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Development and evaluation of woven fabric microfiltration membranes impregnated with silver nanoparticles for potable water treatment

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ABSTRACT

Access to clean and safe drinking water is a fundamental human need, which is commonly lacking in remote rural areas. A simple gravity-fed water treatment unit was developed based on woven fabric microfiltration (WFMF) membranes. However, since these membranes are loose micro-filters, the unit has to be used in conjunction with a disinfectant. This paper explores combining the WFMF membranes with silver nanoparticles (AgNPs) using a modified chemical reduction method. The originally white membranes turned brown–yellow due to the surface plasmon resonance of silver; however, there was no significant difference in the morphology of the membranes after the impregnation with 0.0117 wt% AgNPs. The coated membranes were more hydrophilic and had higher water permeability ($p < 0.05$). Filtration of turbid water (40–700 NTU) showed that both membranes produced clear permeate (< 1 NTU). Treatment of water spiked with bacteria (2500–77,000 CFU/100 mL *Escherichia coli*) showed that the removal efficiency of uncoated membranes was 84–91% and that of coated membranes was 100%. Accordingly, the coated membranes depicted great potential for water treatment. To the best of our knowledge, this is the first study that investigated the incorporation of AgNPs in WFMF membranes and characterized their properties.

1. Introduction

Lack of access to clean and safe drinking water is a major concern worldwide, more especially in rural areas of developing nations. Implementation of conventional water treatment is expensive and unfeasible for these areas [1]. Point-of-use (POU) systems have been recommended as interim solutions to avoid incidences of waterborne diseases. POU systems such as chemical disinfection using chlorine tablets, solar disinfection, filtration using sand filters and ceramic filters, and boiling have been used in remote rural areas. However, they have been found to be unsustainable for reasons that include chlorine tablets are not readily available and their use leads to the formation of disinfection by products (DBPs) [2]; solar disinfection requires a long waiting time and treats small quantities of water at a time [3]; ceramic filters are delicate, break easily and have low flow rates [4]; and boiling of contaminated water is energy intensive and the water can be re-contaminated when cooling [5]. Membrane-based technologies, especially microfiltration (MF) and ultrafiltration (UF), have potential advantages for application in potable water treatment in underdeveloped rural regions as POU systems. These advantages include: the product quality does not depend on the skills of the operator or the mode of operation; and they can be operated under low pressure (gravity), thereby eliminating the energy costs resulting from the use of pumps and electricity.

Despite the wide use of membrane technology in large-scale water treatment, the application of current commercial membrane systems in rural areas faces significant drawbacks. These include: lack of robustness resulting from the delicate nature of the membranes, since most of them if left to dry can easily be damaged; and their costs are relatively high. These factors make current commercial membranes difficult to apply in small water treatment systems that would be sustainable in rural areas [6]. This necessitates the development of appropriate membrane technologies for such areas that meet the following criteria: robust in operation; not require the use of pumps or electricity; easy to use and maintain; and produce treated water that meets drinking water standards.

Researchers at Durban University of Technology and Stellenbosch University, South Africa have developed a membrane technology that is seemingly appropriate for such areas. It is based on a polyester woven-fabric microfiltration (WFMF) membrane that is robust,

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Fig. 1. The WFMFGF: assembled unit (*left*), front view (*centre*) and bottom view (*right*) of membrane pack.

relatively inexpensive and produced locally in South Africa. The filtration unit, known as the woven fabric microfiltration gravity filter (WFMFGF) consists of a pack of flat sheet modules (Fig. 1). It essentially removes suspended matter and produces permeate with turbidities below 1 NTU. It also removes most of the microbial contaminants, for instance up to 95–99% of influent *Escherichia coli* [6].

The separation is achieved by size exclusion of material and formation of a cake layer on the filter surface. The membranes are extremely robust and can be easily cleaned using a brush and tap water when fouled. Previous studies [6] have shown that depending on the raw water quality, the membranes can operate effectively for a month before cleaning is required. Thereafter, the system can still run but the flow rate progressively decreased if not cleaned. The membrane modules can be cleaned by simply brushing them with a bottle brush and hence are reusable. Though this performance is good, it falls short of meeting the set drinking water guidelines that require zero *E. coli* in drinking water [7]. Thus the system requires a separate disinfection step, whereby a disinfectant such as chlorine is added to permeate by the user before consumption.

However, challenges arise during post disinfection especially when left for the user to perform. For instance, over-dosing of disinfectant can lead to formation of harmful DBPs; conversely, under-dosing or forgetting to add the disinfectant can result in ingestion of poorly treated water and hence break out of waterborne diseases.

The objective of the study reported here was to develop a system where the disinfectant is incorporated into the membranes and complete disinfection is achieved in one step in order to prevent the negative effects of human error in disinfectant dosing.

