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Microfiltration membranes as a point of use technology for water treatment

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بِسمِ ٱللَّهِ ٱلرَّحمَٰنِ ٱلرَّحِيم

وَٱللَّهُ أَنزَلَ مِنَ ٱلسَّمَاءِ مَاء فَأَحيَا بِهِ ٱلأَرضَ بَعدَ مَوتِهَا إِنَّ

فِي ذَٰلِكَ لَأَيَةً لِّقَومٍ يَسمَعُونَ

صدق الله العلي العظيم

سورة النحل

الاية (٦٥)

DEDICATION

To those who have never been negligent in providing means of goodness and happiness to me, the loyal friend and the first lover .... ***my father***

To my bright star and my warm sun, the ideal mother who enriched me for everyone ... ***my mother***

To my source of pride and strength ... ***my brothers***

Asmaa

2022

Supervisors' Certificate

I certify that the thesis entitled *"Microfiltration membranes as a point of use technology for potable water treatment in remote rural areas"*, was prepared by *"Asmaa Nadhum Hadi"*, under my supervision at the Environmental Engineering Department/College of Engineering/University of Babylon, as a partial fulfillment of the requirements for the degree of Master in Environmental Engineering.

Signature:

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Date: / /2022

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I will firstly like to thank the All Mighty God for sparing my life and providing me with all I needed to complete this work, All glory is to ***ALLAH***

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Abstract

There are a variety of household water treatment systems (HWTS) on the market. The key differences are the materials used and the water purifying processes used. The majority of available household treatment devices are expensive, necessitating the development of low-cost or low-cost treatment technologies. This study presents the main method of in situ reduction for the preparation of household water treatment systems using such Polyvinyl chloride (PVC) coated membrane with silver nanoparticles by using cloves aromatic extract as a reducing and stabilizing agent. Effectiveness of these filters in reducing physical and biological parameters were also assessed.

Polyvinyl chloride (PVC) flat sheet membranes were prepared by the simplest techniques for membrane preparation by phase inversion at different PVC concentrations (10 – 14 wt. %) in solvents (N, N dimethylacetamide (DMAc). The antimicrobial activity of coated membrane and AgNP solution was investigated against Escherichia Coli (E. coli) by using disk diffusion and well diffusion test. Experiments were conducted to quantify the deactivation of E. coli in relation to different PVC concentration. The results show that the PVC microfiltration membranes in different concentrations are highly effective against waterborne pathogen bacteria (E. coli). Removal efficiencies for coated membranes (10%, 11%, 12%, 13% and 14%) PVC were (88.8%, 90.1%, 90.9%, 91.9% and 94.1%) respectively.

The membrane with (3.5 wt. % PVC; 21.5 wt. % DMAc) was chosen due to its efficiency in removing E.coli, produces permeate with turbidity below 1 NTU, and has a high permeate flow rate. E. coli removal efficiency was above 99.8 % for a period of 2 hour of continuous filtration for synthetic feed. The Atomic Absorption

Spectrometer (AAS) results showed that the leaching of silver from the coated filters over time was always below 0.1 mg/L, which satisfies with the United States Environmental Protection Agency's (US-EPA) drinking water guideline and World Health Organization (WHO).

Scanning Electron Microscopy (SEM), Atomic Force Microscopy (AFM), contact angle, X-ray diffraction (XRD), and UV–Vis spectroscopy, were used to analyze the structure and grain size of the produced particles and membrane. SEM study was appeared that some substance on the surface of the Polyvinyl chloride coated membranes was recognized as AgNPs. The results of surface roughness of the membranes calculated from the AFM show that the average contact angle values of PVC membrane decreased with the addition of AgNP because of that the addition of AgNP had improved membrane hydrophilicity and the membrane with concentration 14 wt. %, had highest contact angle value (70.3º) decrease after the addition of AgNPs to (50.4º). The crystallinity and position of the crystal plane of the produced particles were similar to the standard Nano silver pattern, and the average size of the nanoparticles was 46.99 nm, as established by the XRD pattern. In UV–Vis spectroscopy, the silver colloids' absorption spectrum shows a surface plasmon absorption band with a maximum wavelength of 435 nm.

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List of Abbreviations

Abbreviations	Description
WHO	World Health Organization
PVC	Polyvinyl chloride
POU	Point – of Use
SEM	Scanning Electron Microscopy
AAS	Atomic Absorption Spectrophotometer
XRD	X-Ray Diffraction
MF	Microfiltration
NF	Nanofiltration
PWF	Pure Water Flux
UF	Ultrafiltration
RO	Reverse Osmosis
AgNPs	Silver Nanoparticles
E. coli	Escherichia Coli
CFU	Colony Forming Unit
NTUs	Nephelometric Turbidity Units
DBPs	Disinfection By-Products
PAN	Polyacrylonitrile
PA	Polyamide
PS	Polysulfone
PC	Polycarbonate
PES	Polyether sulfone
PET	Polyethylene terephthalate
PI	Polyimide
PVDF	Polyvinylidene fluoride
PDMS	Pressure Driven Membrane System
HAADF	High Angled Annular Dark Field

STEM	Scanning Transmission Electron Microscopy
WFMF	Woven fabric microfiltration
PWF	Pure water flux
AgNPs-Asp	Aspergillus niger
AgNPs-Cry	Cryptococcus laurentii
AgNPs-Rho	Rhodotorula glutinis
CA	Cellulose acetate
AFM	Atomic force microscopy
TEM	Transmission Electron Microscopy
DAMc	Dimethylacetamide
DMF	Dimethylformamide
NMP	N-methyl-pyrrolidinone
THF	tetrahydrofuran
HRTEM	High-resolution Transmission Electron Microscopy
CNTs	Carbon nanotubes
PAN	Polyacrylonitrile
Ag/MWNTs	Silver nanoparticle/multiwalled carbon nanotubes
AgNPs-Asp	Silver nanoparticles from Aspergillus Niger
AgNPs-Cry	Silver nanoparticles from Cryptococcus Laurentii
AgNPs-Rho	Silver nanoparticles from Rhodotorula Glutinis
SEM-EDS	Scanning Electron Microscopy with Energy Dispersive Spectroscopy

List of Symbols

Abbreviations	Description
NTU	Nephelometric Turbidity Unit
µm	Micro- meter
ºC	Degrees Celsius
nm	Nano Meter
mL	Milliliter
mg/L	Milligram per Liter
hrs	Hours
L/hr	Liters / Hour
cm	Centimeter
gm	Gram
cm^3	Cubic Centimeter
min	Minute
bar	Pressure
kPa	Killo Pascal
L	Liters
%	Percent
Cl_2	Chlorine gas
$Ca(OCl)_2$	Calcium hypochlorite
NaOCl	Sodium hypochlorite
ClO_2	Chlorine dioxide
NH_2Cl	Monochloramne
O_3	Ozone
$H2O_2$	Hydrogen peroxide
$KMnO_4$	Potassium permanganate
I_2	Iodine
Br_2	Bromine

ZnO	Zinc Oxide
MgO	Magnesium oxide
TiO_2	Titanium dioxide
$AgNO_3$	Silver Nitrate
$NaBH_4$	Sodium Borohydride

CHAPTER ONE

INTRODUCTION

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INTRODUCTION

1.1 Background

Water is one of the most essential requirements for life on the earth and most human activities involve the use of water in one way or another. There are different sources of water such as lake, rivers, underground water and precipitate. In general, water stream through lands and cities, take their gate to the rivers, then water need essential treatment for human and industrial consuming. The degree of treatment depends on raw water type. Water is no longer pure today, it contains hundreds of harmful abiotic materials, like heavy metals, salts, dyes, organic and inorganic minerals, in addition to biotic material include bacteria, viruses, and particulate matter, both man-made or natural is commonly present in water, and require removal, [Al-Mamori, 2017].

The main purpose of treating drinking water is to bring it to an acceptable quality level for human consumption, by removing microorganisms (bacteria) and viruses that could cause harm to human health. The removal of these dangerous microbes in conventional water treatment processes is achieved mostly in the filtration and disinfection processes, [Pikwa, 2016].

Water is a basic need essential for the sustenance of all life forms. However, there is a great concern due to the lack of safe and clean drinking water, especially for people living in rural areas of developing nations. Lack of access to clean drinking water for people who live in rural areas of developing countries is a major concern around the world. Measures taken to address the challenges arising from this problem include the improvement of existing water purification methods and

development of new appropriate technologies such as Point of Use (POU) water treatment technologies, [Achisa, 2014].

The Guideline for Drinking Water Quality [WHO, 2018] recommends a maximum acceptable turbidity of 1 NTU, however, it recommended that maximum reductions associated with filtered water turbidity of < 0.1 NTU varies with membrane pore size, integrity of filter medium and filter seals, and resistance to chemical and biological "grow-through" degradation. Water quality must following up the main standards for potable water according to World Health Organization (WHO), United State Environmental Protection Agency (USEPA), and Iraqi Standards Number (417) for the year (2001), that the acceptable turbidity level 5 NTU and preferred less than 1 NTU, [Ministry of Municipalities and Public Works report, 2008].

1. 2 Remote rural areas and water treatment systems

Rural areas in developing economies present unique challenges in terms of potable water provision. These include: rugged topographies; populations distributed over very wide areas; lack of skills for operation and maintenance of water treatment systems; poorly developed infrastructure; and the lack of finances. People living in these areas have to fetch water that is normally untreated from local rivers or dams for use in cooking, washing and other domestic uses. Thus, provision of safe water using conventional piped water systems to households may be a long way off for such people of the developing world, [Achisa, 2014].

Various water treatment devices and safe storage technologies, such as the use of disinfectants (such as chlorine and iodine), filtration, distillation, reverse osmosis, solar disinfectant and water purifiers, have

been reported to decrease endemic diarrhea caused by waterborne pathogens and to improve the microbial and chemical quality of drinking water, [Mwabi et al., 2011].

One of the possible solutions to reducing the microbial contamination of drinking water is small-scale or point-of use (POU) systems for water treatment, [Dankovichab, 2014]. Point-of-use (POU) systems treat only the part of water used for drinking, [pooi and Ng, 2018]. The goal of POU household water treatment and safe storage technologies is to empower people without access to safe water to improve water quality by treating it and storing it safely in the home, [Sobsey et al., 2008].

Point-of-use (POU) systems are key solutions for treating water in developing communities; they are typically user-friendly, low cost, low maintenance, and grid-independent. Importantly, they treat and reduce the number of pathogens in water supplies, and many POU systems have been deployed and used by these communities, improving their livelihood, [pooi and Ng, 2018].

1.3 Statement of the problem

The lack of potable water of adequate quality is widely recognized as being a major barrier to health and economic development in most developing economies, and hence the production and provision of potable water is regarded as a major developmental priority for these economies.

The main drinking-water risks in developing countries are associated with microbial pollution. About two dozen infectious diseases are related to water quality. These diseases are predominantly due to fecal contamination of the water source and are thus strongly linked to the

sanitation conditions . These illnesses can be caused by viruses, bacteria, protozoa or larvae (e.g. cholera, typhoid, bacillary dysentery, infectious hepatitis, leptospirosis, giardiasis and gastroenteritis). Other microorganisms present in water are fungi, algae, rotifers and crustaceans. This is the most relevant category of water supply diseases when discussing the issues surrounding drinking-water treatment.

In Iraq, due to increasing population, anthropogenic use, inappropriate management, limited environmental consciousness effectively limits water resource management, so water storage is a necessity. The user must store the water to always have a sufficient amount of water available.

1.4 Objectives of the study

The main objectives of this study are:

1. Prepare silver nanoparticles (AgNPs) as a disinfection material with high antibacterial efficiency, few side effects, and convenience of use in water treatment.
2. Prepared and characteristics Polyvinyl chloride (PVC) microfiltration membrane incorporated with AgNPs.
3. Determination the removal efficiency of E.coli at different PVC concentrations
4. Determine the performance of the coated filter in terms of disinfection and silver elution as well as how the performance is affected over time.

1.5 Outline of the study

To meet the above-mentioned objectives, the present research is divided into the following tasks:

Chapter One: includes a brief introduction on water problems and some background of potential applications of household water treatment and safe storage, membrane technology, application nanotechnology in water treatment, a statement of the problem, the work objectives are stated, and an outline of the study is provided.

Chapter Two: gives a theoretical background on the theory of filtration, Classification of membrane, disinfection and presents nanomaterial such as silver nanoparticles as one of the recently developed technologies for destruction or removal of organisms capable of causing disease. Brief descriptions of the published works are also given in this chapter.

Chapter Three: in this chapter, the preparation and characterization of a Polyvinyl chloride (PVC) membrane embedded with silver nanoparticles (AgNP) for water purification, and the equipment required to prepare, are presented. A series of laboratory experiments were conducted in order to determine the performance of the coated filter in terms of disinfection and silver elution.

Chapter Four: this chapter discusses the results of the Polyvinyl chloride (PVC) membrane before and after coated with AgNPs characterization and size of nanoparticles that were obtained by using SEM, UV, X-ray, contact angle and AFM , and an analysis of the silver content in the effluent water by using AAS. Factors such as porosity, Permeation flux, and so on which affect the removal of organisms are described.

Chapter Five: the conclusions summarizes the work methodology, recommendations are made for further works are also described. The References and the Appendices follow Chapter 5.

CHAPTER TWO

BASIC CONCEPTS AND LITERATURES REVIEW

CHAPTER TWO

BASIC CONCEPTS AND LITERATURES REVIEW

2.1 Introduction

Globally, trends are now focusing on alternatives for producing high quality drinking water at all times especially as POU. Membrane technology has been seen to be one of such technology as disinfected water with constant high quality is now being produced using membrane technology as an alternative method, [Alfa et al., 2016].

These membranes are used for the water treatment and in this process water to be treated is divided into a stream of filtrate and the remaining quantity is called as retinae or concentrate . The contaminants present in the feed water could be eliminated using membrane system and are accumulated in the retentive. During this procedure, membranes which are being utilized can be assessed on the basis of pore sizes and the variation in pore size can act as a well-defined barrier, [Asif and Tauseef, 2019].

Membranes can be employed in water treatment in two ways. Firstly, they can be used as POU water treatment systems. Secondly, they can be a part of the water purification system before distribution to consumers, [Achisa, 2014].

The purifiers have been categorized into thermal- or light-based treatment techniques, physical removal methods, chemical treatment techniques and integrated water purification, The detailed classification chart is as shown in Fig. 2.1, [Ramprasad et al., 2020].

