and two hours/day
	Operators are exposed to lifting objects more than 20 kg' s for more then two hours/day

35. What is the probability of accidents occurring with regard to chemicals ?

Answer	Operator Options
	There are no potential accidents with chemicals. Precautions have been taken if there are any accidents.
	There is a low risk of accidents with chemicals. There may have been an accident with chemicals in the last five years and no corrective measures have been taken.
	There is a medium risk of accidents with chemicals. There has been some near accidents with chemicals in the last two years.
	There is a very high risk of accidents with chemicals. There are regular near misses.

36. What is the probability of accidents occurring with regard to machinery?

Answer	Operator Options
	There are no potential accidents with machinery. Precautions have been taken.
	There is a low risk of accidents with machinery. There may have been an accident with machinery in the last five years and no corrective measures have been taken.
	There is a medium risk of accidents with machinery. There has been some near accidents with machinery in the last two years.
	There is a very high risk of accidents with machinery. There are regular near misses.

Appendix B2.7: Water use and reuse systems

37. How is the degreaser acid reused ?

Answer	Operator Options
	The acid and degreaser consists of single rinses each with individual fresh water feed.
	The acid and degreaser consists of double rinses each with individual fresh water feed.
	The acid and degreaser consists of double rinses each with fresh water feed to rinse tank one which is then redirected to the other. There is still separate inlets for the degreaser and acid system.
	The acid and degreaser consists of static tanks which are dumped on a regular basis.
	The acid and degreaser consists of double rinses each with a single fresh water feed to the degreaser tanks which is redirected to the acid system.

38. How is effective rinsing achieved ?

Answer	Operator Options
	There exists a single rinse tank after the plating tank. The tank is fed with a single water inlet and the outlet is to drain.
	There exists a double rinse tank after the plating tank. The tank is fed with individual water inlets and the outlets are to drain.
	There exists a double rinse tank after the plating tank. The tank is fed with a single water inlet and the outlet is to drain. Water is redirected between the two tanks.
	There exists a double rinse tank after the plating tank. The tank is fed with a single water inlet and the outlet is to drain. Water is redirected

	between the two tanks. Top up of the plating tank is done from the rinse tanks.
	A minimum of a three stage rinse exists. The water is fed counter current back to the plating tank.

39. Does the plant have flow meters ?

Answer	Operator Options
	Flow meters exists on all inlets to tanks. A water meter exists in each plant section. Water consumptions are monitored and regulated.
	Flow meters exists on some inlets to tanks. A water meter exists. Water consumptions are sometimes monitored.
	A water meter exists. Water consumptions are sometimes monitored.
	Water readings are done via municipal mains. No control of plant water exists.
	No systems exist to to measure or monitor water usage

40. Is the waste water reused ?

Answer	Operator Options
	All rinse water once treated is reused on the plant. Only evaporative losses are required as inlet water.
	Rinse water is segregated and some rinse tater is reused after treatment. Approximately 50 % reuse occurs.
	Some of the rinse water is reused after treatment. Approximately 30 % reuse occurs.
	Some of the rinse water is reused after treatment. Approximately 10 % reuse occurs.

	No reuse of water occurs. Once treated the water is dumped.

41. Is de-ionized water used on the plant ?

Answer	Operator Options
	De-ionized water is used on all rinse tanks
	Plating tank rinses use de-ionised water
	Plating tank rinses use de-ionised water when available
	Make up of plating tanks were done with DI water. All top ups are done with tap water
	All systems are fed with tap water.

Appendix B2.8: Production

42. Is surface area measured ?

Answer	Operator Options
	No determination of production rate is considered.
	Occasional determination of masses is conducted. This is used as an indicator of production. Less than 10 % of production is measured.
	Mass is used as an indication of the rate of production. More than 50% of incoming material is weighted
	Mass is used as an indication of the rate of production. 100% of incoming material is weighted
	Surface areas of some components are measured. The rest is estimated by mass.
	Surface area is measured accurately and used as an indication of production.

43. Is the mass of the article to be plated measured ?

Answer	Operator Options
	Mass of components to be plated is not determined
	Approximately 10% of all components passing through the line is weighted.
	Approximately 30% of all components passing through the line is weighted.
	Approximately 50% of all components passing through the line is weighted.
	Every component passing through the line is accurately weighted

44. Is the plated thickness measured ?

Answer	Operator Options
	Surface thickness is regulated hourly and adjustments made.
	Surface thickness is monitored daily and adjustments made
	Chemical supplier monitors surface thickness once/week
	Chemical supplier monitors surface thickness once/month
	No systems exist to conduct surface thickness tests.

45. Is the voltage and amperage measured ?

Answer	Operator Options
	Systems for determining Amperage/voltage is on every jig exists and adjustments made.
	Amperage/voltage is regulated whenever there is a change in components plated.
	Chemical supplier monitors Amperage/voltage Amperage/voltage

	once/week
	Chemical supplier monitors Amperage/voltage once/month
	No systems exist to conduct Amperage/voltage tests.

46. Is the jig/barrel loading monitored ?

Answer	Operator Options
1	Jigs/ barrel loads are monitored regularly and regulated to ensure optimum production
0.8	Operators monitor jig/barrel loading less than 80 % of the time.
0.6	Operators monitor jig/barrel loading less than 50 % of the time.
0.4	Operators monitor jig/barrel loading less than 20 % of the time.
0.2	Jigs/ barrel loading is never a factor. Weights vary considerably on each load.

47. Based on the supplier/in-house analysis weekly dosage of acid is carried out. Please enter the mass in kg of acid that is added per week.

48. Enter the supplier/operation specification for acid concentration in grams/litre

49. Enter the acid tank operating temperature

50. How often is the acid tank dumped. If weekly then enter 48 times/year. If monthly enter 12 times/year.

51. Enter the tank volume in liters of the acid tank.

52. Please enter the mass in kg of degreaser that is added per week.

53. Enter the tank volume in liters of the degreaser tank.

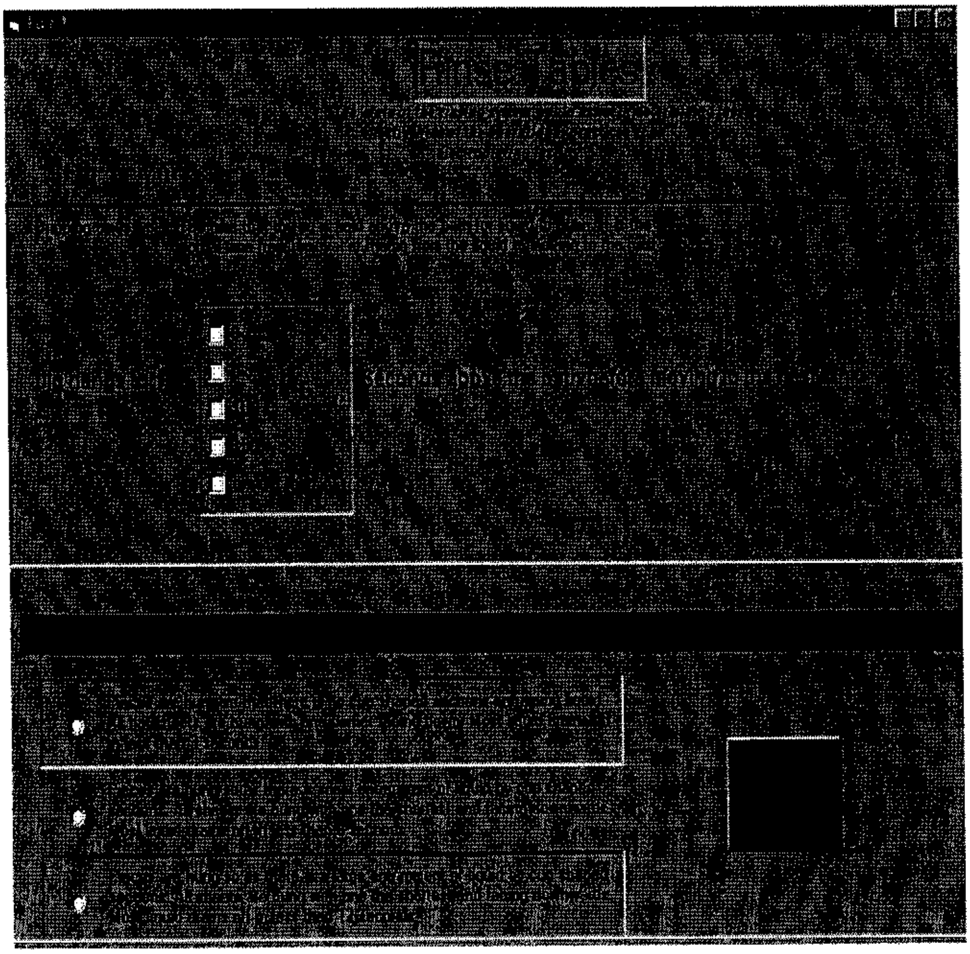
54. Please enter the mass in kg of zinc that is added per week.

55. Enter the tank volume in liters of the zinc tank.

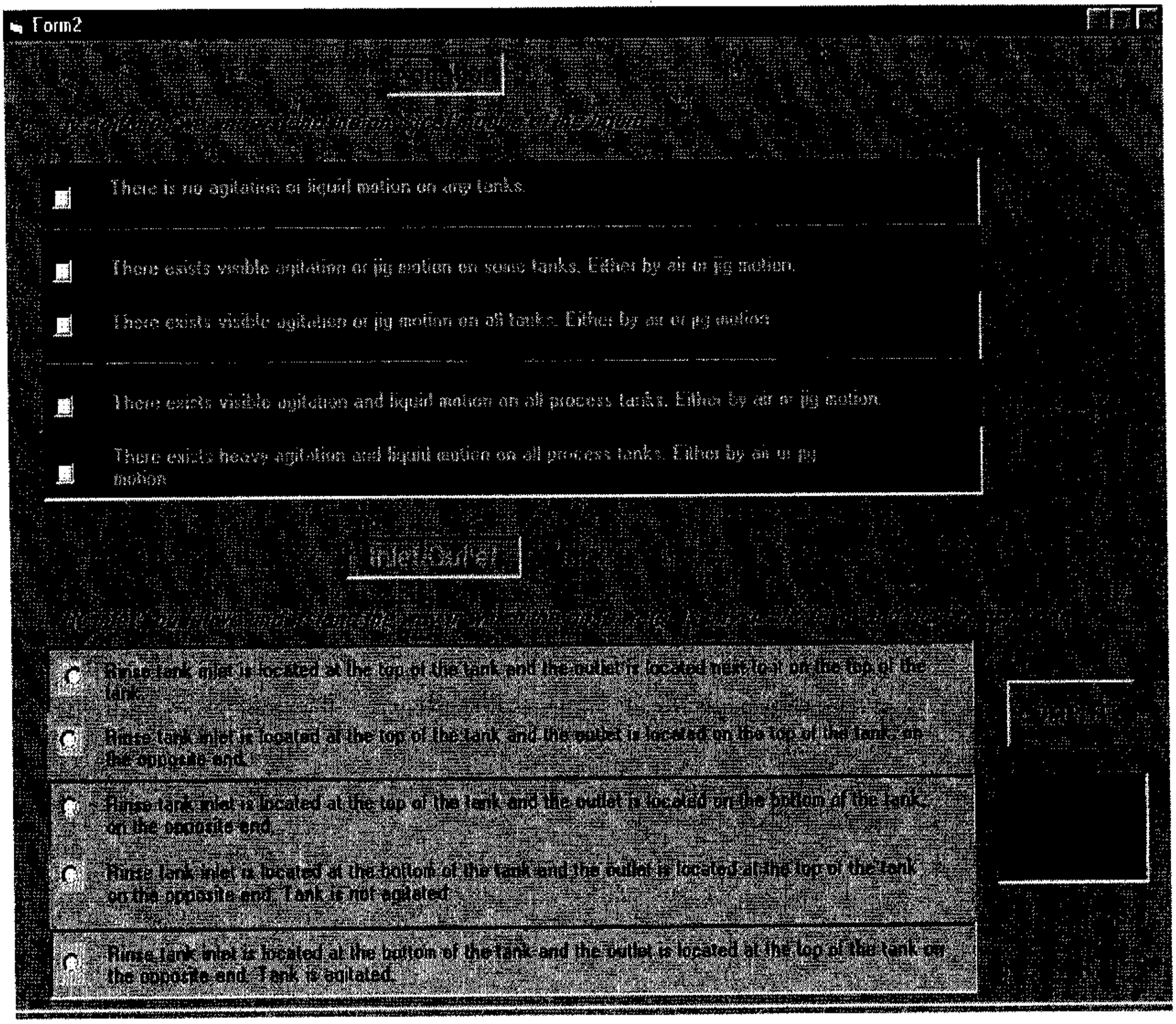
Appendix B3: Visual Basic Screens

Appendix B3.1: Rinse Tables

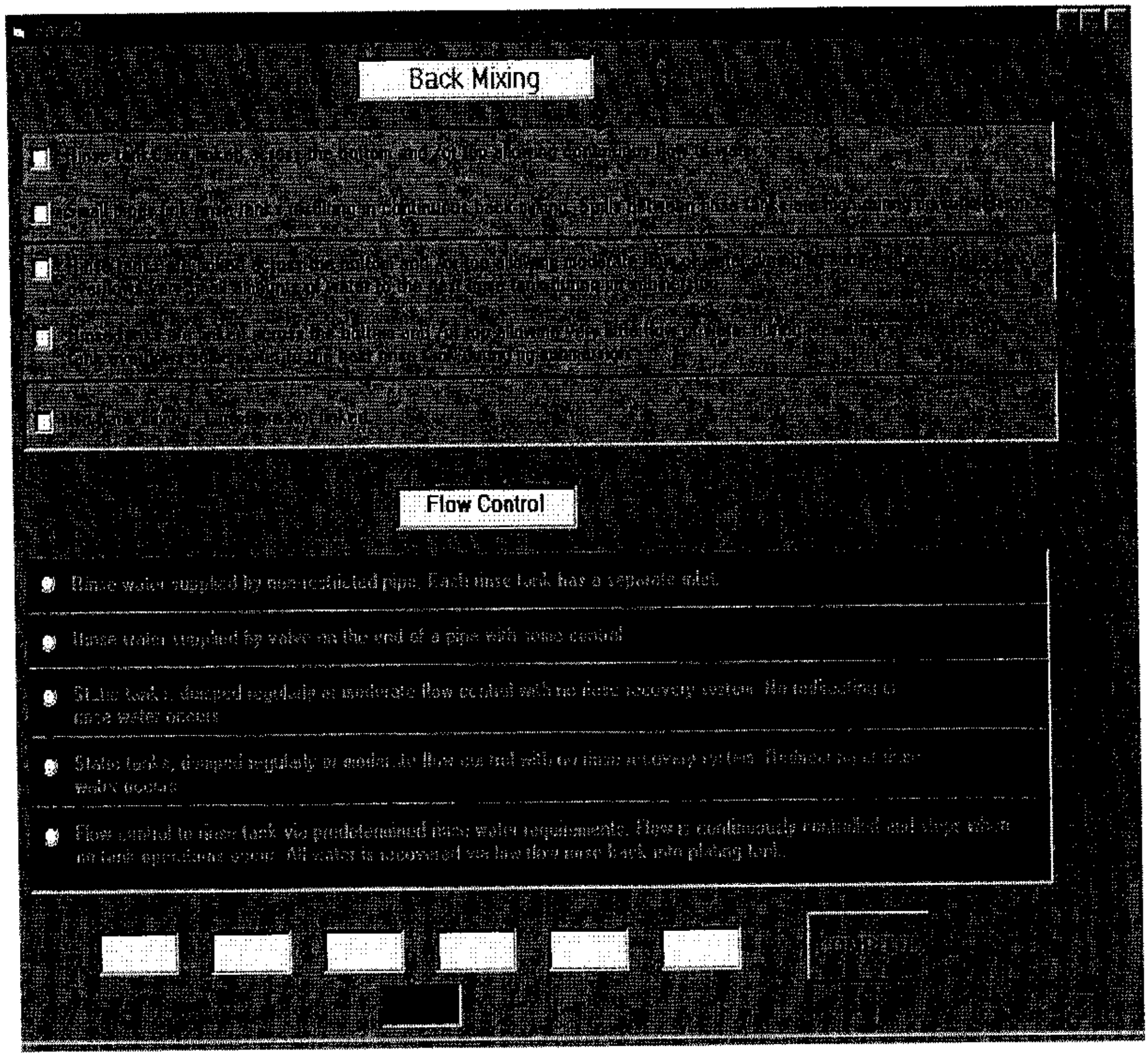
Rinse Table - Screen 1



Rinse Table – Screen 2



Rinse Table – Screen 3



Appendix D: Degreaser Model

Appendix D1: Factorial Method and Design

Table D1: The following factors considered when constructing the degreaser model

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	2	3	4	5

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	-1	-1	-1	-1	1	1	1	1	-1	1	1	-1	1	-1	-1	-1
2	1	-1	-1	-1	-1	-1	-1	1	1	-1	1	1	1	1	-1	-1
3	-1	1	-1	-1	-1	-1	1	-1	1	1	-1	1	1	-1	1	1
4	1	1	-1	-1	1	1	-1	-1	-1	-1	-1	-1	1	1	1	1
5	-1	-1	1	-1	-1	1	-1	-1	1	1	1	-1	-1	1	1	-1
6	1	-1	1	-1	1	-1	1	-1	-1	-1	1	1	-1	-1	1	-1
7	-1	1	1	-1	1	-1	-1	1	-1	1	-1	1	-1	1	-1	1
8	1	1	1	-1	-1	1	1	1	1	-1	-1	-1	-1	-1	-1	1
9	-1	-1	-1	1	-1	1	1	1	-1	-1	-1	1	-1	1	1	-1
10	1	-1	-1	1	1	-1	-1	1	1	1	-1	-1	-1	-1	1	-1
11	-1	1	-1	1	1	-1	1	-1	1	-1	1	-1	-1	1	-1	1
12	1	1	-1	1	-1	1	-1	-1	-1	1	1	1	-1	-1	-1	1
13	-1	-1	1	1	1	1	-1	-1	1	-1	-1	1	1	-1	-1	-1
14	1	-1	1	1	-1	-1	1	-1	-1	1	-1	-1	1	1	-1	-1
15	-1	1	1	1	-1	-1	-1	1	-1	-1	1	-1	1	-1	1	1
16	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

<u>Appendix D2: Experimental Procedure</u>

D2. Experimentation

D2. 1 Key words

Degreaser, Oil, Mild Steel, temperature, Electroplating, Current, Voltage.

D2.2 Protective equipment and safety measures

Face shield, caustic resistant gloves, safety boots, lab coat, Ensure raw material and equipment are labeled properly.

The above protective equipment was worn to avoid injury from hazards that might occur. When conducting the experiment, it was made sure that the electrical coil was immersed in water to avoid burning of the coil that might lead to electric shock.

D2.3 Experimental Procedure

Oil – Metal preparation

- Cut approximately 28 mm of copper wire and place electric clips on both ends of the wire such that it reaches the solution in the bath. Ensure that the wire conduct electricity.
- Weigh four mild steel plates (75 X 35 mm) and record the mass
- Connect the plates to the 4 different wires on the copper rod that is set on the retort stand. Label the 4 wires from A-D.
- Add approximately 30 grams of oil into 4 bowls.
- Weigh the bowl with the oil and record the mass. Label the bowls from A-and place each bowl under the respective metal.
- Drop the entire metal into each respective bowl by adjusting the clamp that is holding the copper rod on the retort stand.

- Lift the rod up slowly ensuring that the oil does not drip outside the respective plate.
- Let the oil to drip for approximately 5 minutes.
- Weigh each plate with the oil and record the mass.

Degreaser solution preparation

Trial A

- 2.4 kg of degreaser was added to 40 l of deionised water
- The solution was heated to 40 °C.
- The solution was then split up into four equal volumes (approx 10 liters +) and was labeled as Experiment 1, 3, 19, and 11.
- The rectifier was started in order to warm it up for accurate readings and good current conductance.
- For Experiment 3, 20 grams of oil was added into the solution
- A sheet of mild steel with a surface area equivalent to four plates combined was immersed into the solution and then connected to the anode of the rectifier.
- The rod with the 4 plates dipped in oil was placed on top of the bath such that the metals are submerged into the degreaser solution.
- The rod was then connected to the cathode side of the rectifier.
- The voltage was set on the rectifier such that in gives a value of 4.2 volts.
- Both current and voltage were measured and recorded.
- The voltage was kept constant for a period of 1 minute and the experiment was finished.
- The rod with the 4 plates was removed from the bath and air dried for a period of 15 minutes.
- Metals were weighed and the mass recorded.
- The procedure was repeated 3 times in-order to check the consistency of the results.