Silver nanoparticles (AgNPs) were selected as the disinfectant to be impregnated into the membranes. They are known to have excellent antimicrobial properties and low toxicity to humans [8]. AgNPs can overcome the limitations of current disinfectants, such as the formation of DBPs which arise when using conventional disinfectants such as chlorine and ozone. This is because AgNPs, unlike conventional chemical disinfectants, are not strong oxidants and are not likely to produce harmful DBPs. Therefore, their incorporation into treatment processes has the potential to replace or enhance conventional disinfection methods [8]. This study investigated the incorporation of AgNPs on the WFMF membrane and characterized the resulting coated membrane. To the best of our knowledge, this is the first study on the incorporation of AgNPs on the WFMF membrane for water disinfection. The study showed that the filtration and disinfection performance of the coated membranes were enhanced, making it a potential promising POU technology for water treatment in remote rural areas.

2. Materials and methods

2.1. Materials

Silver nitrate, sodium borohydride and ethanol were all obtained from Laboratory Supplies Co in Durban, South Africa. The chemicals were of analytical grade and were used as received without further purification. Silver nitrate was stored in a dark container to prevent photo oxidation. All reagents were freshly prepared in “A” grade volumetric flasks and used. Deionized water for dilutions was drawn from pure lab option Q system delivered at a conductivity of 0.055 μS cm^{-1}. WFMF membranes were obtained from Gelvenor Consolidated Fabrics (Pty) Ltd in Durban, South Africa.

2.2. Methods

2.2.1. Incorporation of the AgNPs on the WFMF membranes

The method of Dankovich and Gray [9] was used, with modifications. Uncoated membranes were soaked in 0.05 M $AgNO_3$ solution for 30 min in order to absorb silver ions, and then rinsed in ethanol for 10 min to remove excess $AgNO_3$. They were thereafter soaked in 0.5 M $NaBH_4$ solution for 15 min to reduce silver ions to AgNPs. The membranes were thoroughly rinsed using deionized water and dried in an oven at 100 °C for 3 h.

2.2.2. Membrane characterization

The following membrane characterization tests were carried out.

2.2.2.1. Scanning electron microscopy (SEM) analysis. SEM is a microscopic method used to observe the surface structure and hence provide information about the morphology of the sample. The morphology of the uncoated and coated membranes was therefore investigated using SEM. Clean pieces of the uncoated and coated membranes measuring 0.5 cm by 0.5 cm were dried in an oven at 70 °C for 1 h to remove moisture. The pieces were coated using gold in an inert environment containing Argon gas. The surface structure of the membranes was observed using SEM, at an accelerating voltage of 5.0 kV. This was done at magnifications of 150 × and 2000 × .

2.2.2.2. Silver content in the coated membrane. Pieces of the coated membranes were acid digested in a 50/50 mixture of nitric acid (55%) and deionized water on a hot plate. The solutions were cooled and then filtered using 0.45 μm Millipore filters. The silver concentration of the filtrate was determined using Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES). This test was conducted in triplicate. The mass of silver (mg) was calculated using the equation, mass of silver = (Concentration of silver (mg/L) × (0.05 L).

2.2.2.3. Fourier transform-infrared (FT-IR) analysis. The chemical compositions of as prepared membrane surfaces were investigated by attenuated total reflectance Fourier transform infrared spectroscopy (ATR-FTIR). FT-IR spectra of the uncoated and coated membranes were collected from the Perkin Elmer 100 FTIR-ATR spectrometer. Spectra were obtained for a range of wave numbers (1850–650 cm^{-1}).

2.2.2.4. X-ray diffraction (XRD) analysis. XRD is a spectroscopic method used to identify the presence of elements in a sample. Specific elements have unique crystal structures and hence the crystal structures can be used to distinguish the elements in a sample. The XRD for the coated membrane was conducted in the angle range of $5^\circ < 2\theta < 80^\circ$ in order to determine the presence of silver on the membrane. The equipment voltage and current were set at 40 kV and 40 mA respectively.

2.2.2.5. Thermogravimetric analysis (TGA). TGA was performed using a Perkin-Elmer Thermal Analysis instrument using 10 mg samples that were heated at a rate of 10 °C/min from 30 to 800 °C and the weight loss of the sample recorded.

2.2.2.6. UV–vis spectrophotometry. The presence of AgNPs on the coated membrane was investigated using the UV-2540, Shimadzu Corporation, Kyoto, Japan spectrophotometer. Two disk cuvettes were used, one containing barium sulphate powder (as the standard) and the other having a piece of the membrane (sample). The disk cuvettes were placed in the appropriate sample holders. The uncoated and coated membranes were analysed in turns. They were scanned and the absorbance spectra of the samples recorded in the range of 900–200 nm.