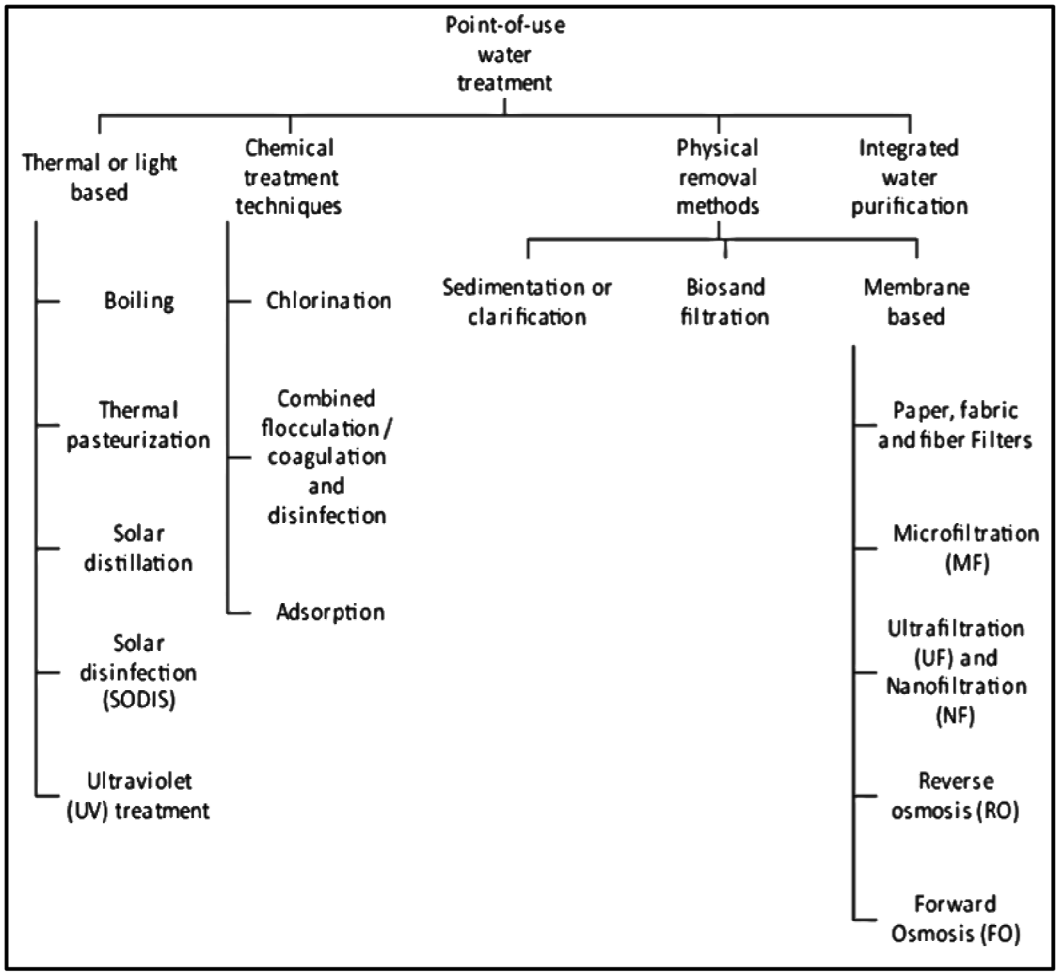


Fig. 2.1: Hierarchical chart depicting the classification scheme of water treatment, [Ramprasad et al., 2020] .

2.2 Membrane technology

Membrane technology is a generic name used when referring to the separation process that uses a membrane. The use of membrane filtration process for the treatment of potable water at household levels has become more attractive recently due to increasing stringent rules in drinking water guidelines., [Pikwa, 2015].

Several types of membranes are used in water treatment processes. Microfiltration (MF), ultrafiltration (UF), reverse osmosis (RO), and

nanofiltration (NF) membranes are examples of these. MF membranes have the largest pore size and typically reject large particles and various microorganisms, [Alyson and Benny, 2004].

The advantages offered by membrane technology have made it suitable for rural communities where topographies are difficult and there is no infrastructure that conventional water treatment plants require, [Chollom et al., 2019].

Membrane technologies are getting more and more attention now days due to their reliable contaminant removal without production of any harmful by-products, especially in water and wastewater treatment processes. In spite of that, the most common disadvantage associated with the application of the membrane process in water and wastewater treatment is membrane fouling, which results in flux decline during the operation, [Ng et al., 2010].

Different membrane compositions, configurations, and characteristics are available, enabling these processes to be used at various sites. The rate of transfer of solutes or solvents across a membrane is controlled by a "driving force," and the rate of solute rejection is controlled by the size and shape of the solute molecules, [Van Ginkel et al., 2010].

Polymeric materials are most typically used to create membranes. Initially, the most common material used to make such membranes was cellulose acetate. Polymers such as polyacrylonitrile (PAN), polyamide (PA), polysulfone (PS), polycarbonate (PC), polyether sulfone (PES), polyethylene terephthalate (PET), polyimide (PI), and polyvinylidene fluoride (PVDF) are now being used to replace this material, [Alslahy et al., 2011].

2.3 Membrane filtration

Membrane filtration is a general term applied to a variety of different separation processes. The membrane acts as a filter, allowing water to pass through while filtering out suspended solids and other substances. A good membrane should be designed to have a higher filtration flux with stable flux and lower filtration pressure, to be space saving, and to have a simple and highly reliable process based on membrane use, high quality of the water produced, and without the need for extensive pretreatment, [Ng et al., 2013].

The efficiency of the membranes depends on the water quality, the load of solids and the formation of fouling during the treatment, [Collivignarelli et al., 2018]. Considering the large diversity of membranes suited for technical applications, it will be useful to introduce the membrane classifications as membrane materials, membrane cross-section, preparation method, and the membrane shape, [Ng et al., 2013].

Table 2.1 displayed the classification of the membranes in four different categories with their respective description.

Table 2.1: Classification and description for membrane, [Ng et al., 2013].

Classification	Description
Membrane materials	Organic polymers, inorganic materials (oxides, ceramics, metals), mixed matrix or composite materials.
Membrane cross-section	Isotropic (symmetric), integrally anisotropic (asymmetric), bi- or multilayer, thin-layer or mixed matrix composite.
Preparation method	Phase separation (phase inversion) of polymers, sol–gel process, interface reaction, stretching, extrusion, track-etching, micro-fabrication.
Membrane module configuration	Flat-sheet, hollow fiber, hollow capsule.

In membrane processes, certain components are separated/ rejected from a sample solution by using pressure, electrical and concentration diferences as a driving force. The flow of a sample solution through the membrane results in the difference in applied pressure of the solvent and the solute in aqueous system, where the solutes are retained. As these membranes have very tiny pores, it is possible to separate/reject analytes from the water using higher pressures, [Madhura et al., 2019].

The hierarchy of pressure-driven membrane processes separation abilities is illustrated in Fig. 2.2.

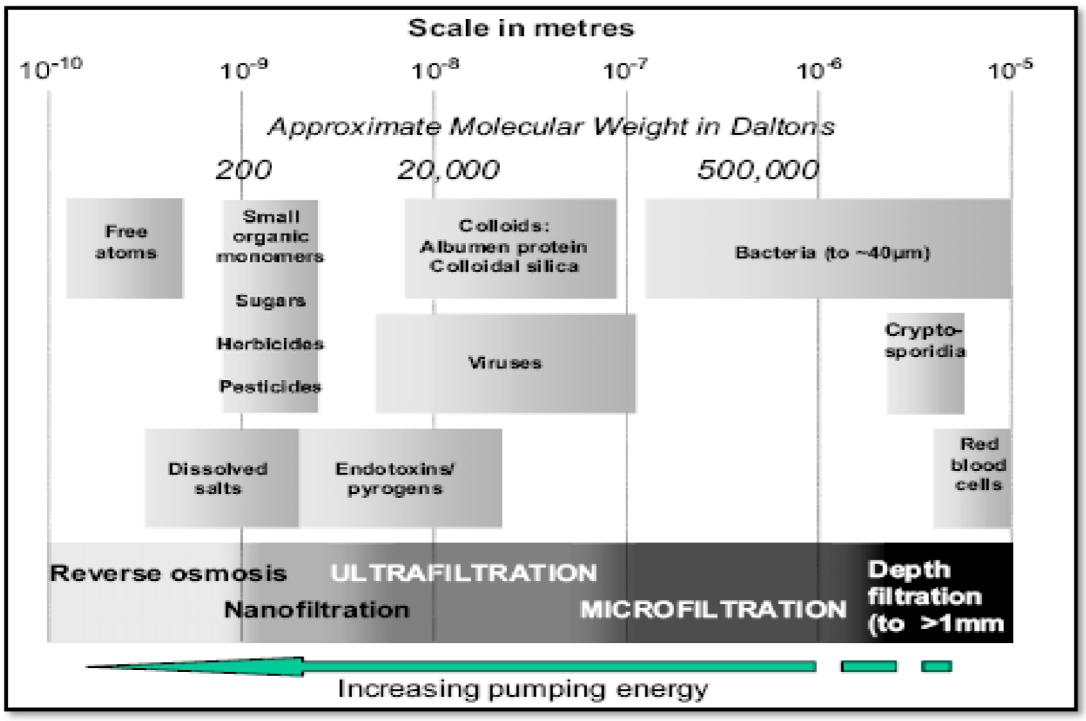


Fig. 2.2: Membrane filtration processes and the separation abilities, [Simon and Claire, 2010].

2.4 Classification of membrane

Membrane can be classified according to:

2.4.1 Membrane processes

a. Microfiltration (MF): Microfiltration (MF) is a Pressure Driven Membrane System (PDMS) process which removes contaminants from a fluid by passage through a micro porous membrane. Microfiltration has been shown to remove major pathogens and contaminants such as Giardia lamblia cysts, Cryptosporidium ocysts, and large bacteria. Microfiltration is typically used to separate suspended solids and can be applied to waters that are easy to treat. Such water bodies are clear cold waters, which are potentially susceptible to microbial contamination. Because of the low pressures and higher porosity of this process, the membranes are unable to remove smaller compounds, [Van Ginkel et al., 2010]. Microfiltration (0.1–10 μm) is capable of removing most bacteria and protozoa cysts, but it is ineffective at removing viruses, [Collivignarelli et al., 2017].

b. Ultrafiltration (UF): Many manufacturing units are taking advantage of UF technology since last two decades. In UF, screening of impurities is carried out on the basis of pore size that lies between 0.01 and 1 μm depending on the size of impurities. Many suspended, colloidal matter, macromolecules, protozoa, bacteria, and most viruses are separated out using the UF, [Asif and Tauseef, 2019].

c. Nanofiltration (NF): Nanofiltration membranes are pressure-driven processes in which particles and molecules less than 0.0005–0.001 μm are rejected by the membrane. These membranes are characterized by a distinctive charge-based repulsion mechanism, allowing the separation of various ions. Nanofltration membranes are used to reduce the color, odor, hardness and separate heavy metal ions from water systems, [Madhura et al., 2019].

d. Reverse Osmosis (RO): Reverse Osmosis distillation system is recognized as the principal significant and extensively used technology for the formulation of pure water from mineral-rich water. It is estimated that almost half of the installed water purification systems prefer RO technology all over the world, due to its easy adaptability and comparatively low energy expenses and higher efficiencies than concentrations required for other thermal procedures used for water purification, [Asif and Tauseef, 2019]. reverse osmosis (<0.001 μm): it is necessary to provide some pre-treatment (flocculation, lime addition, sedimentation, rapid filtration or ultrafiltration) to reduce the content of colloidal substances, suspended solids and organic matter which may cause problems of fouling of membranes with consequent reduction of efficiency and operating flow, [Collivignarelli et al., 2017].

Table 2.2 shows the applications of membrane processes in water treatments.

Table 2.2: The applications of membrane processes in water treatments, [Zioui et al., 2015].

Membrane process	Application	Membrane type	Material
Microfiltration	Sterilisation Removal of suspended solids and colloids	Porous-symmetrical or asymmetrical	Ceramic Polymeric
Ultrafiltration	Removal of viruses and mcromolecules	Porous-symmetrical or asymmetrical	Polymeric
Nanofiltration	Removal of organic compounds	Dense or nano porous asymmetrical	Polymeric
Reverse osmosis	Removal of salts	Dense composite or skinned	Polymeric

2.4.2 Membrane operation:

Membrane filtration can be operated either as dead-end filtration, cross-flow filtration, and immersed membrane .

a. Dead-end filtration

The most basic form of filtration is dead-end filtration. The complete feed flow is forced through the membrane and the filtered matter is accumulated on the surface of the membrane as shown in Fig. 2.3. The dead-end filtration is a batch process as accumulated matter on the filter decreases the filtration capacity, due to clogging. A next process step to remove the accumulated matter is required. Dead-end filtration can be a very useful technique for concentrating compounds, [Munir, 2006].

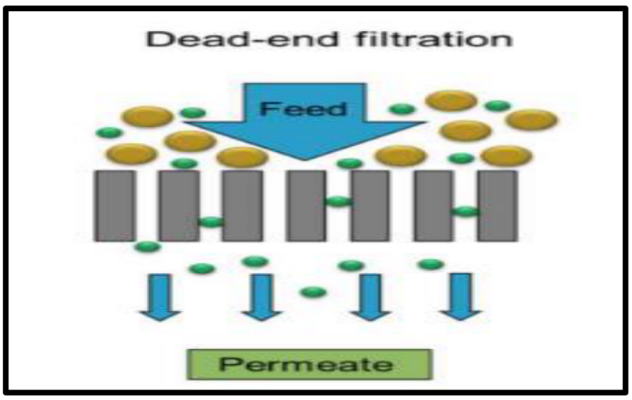


Fig. 2.3 : Schematic drawing for dead-end/deposition mode, [Ketola, 2016].

b. Cross-flow filtration

With cross-flow filtration a constant turbulent flow along the membrane surface prevents the accumulation of matter on the membrane surface as shown in Fig. 2.4. The process is referred to as "cross-flow", because the feed flow and filtration flow direction have a 90 degrees angle. Cross-flow filtration is an excellent way to filter liquids with a high concentration of filterable matter, [Munir, 2006].

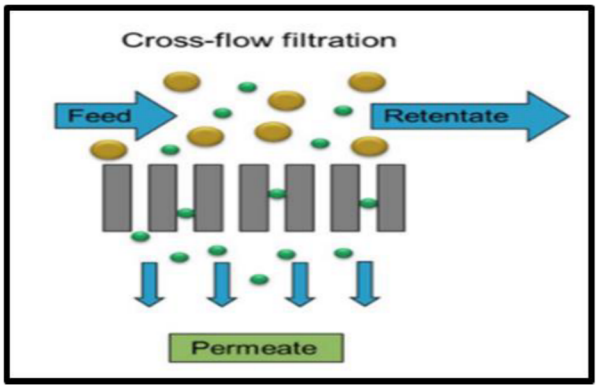


Fig. 2.4 : Schematic drawing for cross flow operation / suspended mode, [Ketola, 2016].

c. Immersed membrane filtration

This mode is commonly employed in membrane bioreactors for waste water treatment. The membranes are immersed in the feed solution contained in the process tank filtration occurs either inside-out or outside-in as shown in Fig. 2.5, [Achisa, 2013].

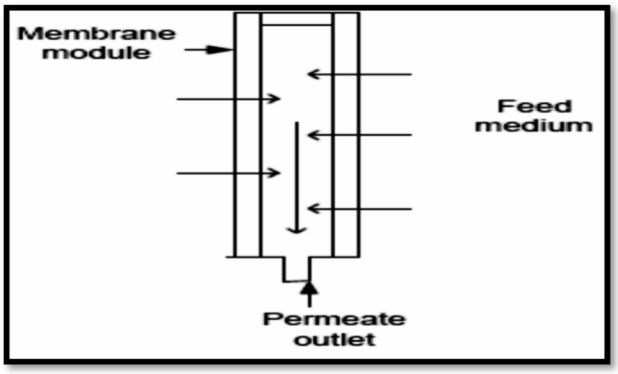


Fig. 2.5: Schematic representation of outside-in immersed membrane filtration,[Achisa, 2013].

2.4.3 Membrane modules

There are four main types of modules: plate-and-frame, tubular, spiral wound, and hollow fiber as shown in Fig. 2.6.

A plate membrane module consists of two sheets of membrane materials stuck/glued together on four sides/edges. In between the two sheets, there is a spacer/mesh to channel permeate and prevent the two sheets from getting stuck together during filtration and stopping the permeate flow. The permeate outlet nozzle is placed on one of the four sides of the plate membrane module. Plate membrane modules are usually stacked on top of each other to form a frame, [Pikwa et al, 2015].

The design of spiral-wound modules is similar to that of flat sheet modules. In the spiral-wound modules, two membrane sheets are separated by a mesh-like spacer with the active membrane sides facing away. Three edges of the two membrane sheets are glued together with the fourth edge open to a perforated center tube for the permeate removal. On the other two sides of "the envelope" another two mesh-like spacers with thicknesses in the range of 0.56-3 mm are placed as the feed channel spacers. The whole assembly is rolled around the perforated center tube in a spiral configuration. spiral-wound modules require relatively clean feed that are with minimum content of suspended particles. The pretreatment to reduce suspended particles is needed for spiral-wound modules, [Cui et al., 2010].