- For Experiment 11, the same procedure as for experiment 3 was repeated except the voltage was changed to 6.2 and time extended to 3 minutes.
- For Experiment 9, the same procedure as for experiment 3 was repeated except the voltage was changed to 6.2, the time dropped to 1 minute and no oil was added to the solution.
- For Experiment 1, the same procedure as for experiment 3 was repeated except the voltage was changed to 4.2, the time was extended to 3 minutes and no oil was added to the solution.

Trial B

- 4.8 kg of degreaser was added to 40 l of deionised water
- The solution was heated to 40 °C.
- The solution was then split up into four equal volumes (approx 10 litres +) and labeled as Experiment 2, 10, 4, and 12.
- The procedure for experiment 1, 3, 9 & 11 was repeated respectively except the following.
- For Experiment 2, voltage was set at 4 .8 volts for 1 minute
- For Experiment 10, voltage was set at 6.2 volts for 3 minutes
- For Experiment 4, voltage was set at 4 .8 volts for 3 minutes
- For Experiment 2, voltage was set at 6.2 volts for 1 minute

Trial C

- 2.4 kg of degreaser was added to 40 l of deionised water
- The solution was heated to 80 °C.
- The solution was then split up into four equal volumes (approx 10 litres +) and labeled as Experiment 5, 13, 7, and 15.
- The procedure for experiment 1, 3, 9 & 11 was repeated respectively except the following.
- For Experiment 5, voltage was set at 4 .8 volts for 1 minute

- For Experiment 13, voltage was set at 6.2 volts for 3 minutes
- For Experiment 7, voltage was set at 6.2 volts for 3 minutes
- For Experiment 15, voltage was set at 4.8 volts for 1 minute

Trial D

- 4.8 kg of degreaser was added to 40 l of deionised water
- The solution was heated to 80 °C.
- The solution was then split up into four equal volumes (approx 10 litres +) and labelled as Experiment 6, 14, 8, and 16.
- The procedure for experiment 1, 3, 9 & 11 was repeated respectively except for the following.
- For Experiment 6, voltage was set at 4 .8 volts for 3 minutes
- For Experiment 14, voltage was set at 6.2 volts for 1 minute
- For Experiment 8, voltage was set at 4 .8 volts for 1 minute
- For Experiment 16, voltage was set at 6.2 volts for 3 minutes.

All glassware and apparatus need to be thoroughly washed and left clean after finishing the experiment.

D2.4 Trial runs setup

Table D2: The limits for the experiment

Variable	**Minimum Value (-1)**	**Maximum Value (1)**
Degreaser	60 g/l	120 g/l
Oil	0	20 g/l
Temperature	40 °C	80 °C
Voltage	4.8 V	6.2 V
Time	1 min	3 min

Table D3: Trial runs setup

		Degreaser	Oil	Temperature	Voltage	Time
	Trial	1	2	3	4	5
Trial A	1	-1	-1	-1	-1	1
	9	-1	-1	-1	1	-1
	3	-1	1	-1	-1	-1
	11	-1	1	-1	1	1
Trial B	2	1	-1	-1	-1	-1
	10	1	-1	-1	1	1
	4	1	1	-1	-1	1
	12	1	-1	-1	1	-1
Trial C	5	-1	1	1	-1	-1
	13	-1	1	1	1	1
	7	-1	1	1	-1	1
	15	-1	1	1	1	-1
Trial D	6	1	1	1	-1	1
	14	1	1	1	1	-1
	8	1	1	1	-1	-1
	16	1	1	1	1	1

D2.5 Difficulties experienced during experimentation

This was not an easy experiment to conduct. Copper wire could not conduct the electricity and the reason was later discovered to be the insulation on top of the wire. So the wire had to be scrubbed to remove the insulation to ensure uniform flow of current.

Maintaining the temperature at 40 °C as well as 80 °C was a little difficult due to the fact that the heater being used had no temperature regulator.

When transporting the metals from the dipping stage to the degreaser some drops of oil might fall which could cause the mass initially placed on the oil not to be equivalent to the mass of oil removed. The oil was not dissolving to the maximum extent for those experiments that need oil as contaminant which, affected the degreasing process.

Appendix D3: Degreaser Control Charts

Trial 1

Table D4: Results obtained from trial 1

	Oil on	UCL	LCL		Oil Removed	UCL	LCL
A	0.3147	0.267017	0.504549	1	0.2066	0.395906	0.03881
B	0.3224	0.267017	0.504549	2	0.0081	0.395906	0.03881
C	0.4233	0.267017	0.504549	3	0.2453	0.395906	0.03881
D	0.2239	0.267017	0.504549	4	0.0879	0.395906	0.03881
A	0.3664	0.267017	0.504549	5	0.2067	0.395906	0.03881
B	0.254	0.267017	0.504549	6	0.1272	0.395906	0.03881
C	0.3993	0.267017	0.504549	7	0.2924	0.395906	0.03881
D	0.5032	0.267017	0.504549	8	0.0879	0.395906	0.03881
A	0.6707	0.267017	0.504549	9	0.5934	0.395906	0.03881
B	0.4445	0.267017	0.504549	10	0.4376	0.395906	0.03881
C	0.3128	0.267017	0.504549	11	-0.0783	0.395906	0.03881
D	0.3942	0.267017	0.504549	12	0.3935	0.395906	0.03881

Figure D1: Graphical representation of results

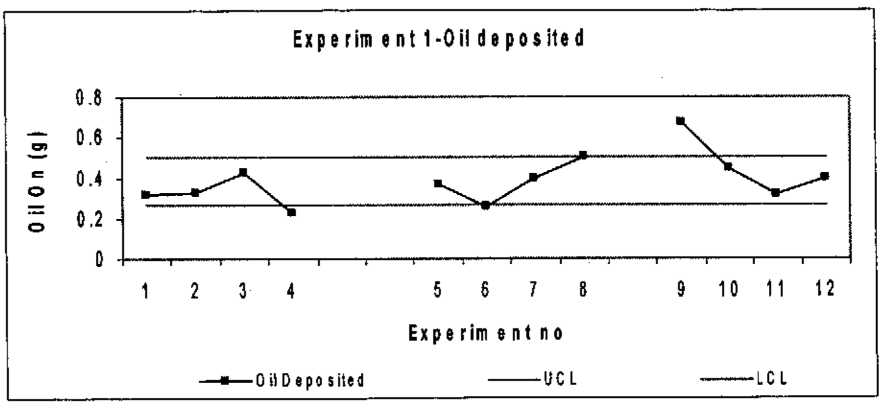
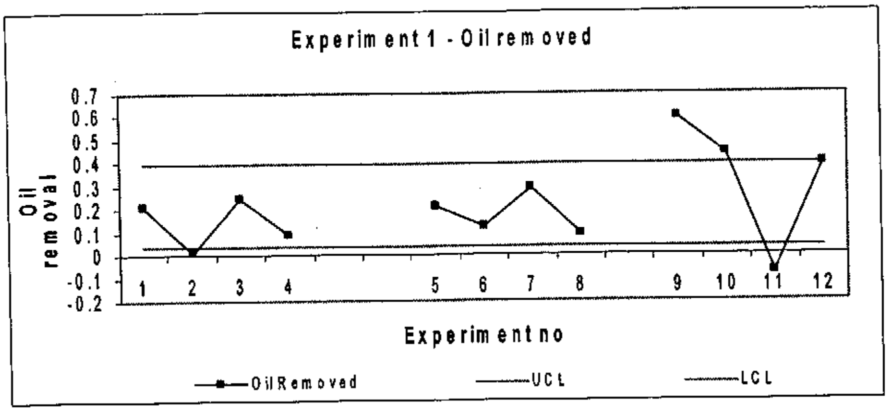


Figure D2: Graphical representation of results



Trial 2

Table D5: Results obtained from trial 2

	Oil On	LCL	UCL		Oil Removed	LCL	UCL
A	0.4967	0.293141	0.482826	1	0.3648	0.011797	0.497069
B	0.3765	0.293141	0.482826	2	0.1944	0.011797	0.497069
C	0.401	0.293141	0.482826	3	0.1826	0.011797	0.497069
D	0.3697	0.293141	0.482826	4	0.2317	0.011797	0.497069
A	0.4007	0.293141	0.482826	5	0.1539	0.011797	0.497069
B	0.4082	0.293141	0.482826	6	0.262	0.011797	0.497069
C	0.1437	0.293141	0.482826	7	-0.0873	0.011797	0.497069
D	0.3546	0.293141	0.482826	8	0.2317	0.011797	0.497069
A	0.4319	0.293141	0.482826	9	0.8255	0.011797	0.497069
B	0.3692	0.293141	0.482826	10	0.2004	0.011797	0.497069
C	0.5005	0.293141	0.482826	11	0.2695	0.011797	0.497069
D	0.4031	0.293141	0.482826	12	0.224	0.011797	0.497069

Figure D3: Graphical representation of results

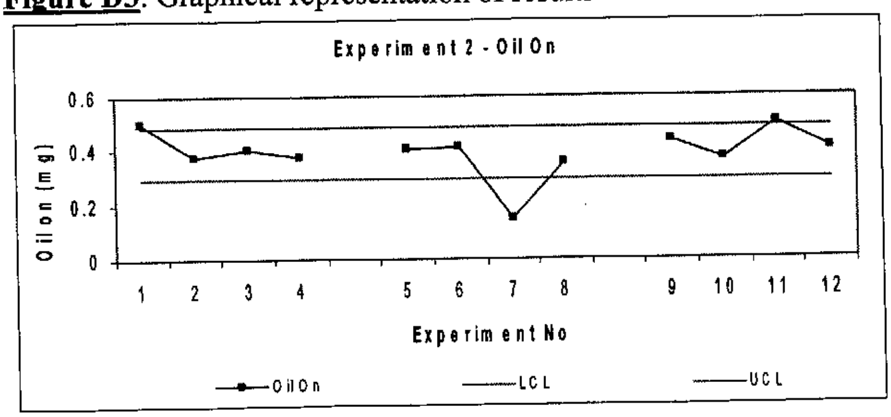
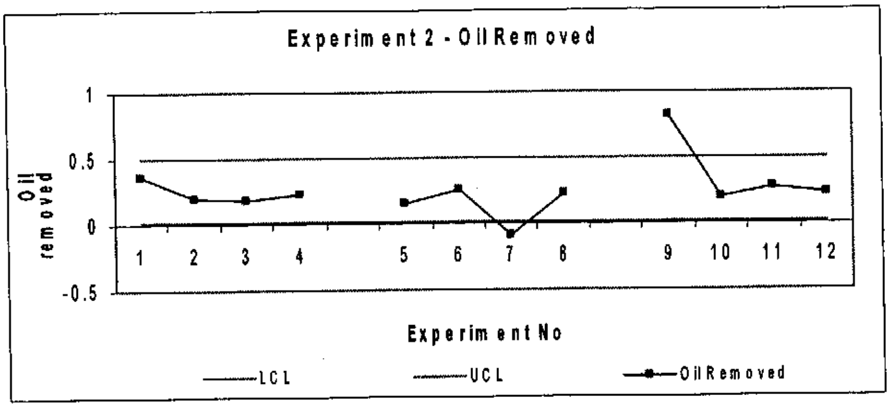


Figure D4: Graphical representation of results



Trial 3

Table D6: Results obtained from trial 3

	Oil On	LCL	UCL		Oil Removed	LCL	UCL
A	0.355	0.344812	0.465705	1	0.24	0.097518	0.278432
B	0.2845	0.344812	0.465705	2	0.0933	0.097518	0.278432
C	0.3928	0.344812	0.465705	3	0.0022	0.097518	0.278432
D	0.3791	0.344812	0.465705	4	0.1608	0.097518	0.278432
A	0.435	0.344812	0.465705	5	0.1442	0.097518	0.278432
B	0.4453	0.344812	0.465705	6	0.2602	0.097518	0.278432
C	0.4812	0.344812	0.465705	7	0.2598	0.097518	0.278432
D	0.4563	0.344812	0.465705	8	0.2133	0.097518	0.278432
A	0.3239	0.344812	0.465705	9	0.1807	0.097518	0.278432
B	0.5119	0.344812	0.465705	10	0.3425	0.097518	0.278432
C	0.3925	0.344812	0.465705	11	0.2109	0.097518	0.278432
D	0.4056	0.344812	0.465705	12	0.1478	0.097518	0.278432

Figure D5: Graphical representation of results

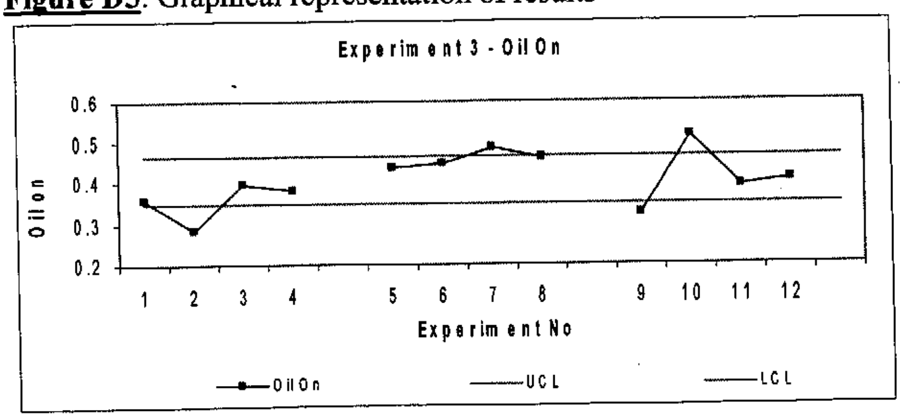
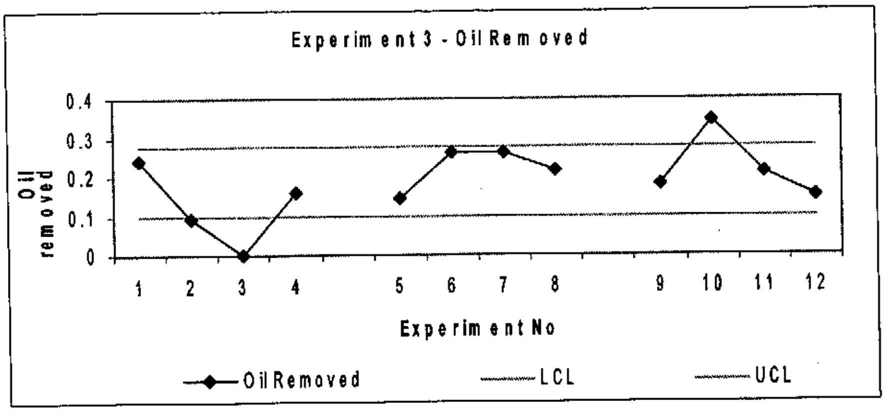


Figure D6: Graphical representation of results



Trial 4

Table D7: Results obtained form trial 4

	Oil on	LCL	UCL		Oil Removed	LCL	UCL
A	0.3138	0.304231	0.360052	1	0.089	0.007068	0.255765
B	0.2848	0.304231	0.360052	2	0.075	0.007068	0.255765
C	0.3217	0.304231	0.360052	3	0.0555	0.007068	0.255765
D	0.3898	0.304231	0.360052	4	0.1891	0.007068	0.255765
A	0.3501	0.304231	0.360052	5	0.079	0.007068	0.255765
B	0.3267	0.304231	0.360052	6	0.1144	0.007068	0.255765
C	0.3206	0.304231	0.360052	7	0.1789	0.007068	0.255765
D	0.3216	0.304231	0.360052	8	0.0185	0.007068	0.255765
A	0.3266	0.304231	0.360052	9	0.4863	0.007068	0.255765
B	0.3435	0.304231	0.360052	10	0.0524	0.007068	0.255765
C	0.3342	0.304231	0.360052	11	0.1806	0.007068	0.255765
D	0.3523	0.304231	0.360052	12	0.0583	0.007068	0.255765

Figure D7: Graphical representation of results

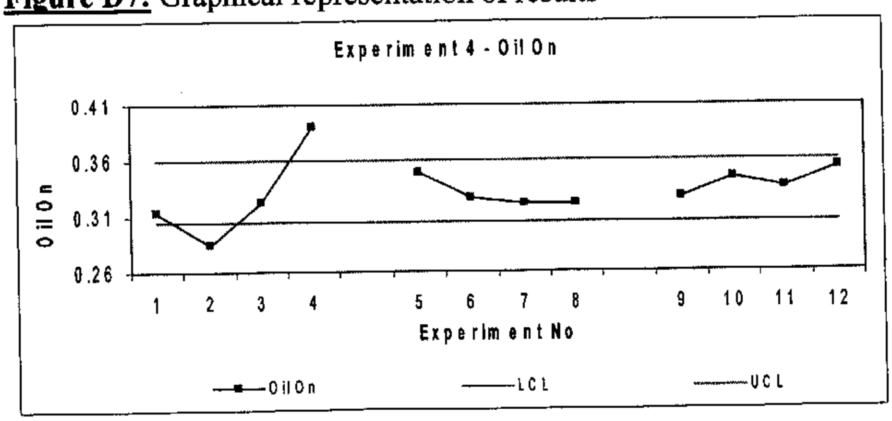
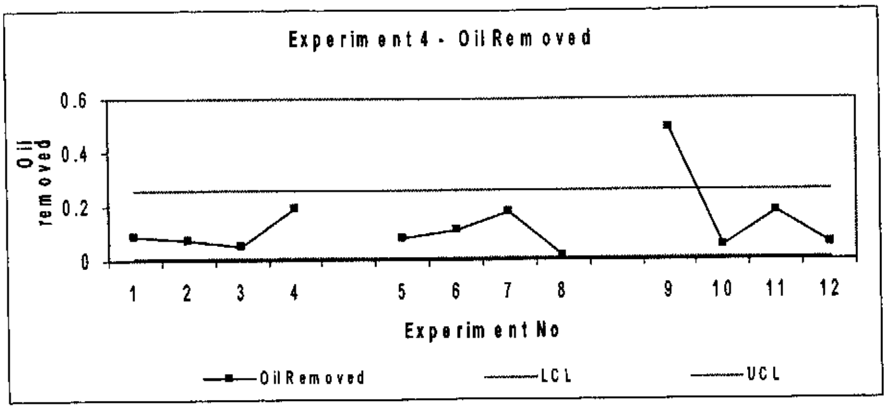


Figure D8: Graphical representation of results



Trial 5

Table D8: Results obtained from trial 5

	Oil On	LCL	UCL		Oil Removed	LCL	UCL
A	0.404	0.313075	0.450608	1	0.2913	0.084624	0.333426
B	0.25	0.313075	0.450608	2	0.1682	0.084624	0.333426
C	0.4581	0.313075	0.450608	3	0.2826	0.084624	0.333426
D	0.386	0.313075	0.450608	4	-0.0821	0.084624	0.333426
A	0.4625	0.313075	0.450608	5	0.2853	0.084624	0.333426
B	0.446	0.313075	0.450608	6	0.2918	0.084624	0.333426
C	0.3487	0.313075	0.450608	7	0.2465	0.084624	0.333426
D	0.5087	0.313075	0.450608	8	0.3859	0.084624	0.333426
A	0.3308	0.313075	0.450608	9	0.228	0.084624	0.333426
B	0.3929	0.313075	0.450608	10	0.2339	0.084624	0.333426
C	0.3282	0.313075	0.450608	11	0.079	0.084624	0.333426
D	0.2662	0.313075	0.450608	12	0.0979	0.084624	0.333426