2.2.2.7. Hydrophilicity. This was determined by measuring the contact angle of pure water on the membrane using the sessile drop method for both the uncoated and coated membranes using Data Physics optical contact angle measuring equipment. The uncoated and coated membrane samples were dried in an oven at 70 °C for 1 h to remove moisture and cooled to room temperature before use. They were placed in turns on the holding cap of the Data Physics contact angle measuring equipment. For each of the membrane pieces, a drop of pure water was deposited on the membrane using a Gilmont syringe located directly above the membrane. Water droplets were contacted with the membrane at different locations on each membrane sample for repeatability. A high resolution camera was used to capture a picture of the droplet as it came into contact with the membrane surface. The results were analysed using software called SCA_U. The average values of the contact angles and surface energies were recorded.

2.2.3. Filtration and disinfection performance

The filtration performance of the membranes was investigated by determining the pure water flux and filtration of turbid water. Disinfection efficacy was evaluated by filtering raw river water and synthetic feed containing *E. coli*.

2.2.3.1. Pure water flux. The pure water fluxes of the uncoated and coated membrane modules (one each) were determined by filtering deionized water through the filter in dead end mode under gravity (Fig. 2). The filtration unit was flushed with deionized water and the drainage valve and permeate outlet tap opened to drain the water. The drainage valve and permeate tap were closed. Deionized water was poured into the feed tank to a height of 0.21 m. The permeate outlets of the coated and uncoated filters were opened and permeate collected in beakers. The volume of permeate collected with time was recorded, as well, as the corresponding water level in the feed tank.

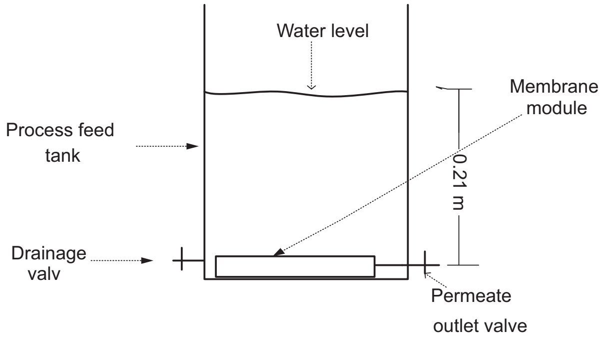

Fig. 2. Laboratory rig for the determination of pure water flux using uncoated and coated membranes filtering deionized water under gravity.

The permeate flux (J) was calculated using the equation,

$$J = V/At \tag{1}$$

where V is the volume of permeate (L), A is the membrane filtration area (m^2), and t is the time of collection of permeate (h).

2.2.3.2. Filtration of turbid water. Two membrane packs (each containing four A4 size flat sheet modules) of the uncoated and coated filters were used to filter feed water with different turbidities (40, 100 and 700 NTU) under gravity (Fig. 3). The permeate turbidity was recorded over time using a Hach 2100P turbidity metre.

2.2.3.3. Disinfection performance (flow test). Two membrane packs of the uncoated and coated membranes (each containing four A4 size flat sheet modules) were immersed in feed tanks containing feed suspension at different concentrations of *E. coli*. The experimental set-up is as shown in Fig. 3. The uncoated membranes were used as the control. Three concentrations of *E. coli* were employed using river water (2500 and 10,000 CFU/100 mL) and synthetic feed water (77,000 CFU/100 mL). The feed water was poured into the feed tank containing the membranes and the permeate outlet was opened. Permeate was collected (within 5 min) and analysed for the presence of *E. coli*. The *E. coli* removal efficiency, R(%) was calculated using the equation,

$$R(\%) = 100(1 - C_p/C_f) \tag{2}$$

where C_f is the *E. coli* concentration in the feed and C_p is the corresponding concentration in permeate.

Disinfection efficacy was also expressed in terms of log removal values (LRV) [10].

$$\text{LRV} = \log_{10}(C_f/C_p). \tag{3}$$

2.2.3.4. Stability of AgNPs (silver elution test). To investigate the stability of the AgNPs on the membranes, an experiment was conducted on silver elution. An A5 size flat sheet AgNPs coated module was constructed and placed in a feed tank vertically (similar set-up to Fig. 3). Deionized water was fed to the tank at a height of 0.25 m. Permeate was collected every 24 h and tested for the presence of silver using ICP-AES over a period of 5 days.

3. Results and discussion

3.1. Visible effects of membrane coating

The colour of the WFMF membrane changed from white to brown–yellow indicating the formation of AgNPs by reduction of silver ions to elemental silver [11]. The brown–yellow colour is a well established characteristic of AgNPs [12]. This was in agreement with the literature [13]. This colour is due to the surface plasmon response (SPR) of AgNPs under the range (390–420 nm) for AgNPs [9,14] as a result of the interaction of light waves on the surface of AgNPs. The colour change indicated that AgNPs were incorporated on the WFMF membrane (Fig. 4).