Tubular modules are composed of a number of membrane tubes assembled in a shell-and-tube arrangement. The membrane tubes are usually made up of porous fabric or plastic support with selective membranes on the inside [Cui et al., 2010]. The tubular membrane modules are 1.5–3 cm in diameter and have the lowest surface area. Tubular membranes are usually preferred to hollow fiber and spiral-wound membranes for high solids (>0.5%) industrial wastewater applications. The module is best suited for feeds with high suspended

solids because it can handle particulates and can be physically cleaned with foam balls. tubular membrane are relatively inexpensive and have a longer life, [Nicholas and Rajindar , 2016].

Hollow fiber modules used for seawater desalination consist of bundles of hollow fibers in a pressure vessel. They can have a shell-side feed configuration where the feed passes along the outside of the fibers and exits the fiber ends. Hollow fiber modules can also be used in a bore-side feed configuration where the feed is circulated through the fibers, [Alyson and Benny, 2004].

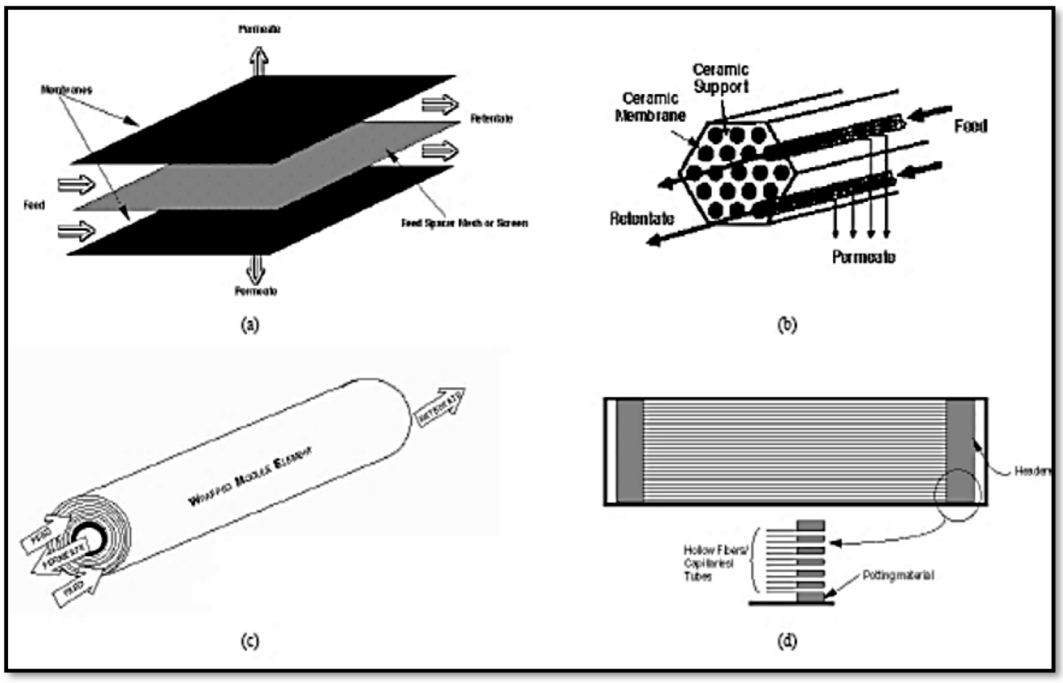


Fig. 2.6: Schematic of a) plate and frame, b) tubular, c) spiral wound and d) hollow fiber modules, [Alyson and Benny, 2004].

2.4.4 Membrane materials

Membrane material varies from one to the other. The most important consideration made in choosing the material to be used is that it must provide a separation performance that conforms to what a

membrane does. This is the reason why a variety of membrane materials are commercially used, [Pikwa et al., 2015].

Membranes are usually fabricated both to have a high surface porosity, or percent total surface pore cross-sectional area, and narrow pore size distribution to provide as high a throughput and selectivity as possible. The membrane must also be mechanically strong (i.e. have structural integrity). Lastly, the material will normally have some resistance to thermal and chemical attacks, that is, extremes of temperature, pH and/or oxidant concentrations that normally arise when the membrane is chemically cleaned, and should ideally offer some resistance to fouling, [Simon and Claire, 2010]. Membranes are usually made of woven fibres, ceramics, polymeric or metallic materials [Hoslett et al., 2018].

2.5 Theory of disinfection

Disinfection is used to deactivate any pathogens which pass through the filters. The pathogens found in water include viruses, bacteria such as Escherichia coli, Campylobacter and Shigella, and protozoanssuch as G. lamblia and other Cryptosporidia, [Tansel, 2008].

The use of water disinfection as a public health measure reduces the spread of diseases. Various disinfection technologies can be used to meet the pathogen inactivation demand in water. The most commonly used disinfectant is chlorine gas, Cl_2 that is dissolved in the water at a certain concentration for a certain minimum contact time. Other disinfectants include ozone, chlorine dioxide and other chlorine compounds such as calcium hypochlorite (HTH), sodium hypochlorite (bleach) and mono chloramine, [Bodzek et al., 2019].

Many of these chemical disinfectants if overdosed or used inappropriately can react with organic and inorganic precursors and bring the formation of disinfection by-products (DBPs) with adverse health effects, [Collivignarelli et al., 2017].

Byproducts of disinfection (DBPs) and oxidation are undesired groups of substances formed during reaction of disinfecting agents or other strong oxidizers with admixtures and contaminants present in water. The group of DBPs mostly comprises organic compounds, but some of inorganic substances are also included (bromates, chlorites and chlorates), [Bodzek et al., 2019].

Nanomateriales are excellent adsorbents, catalysts, and sensors due to their large specific surface area and high reactivity. More recently, several natural and engineered nanomaterials have also been shown to have strong antimicrobial properties (Among different kinds of nano sized antibacterial materials, i.e., ZnO, MgO, and TiO2, the silver nanoparticles have reported to be the most effective antimicrobial agent, [Shuo et al., 2010]. Unlike conventional chemical disinfectants, these antimicrobial nanomaterials are not strong oxidants and are relatively inert in water. Therefore, they are not expected to produce harmful DBPs. If properly incorporated into treatment processes, they have the potential to replace or enhance conventional disinfection methods, [Qilin et al., 2008]. One of the latest applications includes the incorporation of nanoparticles into polymeric membranes in order to increase the performances of the membranes such as permeability, selectivity, strength, and hydrophilicity, [Ng et al., 2013].

Removal efficacy, which is expressed as the log removal value, was determined by the use of Equation, [Alfa et al., 2016]:

$$R\ (\%) = 100\ (1\text{-}Cp/Cf) \quad \ldots\ldots\ldots \quad (2.1)$$

where :

Cf = concentration of E. coli in the feed (CFU/100 mL).

Cp = concentration of E. coli in permeate (CFU/100 mL).

Disinfection efficiency of E.coli is obtained using the expression:

$$LRV = \log10\ (Cf/Cp) \quad \ldots\ldots\ldots \quad (2.2)$$

Where, Cf and Cp have the same meaning as stated above.

The log10 reduction value (LRV) is used to describe the bacterial removal efficiency.

2.5.1 Types of disinfectants and modes of disinfections

Mircoorganisms can be removed, inhibited or killed by various physical processes, physical agents or chemical agents, [Frik, 2006]:

- Physical processes: These include gravity separation and filtration.

Gravity separation (sedimentation and flotation) and filtration play a very important role in the removal of bacteria, viruses and protozoan cysts. It is of utmost importance that these processes are optimised as protozoan cysts are largely resistant to chemical agents and their removal is primarily dependent on efficient coagulation– flocculation, sedimentation and filtration.š

- Physical agents: Include heating and irradiation. Heating water by

boiling or by solar energy in small transparent containers (in which both heating and ultraviolet light (UV) radiation plays a role) is only possible on a very small scale and is more suited to situations where no other form of disinfection is available. Concentrated UV light as a mode of disinfection for drinking water is gaining popularity and has been proven to be very effective in the inactivation of microorganisms.

- Chemical agents: These are by far the most popular means of disinfection in the drinking water industry and many alternatives, each with its own particular application, are available. The most commonly used chemicals are chlorine gas (Cl_2), calcium hypochlorite [Ca $(OCl)_2$], sodium hypochlorite [NaOCl], chlorine dioxide [ClO_2], monochloramne [NH_2Cl], ozone [O_3], hydrogen peroxide [H_2O_2], potassium permanganate [$KMnO_4$], iodine [I_2],and bromine [Br_2]. While the chlorine based disinfectants have historically been the most popular products to use, the unique properties of other compounds such as ozone have caused a rapid increase in their use.

2.5.2 Factors affecting disinfection processes

The factors affecting efficacy of disinfectant against pathogens include, [Sahra, 2018]:

- Temperature and pH of the disinfection process.
- Amount of microorganism.
- Physical factors such as surface type.
- Chemical factors such as chemical composition of surface or disinfectant.
- Antibacterial resistance of microorganism, biofilm production of microorganism.
- Dose of disinfection.
- Duration of exposure to disinfection.

2.6 Silver nanoparticle (AgNPs)

2.6.1 Nanotechnology in water treatment

Nanotechnology is one of the emerging and rapidly growing fields which has shown tremendous revolutionary developments in different

fields of science including physics, chemistry, biology, and engineering, and its meaning varies with each field, [Lugani et al., 2021]. It is an important field of modern research dealing with design, synthesis, and manipulation of particles structure ranging from approximately 1-100 nm, [Raheem, 2019]. Nanoparticles are of great interest due to their extremely small size and large surface to volume ratio, which lead to both chemical and physical differences in their properties compared to bulk of the same chemical composition, such as mechanical, biological and sterical properties, catalytic activity, thermal and electrical conductivity, optical absorption and melting point, [Hassan and Siavash, 2012].

One of application of antimicrobial nanomaterials is their use in decentralized or point-of-use water treatment and reuse systems, [Qilin et al., 2008]. Combination of membrane filtration and antibacterial capability of Nano-silver is a solution for performance of microfiltration process, [Madaeni et al., 2010].

Silver nanoparticle AgNPs have been in use for more than 150 years and are recognized as antimicrobial agent in United States (USA) since 1954. Silver nitrate ($AgNO_3$) is considered as a precursor for the synthesis of Ag-NPS, [Adnan and Kang, 2014].

Silver nanoparticles are appealing due to its excellent properties (e.g., size and shape-dependent optical, electrical, and magnetic properties) that can be incorporated into antimicrobial applications, biosensor materials, composite fibers, cryogenic superconducting materials, cosmetic products, and electronic components, [Abbasi et al., 2014]. The potential of silver nanoparticles for household POU drinking-water disinfection is currently being extensively explored, principally in conjunction with filtration, [WHO, 2018]. Application of polymeric

`materials incorporated with silver nanoparticles in drinking water filtration system may cause the leaching of silver nanoparticles into the drinking water. The leaching process may be caused by physical damage or improper nanoparticl incorporation techniques, [Ng et al., 2013].

Many different kinds of silver nanoparticles have been described besides spherical particles, bipyramids, discs, rods, cubes, prisms, rings, platelets, triangular prisms, and octahedral were found, depending on the reaction conditions, [Raheem, 2019].

2.6.2 Synthesis of silver nanoparticles

A number of studies have shown that the choice of capping or stabilizing agent can change the toxicity of silver nanoparticles, [WHO, 2018].

The main drawback with the chemical and physical methods of silver nanoparticle formation is that they are extremely costly and also involve the use of toxic, hazardous chemicals and they contain potential environmental and biological stakes. The way in which the silver nanoparticles blended must be taken care of by human and must be accessible at low evaluated rates for their compelling usage; hence, there is a requirement for an ecologically and financially doable approach to incorporate these nanoparticles, [Gudikandula and Maringanti, 2016].

Physical approach: In physical processes, metal nanoparticles are generally synthesized by evaporation–condensation, which could be carried out using a tube furnace at atmospheric pressure. The foundation material within a boat centered at the furnace is vaporized into a carrier gas, [Abbasi et al., 2014]. Because of the most common drawbacks of these methods is the higher energy requirement and time consuming, [Adnan and Kang, 2014]. Silver nanoparticles could be synthesized by

laser ablation of metallic bulk materials in solution. The ablation efficiency and the characteristics of produced nanosilver particles depend upon many factors such as the wavelength of the laser impinging the metallic target, the duration of the laser pulses (in the femto-, pico- and nanosecond regime), the laser fluence, the ablation time duration and the effective liquid medium, with or without the presence of surfactants, [Hassan and Siavash, 2012]. Other physical methods for are referring to thermal decomposition method, ceramic heating process, arc discharge technique, [Alexandru et al., 2017].

Chemical approach: Chemical reduction is the most frequently applied method for the preparation of AgNPs as stable, colloidal dispersions in water or organic solvents. Commonly used reluctant are borohydride, citrate, ascorbate and elemental hydrogen. The reduction of silver ions (Ag+) in aqueous solution generally yields colloidal silver with particle diameters of several nanometers. Initially, the reduction of various complexes with Ag+ ions leads to the formation of silver atoms (Ag^0), which is followed by agglomeration into oligomeric clusters. These clusters eventually lead to the formation of colloidal Ag particles, [Abou El-Nour et al., 2009]. It is essential to use protective agents to stabilize nanoparticles during the course of silver nanoparticle preparation, and protect the nanoparticles that can be absorbed on or bind onto nanoparticle surfaces, avoiding their agglomeration, [Abbasi et al., 2014].

Chemical method of synthesis can be subdivided into chemical reduction, electrochemical, irradiation assisted chemical and pyrolysis methods, [Abu Ghalia and Abdelrasoul , 2019]. Normally, the synthesis of Ag-NPs by chemical method banks on three factors (stages): (a) Ag

precursor, (b) reducing agents, and (c) stabilizing agent, [Adnan H. and Kang, 2014] .

Biological approach (green synthesis): Green synthesis is an ecofriendly and biocompatible process, generally accomplished by using a capping agent/stabilizer (to control size and prevent agglomeration), plant extracts, yeast, or bacteria, [Shabir et al., 2019]. biological synthesis of Ag NPs from herbal extract and/or microorganisms has appeared as an alternative approach as these routes have several advantages over the chemical and physical methods of synthesis. It is also a well-established fact that these routes are simple, cost-effective, eco-friendly and a single-step method for biosynthesis process and human friendly. Biosynthesis of metal and metal oxide nanoparticles using biological agents such as bacteria, fungi, yeast, plant and algal extracts has gained popularity in the area of nanotechnology, [Abu Ghalia and Abdelrasoul, 2019; Alvakonda, 2016].Using conventional methods for the synthesis of Ag-NPs requires (a) Ag precursors, (b) reducing agent, and (c) stabilizer/capping agent (for avoiding agglomeration of the newly synthesized Ag-NPs), [Adnan and Kang, 2014].

The plant extract is the most common reducing agent in the green synthesis, [Mudassar et al., 2018]. The plants or plants extract, which act as reducing and capping agents for nanoparticles synthesis, are more advantageous over other biological processes because they eliminate the elaborated process of culturing and maintaining of the cell, and can also be scaled up for large-scale nanoparticle synthesis, [Ibrahim, 2015].