Figure D9: Graphical representation of results

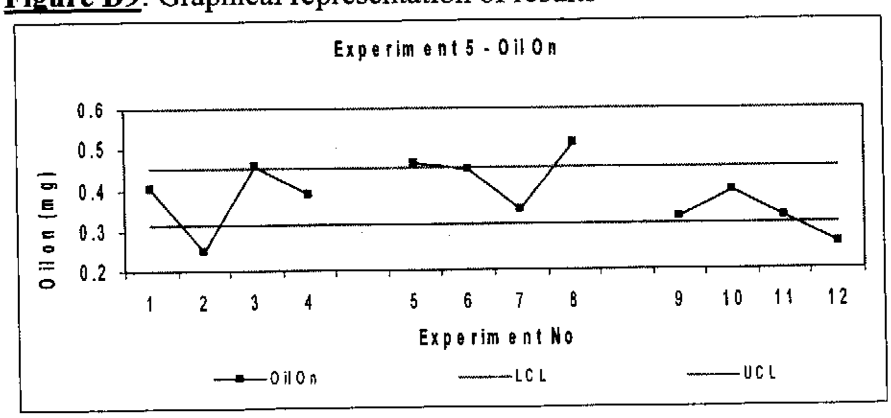
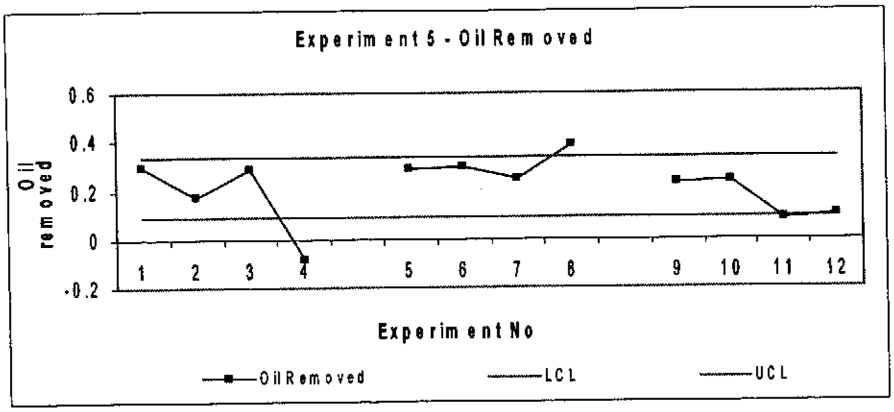


Figure D10: Graphical representation of results



Trial 6

Table D9: Results obtained from trial 6

	Oil On	LCL	UCL		Oil Removed	LCL	UCL
A	0.7454	0.362077	0.706573	1	0.665	0.167908	0.511926
B	0.6768	0.362077	0.706573	2	0.5258	0.167908	0.511926
C	0.7579	0.362077	0.706573	3	0.5693	0.167908	0.511926
D	0.9599	0.362077	0.706573	4	0.7249	0.167908	0.511926
A	0.5048	0.362077	0.706573	5	0.2345	0.167908	0.511926
B	0.4024	0.362077	0.706573	6	0.2221	0.167908	0.511926
C	0.5269	0.362077	0.706573	7	0.1728	0.167908	0.511926
D	0.3119	0.362077	0.706573	8	0.1575	0.167908	0.511926
A	0.3685	0.362077	0.706573	9	0.3015	0.167908	0.511926
B	0.4009	0.362077	0.706573	10	0.2242	0.167908	0.511926
C	0.3865	0.362077	0.706573	11	0.2036	0.167908	0.511926
D	0.37	0.362077	0.706573	12	0.0778	0.167908	0.511926

Figure D11:

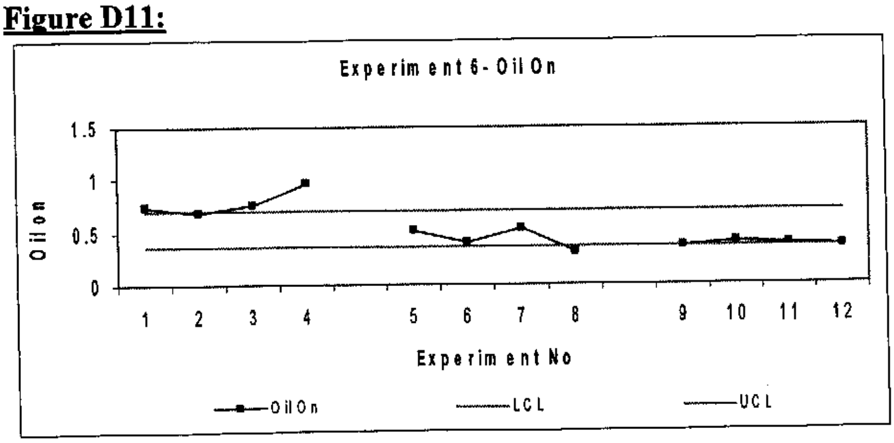
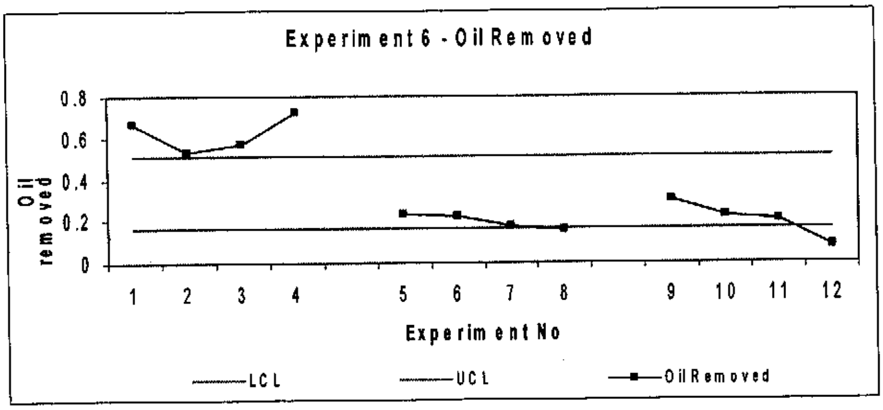


Figure D12:



Trial 7

Table D10: Results from trial 7

	Oil On	LCL	UCL		Oil Removed	LCL	UCL
A	0.3548	0.233321	0.411896	1	0.1431	0.004724	0.263043
B	0.3759	0.233321	0.411896	2	0.219	0.004724	0.263043
C	0.3121	0.233321	0.411896	3	0.0512	0.004724	0.263043
D	0.0918	0.233321	0.411896	4	-0.1308	0.004724	0.263043
A	0.3433	0.233321	0.411896	5	0.1434	0.004724	0.263043
B	0.3054	0.233321	0.411896	6	0.1057	0.004724	0.263043
C	0.3087	0.233321	0.411896	7	0.1225	0.004724	0.263043
D	0.2996	0.233321	0.411896	8	0.1183	0.004724	0.263043
A	0.3675	0.233321	0.411896	9	0.1945	0.004724	0.263043
B	0.3855	0.233321	0.411896	10	0.1173	0.004724	0.263043
C	0.4277	0.233321	0.411896	11	0.3551	0.004724	0.263043
D	0.299	0.233321	0.411896	12	0.1673	0.004724	0.263043

Figure D13: Graphical representation of results

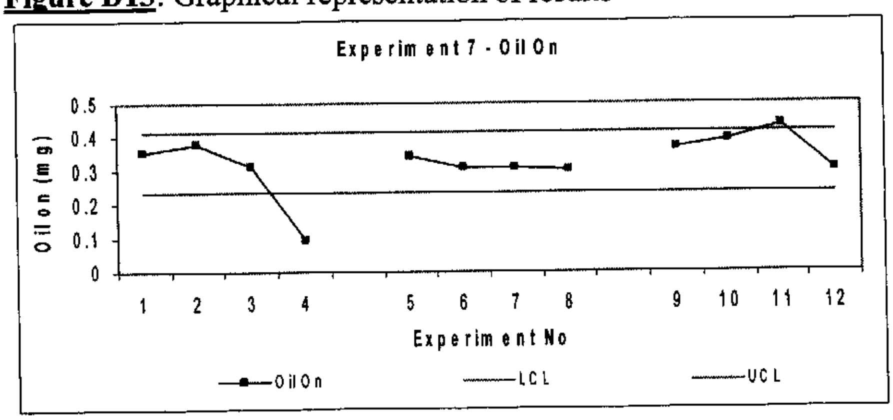
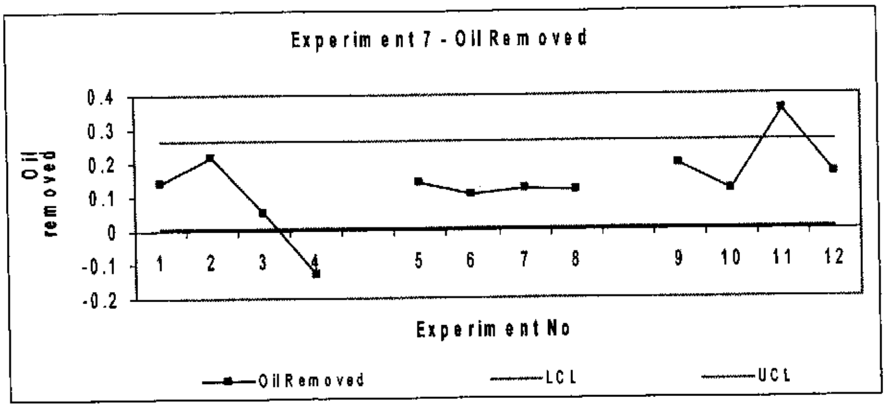


Figure D14: Graphical representation of results



Trial 8

Table D11: Results obtained from trial 8

	Oil On	LCL	UCL		Oil Removed	LCL	UCL
A	0.307	0.294613	0.447404	1	0.2427	0.057386	0.318097
B	0.3205	0.294613	0.447404	2	0.0999	0.057386	0.318097
C	0.3067	0.294613	0.447404	3	0.0747	0.057386	0.318097
D	0.2887	0.294613	0.447404	4	0.0883	0.057386	0.318097
A	0.5307	0.294613	0.447404	5	0.4756	0.057386	0.318097
B	0.4266	0.294613	0.447404	6	0.1976	0.057386	0.318097
C	0.4085	0.294613	0.447404	7	0.2415	0.057386	0.318097
D	0.5188	0.294613	0.447404	8	0.2886	0.057386	0.318097
A	0.2433	0.294613	0.447404	9	-0.0148	0.057386	0.318097
B	0.3488	0.294613	0.447404	10	0.1815	0.057386	0.318097
C	0.3784	0.294613	0.447404	11	0.1296	0.057386	0.318097
D	0.3741	0.294613	0.447404	12	0.2477	0.057386	0.318097

Figure D15: Graphical representation of results

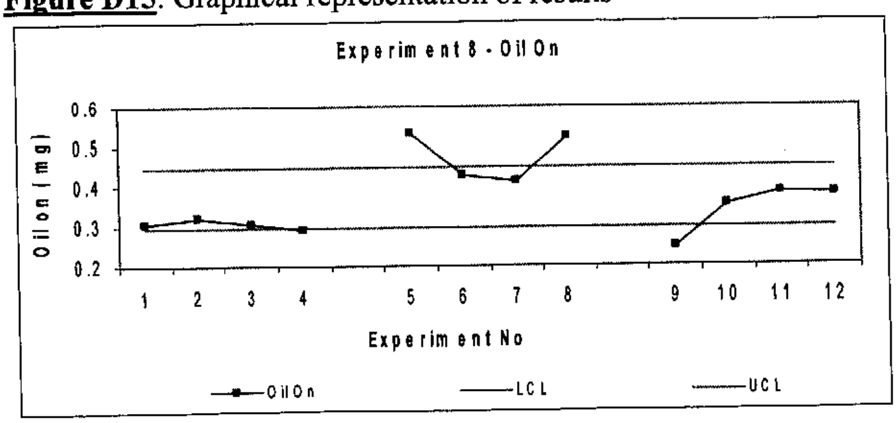
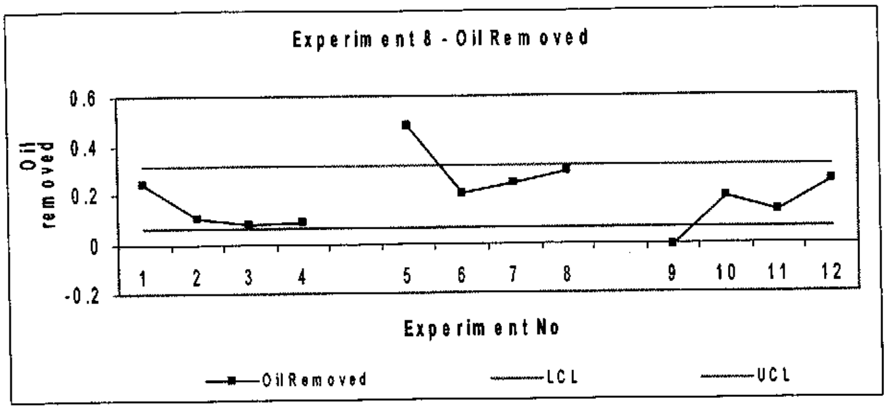


Figure D16: Graphical representation of results



Trial 9

Table D12: Results obtained from trial 9

	Oil on	UCL	LCL		Oil Removed	UCL	LCL
A	0.3022	0.429147	0.282736	1	0.1608	0.336483	0.164767
B	0.4138	0.429147	0.282736	2	0.2455	0.336483	0.164767
C	0.2926	0.429147	0.282736	3	0.1407	0.336483	0.164767
D	0.4049	0.429147	0.282736	4	0.26	0.336483	0.164767
A	0.3687	0.429147	0.282736	5	0.3099	0.336483	0.164767
B	0.2319	0.429147	0.282736	6	0.1098	0.336483	0.164767
C	0.5016	0.429147	0.282736	7	0.4328	0.336483	0.164767
D	0.2262	0.429147	0.282736	8	0.1539	0.336483	0.164767
A	0.3644	0.429147	0.282736	9	0.2992	0.336483	0.164767
B	0.4079	0.429147	0.282736	10	0.2738	0.336483	0.164767
C	0.2608	0.429147	0.282736	11	0.2442	0.336483	0.164767
D	0.4963	0.429147	0.282736	12	0.3769	0.336483	0.164767

Figure D17: Graphical representation of results

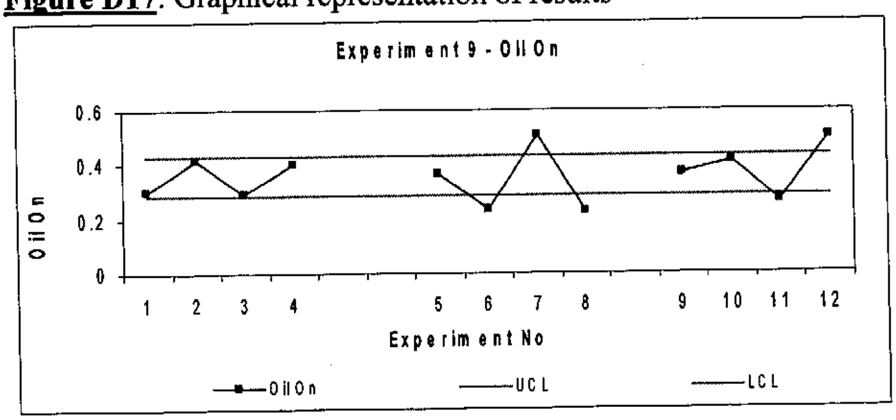
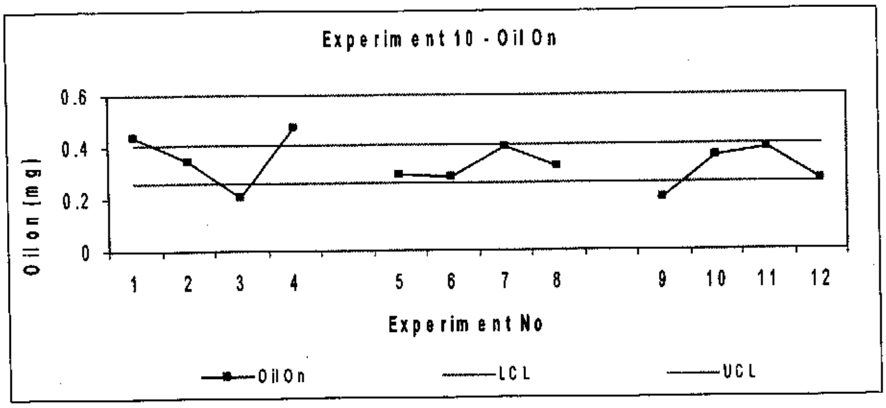


Figure D18: Graphical representation of results



Trial 10

Table D13: Results obtained from trial 10

	Oil On	LCL	UCL		Oil Removed	LCL	UCL
A	0.4385	0.258098	0.40738	1	0.1603	0.042285	0.251694
B	0.3427	0.258098	0.40738	2	0.1907	0.042285	0.251694
C	0.2082	0.258098	0.40738	3	0.0273	0.042285	0.251694
D	0.4794	0.258098	0.40738	4	0.38	0.042285	0.251694
A	0.2918	0.258098	0.40738	5	0.0933	0.042285	0.251694
B	0.2818	0.258098	0.40738	6	0.0679	0.042285	0.251694
C	0.4033	0.258098	0.40738	7	0.1817	0.042285	0.251694
D	0.324	0.258098	0.40738	8	0.1473	0.042285	0.251694
A	0.1986	0.258098	0.40738	9	-0.0139	0.042285	0.251694
B	0.3629	0.258098	0.40738	10	0.3078	0.042285	0.251694
C	0.3888	0.258098	0.40738	11	0.1691	0.042285	0.251694
D	0.27287	0.258098	0.40738	12	0.05237	0.042285	0.251694

Figure D19: Graphical representation of results

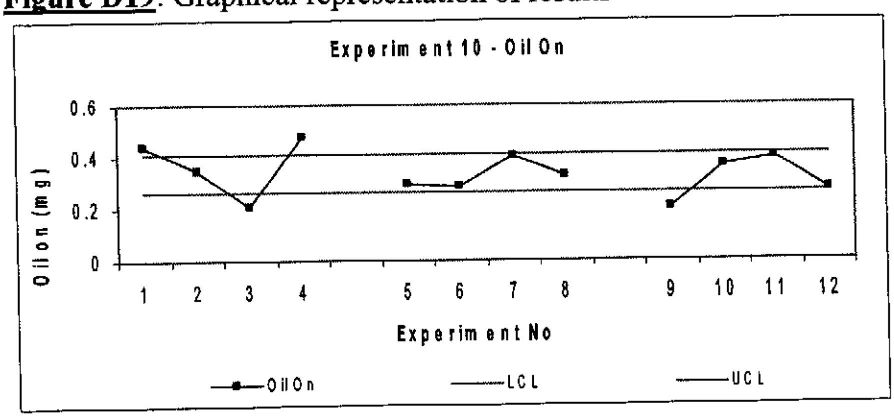
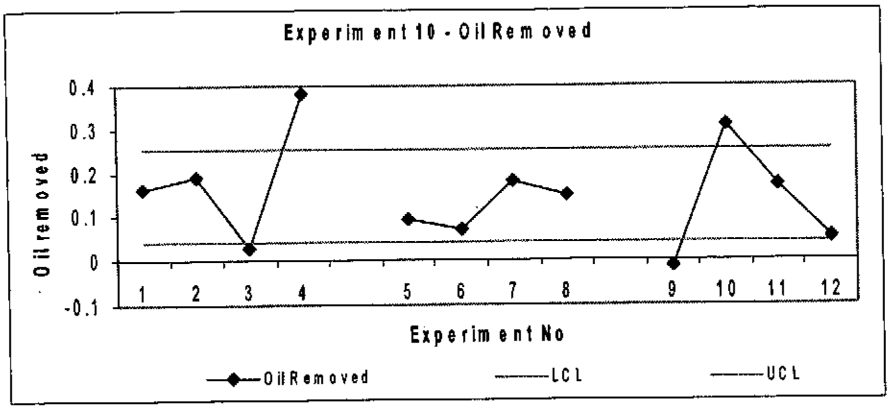


Figure D20: Graphical representation of results



Trial 11

Table D14: Results obtained from trial 11

	Oil On	LCL	UCL		Oil Removed	UCL	LCL
A	0.3967	0.283671	0.476546	1	0.2648	0.290782	0.099501
B	0.3765	0.283671	0.476546	2	0.1944	0.290782	0.099501
C	0.401	0.283671	0.476546	3	0.1826	0.290782	0.099501
D	0.3697	0.283671	0.476546	4	0.2317	0.290782	0.099501
A	0.4007	0.283671	0.476546	5	0.1539	0.290782	0.099501
B	0.4082	0.283671	0.476546	6	0.262	0.290782	0.099501
C	0.1437	0.283671	0.476546	7	-0.0843	0.290782	0.099501
D	0.3546	0.283671	0.476546	8	0.1817	0.290782	0.099501
A	0.4319	0.283671	0.476546	9	0.2555	0.290782	0.099501
B	0.3687	0.283671	0.476546	10	0.1999	0.290782	0.099501
C	0.5065	0.283671	0.476546	11	0.2755	0.290782	0.099501
D	0.4031	0.283671	0.476546	12	0.224	0.290782	0.099501