3.2. Morphology

The SEM micrographs of the surface of the uncoated and coated WFMF membranes were taken at magnifications of 150 × and 2000 × (Fig. 5a–d).

There was no significant difference in the surface morphology of the uncoated and coated membranes at 150 ×. However, at 2000 × some matter was observed on the surface of the coated membrane that was postulated to be the AgNPs.

3.3. Silver content in the coated membranes

The average amount of silver on the coated membrane module was 0.0117 wt% in the module and corresponded to a silver content of 0.0139 mg cm^{-2}. This amount was similar in the three samples tested and indicated that the silver coating was fairly uniform.

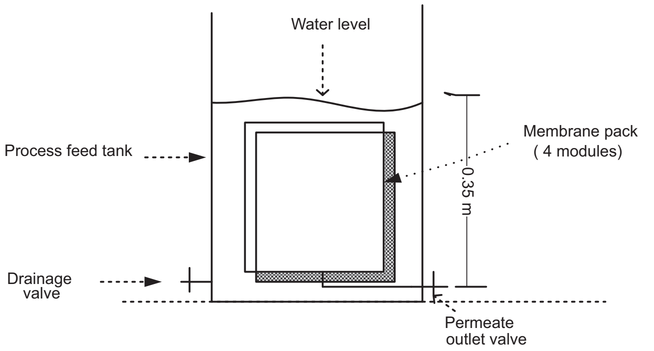

Fig. 3. Schematic representation of the WFMFG unit used for filtering water of different turbidities.

3.4. Membrane hydrophilicity

The polyester fabric without silver coating is known to be hydrophobic in nature [15], and hence the large contact angle of 76° obtained from the sessile drop test. The contact angle for the coated membrane was found to be 17° This meant a 77% decrease in the contact angle due to the incorporation of AgNPs. Thus the coated membrane was significantly more hydrophilic than the uncoated membrane ($p < 0.05$). This was in agreement with other studies incorporating AgNPs on substrates [16,17]. The possible explanation on improvement of the coated membrane hydrophilicity could be due to the AgNPs releasing silver ions in aqueous phase by oxidation. The silver ions can simultaneously be adsorbed on the silver nanoparticles surface in the formation of a hydrated silver ion which was the probable source of silver nanoparticles hydrophilicity [18].

3.5. FTIR spectra

The FTIR spectra of the uncoated and coated membranes are presented in Fig. 6.

There were some minor differences in the position of the peaks between the spectra of both membranes especially the peak at 761 cm^{-1} (uncoated) representing aromatic ring stretch was located at 752 cm^{-1} in the coated. Overall, there was no significant difference in the FTIR peaks of the uncoated and coated membranes. Other studies by Pradeep et al. using AgNPs coated polyurethane reported a significant shift in some peaks between the coated and uncoated polymers [13]. Our findings may have been occasioned by the low amount of AgNPs impregnated on the membranes hence resulting in no significant chemical bonding.

3.6. UV–vis spectroscopy

The UV–vis absorbance spectra of the membranes are shown in Fig. 7.

Metal nanoparticles such as silver display a very intense peak in UV–vis spectroscopic analysis due to SPR. The movement of free electrons between the conduction and valence bands of silver gives rise to SPR absorption band in UV–vis spectroscopy analysis [19]. The characteristic absorbance peak, approximately at 420 nm for the coated membrane [20] indicated the presence of AgNPs on the membrane. There was no characteristic peak at this position (420 nm) for the spectrum of the uncoated membrane, as expected. This indicated that the coated membrane indeed contained the AgNPs.

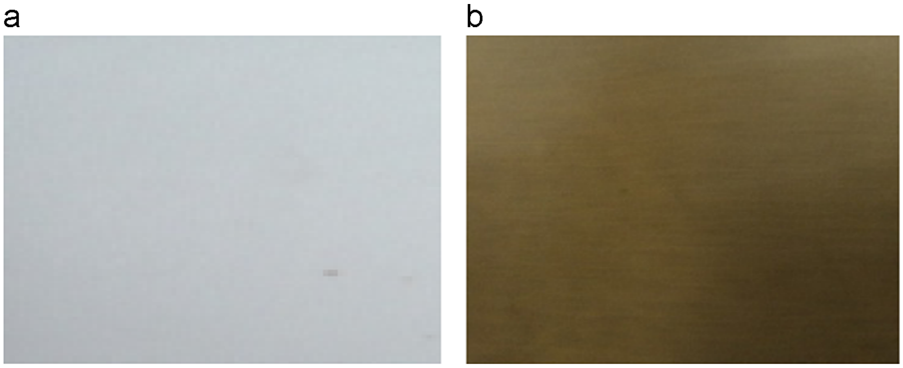

Fig. 4. Photographs of the uncoated (a) and coated (b) membranes showing the colour change as a result of incorporation of AgNPs.