2.6.3 Characterization of silver nanoparticles

The expansion of nanotechnology in various research areas has led to the need to use analytical techniques for the analysis and

characterization of nanoparticles. Nanoparticles are usually characterized in the literature by their size distribution, morphology, surface properties, stability and interactions, [Gamboa et al., 2019]. Characterization is performed using a variety of different techniques such as:

a. UV–vis spectroscopy (UV–vis)

UV–vis spectroscopy is used to confirm sample formation by showing the plasmon resonance. The UV-visible spectroscopy is the most convenient and feasible method for detection of nanosilver as the typical peak of 385–450 nm range predicts the presence of nanoparticles, [Abbas et al., 2018].

b. X-ray diffraction (XRD)

X-ray diffraction pattern is used to obtain the structural image of the prepared nanoparticles and to determine the size of the nanoparticles, [Abbas et al., 2018]. X-rays show wave nature with wavelength ranging from about 10 to 103 nm. According to the quantum theory, the electromagnetic wave can be treated as particles called photons or light quanta, [Waseda et al., 2011].

When X-ray photons reach matter, several types of interactions can take place leading to different absorption and scattering effects, which will not be treated here. An elastic (coherent) scattering, also called Rayleigh scattering, occurs between the photons and the electrons surrounding the atomic nuclei. In this case, the energy of the scattered wave is unchanged and it retains its phase relationship to the incident wave . As a consequence, the X-ray photons impinging on all atoms of an irradiated volume are scattered in all directions, [Epp, 2016]. The working principle of X-ray diffraction is Bragg's law, [Hassan and Siavash, 2012].

c. Scanning electron microscopy (SEM)

The scanning electron microscope (SEM) is one of the most popular and user-friendly imaging tools that reveal the surface topography of a sample, [Yimei and Hiromi, 2012]. SEM is a surface imaging method, fully capable of resolving different particle sizes, size distributions, nanomaterial shapes, and the surface morphology of the synthesized particles at the micro and nanoscales, [Raheem, 2019].

In the SEM, incident electrons interact with the atoms that make up the sample-producing signals that contain information about the sample's surface morphology, composition, and other physical and chemical properties, [Yimei and Hiromi, 2012].

2.6.4 The antimicrobial properties of silver compounds

Antibacterial activity of AgNPs As a broad-spectrum antibiotic, silver is highly toxic to bacteria. It has been of great interest for the past couple of years, due to its wide spectrum of pharmacological activities, with applications in the fields of agriculture, textiles, and especially medicine, [Shabir et al., 2019].

However, the increased use of nanosilver in a range of (as yet largely) experimental drinking-water treatment systems, its use in conjunction with ceramic filters, and its perceived potential to be a water disinfectant that does not result in disinfection by-products in the treated water, have raised the profile of this chemical, [WHO, 2018].

The antimicrobial properties of silver nanoparticles depend on the Size, environmental conditions (size, pH, ionic strength) and capping agent. Natural organic matter has a negative impact of the antimicrobial performance of AgNP. Studies have shown that the organic matter can adsorb on the surface of AgNP and reduce the physical contact between

AgNP and bacterial cells. In addition, the adsorption of organic matters can also inhibit their dissolution, resulting in a decreasing antimicrobial property, [Ahmed et al., 2016].

Three possible mechanisms that can cause bacterial cells death using Ag-NPs particle. The first proposed mechanism states that the bacterial cell growth and proliferation are inhibited by the adhesion of Ag-NPs onto the cell wall (due to the fine particles size) of the bacteria thus causing changes in the cell wall in which intern is unable to protect the internal part of the cell. In the second proposed mechanism the authors stated the penetration of the Ag-NPs into the bacterial cell causing changes in the DNA retarding its normal function thus ultimately causing its death. Silver nanoparticles penetrate through bacterial cell wall, resulting in DNA damage. In the third proposed mechanism they stated that when Ag+ ions interact with the proteins containing sulphur present in the cell wall of the bacteria this ultimately leads to the malfunctioning of the bacterial cell wall, [Adnan H. and Kang, 2014].

2.7 Microbiological quality

It is difficult to determine the presence of all the different pathogenic organisms and therefore certain indicator organisms are used to give an indication of the possible presence of pathogens. The presence of these organisms in water serves as an indication of pollution of the water by human wastes. Such water is therefore unsafe to drink and must be disinfected before use, [Frik, 2006].

No single indicator fulfils all these considerations, nor is any suitable for all cases. The most important point is that the presence of indicators of fecal contamination implies an increased risk of water borne

disease. E. coli is a commonly used bacterial indicator organism for pathogenic contamination, [Shankar et al., 2017]. Table 2.3 gives a list of some disease-causing organisms, the disease that each group causes and the typical source.

Table 2.3: Disease-causing organisms, [Frik, 2006] .

Name of organism	Major disease	Sources
Bacteri		
Salmonella typhi	Typhoid fever	Human faeces
Salmonella paratyphi	Parathypoid fever	Human faeces
Shigella	Bacillary dysentery	Human faeces
Vibrio cholera	Cholera	Human faeces
Enteropathogenic E. coli	Gastroenteritis	Human faeces
Yersinia enterocolitica	Gastroenteritis	Human and animal faeces
Legionella pneumophila	Legionellosis	Warm water systems
Mycobacterium tuberculosis	Tuberculosis	Human respiratory exudates
Enteric viruses		
Polioviruses	Poliomyelitis	Human faeces
Coxsackieviruses A & B	Aseptic meningitis	Human faeces
Echoviruses	Aseptic meningitis	Human faeces
Reoviruses	Upper respiratory and gastrointestinal illness	Human faeces
Rotaviruses	Gastroenteritis	Human faeces
Adenoviruses	Upper respiratory and gastrointestinal illness	Human faeces
Hepatitis A virus	Infectious hepatitis	Human faeces
Norwalk & related viruses	Gastroenteritis	Human faeces
Protozoa		
Giardia lamblia	Giardiasis (dysentery)	Human and animal faeces
Cryptosporidium	Cryptosporidiosis	Human and animal faeces
Entamoeba hystolytica	Amoebic dysentry	Human faeces
Algae (blue-green) also Classified as Arcaobacter		
Anabaena flos-aqua	Gastroenteritis	Nutrient enriched water
Microcystis aeruginosa	Gastroenteritis	Nutrient enriched water

2.8 Indicator bacteria (coliforms)

Coliform bacteria are present in the environment and feces of all warm-blooded animals and humans. Coliform bacteria are unlikely to cause illness. However, their presence in drinking water indicates that disease-causing organisms (pathogens) could be in the water system. Most pathogens that can contaminate water supplies come from the feces of humans or animals. Testing drinking water for all possible pathogens is complex, time-consuming, and expensive. It is easy and inexpensive to test for coliform bacteria. If testing detects coliform bacteria in a water sample, water systems search for the source of contamination and restore safe drinking water, [Daoliang and Shuangyin, 2019].

An ideal indicator of water pollution and therefore of the possible presence of pathogens in water should meet the following criteria, [Frik, 2006]:

- It should always be present when the pathogenic organism of concern is present and be absent in clean, uncontaminated water.
- It should be present in large numbers in faecal material.
- It should respond to environmental conditions and treatment in a similar manner as the pathogen.
- It should be easily detected by simple and inexpensive laboratory tests.
- It should be stable and non-pathogenic.

a. Total coliforms: The term “total coliforms” refers to a large group of Gram-negative, rod-shaped bacteria that share several characteristics. The group includes thermo tolerant coliforms and bacteria of fecal origin, as well as some bacteria that may be isolated from environmental sources. Detection of total coliform in water indicates potential fecal pollution and thus provide information on treatment efficiency and after growth,

[Molelekwa et al., 2014]. In the laboratory total coliforms are grown in or on a medium containing lactose, at a temperature of35 or 37 °C, [Bartram Balance , 1996] .

b. Fecal coliforms: A subset of total coliform bacteria, are more fecal-specific in origin. However, even this group contains a genus, Klebsiella, with species that are not necessarily fecal in origin. Klebsiella are commonly associated with textile and pulp and paper mill wastes. Therefore, if these sources discharge to your stream, you might wish to consider monitoring more fecal and human-specific bacteria. Fecal coliforms are still being used in many states as the indicator bacteria, [Gamboa et al., 2009].

c. E. coli: Escherichia coli (E. coli) is a gram-negative, facultative anaerobic, rod-shaped bacterium of the genus Escherichia that is commonly found in the in the lower intestines of endotherm organisms. Escherichia coli is a member of the family Enterobacteriaceae. Some pathogenic Escherichia coli (E. coli) may cause potentially fatal haemolytic uraemic syndrome, bacteraemia and meningitis . The presence of E. coli in water is a strong indication of recent sewage or faecal contamination from human and animal waste group and is a more specific indicator of faecal pollution than other faecal coliforms, [Stephen and Joseph, 2013; Kinkese et al., 2018] . E. coli is so small they can't be seen without a microscope; however, their growth can be seen as colonies on agar media (like JELL-O) under special conditions, [Channah and Berenise, 2014]. Bacteria are grown aerobically in nutrient broth at 37º C for 18 h, [Gangadharan et al., 2010].

2.9 Literatures review

The application of membranes to water disinfection has already been known for many years. Membrane filters were used during the 2nd World War by German soldiers to control microbiological contamination of water after bombarding. Membranes can be used either directly at consumers' site or as a part of water treatment system, [Michał et al., 2019].

Sondi and Salopek-Sondi, (2004) were investigated the antimicrobial activity of silver nanoparticles against E. coli as a model for Gram-negative bacteria. The silver hydrosols were prepared by adding, under agitation, 10 cm^3 of an aqueous 1 mol dm^{-3} ascorbic acid solution at a flow rate of 3 cm^3 min^{-1} into 90 cm^3 of an aqueous solution containing 5 wt% of Daxad 19 and 0.33 mol dm^{-3} $AgNO_3$. As result the absorption spectrum of this sample a well-defined plasmon band at 405 nm, characteristic of nanosized silver. These particles are slightly smaller, with a modal diameter of 12 nm. The presence of these particles at a concentration of 10 mg cm^{-3} inhibited bacterial growth by 70% while, A concentration of 50–60 mg cm^{-3} caused 100% inhibition of bacterial growth. In conclude, these nontoxic nanomaterials, which can be prepared in a simple and cost-effective manner, may be suitable for the formulation of new types of bactericidal materials.

Morones et al., (2005) studied the effect of silver nanoparticles in the size range of 1– 100 nm on Gram-negative bacteria using High Angled Annular Dark Field microscopy (HAADF) and scanning transmission electron microscopy (STEM). For the study commercially available nanoparticle powder was used and was introduced in water for the interaction of nanoparticles with water. The characterization of

nanoparticles was done by TEM. The TEM analysis demonstrated the nanoparticles in the size range of 16 nm. While, the high resolution TEM (HRTEM) study confirms cuboctahedral, multiple-twinned icosahedral, decahedral shape of nanoparticles. The results indicate that Analysis of the released particles showed a mean size of 16 nm with a standard deviation of 8 nm. Since these nanoparticles were released from the carbon matrix, they can be considered as free surface particles, which will enhance their reactivity compared with the nanoparticles that remained inside the carbon matrix. The High Angled Annular Dark Field (HAADF) images show that the smaller sized nanoparticles (~5 nm) depicted efficient antibacterial activity thus concluding that the activity of silver nanoparticles is size dependent.

Kim et al., (2007) were investigated the antimicrobial activity of Ag nanoparticles against yeast, Escherichia coli, and Staphylococcus aureus. The results suggest that Ag nanoparticles can be used as effective growth inhibitors in various microorganisms, making them applicable to diverse medical devices and antimicrobial control systems. In these tests, Muller Hinton agar plates were used and Ag nanoparticles of various concentrations were supplemented in liquid systems. As results, The prepared aqueous solution of Ag nanoparticles showed an absorption band at 391 nm, which is a typical absorption band of spherical Ag nanoparticles due to their surface plasmon. The TEM image shown the shape and size distribution, the particles are highly mono dispersed with an average diameter of 13.5 nm and a standard deviation of 2.6 nm; yeast and E. coli were inhibited at the low concentration of Ag nanoparticles, whereas the growth-inhibitory effects on S. aureus were mild. The free-

radical generation effect of Ag nanoparticles on microbial growth inhibition was investigated by electron spin resonance spectroscopy.

Maneerung et al., (2008) obtained a zone of inhibition for E. coli of 2 mm, using 15 mm diameter cellulose impregnated with AgNPs. However, they did not indicate the concentration of E. coli used. Silver nanoparticles displayed the optical absorption band around 420 nm. The red-shift and broadening of the optical absorption band was observed when the mole ratio of sodium borohydride $NaBH_4$ to $AgNO_3$ ($NaBH_4$:$AgNO_3$) was decreased, indicating the increase in particle size and particles size distribution of silver nanoparticles that was investigated by transmission electron microscope. The formation of silver nanoparticles was also evidenced by the X-ray diffraction.

Gunawan et al., (2011) have investigated the immobilization of AgNP/CNTs with controlled sizes (2-5 nm) coated on the surface of a polyacrylonitrile (PAN) hollow fiber membrane. A filtration study using E. coli contaminated feed water was conducted for PAN alone and AgNP/CNT/PAN membranes. They were found that the AgNP/CNT coating significantly enhanced antimicrobial activity, as well as antifouling properties of the membrane. Under the continuous filtration mode, the relative flux drop over Ag/MWNTs/PAN was 6%, which was significantly lower than that over the pristine PAN (55%) at 20 h of filtration.

Pikwa et al., (2010) developed a simple gravity fed water treatment unit 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 study explores combining the WFMF membranes with silver nanoparticles (AgNPs) using a

modified chemical reduction method. 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%.

Pikwa K., (2015) was evaluating the performance of the woven fibre membrane filtration unit with respect to its fouling propensity to different feed samples. The synthetic feed solution was made up of 2 g/L of river clay in tap water and 0.5% domestic sewerage was added into the solution accounting for 2% of the total volume. A membrane filtration unit was used for this study consisted of a pack of five membrane modules which were fully immersed into a 100 litres filtration tank. The system was operated under gravity and the level in the filtration tank was kept constant by a level float. The study was concluded Internal fouling was found to occur quickly in the first few minutes of filtration and it was the major contributor for the loss of flux from the woven fabric microfiltration (WFMF) membrane. An aeration rate of 30 L/min improved the average flux by only 36%, where a combination of intermittent backwashing with brushing and intermittent backwashing with aeration (aeration during backwashing only) improved average flux by 187% and 135% respectively. Pre-coating the WFMF membrane with lime reduced the effects of pore plugging and particle adsorption on the membrane and improved the average flux by 66%. The cleaning strategies that were most successful in pure water flux (PWF) recovery were high pressure cleaning and a combination of soaking and brushing

the membrane in a 0.1% NaOCl (desired) solution. PWF recovery by these two methods was 97% and 95% respectively.

Gangadharan et al., (2015) developed Bactericidal water filters, in which, nitrocellulose membrane filters were impregnated with different biosynthesized silver nanoparticles. Silver nanoparticles (AgNPs) from Aspergillus niger (AgNPs-Asp), Cryptococcus laurentii (AgNPs-Cry) and Rhodotorula glutinis (AgNPs-Rho) were used for impregnating nitrocellulose filters. The bactericidal properties of these nanoparticles against Escherichia coli, Enterococcus faecalis and Pseudomona aeruginosa were successfully demonstrated. The higher antimicrobial effect was observed for AgNPs-Rho. Moreover, complete inhibition of bacterial growth was observed on nitrocellulose membrane filters impregnated with 1 mg/L of biosynthesized AgNPs. The maximum average concentration of Ag+ leached from Ag NPs in the liquid filtrate were 16.10-5 mg/L, 2 .10-5 mg/L, 7.10-5 mg/L and 1.10-5 mg/L for AgNPs-Com, AgNPs-Asp, AgNPs-Cry and AgNPs-Rho respectively. According to World Health Organization (WHO), higher levels of silver, up to 0.1 mg/L could then be tolerated without risk to health .This concentration was able to reduce the bacteria colony count by over 5 orders of magnitude, doing suitable for a water purification device.