Figure D21: Graphical representation of results

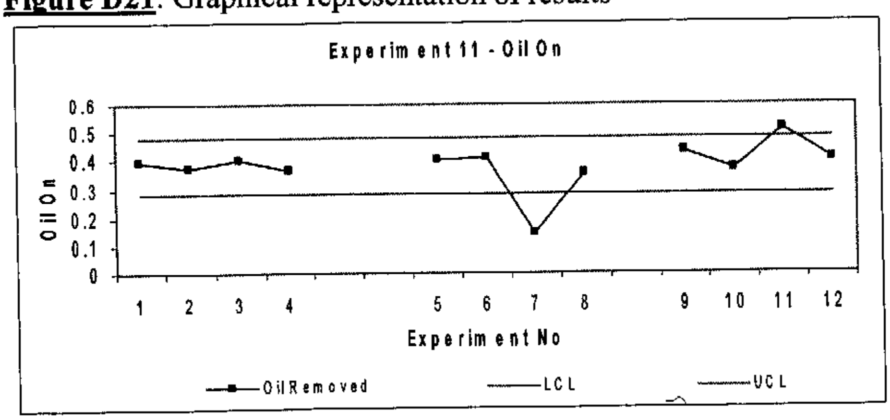
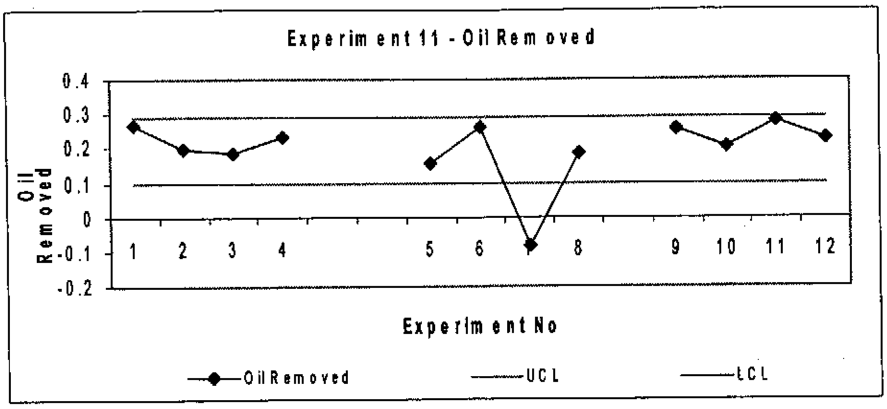


Figure D22: Graphical representation of results



Trial 12

Table D15: Results from trial 13

	Oil On	LCL	UCL		Oil Removed	LCL
A	0.3037	0.270683	0.384133	1	0.1054	0.130541
B	0.335	0.270683	0.384133	2	0.1309	0.130541
C	0.3639	0.270683	0.384133	3	0.2913	0.130541
D	0.4197	0.270683	0.384133	4	0.3002	0.130541
A	0.4387	0.270683	0.384133	5	0.3073	0.130541
B	0.3213	0.270683	0.384133	6	0.1498	0.130541
C	0.3578	0.270683	0.384133	7	0.2827	0.130541
D	0.3521	0.270683	0.384133	8	0.1729	0.130541
A	0.2501	0.270683	0.384133	9	0.1301	0.130541
B	0.2801	0.270683	0.384133	10	0.1315	0.130541
C	0.2812	0.270683	0.384133	11	0.1051	0.130541
D	0.2253	0.270683	0.384133	12	0.1049	0.130541

Figure D23:

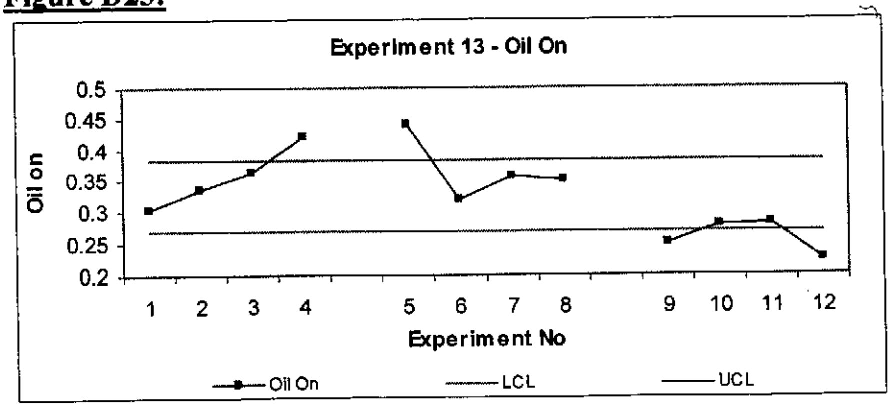
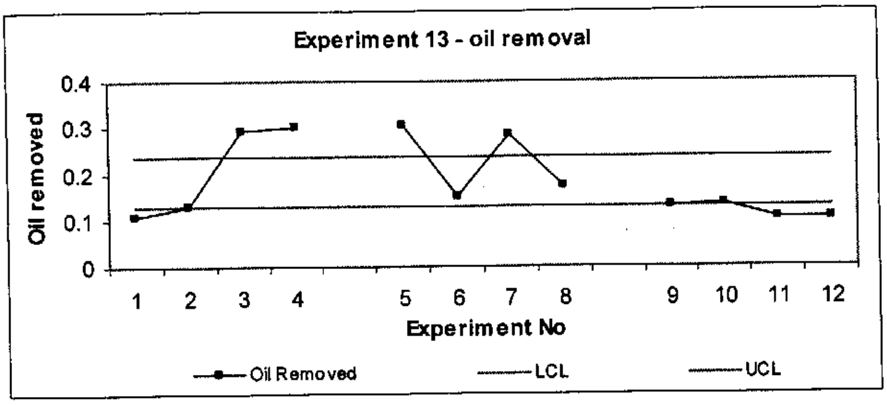


Figure D24:



Trial 13

Table D16: Results from trial 14

	Oil On	LCL	UCL		Oil Removed	LCL	UCL
A	0.3011	0.330895	0.408088	1	0.135	0.130426	0.269341
B	0.3185	0.330895	0.408088	2	0.062	0.130426	0.269341
C	0.2826	0.330895	0.408088	3	0.1544	0.130426	0.269341
D	0.3498	0.330895	0.408088	4	0.0862	0.130426	0.269341
A	0.4097	0.330895	0.408088	5	0.2424	0.130426	0.269341
B	0.3123	0.330895	0.408088	6	0.1328	0.130426	0.269341
C	0.4095	0.330895	0.408088	7	0.217	0.130426	0.269341
D	0.3868	0.330895	0.408088	8	0.2511	0.130426	0.269341
A	0.4247	0.330895	0.408088	9	0.2742	0.130426	0.269341
B	0.4278	0.330895	0.408088	10	0.3233	0.130426	0.269341
C	0.4121	0.330895	0.408088	11	0.2125	0.130426	0.269341
D	0.399	0.330895	0.408088	12	0.3077	0.130426	0.269341

Figure D25:

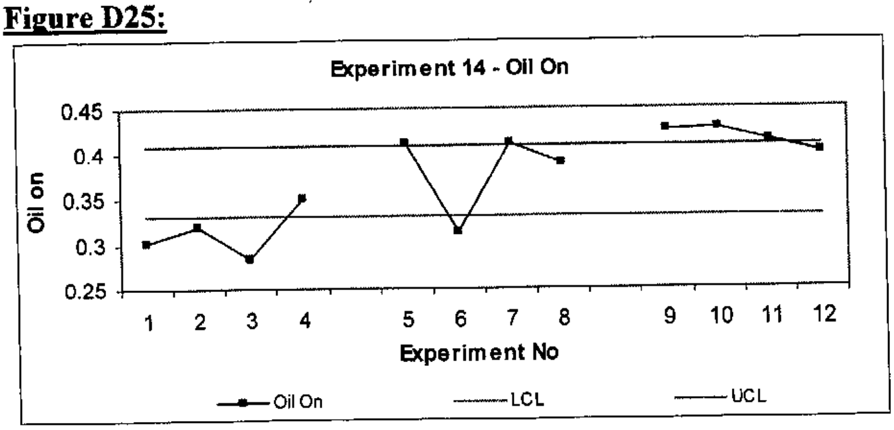
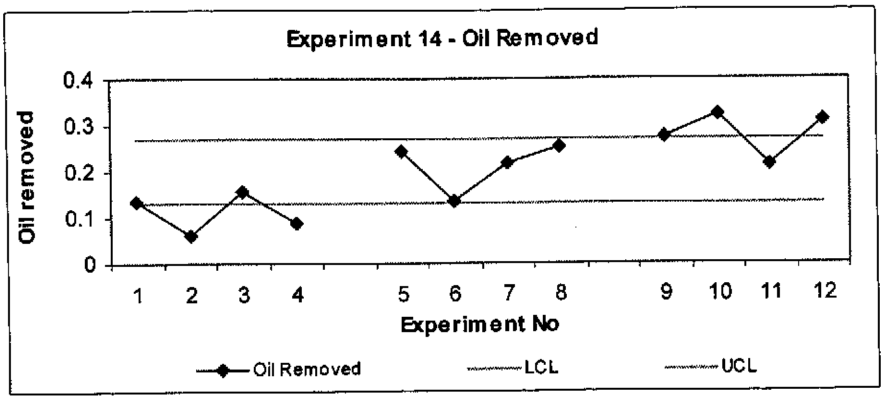


Figure D26:



Trial 14

Table D17: Results from trial 15

	Oil On	LCL	UCL		Oil Removed	LCL	UCL
A	0.3774	0.302199	0.468918	1	0.309	0.09521	0.33859
B	0.426	0.302199	0.468918	2	0.2595	0.09521	0.33859
C	0.3411	0.302199	0.468918	3	0.211	0.09521	0.33859
D	0.3938	0.302199	0.468918	4	0.2888	0.09521	0.33859
A	0.3979	0.302199	0.468918	5	0.2221	0.09521	0.33859
B	0.2842	0.302199	0.468918	6	0.1112	0.09521	0.33859
C	0.3598	0.302199	0.468918	7	0.197	0.09521	0.33859
D	0.3337	0.302199	0.468918	8	0.1224	0.09521	0.33859
A	0.5191	0.302199	0.468918	9	0.375	0.09521	0.33859
B	0.2341	0.302199	0.468918	10	-0.0573	0.09521	0.33859
C	0.5477	0.302199	0.468918	11	0.4005	0.09521	0.33859
D	0.4119	0.302199	0.468918	12	0.1636	0.09521	0.33859

Figure D27:

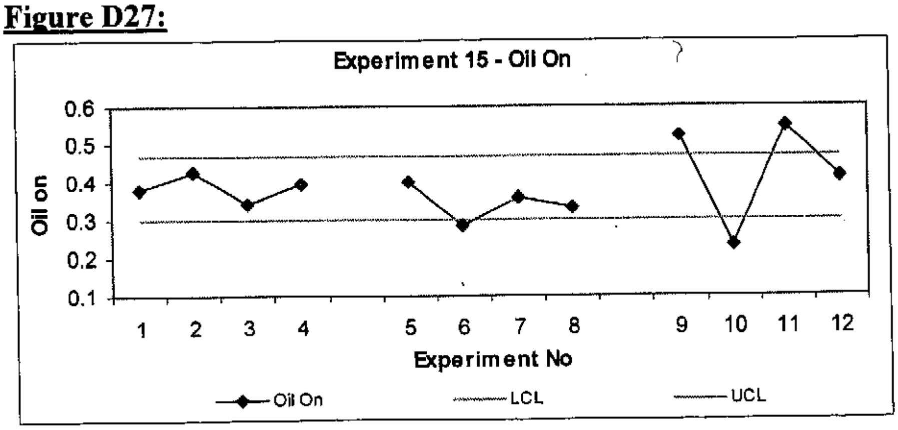
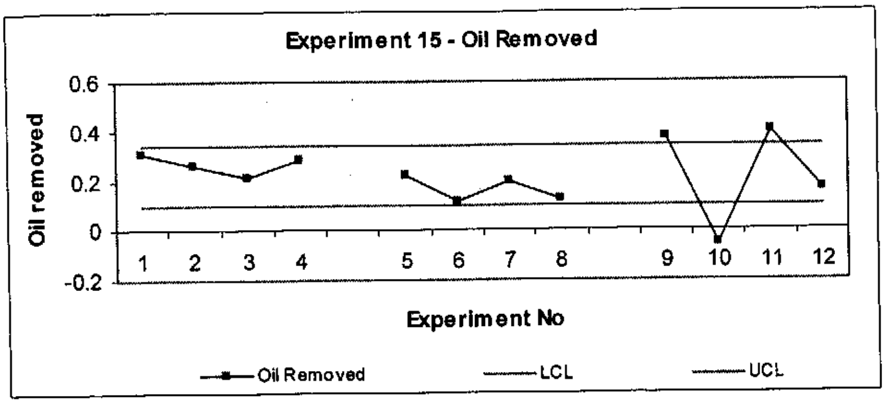


Figure D28:



Trial 15

Table D18: Results from trial 16

	Oil On	LCL	UCL		Oil Removed	LCL	UCL
A	0.2876	0.263307	0.39026	1	0.1777	0.050586	0.280197
B	0.2619	0.263307	0.39026	2	0.192	0.050586	0.280197
C	0.2791	0.263307	0.39026	3	0.1093	0.050586	0.280197
D	0.2396	0.263307	0.39026	4	0.0702	0.050586	0.280197
A	0.449	0.263307	0.39026	5	0.2812	0.050586	0.280197
B	0.3146	0.263307	0.39026	6	0.2097	0.050586	0.280197
C	0.3415	0.263307	0.39026	7	0.1215	0.050586	0.280197
D	0.3018	0.263307	0.39026	8	0.2216	0.050586	0.280197
A	0.2102	0.263307	0.39026	9	-0.0715	0.050586	0.280197
B	0.4405	0.263307	0.39026	10	0.0994	0.050586	0.280197
C	0.3618	0.263307	0.39026	11	0.2132	0.050586	0.280197
D	0.4338	0.263307	0.39026	12	0.3604	0.050586	0.280197

Figure D29:

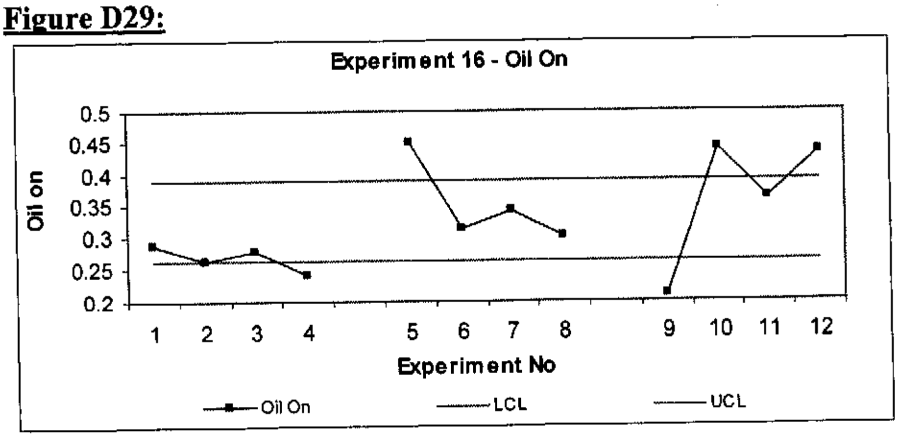
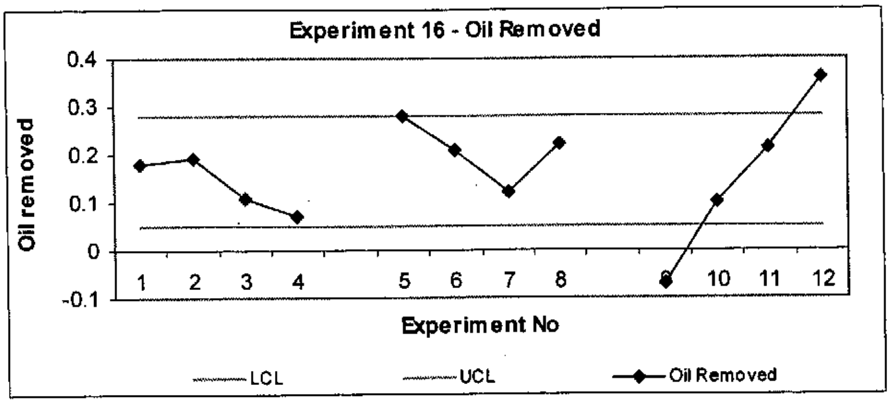


Figure D30:



Experiment 16 - Oil Removed
Oil removed
0.4
0.3
0.2
0.1
0
-0.1
1 2 3 4 5 6 7 8 9 10 11 12
Experiment No
LCL
UCL
Oil Removed

Appendix D4: Detailed spreadsheet calculations for the 16 trials

Table D19: Calculations for trial 1

A	66.8517	23.6324	66.543	23.7405	0.3147	0.2670	0.5045	1	0.2066	0.3959	0.0388
B	74.2354	24.1723	73.913	24.4866	0.3224	0.2670	0.5045	2	0.0081	0.3959	0.0388
C	59.636	24.0249	59.2127	24.2029	0.4233	0.2670	0.5045	3	0.2453	0.3959	0.0388
D	62.6415	23.7419	62.1452	23.8779	0.2239	0.2670	0.5045	4	0.0879	0.3959	0.0388
						0.2670	0.5045			0.3959	0.0388
						0.2670	0.5045			0.3959	0.0388
A	66.543	24.5405	66.1766	24.7002	0.3664	0.2670	0.5045	5	0.2067	0.3959	0.0388
B	73.913	23.41113	73.659	23.5381	0.254	0.2670	0.5045	6	0.1272	0.3959	0.0388
C	59.2127	24.0862	58.6134	24.1931	0.3993	0.2670	0.5045	7	0.2924	0.3959	0.0388
D	61.913	24.3131	61.4098	25.029	0.5032	0.2670	0.5045	8	0.0879	0.3959	0.0388
						0.2670	0.5045			0.3959	0.0388
A	66.1766	23.4855	65.5059	23.563	0.6707	0.2670	0.5045	9	0.5934	0.3959	0.0388
B	73.659	23.5416	73.2145	23.5485	0.4445	0.2670	0.5045	10	0.4376	0.3959	0.0388
C	58.8139	24.1435	58.5011	24.5346	0.3128	0.2670	0.5045	11	-0.0783	0.3959	0.0388
D	61.3974	24.5139	61.0032	24.5146	0.3942	0.2670	0.5045	12	0.3935	0.3959	0.0388
					4.6294				2.6083		

Table D20: Calculations for trial 2

A	59.757	24.0745	59.353	24.1872	0.404	0.3131	0.4506	1	0.2913	0.0846	0.3334
B	66.897	23.3056	66.647	23.3874	0.25	0.3131	0.4506	2	0.1682	0.0846	0.3334
C	53.1419	24.3613	52.6838	24.5368	0.4581	0.3131	0.4506	3	0.2826	0.0846	0.3334
D	54.7842	23.387	54.3982	23.8551	0.386	0.3131	0.4506	4	-0.0821	0.0846	0.3334
						0.3131	0.4506			0.0846	0.3334
A	59.353	24.4732	58.8905	24.6504	0.4625	0.3131	0.4506	5	0.2853	0.0846	0.3334
B	66.649	24.0793	66.203	24.2335	0.446	0.3131	0.4506	6	0.2918	0.0846	0.3334
C	52.6838	24.0467	52.3351	24.1489	0.3487	0.3131	0.4506	7	0.2465	0.0846	0.3334
D	54.3982	23.7327	53.8895	23.8555	0.5087	0.3131	0.4506	8	0.3859	0.0846	0.3334
						0.3131	0.4506			0.0846	0.3334
A	58.8905	23.7288	58.5597	23.8316	0.3308	0.3131	0.4506	9	0.228	0.0846	0.3334
B	66.203	24.2825	65.8101	24.4415	0.3929	0.3131	0.4506	10	0.2339	0.0846	0.3334
C	52.3351	23.5235	52.0069	23.7727	0.3282	0.3131	0.4506	11	0.079	0.0846	0.3334
D	53.8895	24.2867	53.6233	24.455	0.2662	0.3131	0.4506	12	0.0979	0.0846	0.3334
					4.5821				2.5083		