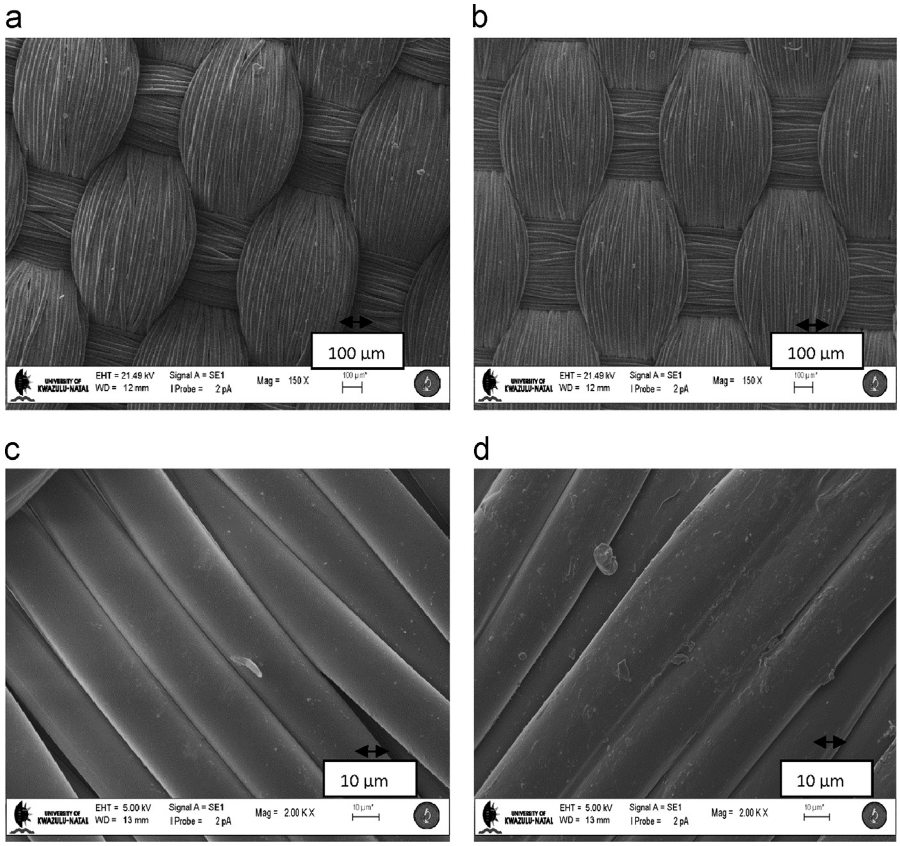

Fig. 5. SEM micrographs of the uncoated and coated membranes at magnifications of 150 × (a and b) and 2000 × (c and d) showing the surface morphologies of the membranes.

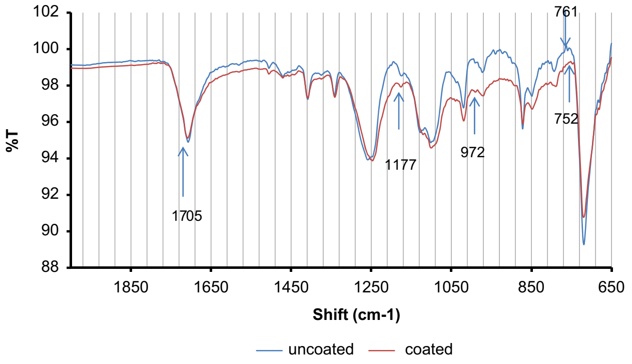

Fig. 6. FTIR spectra of uncoated and coated membranes between 650 cm^{-1} and 1850 cm^{-1}. The characteristic peaks show the functional groups in the membranes. The presence of peaks at 972 cm^{-1}, 1177 cm^{-1}, and 1705 cm^{-1} in the spectra of both membranes confirmed that the membranes were polyester based [18].

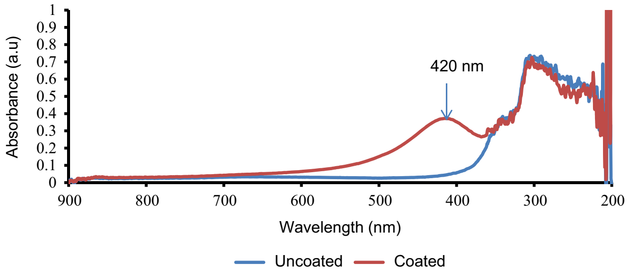

Fig. 7. UV spectra of uncoated and coated WFMF membranes showing a characteristic peak at 420 nm on the coated membrane arising from the presence of AgNPs. The spectra of both membranes appeared similar except for the characteristic peak at 420 nm on the spectrum of the coated membrane.