Swensson et al., (2018) were showed that the percolation of contaminated water through paper sheets containing silver nanoparticles is a promising way to provide emergency drinking water. The silver nanoparticles were deposited by the in situ reduction of silver nitrate on the cellulose fibers of an absorbent blotting paper sheet. They were demonstrated an improved way to produce silver nanoparticles in paper sheets by adding sodium hydroxide to the glucose reductant. For

equimolar $AgNO_3$ and NaOH, the reflection spectra show a broad peak at around 420 nm with reflectance of 20% relative to a sheet without AgNP, in reasonable accord with the reflectance of sheets where the $AgNO_3$ was reduced with $NaBH_4$.The silver content of the sheets, measured by diffuse reflectance spectroscopy, was around 2−3 mg of silver per gram of dry paper. This was sufficient to reduce the concentration of a model Escherichia coli suspension after percolation through the sheet.

Sile-Yuksel et al., (2020) were studied the effect of polymer types on AgNP location into membrane matrix. Polysulfone (PS), polyethersulfone (PES) and cellulose acetate (CA) polymers were used for fabrication of flat-sheet bare and nanocomposite membranes. The location of AgNP in membrane matrix was determined according to viscosity measurements of dope solutions, Atomic force microscopy (AFM), Scanning Electron Microscopy with Energy Dispersive Spectroscopy (SEM-EDS) and contact angle analysis. It was found that AgNPs should mostly accumulate onto the top and skin layers of polyethersulfone (PES) and Polysulfone (PS) nanocomposite membranes while it settled down the sub layer of cellulose acetate (CA) nanocomposite membrane. The location of AgNP into membrane matrix changed to the bacteriostatic effects of nanocomposite membranes because the interaction between AgNP and bacteria depends on the release of ionic silver from AgNP embedded in membrane. The nanocomposite membranes which stored AgNP at surface had the best antibacterial properties. From the EDS analysis of the top surface (typical penetration depth of ~10 nm) of membranes, the silver intensity (y-axis values of EDS analysis) indicates that AgNP located further at the surface of PS and PES membranes according to CA membranes. The silver

intensity values of PS and PES nanocomposite membranes were 5.1 and 7.8% while at CA nanocomposite membrane, it was measured as 1.5%.

Raheem, (2019) were impregnated silver nanoparticles in cellulose paper for the purpose of drinking water disinfection. AgNPs were embedded by in situ reduction using various concentrations (1 mM, 5mM, 10mM 15mM, 25mM, 30mM, 50mM) of AgNO3 using two different ratios of sodium borohydride (NaBH4) and silver nitrate ($AgNO_3$) (2:1 and 10:1). AgNPs papers were characterized using Scanning Electron Microscopy (SEM) to show the presence of AgNPs in the paper fibers and Transmission Electron Microscopy (TEM) to obtain the particles sizes of AgNPs. TEM images showed that the AgNPs particles size was ranged between 0.352 nm and 75 nm and that the 10:1 ratio of NaBH4/$AgNO_3$ resulted in smaller particles sizes than the 2:1 ratio.

Hussein, (2020) were designed and evaluated cost effective household water treatment systems using readily available material and environmentally friendly such as kaolin clay, jute fibers, and castor leaves. The household filters achieved greater than 98.55% of Tur, 8.7% of pH, 73.1% of TDS, 82.46% of TSS, 71.3% of EC, 70.5% of T.H, 77.9% of ALK, 71.54% of Cl, 70.5% of Ca, 80.7% of Mg, 85.5% of SO_4, 71.64% of Na, and 69.6% of K. These contaminants were reduced to acceptable levels of the USEPA. Water is filtered by Kaolin-jute fibers (85% kaolin clay, 15% jute fibers), taken in two cases (soaked and un soaked with AgNPs). A solution of silver nanoparticles was prepared using a local substance which is castor plant extract with a very low percentage (0.002 M) of silver nitrate ($AgNo_3$). Five volumetric ratios of Nano-silver solution were tested: (0.05%, 0.1%, 0.2 %, 0.25%, and

0.3%). Soaked filter achieved highest removal efficiency which was equal to 99.7%. The silver concentrations in the effluent filter water was below the EPA limit which was equal to 0.1 mg/L.

2.10 Research advantages

The most important feature of this research is the use of environmentally friendly materials that have a low cost, and also the use of PVC, which is used for one time with nano silver for water treatment purposes. The results showed that the amount of water resulting from the filtration process is sufficient for the purposes of cooking, drinking and family use, and the concentrations of silver ions in the filtered water are very low and conforming to the specifications of the World Health Organization for drinking water. In addition, the use of the coated polyvinyl chloride membrane limits the addition of dangerous and carcinogenic chemicals to humans.

CHAPTER THREE

EXPERIMENTAL WORK

CHAPTER THREE

EXPERIMENTAL WORK

3.1 Introduction

In this chapter, the preparation and characterization of Polyvinyl chloride (PVC) microfiltration membrane impregnated with silver nanoparticles for water disinfection, as well as the equipment utilized in the process, are described and illustrated. Fig. 3.1 depicts the flowchart of the experimental work. A series of laboratory tests are carried out to see how effective AgNPs membrane on removing bacteria from contaminated water, and the effluent water was tested for viable bacteria.

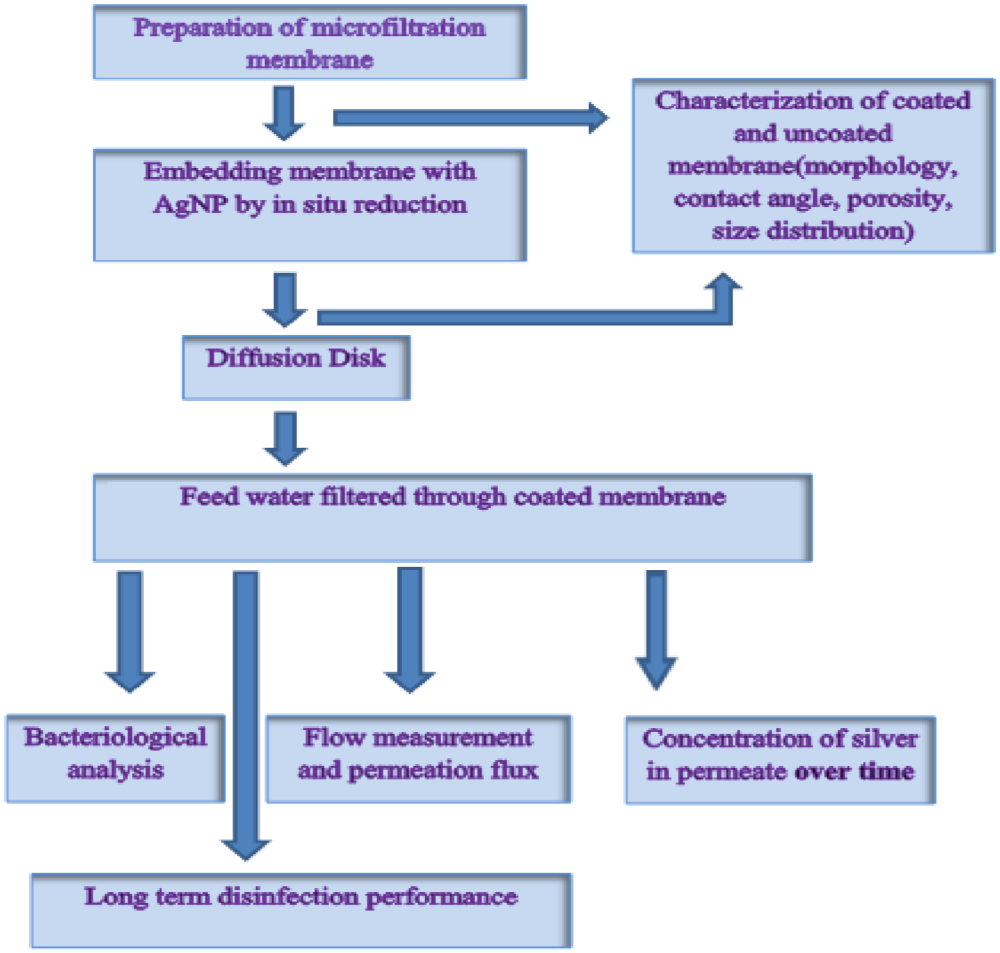


Fig. 3.1: Flow chart of experimental work.

3.2 Tools and Equipment

The tools and equipment were used are listed in table 3.1:-

Table 3.1: Tools and Equipment used in experimental work.

Tools or Equ.	Type	Made in	Availability
Polymer casting machine	AFA-IV	Chaina	Chemical Department/ University of Technology
Electronic Balance	JA203P	Japan	University of Babylon /Environmental Engineering Department
pH meter	5011A	Japan	University of Babylon /Environmental Engineering Department
Turbidity meter	Lovibond, SN10/1467	Germany	University of Babylon /Environmental Engineering Department
Culturing Hood	LBC1203B-B2	Korea	Al - Fadhel for Educational Services /Babylon
Autoclave	TR250N	Chaina	Al - Fadhel for Educational Services /Babylon
Incubator	LIB-030M	Korea	Al - Fadhel for Educational Services /Babylon
Micro wave	Daewoo	Germany	Al - Fadhel for Educational Services /Babylon
Heating magnetic stirrer	Velp	Korea	Al - Fadhel for Educational Services /Babylon
Atomic Absorption Spectrometer	AA320N	Japan	Iraqi Ministry of Science and Technology
Scanning Electron Microscopy	Inspect S50	Japan	Applied Science Departments/ University of Technology
X-ray spectroscopy	Shimadzu, XRD-6000	Japan	University of Babylon /college of material Engineering
UV-visible spectroscopy	Mega-2100	Japan	University of Babylon /college of material Engineering
contact angle	Si-plasma, CAM 110	Taiwan	Chemical Department/ University of Technology
Casting machine	AFA-IV	Korea	Chemical Department/ University of Technology

3.3 Polyvinyl chloride (PVC) membrane

There is an increasing interest to the hydrophobic polymeric materials in the membrane technologies because of their stability during the work, [Vladkova, 2003].

Polyvinyl chloride (PVC) is an excellent membrane material due to its stiffness, low cost, excellent physical and chemical properties, acid, alkali, and solvent resistance, and mechanical properties, [Jian and Zhen, 2002]. Another significant advantage of PVC as a membrane material is its ability of dissolution in common organic solvents like dimethylacetamide (DMAc), dimethylformamide (DMF), tetrahydrofuran (THF), and N-methyl-pyrrolidinone (NMP), [Shuo et al., 2010].

PVC flat sheet membranes were prepared by the simplest techniques for membrane preparation by phase inversion at different PVC concentrations (10 – 14 wt. %).

3.3.1 Preparation of the PVC solution

To prepare 25 g of the dope solution, the following steps were conducted:

1. PVC powder was dried in oven at 40 °C for 30 min.
2. Solutions of PVC in solvents (N, N-dimethylacetamide (DMAc) were prepared by mixing the solvent and the polymer in a glass flask under magnetic stirring at 35 °C for 48 h until the solution became homogeneous.
3. PVC solutions were casting on glass plates with uniform thickness of 200 μm by using casting machine as shown in Fig. 3.2.
4. Immerse glass plates in water bath containing distilled water immediately after casting.
5. The prepared flat membranes was stored into a fresh water.

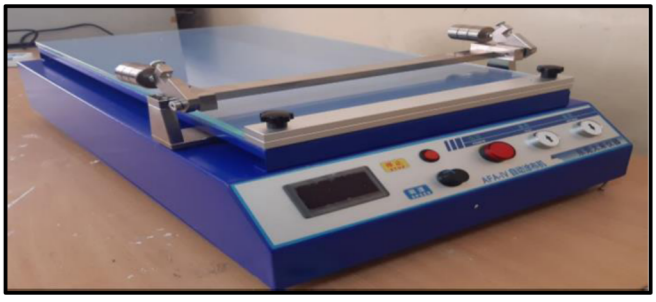


Fig. 3.2: Polymer casting machine, type (AFA-IV).

Table 3.2 shows weight of PVC and DMAc for each sample.

Table 3.2: Casting Solution Compositions (wt. %) of PVC and DMAc .

Sample	PVC (g)	DMAc (g)
Pv_1	2.5	22.5
Pv_2	2.75	22.25
Pv_3	3	22
Pv_4	3.25	21.75
Pv_5	3.5	21.5

3.3.2 Membrane characterization

3.3.2.1 Membrane morphology

Scanning Electron Microscopy (SEM) has been widely used to characterize the surface and cross section of polymeric membranes, both clean and coated as shown in Fig. 3.3.

The procedure for preparing specimens is relatively simple. The membrane surfaces can be seen directly, while the cross-sections are obtained through a simple cold (liquid N_2) fracture, [Tylkowski and Tsibranska, 2014].

Fig. 3.3: Scanning Electron Microscopy (SEM), type (Inspect S50) .

3.3.2.2 Membrane hydrophilicity

One of the most important factors in determining membrane performance is hydrophobicity. Water contact angle measurements are commonly used to evaluate the hydrophobicity and wetting properties of membrane surfaces, [Ladewig and Al-Shaeli, 2017]. All membranes were tested for contact angle using distilled water in order to determine their hydrophobicity. The image is captured using a camera. The contact angle is measured by the computer that is connected. The water contact angle of both coated and uncoated membranes was measured.

3.3.2.3 Porosity

The total void volume present within the membrane is defined as the membrane porosity, which is commonly defined as the pore volume divided by the total volume of the membrane, [Shrestha, 2008].

Briefly, the overall porosity was calculated according to the following formula:

$$\varepsilon_m\% = (1 - (\rho_{membrane} / \rho_{pvc})) * 100\% \quad \ldots\ldots\ldots \quad (3.1)$$

$\rho_{membrane}$ = (weight / volume)

ρ_{pvc} : the density of PVC is 1.4 (g / cm^3)

Membrane with (3 * 6) cm dimension was measured by using Venire. The sample was dried using an oven and then weighed using a sensitive electronic balance.

3.3.2.4 Atomic Force Microscopy (AFM)

Atomic Force Microscopy (AFM), is a versatile tool for physically characterizing surfacesas shown in Fig. 3.4. At the membrane surface, AFM is also used to measure pore size, porosity, pore size distribution, aggregate size, and nodule size, [Ladewig and Al-Shaeli, 2017]. AFM provides a number of advantages over conventional microscopy techniques. AFMs probe the sample and make measurements in three dimensions, x, y, and z (normal to the sample surface), thus enabling the

presentation of three-dimensional images of a sample surface. This provides a great advantage over any microscope available previously, [Cheryl, 1996].

Fig. 3.4: Atomic Force Microscopy(AFM).

3.4 Preparation of AgNPs membrane

3.4.1 Preparation of clove extract

The nano silver is prepared from the aqueous extracts of cloves aromatic plant (Fig. 3.5) as shown in the following procedure:

1. Cloves aromatic powder weighting (2.5 g) were washed with 150 mL of deionized water after drying and grinding.
2. The mixture was filtered through Whitman No.1 filter paper.
3. Typical reaction mixtures contained the resultant precipitate was re suspended and boiled in 50 mL of deionized water for 30 min at 90 °C with constant stirring by using a magnetic stirrer.
4. The extract was centrifuged at 1200 rpm for 5 min and cooled at room temperature.
5. The resultant extract was stored at 4°C .

Fig. 3.5: Dry cloves aromatic plant.

3.4.2 Preparation coating membrane with AgNPs

The PVC membrane was embedded with AgNPs by in-situ reduction of Ag ions by cloves aromatic plant extract, which was used as the reducing agent and stabilizer as shown in Fig. 3.6.