Table D21: Calculations for trial 3

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
A	64.6822	23.6269	64.1855	23.7588	0.4967	0.2931	0.4828	1	0.3648	0.0118	0.4971
B	71.8581	24.0817	71.4816	24.2638	0.3765	0.2931	0.4828	2	0.1944	0.0118	0.4971
C	57.2023	24.0176	56.8013	24.236	0.401	0.2931	0.4828	3	0.1826	0.0118	0.4971
D	59.7835	23.3979	59.4138	23.5359	0.3697	0.2931	0.4828	4	0.2317	0.0118	0.4971
						0.2931	0.4828			0.0118	0.4971
A	64.1855	23.48	63.7848	23.7268	0.4007	0.2931	0.4828	5	0.1539	0.0118	0.4971
B	71.4816	23.7413	71.0734	23.8875	0.4082	0.2931	0.4828	6	0.262	0.0118	0.4971
C	56.5013	24.3456	56.3576	24.5766	0.1437	0.2931	0.4828	7	-0.0873	0.0118	0.4971
D	59.4138	23.5188	59.0592	23.6417	0.3546	0.2931	0.4828	8	0.2317	0.0118	0.4971
						0.2931	0.4828			0.0118	0.4971
A	63.7848	24.8049	63.3529	24.4113	0.4319	0.2931	0.4828	9	0.8255	0.0118	0.4971
B	71.0734	24.4835	70.7042	24.6523	0.3692	0.2931	0.4828	10	0.2004	0.0118	0.4971
C	56.3576	23.4025	55.8571	23.6335	0.5005	0.2931	0.4828	11	0.2695	0.0118	0.4971
D	59.0592	24.0611	58.6561	24.2402	0.4031	0.2931	0.4828	12	0.224	0.0118	0.4971
				288.5644					3.0532		
			[illegible]	[illegible]					[illegible]		
			[illegible]	[illegible]							

Table D22: Calculations for trial 4

A	65.8069	23.7356	65.4519	23.8506	0.355	0.3448	0.4657	1	0.24	0.0975	0.2784
B	73.108	23.8127	72.8263	24.0039	0.2845	0.3448	0.4657	2	0.0933	0.0975	0.2784
C	58.5084	23.4823	58.1156	23.8729	0.3928	0.3448	0.4657	3	0.0022	0.0975	0.2784
D	61.0586	24.2938	60.6795	24.5121	0.3791	0.3448	0.4657	4	0.1608	0.0975	0.2784
						0.3448	0.4657			0.0975	0.2784
A	65.4489	24.0907	65.0139	24.3815	0.435	0.3448	0.4657	5	0.1442	0.0975	0.2784
B	72.8234	24.064	72.3781	24.2491	0.4453	0.3448	0.4657	6	0.2602	0.0975	0.2784
C	58.0906	23.0739	57.6094	23.2953	0.4812	0.3448	0.4657	7	0.2598	0.0975	0.2784
D	60.653	23.7571	30.1967	24.0001	0.4563	0.3448	0.4657	8	0.2133	0.0975	0.2784
						0.3448	0.4657			0.0975	0.2784
A	65.0106	24.4978	64.6867	24.641	0.3239	0.3448	0.4657	9	0.1807	0.0975	0.2784
B	72.3752	24.3638	71.8633	24.5332	0.5119	0.3448	0.4657	10	0.3425	0.0975	0.2784
C	57.6038	23.1098	57.2113	23.2914	0.3925	0.3448	0.4657	11	0.2109	0.0975	0.2784
D	60.179	24.2947	259.7734	24.5525	0.4056	0.3448	0.4657	12	0.1478	0.0975	0.2784
				264.6311					2.1079		

Table D23: Calculations for trial 5

[redacted]											
A	61.3798	23.0585	61.066	23.2833	0.3138	0.3042	0.3601	1	0.089	0.0071	0.2558
B	68.6447	23.8022	68.3599	24.012	0.2848	0.3042	0.3601	2	0.075	0.0071	0.2558
C	53.8299	24.2839	53.5082	24.5501	0.3217	0.3042	0.3601	3	0.0555	0.0071	0.2558
D	56.5607	24.08	56.1709	24.2807	0.3898	0.3042	0.3601	4	0.1891	0.0071	0.2558
						0.3042	0.3601			0.0071	0.2558
A	61.066	23.7487	60.7159	24.0198	0.3501	0.3042	0.3601	5	0.079	0.0071	0.2558
B	68.3599	23.4666	68.0332	23.6789	0.3267	0.3042	0.3601	6	0.1144	0.0071	0.2558
C	53.5082	23.0942	53.1876	23.2359	0.3206	0.3042	0.3601	7	0.1789	0.0071	0.2558
D	52.1709	24.3605	51.8493	24.6636	0.3216	0.3042	0.3601	8	0.0185	0.0071	0.2558
						0.3042	0.3601			0.0071	0.2558
A	60.7159	23.7264	60.3893	23.5667	0.3266	0.3042	0.3601	9	0.4863	0.0071	0.2558
B	68.0332	24.2827	67.6897	24.5738	0.3435	0.3042	0.3601	10	0.0524	0.0071	0.2558
C	54.2206	24.4747	53.8864	24.6283	0.3342	0.3042	0.3601	11	0.1806	0.0071	0.2558
D	55.8493	24.0528	55.497	24.3468	0.3523	0.3042	0.3601	12	0.0583	0.0071	0.2558
					3.9857				1.577		

Table D24: Calculations for trial 6

A	53.3979	23.7987	52.6525	23.8791	0.7454	0.3621	0.7066	1	0.665	0.1679	0.5119
B	60.5697	24.0742	59.8929	24.2252	0.6768	0.3621	0.7066	2	0.5258	0.1679	0.5119
C	46.4353	23.0857	45.6774	23.2743	0.7579	0.3621	0.7066	3	0.5693	0.1679	0.5119
D	50.801	24.3567	49.8411	24.5917	0.9599	0.3621	0.7066	4	0.7249	0.1679	0.5119
						0.3621	0.7066			0.1679	0.5119
A	52.6525	24.3399	52.1477	24.6102	0.5048	0.3621	0.7066	5	0.2345	0.1679	0.5119
B	59.8929	23.5006	59.4905	23.6809	0.4024	0.3621	0.7066	6	0.2221	0.1679	0.5119
C	45.6774	24.0476	45.1505	24.4017	0.5269	0.3621	0.7066	7	0.1728	0.1679	0.5119
D	49.8411	24.2267	49.5292	24.3811	0.3119	0.3621	0.7066	8	0.1575	0.1679	0.5119
						0.3621	0.7066			0.1679	0.5119
A	52.1477	23.7436	51.7792	23.8106	0.3685	0.3621	0.7066	9	0.3015	0.1679	0.5119
B	59.4905	23.3894	59.0896	23.5661	0.4009	0.3621	0.7066	10	0.2242	0.1679	0.5119
C	45.1505	24.4673	44.764	24.6502	0.3865	0.3621	0.7066	11	0.2036	0.1679	0.5119
D	49.5292	23.0534	49.1592	23.3456	0.37	0.3621	0.7066	12	0.0778	0.1679	0.5119
					6.4119				4.079		

Table D25: Calculations for trial 7

A	57.5626	23.5235	57.2078	23.7352	0.3548	0.2333	0.4119	1	0.1431	0.0047	0.2630
B	64.8718	23.7305	64.4959	23.8874	0.3759	0.2333	0.4119	2	0.219	0.0047	0.2630
C	50.8994	24.2824	50.5873	24.5433	0.3121	0.2333	0.4119	3	0.0512	0.0047	0.2630
D	52.2223	24.2263	52.1305	24.4489	0.0918	0.2333	0.4119	4	-0.1308	0.0047	0.2630
						0.2333	0.4119			0.0047	0.2630
A	57.2078	24.0523	56.8645	24.2522	0.3433	0.2333	0.4119	5	0.1434	0.0047	0.2630
B	64.4959	23.8073	64.1905	24.007	0.3054	0.2333	0.4119	6	0.1057	0.0047	0.2630
C	50.5873	24.0179	50.2786	24.2041	0.3087	0.2333	0.4119	7	0.1225	0.0047	0.2630
D	52.1305	24.3607	51.8309	24.542	0.2996	0.2333	0.4119	8	0.1183	0.0047	0.2630
						0.2333	0.4119			0.0047	0.2630
A	56.8645	24.3447	56.497	24.5177	0.3675	0.2333	0.4119	9	0.1945	0.0047	0.2630
B	64.1905	23.3946	63.805	23.6628	0.3855	0.2333	0.4119	10	0.1173	0.0047	0.2630
C	50.2786	23.7494	49.8509	23.822	0.4277	0.2333	0.4119	11	0.3551	0.0047	0.2630
D	51.8309	23.0591	51.5319	23.1908	0.299	0.2333	0.4119	12	0.1673	0.0047	0.2630
					3.8713				1.6066		

Table D26: Calculations for trial 8

A	50.671	23.7427	50.364	23.807	0.307	0.2946	0.4474	1	0.2427	0.0574	0.3181
B	59.841	23.4715	59.5205	23.6921	0.3205	0.2946	0.4474	2	0.0999	0.0574	0.3181
C	47.7369	24.0453	47.4302	24.2773	0.3067	0.2946	0.4474	3	0.0747	0.0574	0.3181
D	48.0154	24.0708	47.7267	24.2712	0.2887	0.2946	0.4474	4	0.0883	0.0574	0.3181
						0.2946	0.4474			0.0574	0.3181
A	50.364	23.7993	49.8333	23.8544	0.5307	0.2946	0.4474	5	0.4756	0.0574	0.3181
B	59.5205	23.4973	59.0939	23.7263	0.4266	0.2946	0.4474	6	0.1976	0.0574	0.3181
C	47.4302	24.076	47.0217	24.243	0.4085	0.2946	0.4474	7	0.2415	0.0574	0.3181
D	47.7267	24.3554	47.2079	24.5856	0.5188	0.2946	0.4474	8	0.2886	0.0574	0.3181
						0.2946	0.4474			0.0574	0.3181
A	49.8333	23.0516	49.59	23.3097	0.2433	0.2946	0.4474	9	-0.0148	0.0574	0.3181
B	49.0939	24.4485	48.7451	24.6158	0.3488	0.2946	0.4474	10	0.1815	0.0574	0.3181
C	47.0217	24.2183	46.6433	24.4671	0.3784	0.2946	0.4474	11	0.1296	0.0574	0.3181
D	47.2079	23.3876	46.8338	23.514	0.3741	0.2946	0.4474	12	0.2477	0.0574	0.3181
					4.4521				2.2529		

Table D27: Calculations for trial 9

A	50.671	23.7427	50.364	23.807	0.307	0.2946	0.4474	1	0.2427	0.0574	0.3181
B	59.841	23.4715	59.5205	23.6921	0.3205	0.2946	0.4474	2	0.0999	0.0574	0.3181
C	47.7369	24.0453	47.4302	24.2773	0.3067	0.2946	0.4474	3	0.0747	0.0574	0.3181
D	48.0154	24.0708	47.7267	24.2712	0.2887	0.2946	0.4474	4	0.0883	0.0574	0.3181
						0.2946	0.4474			0.0574	0.3181
A	50.364	23.7993	49.8333	23.8544	0.5307	0.2946	0.4474	5	0.4756	0.0574	0.3181
B	59.5205	23.4973	59.0939	23.7263	0.4266	0.2946	0.4474	6	0.1976	0.0574	0.3181
C	47.4302	24.076	47.0217	24.243	0.4085	0.2946	0.4474	7	0.2415	0.0574	0.3181
D	47.7267	24.3554	47.2079	24.5856	0.5188	0.2946	0.4474	8	0.2886	0.0574	0.3181
						0.2946	0.4474			0.0574	0.3181
A	49.8333	23.0516	49.59	23.3097	0.2433	0.2946	0.4474	9	-0.0148	0.0574	0.3181
B	49.0939	24.4485	48.7451	24.6158	0.3488	0.2946	0.4474	10	0.1815	0.0574	0.3181
C	47.0217	24.2183	46.6433	24.4671	0.3784	0.2946	0.4474	11	0.1296	0.0574	0.3181
D	47.2079	23.3876	46.8338	23.514	0.3741	0.2946	0.4474	12	0.2477	0.0574	0.3181
					4.4521				2.2529		

Table D28: Calculations for trial 10

A	62.3087	24.2296	61.8702	24.5078	0.4385	0.2581	0.4074	1	0.1603	0.0423	0.2517
B	69.6321	24.0179	69.2894	24.1699	0.3427	0.2581	0.4074	2	0.1907	0.0423	0.2517
C	54.8306	24.3459	54.6224	24.5268	0.2082	0.2581	0.4074	3	0.0273	0.0423	0.2517
D	57.631	24.4509	57.1516	24.5503	0.4794	0.2581	0.4074	4	0.38	0.0423	0.2517
						0.2581	0.4074			0.0423	0.2517
A	61.8702	23.4763	61.5784	23.6748	0.2918	0.2581	0.4074	5	0.0933	0.0423	0.2517
B	69.2894	23.5069	69.0076	23.7208	0.2818	0.2581	0.4074	6	0.0679	0.0423	0.2517
C	54.622	24.0822	54.2187	24.3038	0.4033	0.2581	0.4074	7	0.1817	0.0423	0.2517
D	58.1576	24.0639	57.8336	24.2406	0.324	0.2581	0.4074	8	0.1473	0.0423	0.2517
						0.2581	0.4074			0.0423	0.2517
A	61.5784	23.4017	61.3798	23.6142	0.1986	0.2581	0.4074	9	-0.0139	0.0423	0.2517
B	69.0076	23.3176	68.6447	23.3727	0.3629	0.2581	0.4074	10	0.3078	0.0423	0.2517
C	54.2187	23.5339	53.8299	23.7536	0.3888	0.2581	0.4074	11	0.1691	0.0423	0.2517
D	56.8336	23.4	56.56073	23.6205	0.27287	0.2581	0.4074	12	0.05237	0.0423	0.2517
					3.99287				1.76387		

Table D29: Calculations for trial 12

A	64.5822	23.6269	64.1855	23.7588	0.3967	0.2837	0.4765	1	0.2648	0.0995	0.2908
B	71.8581	24.0817	71.4816	24.2638	0.3765	0.2837	0.4765	2	0.1944	0.0995	0.2908
C	57.2023	24.0176	56.8013	24.236	0.401	0.2837	0.4765	3	0.1826	0.0995	0.2908
D	59.7835	23.3979	59.4138	23.5359	0.3697	0.2837	0.4765	4	0.2317	0.0995	0.2908
A						0.2837	0.4765			0.0995	0.2908
B	64.1855	23.48	63.7848	23.7268	0.4007	0.2837	0.4765	5	0.1539	0.0995	0.2908
C	71.4816	23.7413	71.0734	23.8875	0.4082	0.2837	0.4765	6	0.262	0.0995	0.2908
D	56.5013	24.3486	56.3576	24.5766	0.1437	0.2837	0.4765	7	-0.0843	0.0995	0.2908
	59.4138	23.5188	59.0592	23.6917	0.3546	0.2837	0.4765	8	0.1817	0.0995	0.2908
A											
B	63.7848	24.2349	63.3529	24.4113	0.4319	0.2837	0.4765	9	0.2555	0.0995	0.2908
C	71.0734	24.4835	70.7047	24.6523	0.3687	0.2837	0.4765	10	0.1999	0.0995	0.2908
D	56.3576	23.4025	55.8511	23.6335	0.5065	0.2837	0.4765	11	0.2755	0.0995	0.2908
	59.0592	24.0611	58.6561	24.2402	0.4031	0.2837	0.4765	12	0.224	0.0995	0.2908
					4.5613				2.3417		

Table D30: Calculations for trial 13

A	58.5596	23.4662	58.2559	23.6645	0.3037	0.2707	0.3841	1	0.1054	0.1305	0.2381
B	65.8101	24.2234	65.4751	24.4275	0.335	0.2707	0.3841	2	0.1309	0.1305	0.2381
C	52.0069	23.0917	51.643	23.1643	0.3639	0.2707	0.3841	3	0.2913	0.1305	0.2381
D	53.6233	24.051	53.2036	24.1705	0.4197	0.2707	0.3841	4	0.3002	0.1305	0.2381
						0.2707	0.3841			0.1305	0.2381
A	58.2559	23.0573	57.8172	23.1887	0.4387	0.2707	0.3841	5	0.3073	0.1305	0.2381
B	65.4751	22.476	65.1538	22.6475	0.3213	0.2707	0.3841	6	0.1498	0.1305	0.2381
C	57.643	23.7469	57.2852	23.822	0.3578	0.2707	0.3841	7	0.2827	0.1305	0.2381
D	53.2036	23.3933	52.8515	23.5725	0.3521	0.2707	0.3841	8	0.1729	0.1305	0.2381
						0.2707	0.3841			0.1305	0.2381
A	54.8172	24.3438	54.5671	24.4638	0.2501	0.2707	0.3841	9	0.1301	0.1305	0.2381
B	65.1538	24.0172	64.8737	24.1658	0.2801	0.2707	0.3841	10	0.1315	0.1305	0.2381
C	51.2852	23.5052	51.004	23.6813	0.2812	0.2707	0.3841	11	0.1051	0.1305	0.2381
D	52.8515	24.2841	52.6262	24.4045	0.2253	0.2707	0.3841	12	0.1049	0.1305	0.2381
					3.9289				2.2121		

Table D31: Calculations for trial 14

A	51.8065	24.0145	51.5054	24.1806	0.3011	0.3309	0.4081	1	0.135	0.1304	0.2693
B	60.8998	23.5211	60.5813	23.7776	0.3185	0.3309	0.4081	2	0.062	0.1304	0.2693
C	48.8411	24.2776	48.5585	24.4058	0.2826	0.3309	0.4081	3	0.1544	0.1304	0.2693
D	49.151	24.2794	48.8012	24.543	0.3498	0.3309	0.4081	4	0.0862	0.1304	0.2693
						0.3309	0.4081			0.1304	0.2693
A	51.5054	24.0472	51.0957	24.2145	0.4097	0.3309	0.4081	5	0.2424	0.1304	0.2693
B	60.5813	23.3876	60.269	23.5671	0.3123	0.3309	0.4081	6	0.1328	0.1304	0.2693
C	48.5585	23.4687	48.149	23.6612	0.4095	0.3309	0.4081	7	0.217	0.1304	0.2693
D	48.8012	23.7223	48.4144	23.858	0.3868	0.3309	0.4081	8	0.2511	0.1304	0.2693
						0.3309	0.4081			0.1304	0.2693
A	51.0957	23.0852	50.671	23.2357	0.4247	0.3309	0.4081	9	0.2742	0.1304	0.2693
B	60.269	23.7292	59.8412	23.8337	0.4278	0.3309	0.4081	10	0.3233	0.1304	0.2693
C	48.149	24.3424	47.7369	24.542	0.4121	0.3309	0.4081	11	0.2125	0.1304	0.2693
D	48.4144	24.4656	48.0154	24.5569	0.399	0.3309	0.4081	12	0.3077	0.1304	0.2693
					4.4339				2.3986		

Table D32: Calculations for trial 15

A	54.1759	24.4735	53.7985	24.5419	0.3774	0.3022	0.4689	1	0.309	0.0952	0.3386
B	61.2799	23.4671	60.8539	23.6336	0.426	0.3022	0.4689	2	0.2595	0.0952	0.3386
C	47.1367	24.2806	46.7956	24.4107	0.3411	0.3022	0.4689	3	0.211	0.0952	0.3386
D	51.5285	23.7202	51.1347	23.8252	0.3938	0.3022	0.4689	4	0.2888	0.0952	0.3386
						0.3022	0.4689			0.0952	0.3386
A	53.7958	23.3865	53.3979	23.5623	0.3979	0.3022	0.4689	5	0.2221	0.0952	0.3386
B	60.8539	23.0865	60.5697	23.2595	0.2842	0.3022	0.4689	6	0.1112	0.0952	0.3386
C	46.7956	24.0471	46.4358	24.2099	0.3598	0.3022	0.4689	7	0.197	0.0952	0.3386
D	51.1347	23.5045	50.801	23.7158	0.3337	0.3022	0.4689	8	0.1224	0.0952	0.3386
						0.3022	0.4689			0.0952	0.3386
A	53.3979	24.0753	52.8788	24.2194	0.5191	0.3022	0.4689	9	0.375	0.0952	0.3386
B	60.5697	23.5259	60.3356	23.8173	0.2341	0.3022	0.4689	10	-0.0573	0.0952	0.3386
C	46.4358	23.7343	45.8881	23.8815	0.5477	0.3022	0.4689	11	0.4005	0.0952	0.3386
D	50.801	24.2854	50.3891	24.5337	0.4119	0.3022	0.4689	12	0.1636	0.0952	0.3386
					4.6267				2.6028		

Table D33: Calculations for trial 16

A	49.59	23.7283	49.3024	23.8382	0.2876	0.2633	0.3903	1	0.1777	0.0506	0.2802
B	58.7451	23.0818	58.4832	23.1517	0.2619	0.2633	0.3903	2	0.192	0.0506	0.2802
C	46.6433	24.463	46.3642	24.6328	0.2791	0.2633	0.3903	3	0.1093	0.0506	0.2802
D	46.8338	23.3852	46.5942	23.5546	0.2396	0.2633	0.3903	4	0.0702	0.0506	0.2802
						0.2633	0.3903			0.0506	0.2802
A	49.3024	24.0474	48.8534	24.2152	0.449	0.2633	0.3903	5	0.2812	0.0506	0.2802
B	58.4832	24.2783	58.1686	24.3832	0.3146	0.2633	0.3903	6	0.2097	0.0506	0.2802
C	46.3642	24.2808	46.0227	24.5008	0.3415	0.2633	0.3903	7	0.1215	0.0506	0.2802
D	46.5942	23.7283	46.2924	23.8085	0.3018	0.2633	0.3903	8	0.2216	0.0506	0.2802
						0.2633	0.3903			0.0506	0.2802
A	48.8538	23.4643	48.6436	23.746	0.2102	0.2633	0.3903	9	-0.0715	0.0506	0.2802
B	58.1686	23.5219	57.7281	23.863	0.4405	0.2633	0.3903	10	0.0994	0.0506	0.2802
C	46.0227	24.3361	45.6609	24.4847	0.3618	0.2633	0.3903	11	0.2132	0.0506	0.2802
D	46.2924	23.382	45.8586	23.4554	0.4338	0.2633	0.3903	12	0.3604	0.0506	0.2802
					3.9214				1.9847		

Appendix D5: Matlab and Visual Basic Program

Matlab Program

File on disc
D:/Models/degreaser

Appendix E: Zinc

Appendix E1.1: Factorial Table

Table E1: Factorial table

Trial	Zinc	Carbonate	Caustic	Temperature	Brightener
1	-1	-1	-1	-1	1
2	1	-1	-1	-1	-1
3	-1	1	-1	-1	-1
4	1	1	-1	-1	1
5	-1	-1	1	-1	-1
6	1	-1	1	-1	1
7	-1	1	1	-1	1
8	1	1	1	-1	-1
9	-1	-1	-1	1	-1
10	1	-1	-1	1	1
11	-1	1	-1	1	1
12	1	1	-1	1	-1
13	-1	-1	1	1	1
14	1	-1	1	1	-1
15	-1	1	1	1	-1
16	1	1	1	1	1

E1.2. Experimentation

E1.2.1. Key words

Zinc, Mild Steel, temperature, Electroplating, Current, Voltage.