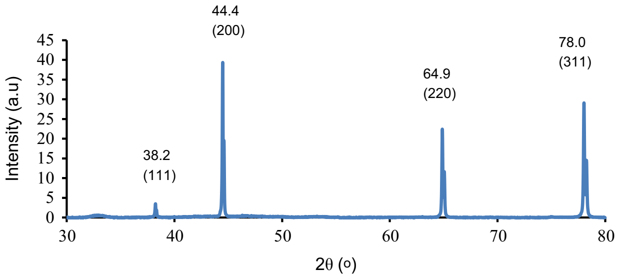

Fig. 8. XRD patterns of the AgNPs on the coated membrane. There were notable peaks at 2θ values of 38.2°, 44.4°, 64.9° and 78.0° corresponding to the face-centred cubic (fcc) structure of silver.

3.7. XRD spectra

The XRD spectrum for the coated membranes is shown in Fig. 8.

The diffraction pattern showed characteristic Bragg peaks at 2θ values of 38.2° (111), 44.4° (200), 64.9° (220) and 78.0° (311) which match the face-centred cubic structure of silver. This indicated the formation of AgNPs on the surface of the coated membranes [21,22]. The intensive peak located at $2\theta = 44.4°$ corresponds to the diffraction of (200) lattice plane of fcc structure. This indicates that (200) planes of AgNPs were highly oriented parallel to the WFMF membrane [23]. The peaks in XRD pattern are in good agreement with that of fcc of metallic silver.

3.8. TGA

Fig. 9 shows the results of the thermogravimetric analysis.

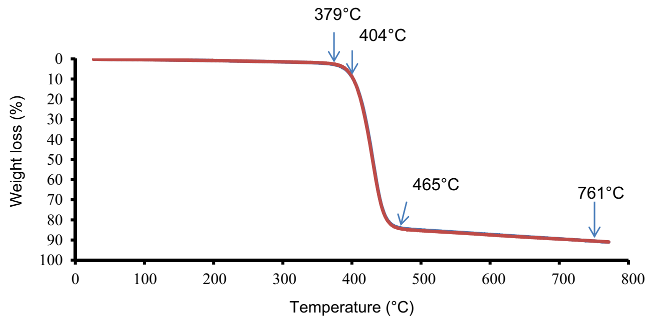

Fig. 9. TGA curves for the uncoated and coated membranes showing the thermal properties of the membranes over the temperature range (30–800 °C). The TGA curves were similar for both the uncoated and coated membranes due to the dominant polyester structure.

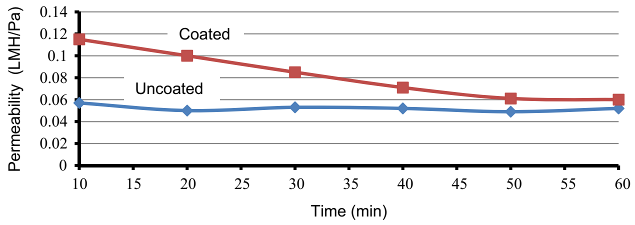

Fig. 10. Permeability for new uncoated and coated membranes with time filtering deionized water.

The curve showed initial decomposition occurring at 379 °C due to thermal breaking of the double bonds (–C═O–). Furthermore, there was a 10% weight loss at about 404 °C, and the residual weight of less than 10% at 76 °C due to the presence of high aromatic rings in the polymer structure. The similarity in the TGA curves for both membranes showed that the incorporation of AgNPs did not compromise the thermal properties of the WFMF membrane.

3.9. *Pure water flux*

Fig. 10 illustrates the permeability of the membranes.

The permeability was fairly constant for the uncoated membranes over time as expected for new membranes. The permeability of the coated membrane was higher than that of the uncoated membranes as expected since the former have a higher hydrophilicity. However, the permeability appeared to decrease with time, a phenomenon that we postulate could have been as a result of the AgNPs coating. This observation was unusual but was not investigated further since it was beyond the scope of our study. However, the experiment was conducted for 5 h using the coated membranes and the result is shown in Fig. 11.

The permeability appeared to stabilize after 3 h of filtration.

The pure water flux is shown in Fig. 12.

The flux increased with increase in TMP for both filters. The average flux of the uncoated filters was 114 ± 14 LMH while that of the coated filters was 183 ± 60 LMH. There was a significant difference in the fluxes of the two filters ($p < 0.05$). This was expected because, it is known that the specific flux increases with increasing hydrophilicity of the membrane material [24,25], which in this case was as a result of coating with AgNPs. The advantage of hydrophilic membranes is that they are easily wetted hence promoting higher permeabilities relative to pore size [26]. The fluxes obtained for both filters in our study were typical of MF membranes. Similar observations have been reported elsewhere [27].