1. The PVC membrane immersed in 7.5 mL of $AgNO_3$ solution concentration of 0.003M for 30 min.
2. The reaction mixture was incubated in dark to avoid the photo activation of nitrate under static conditions.
3. About 1 mL of clove extract was taken in a 100 mL beaker containing 41.5 mL deionized water and stirred for 30 min with final pH was adjusted to 3.7.
4. The embedded membrane with the remaining silver nitrate ($AgNO_3$) was added to the mixture.
5. After the addition of the reaction mixture by stirring at 70 °C for 20 minutes.
6. The membrane was incubated for 24 h with constant stirring.

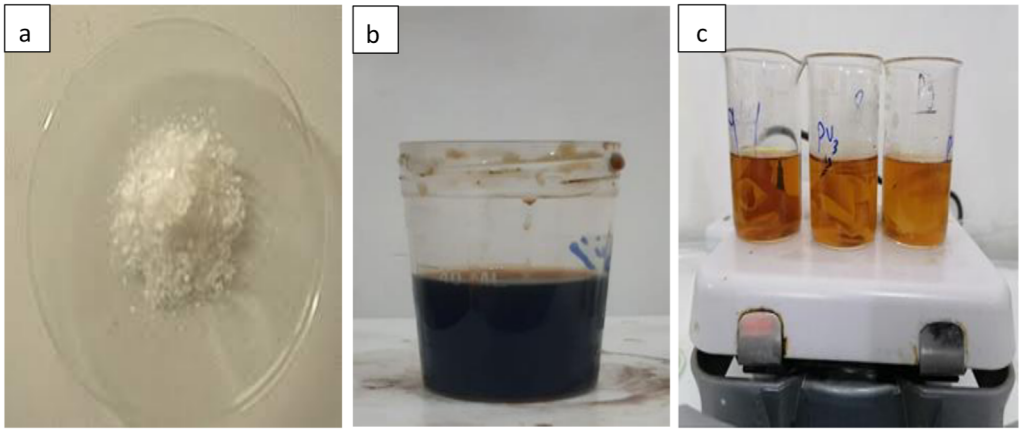


Fig 3.6: Preparation coating membrane with AgNPs: a) $AgNO_3$, b) cloves extract, c) coated membranes.

3.5 Flow measurement and permeation flux

Ten piece of flat sheet micro filtration membrane from Polyvinyl chloride coated and uncoated with AgNPs were used. Each piece was immersed in distilled water for 24 h and run in the test system. Fig. 3.7 shows a schematic diagram of solute water separation unit.

During the water purification tests, the flow rate was determined by recording the volume of filtered water collected at 1 h intervals. All experiments were carried out at a transmembrane pressure of 1bar. The following expression was used to determine permeation flux, [Alsalhy et al., 2011]:-

$$J_w = Q_w / (\Delta P * A_s) \quad \ldots\ldots\ldots \quad (3.2)$$

where J_w is the permeation flux of membrane ($L/(m^2\ h\ bar)$), Q_w the volumetric flow rate (L/h), ΔP the transmembrane pressure drop (bar), and A_s is the membrane surface area (m^2).

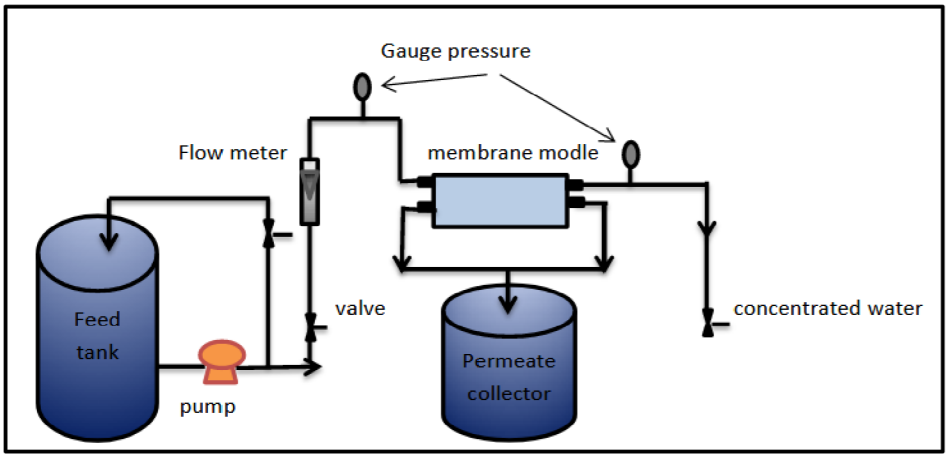


Fig. 3.7: Schematic diagram of the MF experiment setup.

3.6 Determining disinfection efficacy

3.6.1 Well diffusion methods

The silver nanoparticles (AgNPs) synthesized from clove aromatic plant extract was tested for their antimicrobial activity by well diffusion method against pathogenic organisms Escherichia coli (E. coli). Twenty mL of nutrient agar medium was poured into sterilized Petri plates and allowed to solidify in a sterile environment. Thereafter, 1 mL of synthetic feed of $333*10^3$ E.coli concentrations was streaked on the nutrient agar plates and spread uniformly using sterile cotton swabs. With the help of a sterilised borer, agar wells of 8 mm diameter were prepared. The wells were injected by using micropipette (50 µl, 100 µl and 150 µl) of the sample of nanoparticles solution. The plates were further incubated at 37 °C for 24 h and were then examined for the presence of zones of inhibition. The inhibition zone was measured and expressed in mm unit.

3.6.2 Disk diffusion method

The disk diffusion method is among the most flexible susceptibility testing methods in terms of antimicrobial agents that can be tested, [Jindal and Goswami, 2020].

1. Nutrient agar was poured into petri dish and allowed to solidify in a sterile environment.

2. Thereafter, 1 mL of synthetic feed of $1.5*10^8$ E.coli concentrations was streaked on the nutrient agar plates and spread uniformly using sterile cotton swabs.

3. Four piece of coated and uncoated membranes were sterilized by using autoclaving.

4. Three circle pieces of the coated and one of the uncoated membranes measuring 7 mm in diameter were placed on the lawn of bacteria.

5. The uncoated membranes were used as controls.

6. The plates were incubated in an upside down position for 24 h at 37°C.

7. After 24 h the inhibition ring formed was served as an indicator of the antibacterial activity and was determined by measuring the diameter of the inhibition zone around the membrane.

3.7 Water samples

3.7.1. Synthetic feed water

Synthetic feed water was prepared by the following procedure:-

1. deionized water was autoclaved at a temperature (121^0C) for 15 min.

2. A loop of E.coli was taken and mixed with 100 mL of deionized water.

3. To achieve equal feed suspension, 40 mL of the well mixed solution were added to 20 L of autoclaved deionized water in a sterile bucket and thoroughly mixed.

3.7.2. Raw water

The raw water samples used in this study were taken from Shatt Al Hillah river. Samples of water with turbidity 60 NTU. Various volumes of filtrates were collected over 1 hour filtration period, with the assumption that enough treated water would have been produced for drinking and cooking during this time.

The samples were transported to the laboratory and assayed to determine the turbidity of the water before and after treatment.

3.8 Microbiological Analyses

Microbiological testing was performed to determine the presence of E. coli in the water samples. E. coli was chosen as a model for the reduction of bacterial pathogens in water through the separation process of filtration due to its small size and relative ease of production.

1.Untreated water was used as a control.

2. The test system was sterilized by poured 250 mL of ethanol after then the system is washed by passing 1 L of Norman saline.

3. The effluent was collected and used in each experiment under sterilizing conditions after the water had been filtered with the membrane.

4. Control and effluent water were diluted four times each by Norman Saline.

5. For each dilution, use 150 μL with two duplicates per sample and brush on container dishes (Nutrient Agar).

6. In the incubator, the plates were incubated at 37°C for 24 hours.

7. After 24 hours, the results were read and the number of colonies created in each dish was calculated. Dilution was used, resulting in distinct colonies that could be calculated. Colony Forming Unit (CFU/mL) was calculated according to the following equation:

$$(\text{CFU/mL}) = \frac{\text{Average number of colonies} * \text{Dilution coefficient} * 1000}{150} \quad \ldots (3.3)$$

3.9 Culture Media Preparation

Nutrient agar was prepared by suspending 28 g of the medium in 1000 mL of distilled water. The mixture was mixed well and dissolved by heating with frequent agitation. Then it was boiled for 1 min until complete dissolution. The media was sterilized by placing it in an autoclave at 121 °C for 15 min then it was cooled to 45-50 °C and

mixed well and dispensed into plates and left to be solidified as shown in Fig. 3.8.

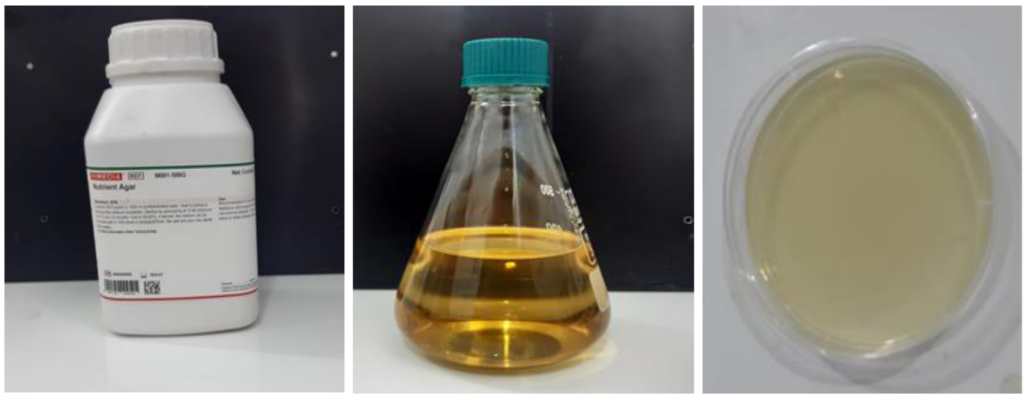


Fig. 3.8: Nutrient agar preparation.

3.10 Culturing Method

A 0.15 mL of the filtered water samples was spread over a media plate with two replicates per sample and then left the sample to be absorbed by the media. The process was done in a culturing hood (LCB-1203B-B2), shown in Fig. 3.9. and then the plates were incubated at 37 °C for 24 hrs in an incubator (LIB-030M).

Fig. 3.9: Culturing hood.

3.11 Membrane System Test

The Membrane System Test was designed for the purpose of water filtration through the AgNPs membranes, as illustrated in Fig. 3.10.

In this work, A cross-flow experimental system was used. The outer area of the membrane cell was 54.76 cm^2, with an effective area of 18.1 cm^2, was connected to a high pressure pump. One layer of fabric mesh was erected below the membrane model to support it. The pure water of the membranes was collected at collection tank. Specific membrane modules were prepared from the microfiltration membrane strings which are flat sheets, made of Polyvinyl chloride with a pore size of (0.1 - 0.84) μm were prepared in Chemical Department Engineering/ University of Technology. Membrane modules were prepared, in which were coated with AgNPs, and the other were unmodified to differentiate the effects of AgNPs on membrane. Their efficiency is dependent on the size of the pores and are impregnated with a Nano silver solution for additional bacteriostatic effect (to prevent biofilm formation on the filter and excessive bacterial numbers in the water).

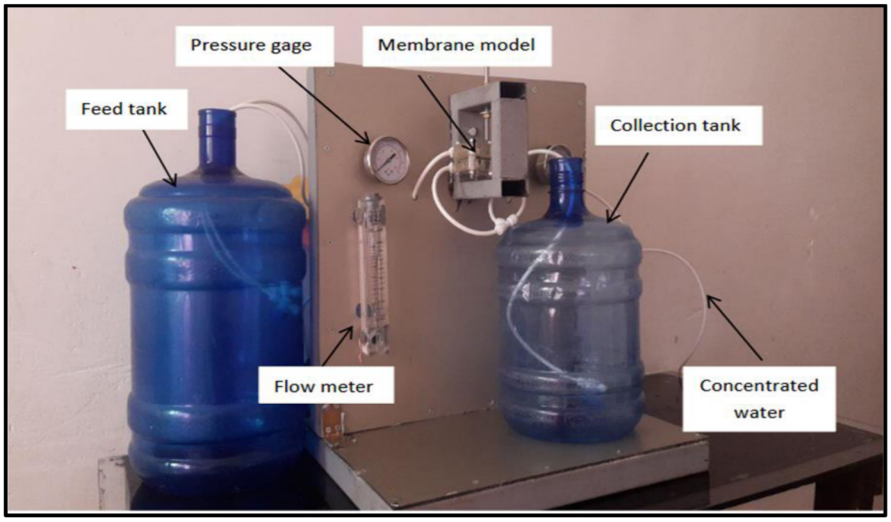


Fig. 3.10: Membrane system set test .

CHAPTER FOUR

RESULTS AND DISCUSSION

CHAOTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter discusses the results of the incorporation of AgNPs on the Polyvinyl chloride (PVC) membranes, investigate the characteristics of the coated membrane, the bacteriological analysis of the filtered water samples before and after percolation through AgNPs membrane, evaluate the antibacterial effectiveness of the coated membrane whenever it comes into contact with bacteria medium, and an analysis of the silver content in the effluent water by using AAS.

4.2 Coated membrane with silver nanoparticles

Ag nanoparticles have been synthesized by reducing the aqueous solution of $AgNO_3$ with clove extract. One interesting aspect here is that reduction time is quite small (few minutes instead of hours as compared to other natural precursors).The membranes color was changed from white to brown as shown in Fig. 4.1. This change was indicating the presence of silver nanoparticles and due to surface Plasmon resonance of silver nanoparticles.

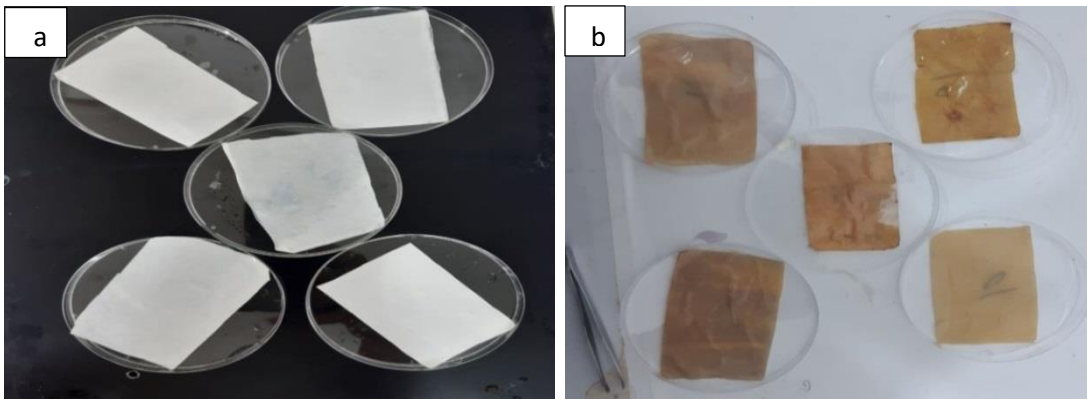


Fig. 4.1: Membranes; a) uncoated membranes, b) coated membranes.

4.2.1 Characterization

4.2.1.1 UV–vis spectroscopy

UV-visible spectroscopy is one of the most widely used techniques for structural characterization of silver nanoparticles. The absorption spectrum (Fig. 4.2) of the pale yellow-brown silver colloids showed a surface Plasmon absorption band with a maximum of 435 nm indicating the present of AgNPs. a surface Plasmon absorption band dictates the optical absorption spectra of metal NP.