E1.2.2. Protective equipment and safety measures

Face shield, acid and caustic resistant gloves, safety boots, lab coat, Ensure raw material and equipment are labeled properly.

The above protective equipment was worn to avoid injury from hazards that might occur. When conducting the experiment, it was made sure that the electrical coil was immersed in water to avoid burning of the coil that might lead to electric shock.

E1.2.3. Experimental Procedure

- Mild steel buttons were cleaned in caustic and acid to remove the oil and dirt respectively from the metal surface.
- The mild steel buttons were air dried and individually weighed using a four digit laboratory scale.
- The mass of the metal pieces were summed up and the barrel mass calculated.
- The barrel, with the mild steel buttons, was then degreased and acid cleaned respectively.
- The amperage and voltage of the plating bath was set at its required level.
- The barrel was immersed in the plating bath for the stipulated period.
- The barrel was removed from the plating bath and the mild steel buttons air dried.
- The individual mild steel buttons were reweighed and the individual and total mass plated was determined.
- The procedure was repeated 3 times in-order to check the consistency of the results.

E1.2.4. Limits for Experimentation

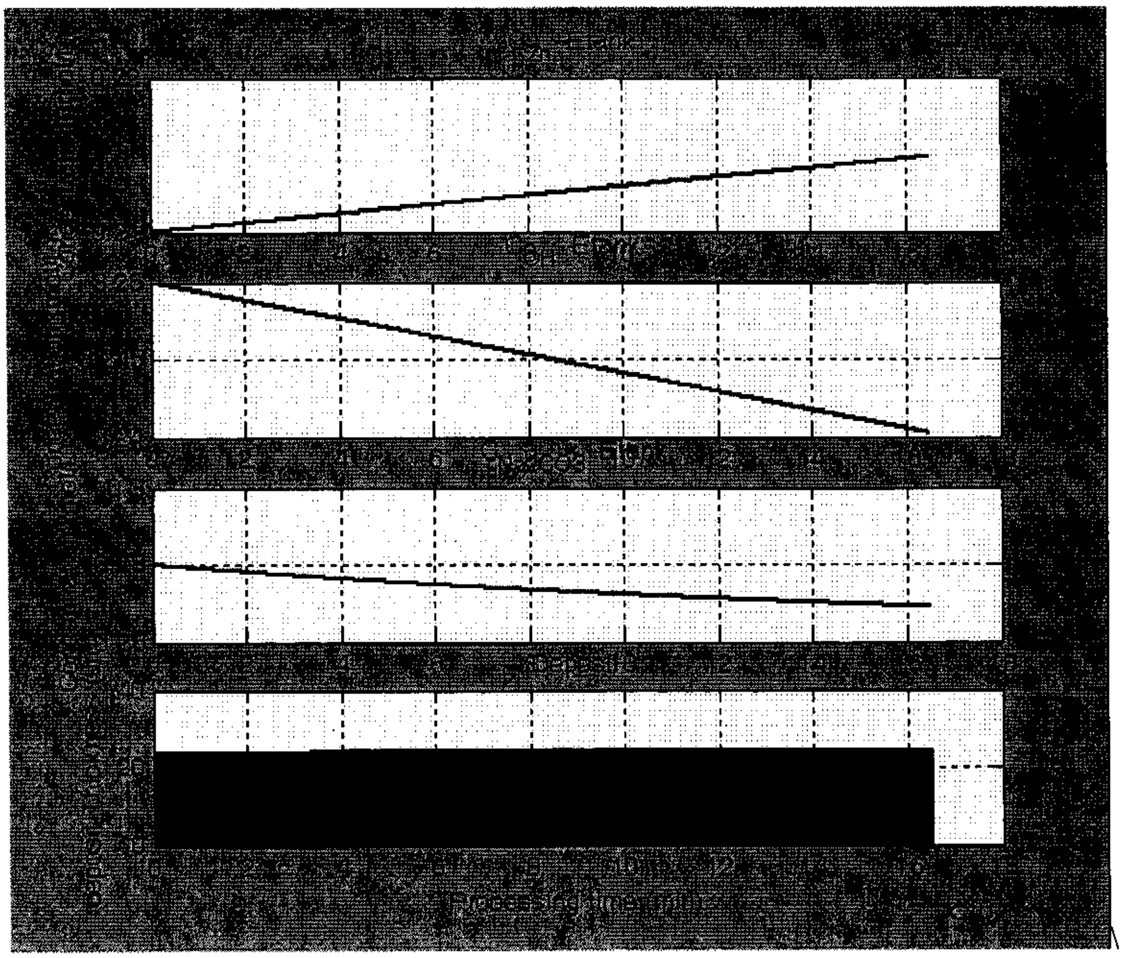
	Min	Max	Optimum
Zinc(Moles/l)	0.15	0.27	0.21
Sodium carbonate (Moles/l)	0	0.65	0.32
NaOH (Moles/l)	2.5	4	3.25
Brightener	10 ml/l	20 ml/l	15 ml/l
Temp (^{0}C)	22	28	34

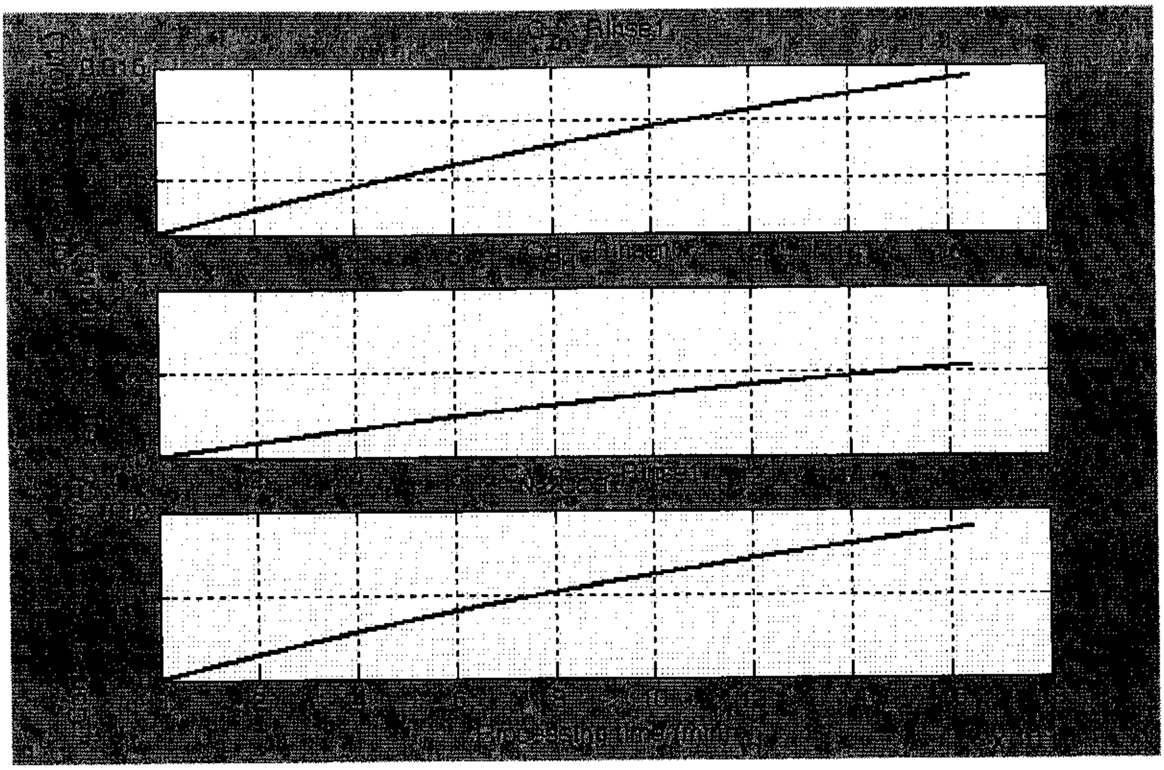
Appendix E2: Matlab Simulation and Program

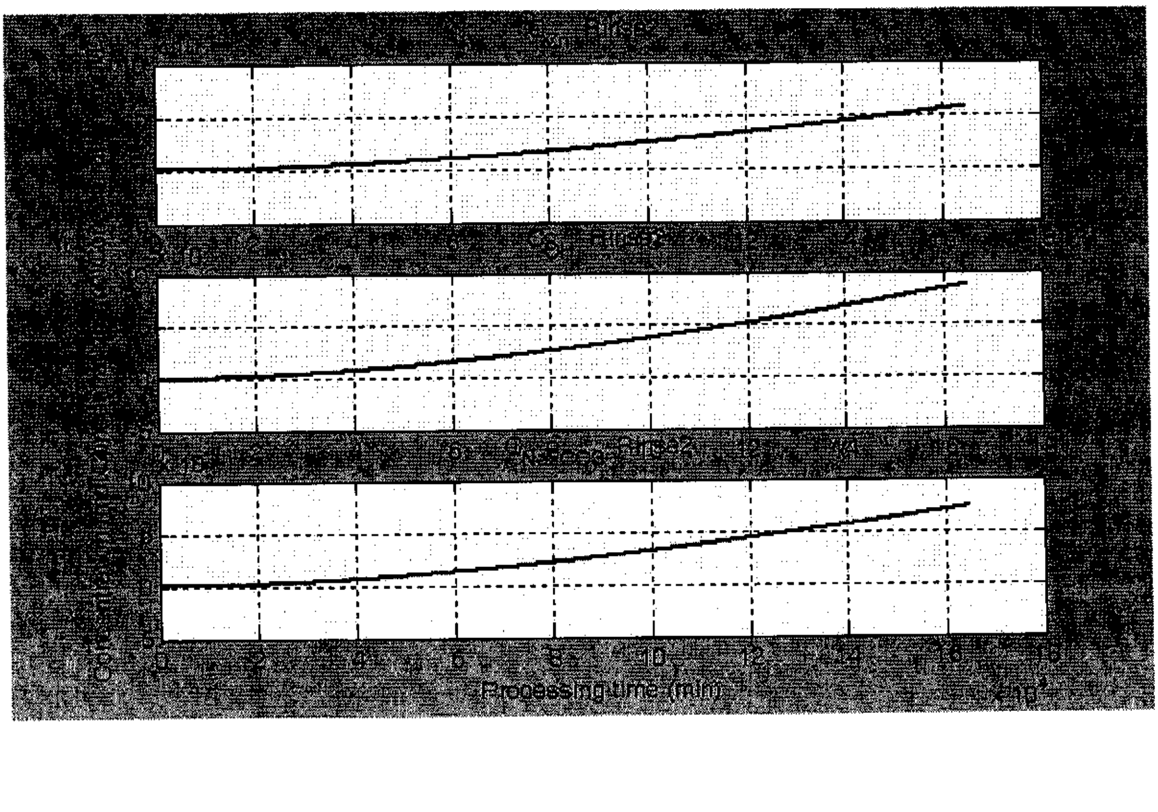
Model is attached on disc

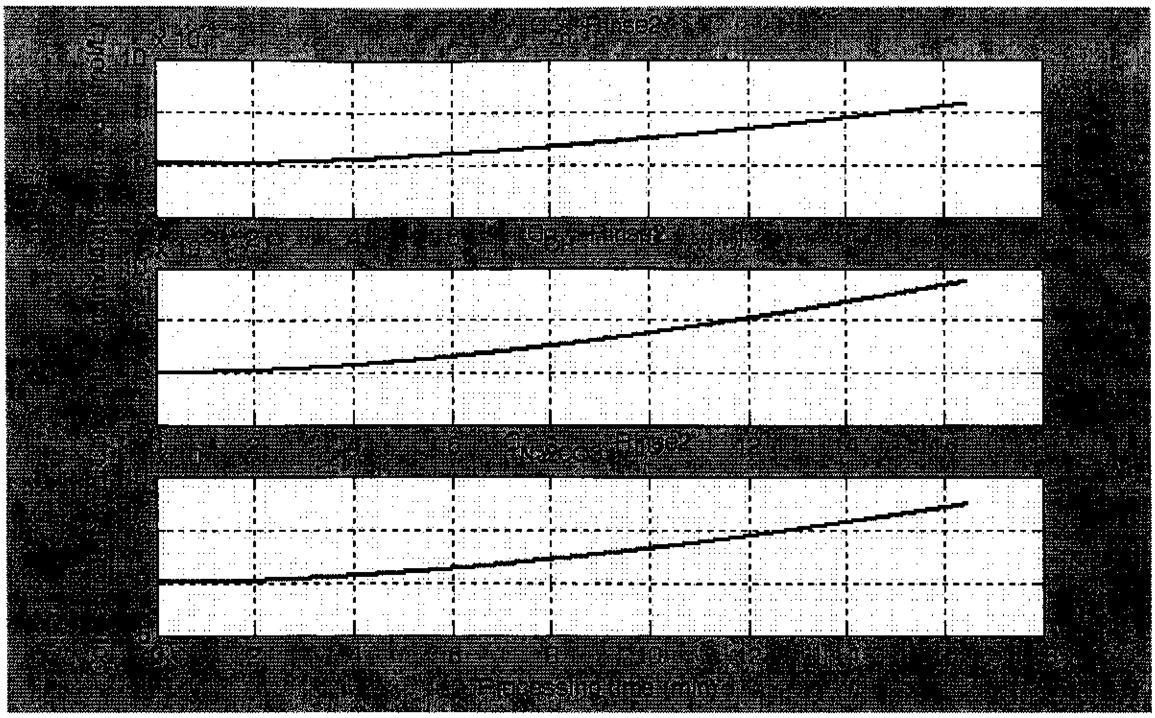
C:/Models/zinc

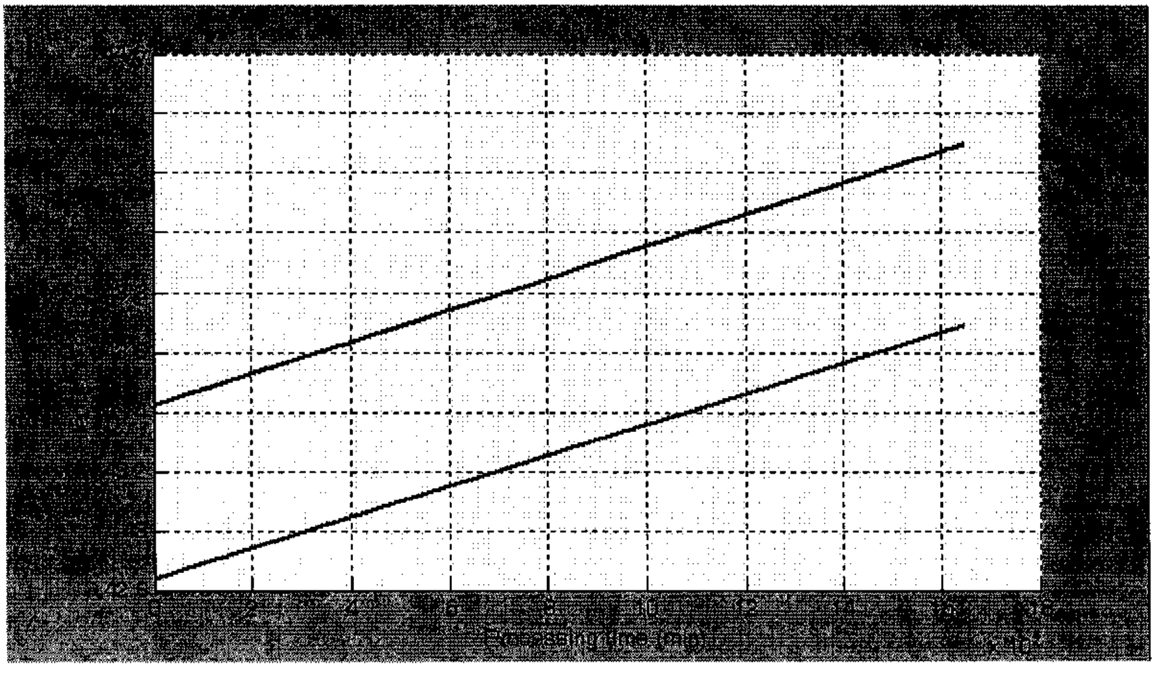
Matlab Simulation/Trend






Processing time (min)




Processing time (min)

Appendix F: Case Study

A Case study

1. Company Introduction

Saayman Danks Electroplaters is a jobbing shop plating nickel, zinc and chrome finishes for a wide range of application. The company has various clients ranging from car component manufacturers to private customers. The zinc electroplating facility was established in 1971 and is thus 33 years old. Due to space constraints very little upgrading has been conducted on the facility. The chemicals for the alkali zinc plating plant are supplied by Chemserve systems.

The plant operates 24 hours per day, six days per week. There are a total of 11 operators, working a two-shift cycle, operating the plant. This includes jiggers, plant operators and foreman.

The plant is contained within a complex consisting of +/- 10 electroplating facilities. These include acid zinc, nickel, chrome, cadmium, silver and gold plating. There are separate lines for jig and barrel plating.

The wastewater from these facilities is treated at a central wastewater treatment facility. The wastewater treatment plant operates with automatic control and dosing.

A key factor for consideration for this case study is the fact that the owner of this facility has been involved in cleaner production initiatives over the past 10 years. He has had the privilege of being the provincial chairperson, national chairperson and South African representative on international funding agencies. It can thus be assumed that information was reasonably available at this company.

2. Discussion of spreadsheets

The review conducted at Saayman Danks is meant to indicate key figures for their plating process. The figures are related to international best available practice and accordingly benchmark the environmental performance of the company. These figures are to assist with cleaner production initiatives at the company.

The review was based on tables, extracted from the excel spreadsheet developed for the environmental review. The tables cover production and environmental issues for the production line. The wastewater treatment plant was also evaluated and is reported.