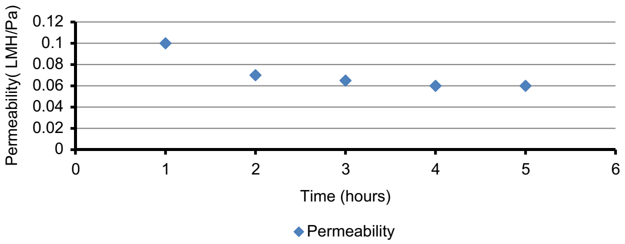

Fig. 11. Permeability of coated membrane for 5 h of filtration.

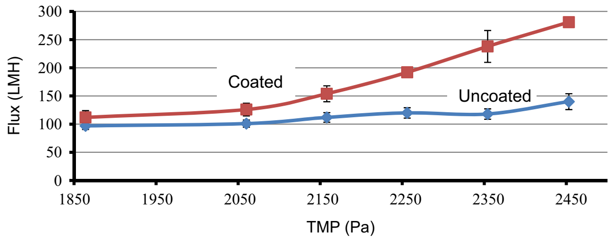

Fig. 12. Pure water flux of uncoated and coated membranes using deionized water under gravity filtration. The error bars represent standard deviations.

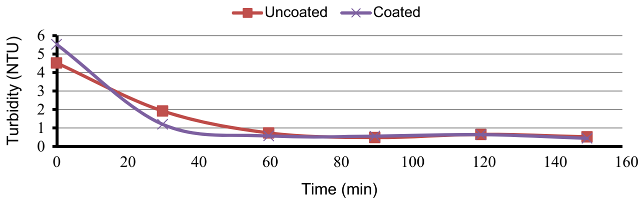

Fig. 13. Average turbidity of permeate (NTU) from the uncoated and coated membranes for feed water containing 700 NTU. Turbidities of less than 1 NTU were also recorded when filtering feed water with 100 NTU and 40 NTU and hence are not shown.

However, the results obtained in the current study were different from those obtained by Zodrow et al. [16], who impregnated UF polysulfone membranes with 0.9 wt% AgNPs. They showed that the hydrophilicity of the coated membrane increased by 10% and found out that the coated membrane had similar permeability to the control polysulfone membrane without AgNPs ($p < 0.05$). The difference in results may have been due to the difference in the degree of hydrophilicity achieved. In the study by Zodrow et al. [16] the water contact angle decreased by 10% while in the current study it decreased by 77%. Our findings indicate that impregnation of the WFMF membrane with AgNPs resulted in a significant increase in the permeability.

3.10. *Filtration performance*

Fig. 13 shows the filtration performance of the uncoated and coated membranes.

Since the membranes were being used for the first time, the initial turbidity was high but decreased as a cake layer formed on the membranes. The turbidity decreased with time for both membranes until it was generally below 1 NTU after 40 min. This phenomenon is only observed for a new membrane, but afterwards, the membranes produce permeate having less than 1 NTU irrespective of the turbidity of the feed water. This is because the cake layer formed on the membranes aids in the size exclusion of particulate matter. The WFMF membrane is an absolute barrier to substances that are larger than the equivalent pore size of the fabric [6]. Thus the filtration performance was not compromised by incorporation of AgNPs in the membranes.

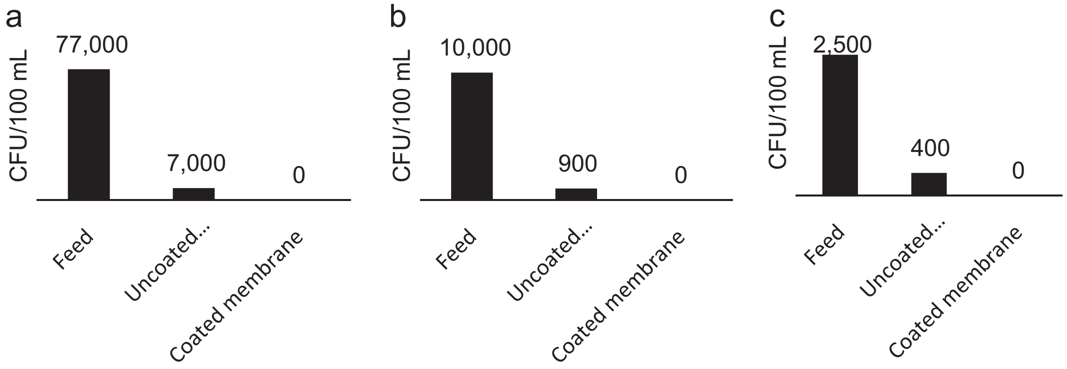

Fig. 14. Flow test at different *E. coli* concentrations. The corresponding LRVs were (a) 4.0, (b) 1.045 and (c) 0.8 for the uncoated membranes and (a) 4.9, (b) 4.0 and (c) 3.4 for the coated membranes. (a) High *E. coli* concentration. (b) Medium *E. coli* concentration. (c) Low *E. coli* concentration.