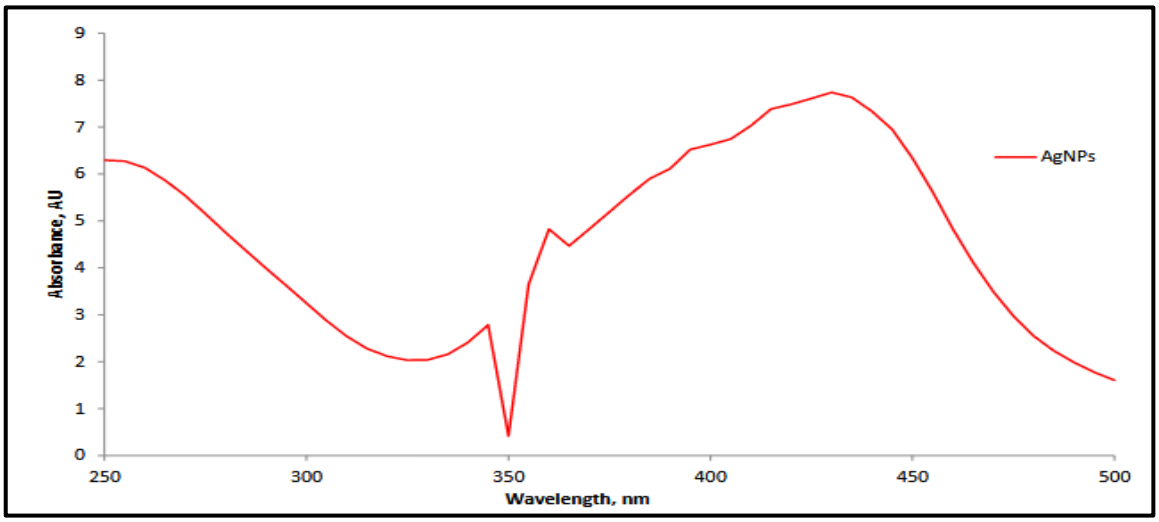


Fig. 4.2: UV–Vis absorption spectrum of silver nanoparticles obtained.

4.2.1.2 X-ray spectroscopy (XRD)

The XRD spectra for the AgNPs coating is shown in Fig. 4.3. X-ray spectroscopy is widely used for qualitative and quantitative chemical analysis, in particular, in electron microscopes. The X-ray results show that the silver nanoparticle is a pseudo-random substance with crystal structure in some directions and in the main direction 38.2°, 44.4°, 64.9° and 78.0°. The SEM results are supports these results, which show that the particle size ranges between (35-110) nm and the average nanoparticle size ranges between (41-72.5)nm, and this support the results of X-ray

diffraction in some directions, which tend to randomly structure (nanostructure).

Smaller Ag nanoparticles have a number of advantages, including high conductivity, chemical stability, and catalytic and antibacterial activity, making them ideal for a variety of applications.

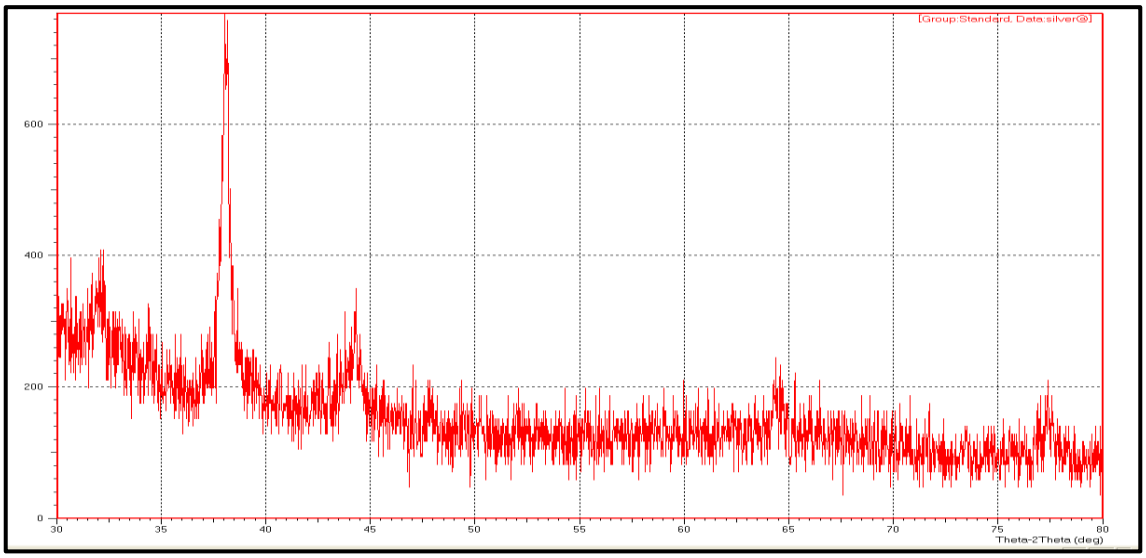
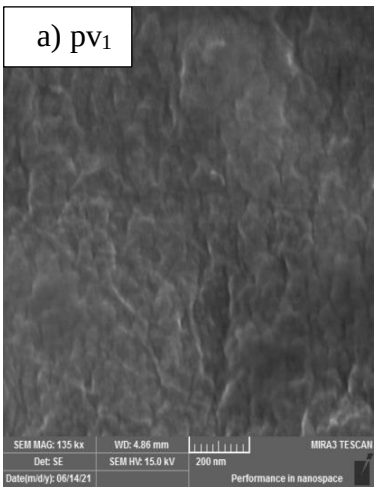
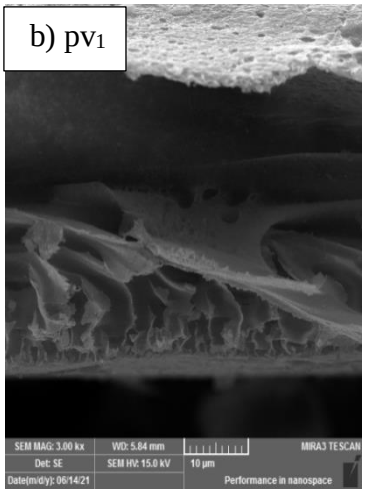


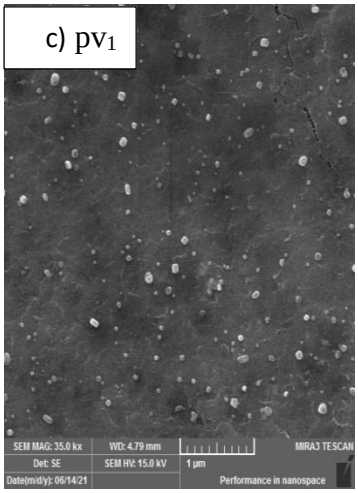
Fig. 4.3: XRD patterns of the AgNPs on the coated membrane for 2 theta angles between 30º and 80º.

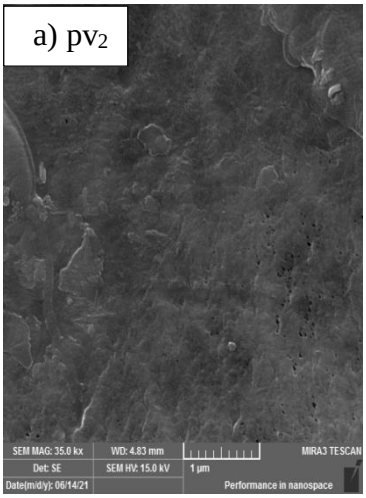
4.2.1.3 Morphology

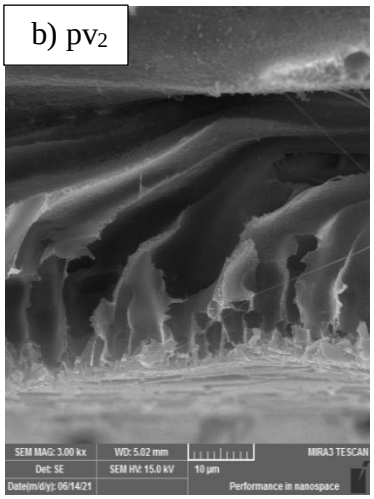
In SEM, the membrane sample is struck with a narrow beam of electrons and these electrons cause the sample to release secondary electrons which are then detected and an image of the surface is formed, [Shrestha, 2012]. Surface morphologies of the membranes were observed using SEM to find numerous small particles generated on all membrane surfaces. Fig. 4.4 shows the SEM micrographs of the uncoated and coated membranes .

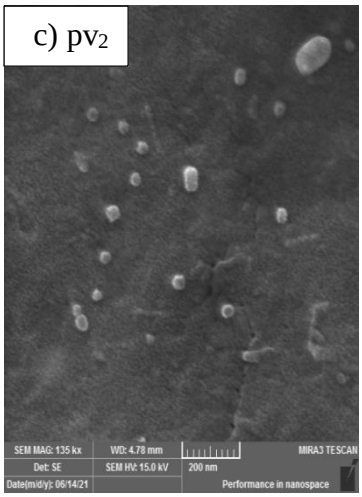

a) pv1
SEM MAG: 135 kx
WD: 4.86 mm
MIRA3 TESCAN
Det: SE
SEM HV: 15.0 kV
200 nm
Date(m/d/y): 06/14/21
Performance in nanospace

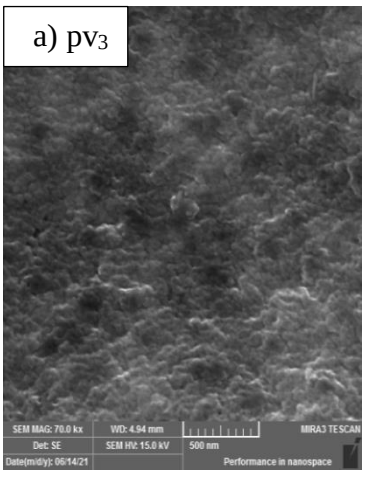

b) pv1
SEM MAG: 3.00 kx
WD: 5.84 mm
MIRA3 TESCAN
Det: SE
SEM HV: 15.0 kV
10 µm
Date(m/d/y): 06/14/21
Performance in nanospace

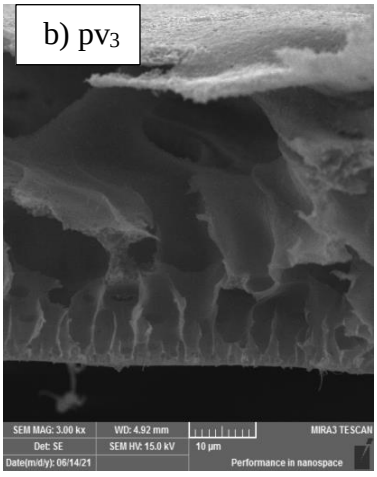

c) pv1
SEM MAG: 35.0 kx
WD: 4.79 mm
MIRA3 TESCAN
Det: SE
SEM HV: 15.0 kV
1 µm
Date(m/d/y): 06/14/21
Performance in nanospace

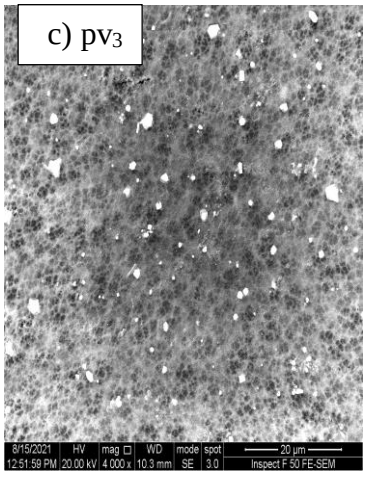

a) pv2
SEM MAG: 35.0 kx
WD: 4.83 mm
MIRA3 TESCAN
Det: SE
SEM HV: 15.0 kV
1 µm
Date(m/d/y): 06/14/21
Performance in nanospace


b) pv2
SEM MAG: 3.00 kx
WD: 5.02 mm
MIRA3 TESCAN
Det: SE
SEM HV: 15.0 kV
10 µm
Date(m/d/y): 06/14/21
Performance in nanospace


c) pv2
SEM MAG: 135 kx
WD: 4.78 mm
MIRA3 TESCAN
Det: SE
SEM HV: 15.0 kV
200 nm
Date(m/d/y): 06/14/21
Performance in nanospace


a) pv3
SEM MAG: 70.0 kx
WD: 4.94 mm
MIRA3 TESCAN
Det: SE
SEM HV: 15.0 kV
500 nm
Date(m/d/y): 06/14/21
Performance in nanospace


b) pv3
SEM MAG: 3.00 kx
WD: 4.92 mm
MIRA3 TESCAN
Det: SE
SEM HV: 15.0 kV
10 µm
Date(m/d/y): 06/14/21
Performance in nanospace


c) pv3
8/15/2021
HV
mag
WD
mode
spot
20 µm
12:51:58 PM
20.00 kV
4 000 x
10.3 mm
SE
3.0
Inspect F 50 FE-SEM