The conclusions listed, can be addressed by installing and modifying processes to facilitate cleaner production improvements. These modifications would result in a more cost effective and environmentally friendly facility. The actual layout and details on equipment required together with chemical consumptions and water usage would be done in a comprehensive feasibility study.

Detailed discussions on the individual tables follows:

2.1. Production, chemicals and process baths: Table 2 + 3

Table 1 and Tables in appendix F1 were used as indicators for the use of process chemicals. The consumption and production in square meters is used to establish the process chemical requirements. The consumption is compared to figures of international best available practice.

The consumptions are rated on a scale of 1 to 5; a rating of 5 implies greatest room for improvement and a rating of 1 would imply minimum room for improvements.

The sulphuric acid, caustic and conditioner is rated three or above. This indicates a high consumption of these chemicals.

Table 1: Production and chemicals-Zinc

	Chemicals			Thickness in µm		Production		Key figures: kg chemicals/1000m2		
Process bath	Type	kg/yr	R/yr	Calculated	Estimated	m2/yr	m2/h	Calculated	Goal	Score, 1-5
Zinc line:										
Degreasing bath	Soak clean	1,749				55,440	33	31.5	25	2
Sulfuric acid pickling	Sulfuric acid, 96%	4,547				55,440	33	82.0	50	4
HCl pickling	HCl, 32%					0	0	0.0	75	
Pickling-degreaser	Sulfuric acid, 96%					0	0	0.0	50	
Electrolytic cleaner	Cleaner salt					0	0	0.0	25	
Acid dip	HCl, 32%					0	0	0.0	10	
(Pre-treatment)	(Other)					0	0	0.0		
Zinc bath	Zinc anodes	3,724		9.4078035	7	55,440	33	67.2		
Zinc bath	NaOH	1,023				55,440	33	18.5	10	3
Zinc bath	H3BO3, 100%					0	0	0.0	2.0	
Zinc bath	ZnCl2, 100%					0	0	0.0	3.5	
Zinc bath	NCZ A	161								
Zinc bath	NCZ B	324								
Zinc bath	NCZ C	178								
Zinc bath	Condiioner	1,494				55,440	33	26.9	12	3
Zinc bath	(Other)					0	0	0.0		
Deoxidizer	Nitric acid					0	0	0.0	5	
Chromating, Gold	HCL	176								
Chromating, gold	Chrome	24								
Chromating, blue	Chemoxy	55				55,440	33	1.0	2.0	1
Chromating, blue	Nitric acid	286				55,440	33	5.2		
Chromating, black	Chemoxy 75	77				55,440	33	1.4	5	1
Chromating, black	Chemoxy 76	70				55,440	33	1.3		
HCL		308								
BTS	(Other)	51				55,440	33	0.9		
Sum:		14,247	0					235.9		2
Operation time: h/yr	1700							Score: 1 = good, 5 = unsatisfactory		

As discussed in chapter three of this thesis, Flemming's model contains many tables similar to Table 1. These tables are attached in appendix F2

2.2. Rinsing and water consumption

In Table 2, Appendix F1, the goal-values for water consumption's are based on a theoretical calculation for 3-stage counter current rinse for each rinsing process. Compared to this goal-value the consumption of water is high and in excess of 75 % of the current water used can be saved. The potential water saving for the zinc line is 73 %.

The following improvements can be carried out to optimise the present system.

- Dripping time should be prolonged to at least 20 seconds
- Tilting of jigs after every process and rinse tank
- Introduction of drag-in from the drag–out tank.
- Redirecting rinses
- Reusing rinse water from the WWTP
- Reduce contamination of tanks by reducing chemical drag-out
- Introduction of a low flow counter current rinse system after process tanks

Some realistic proposals for the existing line are:

- The plating tanks - convert these to a low flow counter current rinse, (zinc)
- Use rinse water to make up new solutions when required
- Increase drip times to 20 seconds
- Installation of water flow meter

All the above-mentioned proposals may be further assessed individually or collectively in a comprehensive feasibility study.

2.3. Waste minimisation

The sludge currently accumulated at the wastewater treatment plant is not an accurate indication of the amount of sludge generated from the plant. This is clear from the wastewater analysis.

The most effective way to reduce sludge generation, is to control the flows of chemicals in the line and return as much as possible to the respective solutions and/or reduce the drag-out of chemicals to the rinsing system. This will increase the efficiency of chemical utilisation before they are treated in the WWTP. If the dumping frequency is reduced, less sludge is generated. Continuous oil and grease removal from degreasers will prolong the lifetime of the solutions and reduce the need for replacement. Oil and greases in effluent inhibits the precipitation of metal hydroxides.

If the process baths were run at the optimum operating conditions then their efficiency would be improved and would result in less waste being generated. Scheduling the dumping of acids and alkali can reduce consumption of treatment chemicals. Plating rinse tanks should never be dumped.

2.4. Wastewater treatment: Table E 6 + 7

The wastewater treatment plant is a standard neutralisation method where precipitated sludge particles are separated. The plant consists of a treatment tank, 10 000 l approximately, here the pH of the incoming wastewater is measured and adjusted. The tank contains a mechanical stirrer. The pH probe is located next to the inlet line. This control loop is less than ideal, as the outlet pH is not regulated. The effluent is treated continuously. The plant is sufficiently sized for its load, although once sludge builds up in the settling tank the capacity becomes a problem. Currently, only pH adjustment is done at the WWTP. No separation of waste streams is currently employed. This is not ideal and more formal tests for metals etc need to be conducted together with the separation of chemicals. Discharge values for heavy metals in the treated water are generally high (Metro Wastewater results); some non-compliance's have been noted. The company is sampled twice a month by Metro.

Controls for testing wastewater treatment can be improved by:

- Monitoring of metal levels in treated effluent
- Training of personnel to carry out tests
- Installation of outlet monitoring to metro drains

Both caustic and acid, is currently used at the WWTP, this is less than ideal. pH should only be regulated in one direction.

Separation of waste streams would result in a more cost effective system of wastewater treatment.

2.5. Occupational health and safety (OHS) Table E8:

The impacts of chemistry, noise, temperature, heavy lifts and risks were assessed for the process lines. In general the OHS conditions are acceptable but minor improvements can be initiated.

- **Chemistry:**

Workers are continuously exposed to fumes from the process baths.

- **Noise:**

No major noise risk exist

- **Temperature:**

Workers are exposed to tank heat for prolonged periods, therefore is considered to cause discomfort.

- **Heavy lifts:**

Some lifting of jigs are required, Jigs are small

- **Risks:**

The general risk is low but further risk assessments should be conducted.

2.6. Cleaner production options Table E9:

Alkaline cleaners may be purified to prolong the lifetime. Process alkali cleaners/ acids can be used for neutralisation; this process needs to be streamlined. Some holding tanks would be required.

The existing rinse system should be improved by prolonging the dripping time. This will reduce consumption of rinse water, but further reduction may be obtained by implementation of low flow counter current rinsing with drag-in and drag-out. Better control of rinse water needs to be introduced i.e. flow meters on inlet lines. A separate inlet flow meter is required

The company can consider the re-use of rinse water to make up process tanks.

2.7. Environmental profile: Graph 8.1

The graph and table is a summary of the key areas evaluated. The graphs rate the company on eight key indicators on a scale of 0 to 100.

On this graph a value of:

- Between 0-20 would imply a very low potential for saving
- Between 21-50 would imply a medium potential for saving
- Greater than 50 would imply a high potential for saving

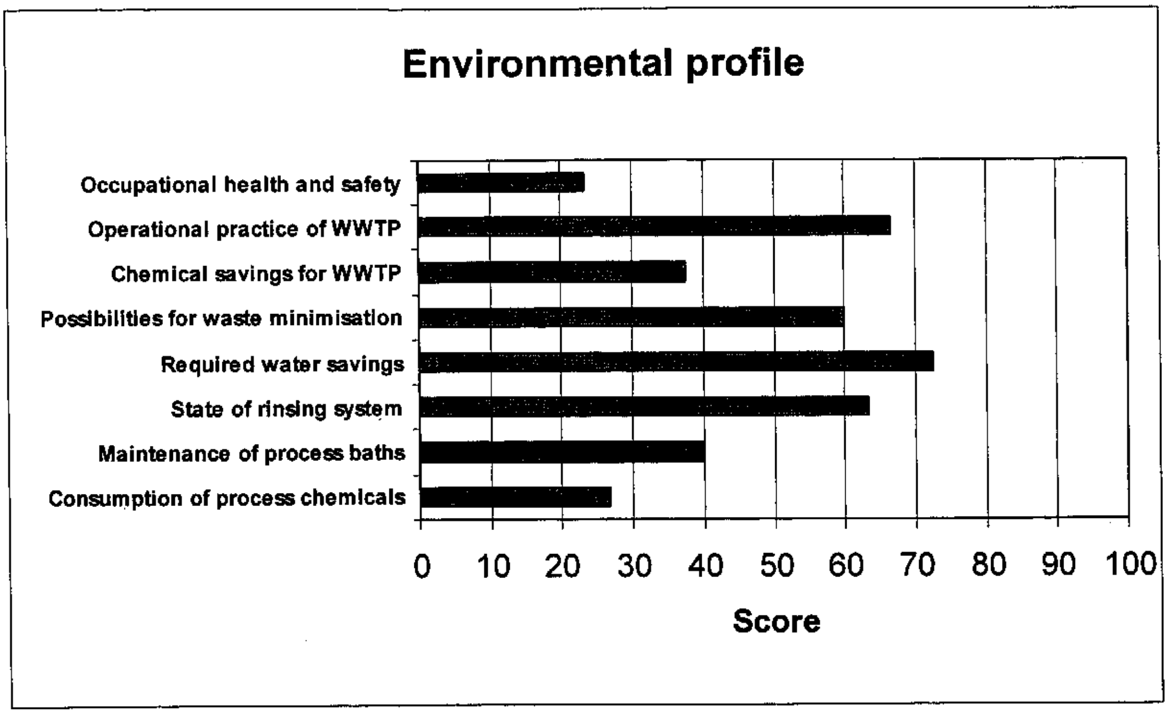
From the graphs it can be clearly seen that the following areas have a medium to high potential for improvement and for implementation of cleaner production strategies to improve the environmental performance and obtain further waste and cost reductions:

- Better maintenance/operation of process baths to prolong their lifetime
- Water consumption
- Chemicals savings of waste water treatment plant
- Reduction of consumption of process chemical
- Operational practice at wastewater treatment plant
- Improvements to the rinsing system
- Reduction of chemical waste

The square meterage is a key component in this study and the owner determined this from production figures. During the audit the owner corrected these figures when it was indicated that it was extremely low.

This study continues to discuss the above conclusions in detail and with reference to the relevant tables.

Figure 1: Environmental status of company



2.8. Recommendations

The review details many areas for improvement. Stemming from this the following recommendations can be considered for further investigations. These recommendations if implemented would result in improvements in the key areas reported in this report.

2.8.1. The rinsing system

The key to minimizing water usage and reducing process chemicals consumption in any plant is the rinsing system. By introducing a three-stage counter current rinse both these objectives can be achieved. Dragging in the drag out solution before a process tank can also reduce process chemicals consumption.

The following is recommended:

- Introduction of a low flow counter current rinse system after all plating tanks
- Depending on drag out losses this system can be used to top up the process tank and if insufficient evaporation occurs (Evaporation can be induced) the water can be redirected to the wastewater treatment plant.

- Explore the possibility of redirecting the rinse water

This might be possible depending on the compatibility of the chemicals. This would result in a large saving on water and more effective neutralisation of acid and alkali.

2.8.2. Increasing dripping time

Low dripping times results in wastage of valuable chemicals. These chemicals have to be treated in the wastewater treatment plant and are thus a double wastage. By increasing the drip time to twenty seconds drag-out can be drastically reduced.

2.8.3. Using spent process chemicals for neutralization

Although this facilitates fresh solution into the process tanks, large volumes of water are lost to the wastewater treatment plant. This results in the overloading of this facility. This entire system needs to be reviewed, with due consideration to the possibility of a 60% reduction in volume to the wastewater treatment plant.

2.8.4. Measurement and dosage of process chemicals

Process chemicals are supplied in bulk but the process requirements are normally in small quantities. Use of smaller dosing equipment (e.g. dosing pumps) would ensure accurate dosing and minimize wastage. Continuous dosing narrows the operating band and would facilitate improved product quality and lower chemical consumption.

2.8.5. Health and safety

Health and safety is imperative in ensuring good productivity and the use of personal protective equipment is essential, especially when dealing with dangerous chemicals. Operator training needs to be done to ensure protective equipment is worn at all times and the hazards of chemicals are known.

2.8.6. Wastewater treatment

Better measurement and control should be carried out at the wastewater treatment plant with regards to all treatment i.e.

- Variables (pH and Concentration) need to be measured before and after treatment
- Improved dosing accuracy by proper measurement and control
- Proper flocculation should be carried out

2.9. Review Conclusion

The review highlights the main problem areas where CP-options should be further assessed. In this report some obvious possibilities are identified and presented very briefly. It is recommended that a more detailed study be done on the possibilities for reduction of chemical consumption.

A more detailed assessment and feasibility study on the plant is necessary to specify proposals for actual and detailed solutions for implementation to the process line.

3. Application of New model

The application of the artificial intelligence based model was also applied at Saayman Danks electroplaters. The questionnaire is attached in appendix F2. This comprised of 54 questions as detailed in chapters 4-8.

In order to ensure an independent assessment, the questionnaire was completed by an independent reviewer. The reviewer had no prior knowledge of the plating process and no experience in conducting reviews.

The company had availed their plant foreman to answer the questions, as the plant operators did not communicate in English. The foreman was also responsible for day to day running of the plant, including dosing of chemicals.

The questionnaire was conducted on site and was completed in 34 minutes. The data gathered was then plugged into the various models and the results analyzed. No further contact was made with the company for further data.

3.1. Results from AI model

The operator inputs for the fuzzy logic category from the questionnaire was entered into the visual basic software, that was specifically developed to determine the different ratings for the eight categories. The eight categories were described in chapter 4. The visual basic program is attached in Appendix B.

The results are indicated on a scale of 0-100, with zero indicating an excellent facility with no room for improvement whilst 100 indicates significant room for improvements.

The comments made under each of the categories can be developed as automatic outputs, based on the operator inputs i.e. the important categories can be highlighted if a high fuzzy rating is allocated to this question.

The results for the eight categories are:

3.2. Rinse Management

The evaluation results indicate a 66.9% potential as compared to Flemming's 63%. This indicates significant room for improvement with regards rinse management at Saayman Danks. From the fuzzy logic multi variable analysis, drip time was regarded as the key contributor to the rinse management rating. From the operator inputs, it can be seen that the company obtained the worst possible rating.

The other key areas that obtained the highest fuzzy ratings were the location of the inlet and outlet rinse water and agitation of the tanks.

Intermediate ratings were obtained for the hanging and inlet water flow control. It was noted that there was no back mixing present.

3.3. Sludge reduction

The evaluation results indicate a 55.25 % saving potential as compared to 60% in Flemming's waste minimization tables. This indicates that improving on the chemical losses can reduce the sludge generated at Saayman Danks. The fuzzy decision system highlights dragout as the most significant variable to consider for sludge reduction. The company obtained the maximum penalty for having just a single rinse tank after their process tanks. From the operator feedback, it was noted that Saayman Danks scored in the intermediate range for the rest of the questions. This indicated that if the dragout was improved then significant sludge reductions would be encountered.

3.4. Wastewater treatment plant chemicals

The evaluation results indicate a 33.1% potential as compared to 38% in Flemming's Wastewater chemical tables.

The potential for improvement, for chemicals used at the wastewater treatment plant can be considered to be low. The fuzzy system highlights using less excess of treatment chemicals as the major contributor to the wastewater chemical rating. Although automatic dosing occurs at Saayman Danks, the chrome is treated manually.

3.5. Wastewater treatment plant equipment

The model generated a 45.5% rating as compared to Flemmings rating of 50%.

This indicates a medium potential for improvement with regards to the operations at the wastewater treatment plant. Inputs were only received for pH adjustment. It was found that calibration was conducted once/month. This should be once every two weeks.

The fuzzy decision making system highlights the management of the treatment equipment for cyanide, chrome and metal monitoring as being most crucial for wastewater treatment. The company rated badly in the metal monitoring category, as no metal monitoring was carried out.

3.6. Chemical consumption and management

The company faired fairly well on this category obtaining a score of 29% from the fuzzy system and a score of 27% via the Flemming system. This indicates a low potential for improvement.

The fuzzy system indicates the chemical dosing and the monitoring to be of highest importance for this category. The company scored well in this category as a dedicated chemical analyst manages the process chemicals in house. Dosing is done in accordance with in house analysis.

3.7. Occupational health and safety

Here again the fuzzy evaluations system indicated a low potential for improvements, the company scored 25% on the fuzzy system and 23% via the Flemming system. The major considerations under the occupational health and safety category are the temperature and the chemistry of the process tanks.

At Saayman Danks only the degreaser operates at a significantly high temperature. The plant is semi automatic so the scores for the other questions such as lifts etc were low and thus the overall score for this category was considered low.

3.8. Water Reuse

There was no equivalent category from the Flemming model. The fuzzy model score for this category was 49. From the fuzzy decision analysis, the redirecting of the acid and degreaser rinse together with closed circuit counter current rinsing were rated as the most important factors for water re-use. The company does redirect the acid rinse water but does not have closed circuit counter current rinses. This can potentially prove to be a significant source of water saving for the company. The exact potential water saving is quantified later in this chapter.

3.9. Production

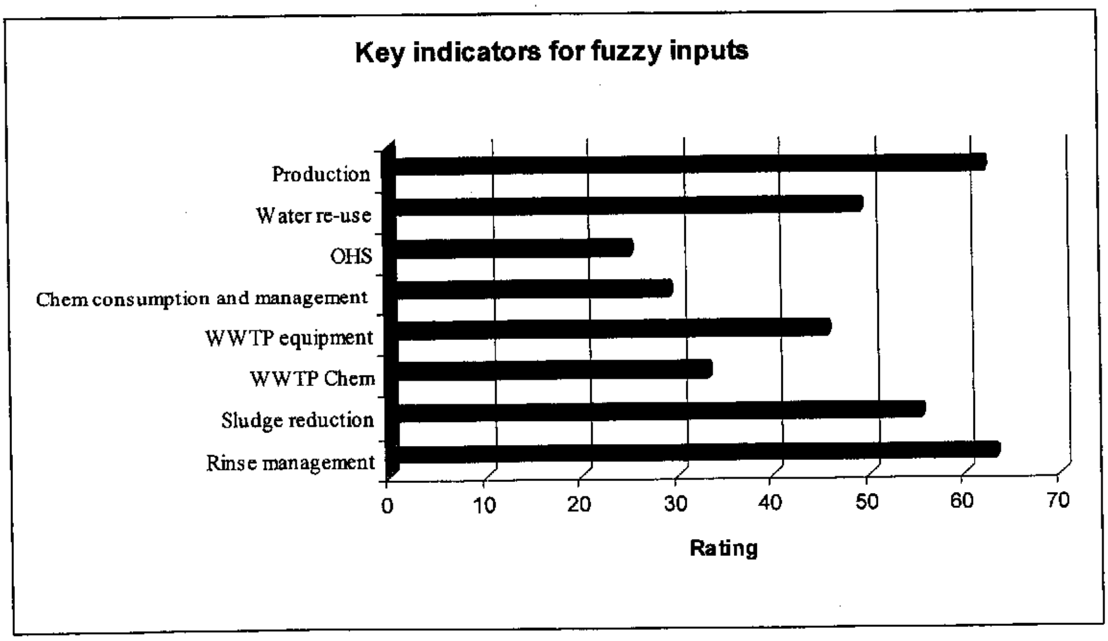
Flemming's model does not contain an equivalent category so there are no comparative figures. The fuzzy model generates a score of 62%, which is indicative of a medium to high potential for improvement. The fuzzy decision analysis indicated that the determination of the plant production in surface area was the key-determining factor for this category. Saayman Danks does not measure surface area but rather measures the weight of components as a measure of production. This creates a problem in predicting the chemical and water consumption of an electroplating facility.

The determination of the plated thickness by sampling components ensures optimum operations. This is done once every month at Saayman Danks, this contributes to the score.

The other areas of improvement are the monitoring of the loading of the jigs as this is currently done infrequently.

The results from the above categories is graphically represented in figure 8.2.

Figure 2: Model output for eight categories



3.10. Determination of the plant production

The acid model was used to determine the plant production in square meters. The model required various inputs that were obtained from the operator questionnaire. The inputs that were required were: weekly acid dosage, number of jigs plated/hour, acid target concentration, dumping frequency for acid and time spent in the acid. See Appendix F2 for questionnaire.