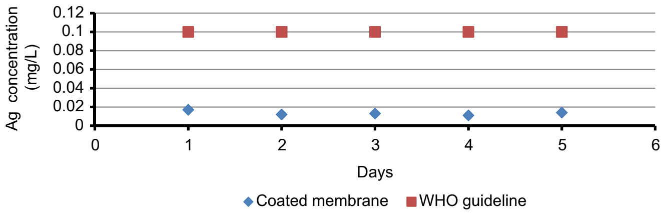

Fig. 15. Silver elution from the coated filters over a period of five days compared to the WHO guideline value.

3.11. Disinfection performance

The term disinfection is used here to refer to both physical removal of *E. coli* due to size exclusion by filtration and inactivation by AgNPs. The disinfection results for different *E. coli* concentrations using both filters are shown in Fig. 14a–c.

The *E. coli* removal efficiency of the uncoated was 84–91% in the three tests reported. It was observed that the *E. coli* removal improved with increase in the amount of *E. coli* in the feed water probably due to the higher concentrations leading to more *E. coli* deposition on the filter surface which enhanced the removal efficiency. The coated membranes, on the other hand, achieved 100% *E. coli* removal for all the three tests. No *E. coli* was detected in permeate. These results indicated that the antibacterial mechanisms for the coated filter were due to physical removal (filtration by size exclusion), which is attributed to the filtration of matter that cannot pass through the filter due to its large size; and inactivation using the AgNPs. This test demonstrated that the incorporation of AgNPs indeed significantly improved the disinfection efficacy of the WFMF membrane.

It was noted that despite the relatively low concentration of AgNPs used (0.0117 wt%), excellent disinfection performance was observed. This was because the concentration of *E. coli* investigated was not high (2500–77,000 CFU/100 mL) and it was based on the *E. coli* concentrations in the raw river water available in the target population. Other studies have employed much higher *E. coli* concentrations in the order of millions of CFU/100 mL [13,28,29]. However, such large amounts of *E. coli* are not generally found in river water and therefore were not used in this study. Similarly other researchers have employed higher silver loadings [16] and generally disinfection performance improves with increase in disinfectant concentration.

3.12. Silver elution test

The silver concentration in permeate was determined using ICP-AES for a period of five days and is shown in Fig. 15.

The silver eluted from the filters was below 0.02 mg/L which is far below the 0.1 mg/L limit recommended by the WHO [7] for safe drinking water. The elution of silver is however, inevitable since the mechanism of disinfection is postulated to be mostly due to the release of silver ions from the AgNPs [30–32]. Although the elution of silver contributes to the disinfection efficacy, on the other hand it reduces the amount of silver on the membranes and hence may eventually decrease the effectiveness of the filter. However, the WFMF membrane is robust and can be reused after cleaning [7] hence silver can be reloaded on the membranes using the same procedure (Section 2.2.1). In this case the fabric will be removed from the modules, chemically cleaned to remove the fouling matter, reloaded with the AgNPs and then glued back to the module. The frequency of reloading the AgNPs will depend on the frequency of use of the filter and the level of microbial contamination of the raw water.

Overall, the results indicate that the coated membranes can be employed to produce clean and safe drinking water at the point of use. The system developed is robust and the investigations have shown that it is effective. The woven fabric is locally available in South Africa and the other accessories used to assemble the filtration unit can be sourced locally. The chemicals used to synthesize the AgNPs and the process of chemical reduction employed in this study is relatively easy to follow and use. Therefore the system developed is cost effective.

4. Conclusions

Impregnation of the WFMF membranes with AgNPs improved their disinfection performance, thereby eliminating the extra disinfection step required previously to make the water safe for drinking. Furthermore, it resulted in higher hydrophilicity, which improved the membrane permeability significantly. This means that the coated membranes not only produce water with better quality (turbidity <1 NTU, zero *E. coli* and silver concentration $\leqslant$0.1 mg/L), but also greater quantity because of high permeability. The significance of this is that the membranes can be used as a standalone POU system to provide clean and safe water for poor people in remote rural areas. They can also be used to provide drinking water in cases of emergency such as floods, which can impair the existing conventional water treatment systems. The treatment system using coated membranes can be adapted to rural areas since the materials needed to develop it can be locally sourced at affordable costs. This study provided useful information on the potential of the coated WFMF for potable water treatment. Future work will be undertaken to determine how long the disinfection ability lasts.

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