The aim of the acid model was to determine the production rate and to determine the efficiency of the acid usage.

The operator inputs were plugged into the model and the simulation was run. The Monte Carlo simulation was run 100 times generating a surface area of 1354.3 m^2 as the mean weekly surface area. Multiplying this by 49 weeks a total production in square meters of 66346 m^2 was obtained. The surface area supplied by the company was 69300 m^2.

The most important aspect of chemical consumption is determining the optimum dumping of chemicals based on usage. The iron is considered the main contaminant in the acid and results in the premature dumping of the acid. Saayman Danks dump their acid every two months. From the Monte Carlo simulation the mean contamination of the acid after a period of two weeks was 12.16 g/l. This is indicative of premature dumping of the acid.

The acid lost to waste water treatment plant was quantified as $(66246\ m^2*0.3\ L/m^2)*100g/L=2266kg/year$. Which amounts to almost half the acid consumption.

The surface area determined by the acid model was used for the degreaser and zinc models.

4. The degreaser model

The operator inputs are entered into the Mathlab simulation and Monte Carlo is used to complete the simulation 1000 times. The results indicate that the concentration of the caustic component of the degreaser solution has been reduced by 1.07 g/l, but more importantly that a high dragout has resulted in a liquid loss of 420 liters over the week.

Thus the total degreaser consumption for Saayman Danks is 46.2 kg degreaser top up /week. This is divided into 4.2 kg/week for the reaction and 24 kg/week for the dragout losses.

The oil is considered to be the main contaminant in the degreaser solution. The model is able to predict the precise amount of oil removed. The model predicts an increase in oil/contaminant of 6.67 g/l over the period of the week. At this rate the solution saturation point can be determined and hence the lifespan of the degreaser solution.

5. Zinc plating model

The operator indicated an addition of caustic to the zinc plating tank of approximately 25 kg /week and anode additions at 80kg/week or 300kg/month. This data was used to simulate the zinc tank operations using the model developed in Chapter 7 of this study.

The Monte Carlo simulation results indicate that the concentration of caustic at the end of the week was 3.9304 mol/l a decrease from 4 mol/l, whilst the zinc had increased to 0.2706 mol/l from 0.27 mol/l. This increase in zinc concentration is mainly due to the difference in cathode and anode efficiencies. The actual required weekly top up is thus generated to maintain the solution as optimum as possible. The model can also generate daily top up figures to improve efficiency.

6.Water consumption

The information received from the operator on water consumption was not considered accurate, as there was more than a single plant releasing wastewater to the wastewater treatment plant and there were no water meters for the zinc line. Hence for the purpose of this investigations the values obtained via the bucket and stopwatch measurements were used as water consumptions. The water consumption of the zinc section was determined to be 1198 l/hr.

For the acid and degreaser, two rinse tanks, a dragout of 160 ml/m^2 and a dilution factor of 1000 was used to develop the optimum water consumption. This was classified as the cleaning section of the line. For the acid and degreaser system the optimum water consumption should be 42 l/hr. The company currently uses 444l/hr. The model indicates a potential 90% saving in water in this section of the plant.

For the zinc plating system, if optimum evaporation was achieved then, for a three tank low flow counter current system the water consumption would be 12.5 l/hr. Thus the total water consumption including the Passivate would be 96.5 l/hr. This would result in potential water saving of 630 l/hr or 85 % of the current water used in this section.

The above figures were obtained from the models developed for the individual systems and are described in this thesis.

Table F1: Chemical Consumption

	Chemicals			Production	Process baths		Replaced Process Baths			Cost of Baths	Key figures: litre bath per 1000m2		
Process bath	Type	kg/yr	R/yr	m2/yr	Volume, litre	Maintenance	Disposal	m3/yr	R/yr	R/yr	Calculated	Goal	Score, 1-5
Zinc line													
Degreasing bath	Soak clean	1,749	0	55,440	3,500		0.5	1.8		0	32.4675325	75	1
Sulfuric acid pickling	Sulfuric acid, 96%	4,547	0	55,440	3,500		8	21		0	378.787879	45	5
HCl pickling	HCl, 32%	0	0	0						0	0	30	
Pickling-degreaser	Sulfuric acid, 96%	0	0	0						0	0	45	
Electrolytic cleaner	Cleaner salt	0	0	0						0	0	50	
Acid dip	HCl, 32%	0	0	0						0	0	15	
(Pre-treatment)	(Other)	0	0	0						0	0		
Zinc bath	Zinc anodes	3,724	0	55,440	10,500	2				0	0	0	
Zinc bath	NaOH	1,023	0	55,440						0	0		
Zinc bath	H3BO3, 100%	0	0	0						0	0		
Zinc bath	ZnCl2, 100%	0	0	0						0	0		
Zinc bath	Conditioner	1,494	0	55,440						0	0		
Zinc bath	(Other)	0	0	0						0	0		
Deoxidizer	Nitric acid	0	0	0						0	0	50	
Chromating, blue	Chemoxy	55	0	55,440	3,500					0	0	500	
Chromating, blue	Nitric acid	288	0	55,440						0	0		
Chromating, black	Chemoxy 75	77	0	55,440	3,500					0	0	75	
Chromating, black	Chemoxy 76	70	0	55,440						0	0		
BTS	(Other)	81	0	55,440						0	0		
Sum:		14,247	0		24,500			22.8	0	0	411.255411		3

Score: 1 = good, 5 = unsatisfactory

Table F2: Rinsing and water consumption-Zinc

Rinse	Rinse	Process bath	Raw water	Tank	Rinse system data score (1=OK, 5=unsatisfactory)						Total,%	Water flow, l/h		Water consumption: l/m2		Savings
tank no.	system	before rinse		litre	Drip-ping	Hang-ing	Agita-tion	Inlet-outlet	Back-mix	Flow-control	Max100	Actual	Goal	Calcu-lated	goal	m3/yr
2	1	Degrease	T	3500	5	2	3	4	1	3	63	219	50.4	17.4	4.0	741.8
4	1	Acid	T	3500	5	2	3	4	1	3	63		50.4	0.0	4.0	0.0
8	1	Desmut	T	3500	5	2	3	4	1	3	63	225	50.4	17.9	4.0	768.2
10	4	Zinc	T	2200	5	2	3	4	1	3	63		63.5	0.0	5.0	0.0
11	1	Zinc	T	3500	5	2	3	4	1	3	63	514	63.5	40.8	5.0	1982.2
14	1	Passivate	T	3500	5	2	3	4	1	3	63	240	50.4	19.0	4.0	834.2
Sum:												1198	328.6	95.1	26.1	4326.5

Abbreviations for rinse system:
1 = running rinse
2 = static rinse (drag-out rinse)
3 = Spray rinse
4 =static + running rinse
5 =static +2-running rinse
6 =static +3-running rinse
10=
11 = 2-step counter current rinse
12 = 3-step counter current rinse
13 = 4-step counter current rinse
14 = static + 2-step counter current rinse
15 = static + 3-step counter current rinse

Abbreviations for raw water types:
T-water = tap water
I-water = ion-exchanged water
C-water = chemical treated water
R-water = reuse water from another rinse tank
DI-water = de-ionised water

Agitation and Liquid Motion
1 = agitation and motion
2 = agitation and motion
3 = heavy motion, no agitation
4 = some motion, no agitation
5 = no motion, no agitation

Inlet/outlet in Rinsing Tanks
1 = Inlet (top) reverse outlet (bottom)
2 = Inlet (top) reverse outlet (dived)
3 = Inlet reverse outlet, bottom
4 = Inlet reverse outlet, top
5 = Inlet near outlet, top

Back-Mix in Rinsing Tank
1 = No back-flow
2 = Minimum back-flow
3 = Moderat back-flow
4 = Some back-flow

Score for Dripping
1 = 20- sek
2 = 15-19 sek
3 = 10-14 sek
4 = 5-9 sek
5 = 0-4 sek

Score for Hanging
1 = All water run off immediately
2= All water run off after some time
3 = Moderat run off
4 = Slow run off
5 = Slow run off + water pockets

Score for flow-control
1 = Complete flow-control
2 = Some flow adjustment
3 = Coarse flow-control
4 = Very little flow-control
5 = Totally open valve

Support table							
F-value	h/yr	m2/yr	Drag-out, l/m2	L * M	Helping Score	PARCOM Water Consumption, m3/yr	Present Water Consumption, m3/yr
1000	4400	55,440	0.4	13,870.00	63	221.76	963.60
1000	4400	55,440	0.4	0.00	63	221.76	0.00
1000	4400	55,440	0.4	14,250.00	63	221.76	990.00
2000	4400	55,440	0.4	0.00	63	279.40	0.00
2000	4400	55,440	0.4	32,553.33	63	279.40	2,261.60
1000	4400	55,440	0.4	15,200.00	63	221.76	1,056.00
				75,873.33		1,445.84	5,271.20

Possibilities for optimisation, total		63.33
Possibilities for relative savings		72.57
Possibilities for absolute savings		3825.36

Table F3: Waste minimisation-Zinc

Type of waste	Waste	Disposal methods	Costs		Possibilities for waste reduction: 5=big and 1=small					
Write the types below	ton/yr		R/ton	R/yr	Reduction of drag-out and drag-in	Optimising bath chemistry	Concentrating of waste	Improved maintenan-ce of process baths	Recovery from waste	Relative ranking of saving possibilities
Liquid sludge	15	CT	500	7500	5	3	2	4	3	100
Filter cakes										
Sum	15			7500						100
					Score: 1 = good, 5 = unsatisfactory					
								Total score		60.0

Support table

Number of score-cells >0	% potential savings	T * B
5	60	900
0		
	4	900

Disposal methodes (codes):
CT = Treatment on a central plant
ER = External Recovery
ED = External Destruction
DL = Disposal at landfill

Table F4: Consumption of chemicals for wastewater treatment

Chemicals	Concentration	Consumption	Costs	Possibilities of savings					
		kg/yr	R/year	5=big and 1=small possibilities					
				Using less excess of chemicals	Use spent process baths instead	Optimising the treatment of spent baths	Better separation of wastewater streams	Total score, 0-100%	Saving index = consumption * score
Sodium hydroxide	100%	400		2	2	2	4	37.5	150
Sodium hydroxide	28%								
Hydrochloric acid	30%								
Sulfuric acid	96%	50		2	2	2	4	37.5	18.75
Sodium disulfite	100%								
Sodium dithionite	100%								
Hydrogen peroxide	35%								
Polymer	100%								
Iron(III) chloride									
Sodium hypochlorite	15%								
Calcium chloride	100%								
Sum		450	0						37.5

Table F5: Operational practice for waste water treatment

Operation monitoring	Cleaning and calibration		Control Measurement			Total
	Frequency	Score	Frequency		Score	
pH, neutralisation	3	3				
pH, chromate reduction	3	3				
mV, chromate reduction	5	5				
pH, cyanide oxidation	5	5				
mV, cyanide oxidation	5	5				
pH, outlet	5	5				
Chlorine monitoring						
Cr+6 monitoring			5		5	
SO3 monitoring						
Metal monitoring			5		5	
Avarage score		4.3			5.0	
Total score-%		83.3			100.0	88.9

Table F6: Cleaner production Options

	Potential for introduction of cleaner production (CP)				
CP methods	Not relevant	Low	Medium	High	Is the technique applied today?
Treatment and purification of process baths:					
Oil skimming and sludge removal from cleaners			x		
Purification of cleaners by UF or centrifuges		x			
Purifikation of pickling acid by dialysis or crystallisation		x			
Purification of nickel baths by carbon filtration	x				
Purification of acid zinc baths by carbon filtration		x			
Purification of chromating and chrome bath by membrane electrolysis	x				
Purification of chromating and chrome bath by ion-exchanging	x				
Removal of carbonate from cyanide plating baths	x				
Removal of metal contaminations from nickel baths	x				
Substitution of process chemicals:					
Replacing cyanide	x				
Replacing EDTA	x				
Replacing complexing chemicals	x				
Replacing ammonia	x				
From high to low metal concentration	x				
Reuse of collected process chemicals from rinse water:					
Alkaline cleaners		x			
Zinc bath		x			
Chromating bath	x				
Copper bath	x				
Nickel bath	x				
Bright chrome bath	x				
Tin bath	x				
Silver bath	x				
Recovery of metals by electrolysis:					
Zinc		x			
Copper	x				
Nickel	x				
Chromium	x				
Tin	x				
Silver	x				
Rinsing processes:					
Optimising existing rinse system				x	
Counter current rinse				x	
Static rinse tanks with reuse (drag-out rinse)				x	
Spray rinse		x			
Water recycling by ion-exchangers		x			
Recycling of purified wastewater			x		
Control of rinse water flow				x	
Wastewater treatment plant (WWTP):					
Saving of chemicals		x			
Chemical or hazardous waste					
Internal processing and recovery		x			
External processing and recovery		x			

Table F7: Occupational health and safety-Zinc

		Chemistry	Temperatur	Noise	Heavy Lifts	Occupational safety risks	
Zinc1	Alkaline degreaser	100	100	27	27	8	
	Zinc bath	27	27				
Zinc2	Alkaline degreaser						
	Zinc bath						
Zinc3 (CN)	Alkaline degreaser						
	Zinc bath						
Zinc4 (CN)	Alkaline degreaser	27	27	27			
	Zinc bath						
Cu-Ni-Cr-1	Nickel bath						
	Chromium bath						
Cu-Ni-Cr-2	Nickel bath						
	Chromium bath						
Cu-Ni-Sn-1	Alkaline degreaser						
	Nickel bath						
Cu-Ni-Sn-2	Alkaline degreaser						
	Nickel bath						
Aluminium1	Alkaline pickling						
	Anodising						
Aluminium2	Alkaline pickling						
	Anodising						
Phosphating 1	Alkaline pickling						
	Phosphating						
Phosphating 2	Alkaline pickling						
	Phospahting						
	Sum	154	154	54	27	8	Total
Occupational Health and Safety	Total score	51.3	51.3	26.9	26.9	7.7	23.4

		Chemistry			Temperature			Noise			Heavy lift			Risk	
		Quantity	Time	Effect	Quantity	Time	Effect	Quantity	Time	Effect	Quantity	Time	Effect	Score	
Zinc1	Alkaline degreaser	3	3	3	3	3	3	2	2	2	2	2	2	3	
	Zinc bath	2	2	2	2	2	2								
Zinc2	Alkaline degreaser														
	Zinc bath														
Zinc3 (CN)	Alkaline degreaser														
	Zinc bath														
Zinc4 (CN)	Alkaline degreaser	2	2	2	2	2	2	2	2	2					
	Zinc bath														
Cu-Ni-Cr-1	Nickel bath														
	Chromium bath														
Cu-Ni-Cr-2	Nickel bath														
	Chromium bath														
Cu-Ni-Sn-1	Alkaline degreaser														
	Nickel bath														
Cu-Ni-Sn-2	Alkaline degreaser														
	Nickel bath														
Aluminium1	Alkaline pickling														
	Anodising														
Aluminium2	Alkaline pickling														
	Anodising														
Phosphating 1	Alkaline pickling														
	Phosphating														
Phosphating 2	Alkaline pickling														
	Phospahting														

Scores: 3=high, 2=medium, 1=low   Risk score: from 1 - 27

Table F8

	Recommendation	Action	Resource
.	Low flow counter current rinses	Installation of additional tanks and piping. Arrange cascade from tanks Introduce water at last rinse tank	To be determined comprehensively in a feasibility study
.	Redirecting of rinse waters	Redirect water between rinse tanks so as to optimise water consumption	To be determined comprehensively in a feasibility study
.	Increased dripping time	Increase drip times to 20 seconds. This would ensure proper liquid drainage	Can be implemented immediately
.	Improved dripping techniques	Spills into adjacent baths can be prevented by proper tilting of cup shaped items	Can be implemented immediately
.	Use of process chemicals for neutralisation	Spent process chemicals can be stored and used for neutralisation	To be determined comprehensively in a feasibility study
.	Measurement and dosing of process chemicals	Proper dosage of chemicals ensure optimal use of chemicals	To be determined comprehensively in a feasibility study
.	Health and safety	Operator training needs to be conducted on the chemical hazards	Development of hazop procedures
.	Improved flocculation	Addition of flocculent to settle out metals	Needs to be done immediately
.	Waste water treatment plant	Proper control and management with regards, control and dosing	To be determined comprehensively in a feasibility study

0.	Installation of flow-meters	Installation of flow meters on all water inlets, overall process	Can be implemented immediately
1.	Replacement of chemicals	Replacement of chemicals such as cyanide	To be determined comprehensively in a feasibility study

Figure F1: Flow sheet for process line-Zinc

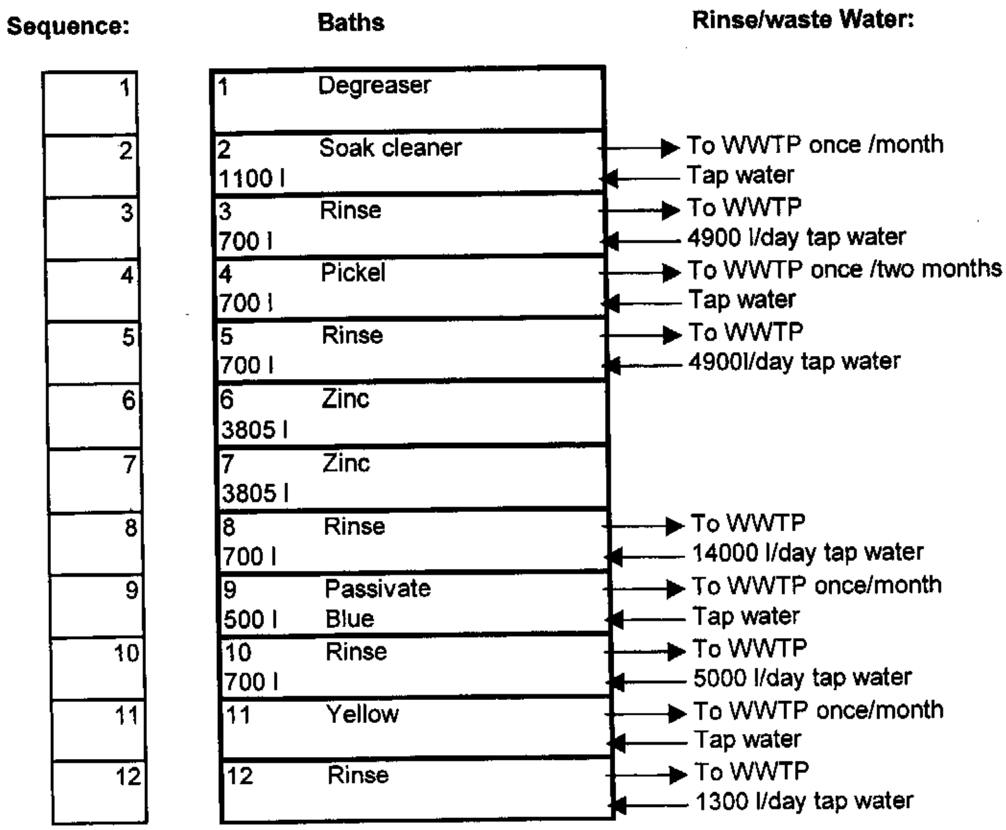


Figure F2: Flow sheet for process line –Chrome

Sequence:	Baths			Rinse/waste Water:
1	1	Vapor degreaser		Desludge every two m
2	2	Soak cleaner	1100 l	→ To WWTP twice/year ← Tap water
3	3	Rinse	700 l	→ To WWTP ← 1100 l/day tap water
4	4	HCL	700 l	→ To WWTP once/week ← Tap water
5\7	5	Rinse	700 l	→ To WWTP ← 3200 l/day tap water
6	6	Etch	700 l	→ To WWTP twice/year ← Tap water
8	8	Nickel	1700 l	
8	9	Nickel	1700 l	
8	10	Nickel	2000 l	
8	11	Nickel	2800 l	
9	9	Rinse	1200 l	→ To WWTP ← 900 l/day tap water
10	10	Chrome 2 tanks	1800 l	
11	11	Static rinse	1200 l	
12	12	Rinse	700 l	→ To WWTP ← 962 l/day Tap water
13	13	Neutrachrome	700 l	→ To WWTP twice/year ← Tap water
14	14	Rinse	700 l	→ To WWTP ← 514 l/day tap water
15	15	Hot rinse	700 l	→ To WWTP ← 1000 l/day tap water