- continued

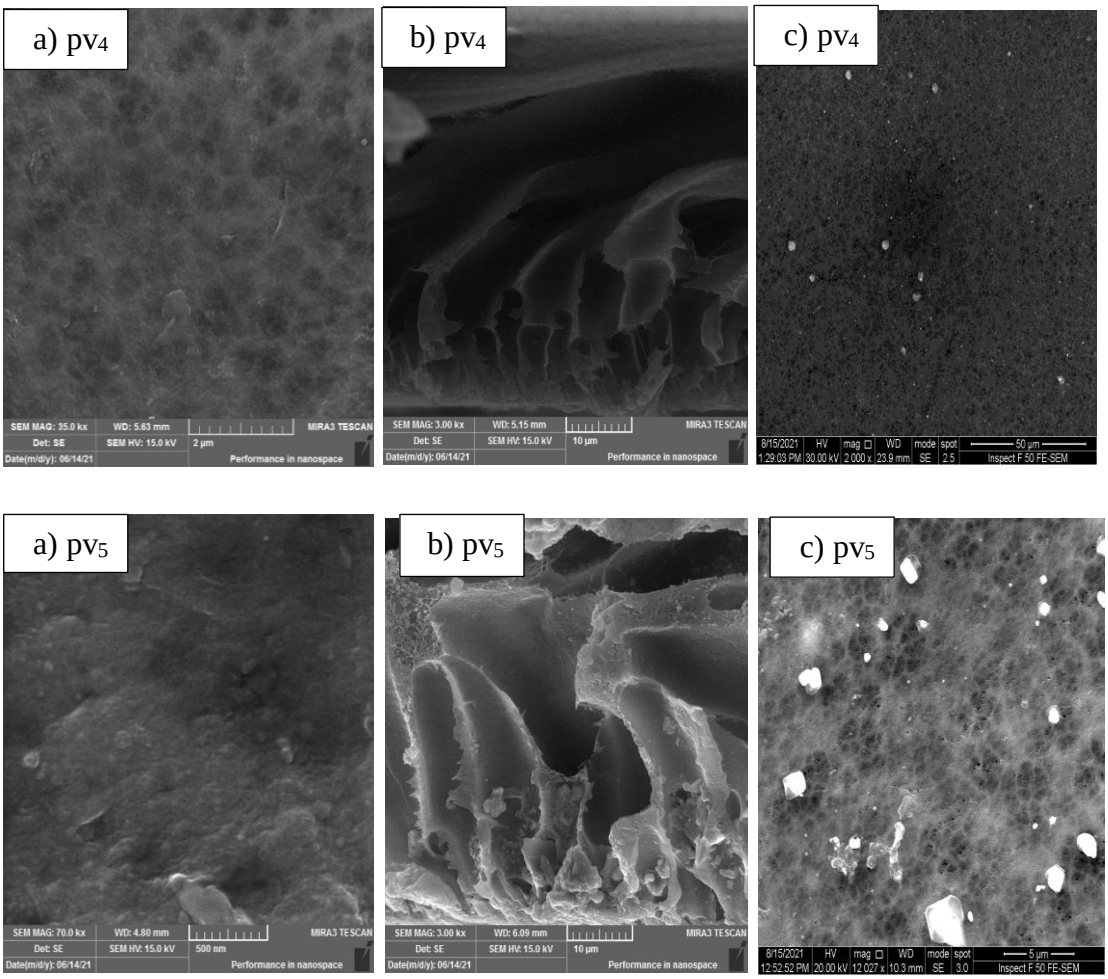


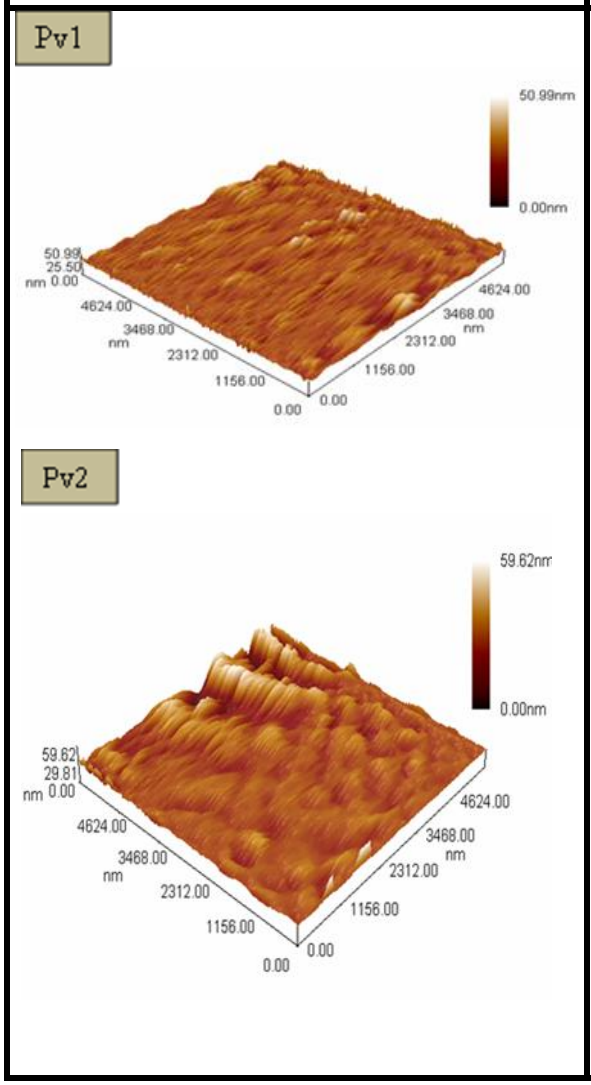
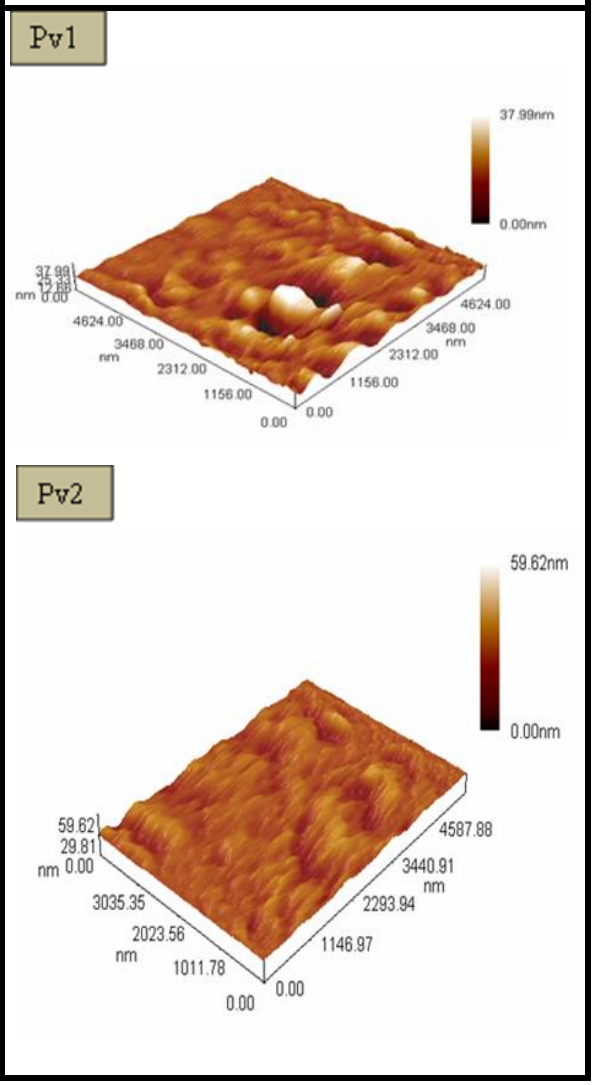
Fig. 4.4: Structure of Polyvinyl Chloride obtained by SEM: a) the membrane before embedding with AgNPs, b) cross section of uncoated membrane, c) the membrane after embedding with $AgNP_S$.

The Polyvinyl Chloride (PVC) structure of membranes was visible in micrographs. There appeared to be no significant difference in the morphology of uncoated and coated membranes and the cross section of MF membrane showed a sponge-like morphology with interconnected pores. However, some matter was observed on the surface of the coated membranes that was postulated to be the $AgNP_S$. The low magnification SEM image of Ag NPs loaded PVC membrane illustrates that the AgNPs

uniformly distributed on membrane surface on a relatively large surface area. The present of silver on PVC membranes did not significantly affect the original pore structure of membranes on the macroscopic scale.

4.2.1.4 Atomic Force Microscopy (AFM)

As seen in 3-D image in Fig. 4.5, AFM images gave further information concerning the topography of the PVC-based membranes before and after the addition of AgNPs . The brightest regions in this 3-D image show the most elevated areas of the material surface, while the darkest regions represent the membrane pores.

Uncoated membrane	Coated membrane
	

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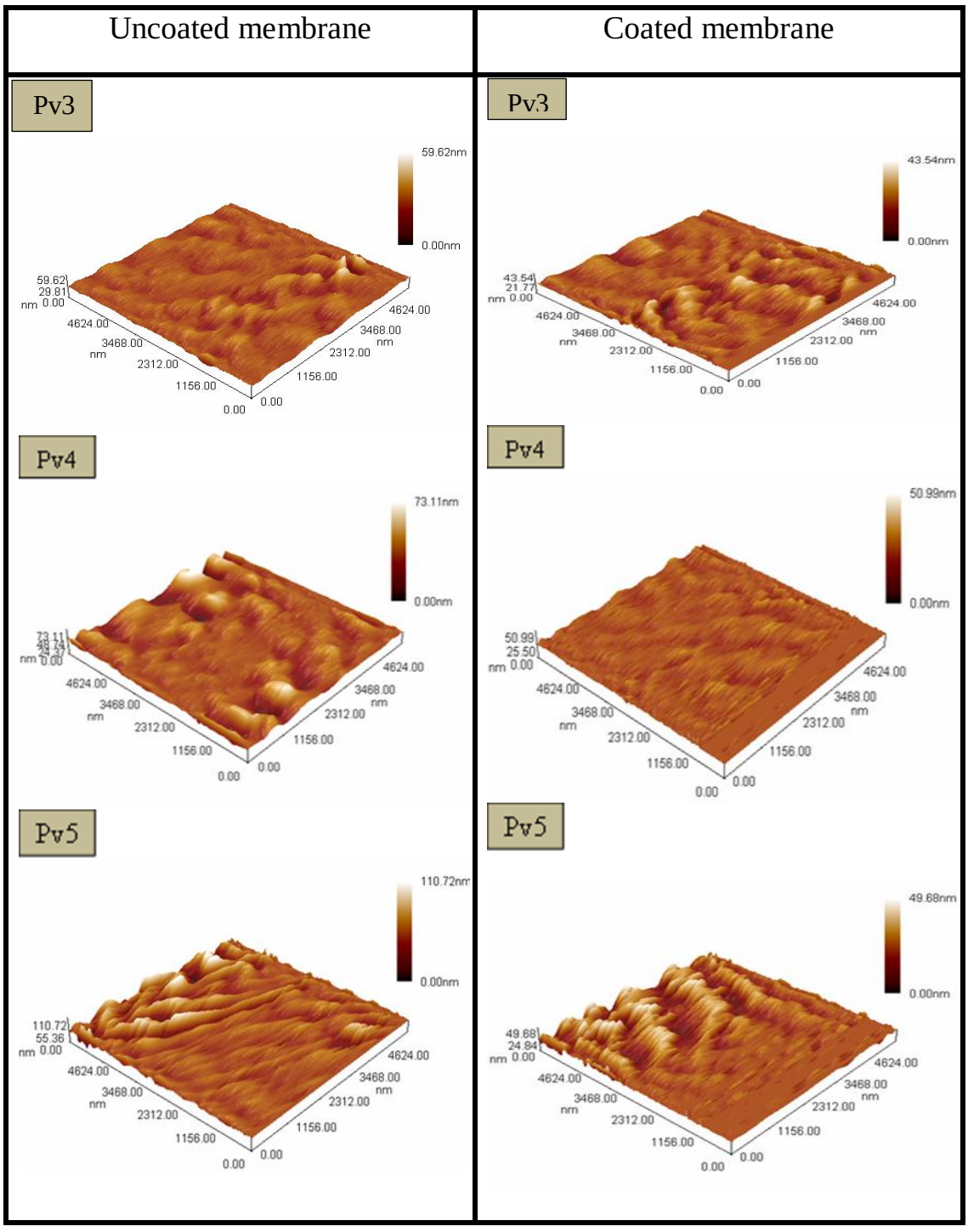

Fig. 4.5: Three-dimensional (3-D) Atomic Force Microscope (AFM) images of the uncoated and coated surfaces of the PVC membranes.

The results of the AFM assays do not show the particle size, but rather the size of the folds of the surface of the membrane and may include more than one particle due to the agglomeration of nanoparticles, which is evidenced by the UV results, which indicate that high absorption occurs after 435 nm and this is the result of nanoparticles agglomeration in the liquid The result of the delay in conducting the examination.

The surface roughness of the membranes calculated from the AFM analysis play a decisive role in the fouling propensity of the membranes. One of the most effective variables to enhance the antifouling capacity of membranes is the surface roughness. Thus, membranes with a smoother surface have better fouling impedance, as conducted by Ghadhban, 2020. The roughness value of PVC membrane decreased after the addition of AgNP. These results agree with Mollahosseini et al., 2012, has been reported that smoother surface was formed by the introduction of inorganic nanoparticles into polymeric membrane. AgNP aggregates onto membrane surface could cause the increase in surface roughness,this is what happened in the membranes pv_1 and pv_3. The mean pore size refers to the diameter on the entrance of the pores where AFM generally gives a funnel structure due to the tip-sample convolution, which is agree with the finding conducted by Carvalho et al., 2011. All membranes present a mean pore size in the range of microfiltration. Table 4.1 supports these outcomes.

Table 4.1. Mean pore size and the mean roughness (Ra) of prepared membranes.

Membrane	Mean roughness (Ra), nm		Mean pore size, nm	
	Uncoated pvc	Coated pvc	Uncoated pvc	Coated pvc
Pv_1	2.75	2.95	204.71	298.24
Pv_2	3.99	2.57	308.53	273.76
Pv_3	2.52	2.7	259.28	281.14
Pv_4	5.01	1.46	462.63	206.41
Pv_5	8.66	4.17	322.67	278.08

4.2.1.5 Contact angle

The membrane hydrophilicity was evaluated from the surface contact angle, [Samree et al., 2020]. The average contact angle values of the uncoated and coated PVC membranes are given at Table 4.2. It was clearly seen that the contact angle of PVC membrane decreased with the addition of AgNP, because that the addition of AgNP had improved the membrane hydrophilicity and the membrane with 14 wt. % had highest contact angle value (70.3º) decrease after the addition of AgNPs to (50.4º). This decrease in hydrophobicity can be potentially beneficial in preventing chemical fouling, but is beyond the scope of this study and will not be discussed here. This results agree with the results conducted by Basri et al., 2011, they are found that Ag particles had low surface tension of pristine PES and so the water can easily spread on membrane surfaces. Thus the membrane hydrophilicity was improved.

Table 4.2: The average water contact angle values of the uncoated and coated PVC membrane with AgNps.

Membrane	Average Contact Angle, ^{o}	
	Uncoated PVC	Coated PVC
PV_1	54.2	18.2
PV_2	63.1	37.6
PV_3	65.4	41.95
PV_4	67.02	46.7
PV_5	70.3	50.4

Many attempts have been made to enhance the hydrophilic layer on the existing membrane surface in order to enhance the hydrophilicity, antibacterial characteristics and membrane performance, resulting in more efficient membrane applications such as water and wastewater treatment.

The contact angle values of microfiltration and ultrafiltration membranes depend on their surface hydrophilicity (or hydrophobicity), roughness, porosity, pore size, and pore size distribution. For a membrane with a highly porous nature, the contact angle value may become very low, although the membrane is not necessarily hydrophilic. Similarly, the contact angle value of a membrane of higher surface roughness is higher compared to that of another membrane of lower surface roughness, although both membranes are of similar hydrophilic nature, [Kumar et al, 2013].

4.2.2 Measurements of permeation flux

In order to investigate the effects of deposition of AgNPs on the permeability of different membranes, the permeability of PVC immobilized with AgNPs using the method described in chapter three

(section 2). The results of permeation flux and flow rate are illustrated in Table 4.3

Table 4.3: Membrane flow rate and permeation flux for different PVC microfiltration membranes.

Sample	Flow rate, (L/h)	
	Uncoated PVC	Coated PVC
Pv_1	10	7.8
Pv_2	9.7	7.5
Pv_3	9.4	7.2
Pv_4	9.2	7
Pv_5	9.1	6.6

The decrease in membrane permeability were attributed to the deposited AgNPs on the membranes, which reduced the membrane surface porosity and pore size. Because that an increase in the number and size of the silver nanoparticles on membrane surface lead to the reduction of water permeability because the nanoparticles create a barrier to water transport. The same phenomena were explained by Sawada et al., 2012. Generally, pv_1 appeared to have the highest flow rate and flux, as expected, and the flow rate of pv_5 were slightly lesser than another membrane, also as it was expected.

Furthermore, incorporated Polyvinyl Chloride with AgNP exhibited the increased hydrophilicity, leading to the increase of water permeability associated with higher affinity. This was because of high specific surface area and fraction of nanoparticles that provide specific functionality to the modified membrane for facilitating the hydrophilicity and permeability.

4.2.3 Porosity

Table 4.4 shows the porosity of the uncoated and coated membranes prepared from different PVC concentrations in dope solution. As it can be seen, the porosity of the flat sheet PVC uncoated membranes decreased from 90.5% to 70.84% with increasing of PVC concentration in dope solution from 10 wt.% to 14 wt.%, and the porosity of the flat sheet PVC coated membranes with AgNPs decreased from 79.8% to 65% with increasing of PVC concentration in dope solution. However, among the modified membranes, the porosity was decreased, which might be due to the blockage of membrane pores by the aggregation of nanoparticles.

Table 4.4: The porosity of the uncoated and coated membranes prepared from different PVC concentration in dope solution.

Sample	Porosity, %, PVC	Porosity, %, PVC/AgNPs
Pv_1	90.5	79.8
Pv_2	89.1	79.5
Pv_3	73.1	78.3
Pv_4	71.1	73.8
Pv_5	70.84	65.8

4.3 Determining disinfection efficacy

4.3.1 Well diffusion

The silver nanoparticles synthesized by natural plants extract was showed efficient antimicrobial property. The diameter of inhibition zones around each well (50, 100, and 150µL) is recorded in table 4.5. 150 µL of silver nanoparticles were found to have highest antimicrobial activity against E. coli (20 mm) and 50 µL the lesser antimicrobial activity of silver nanoparticles was found (17 mm) as shown in Fig. 4.7.

Table 4.5: Zone of inhibition of silver nanoparticles synthesized by natural plant extracts against Escherichia coli.

Silver nanoparticle samples, µL	Zone of inhibition (mm) against E.coli
50	17
100	18
150	20

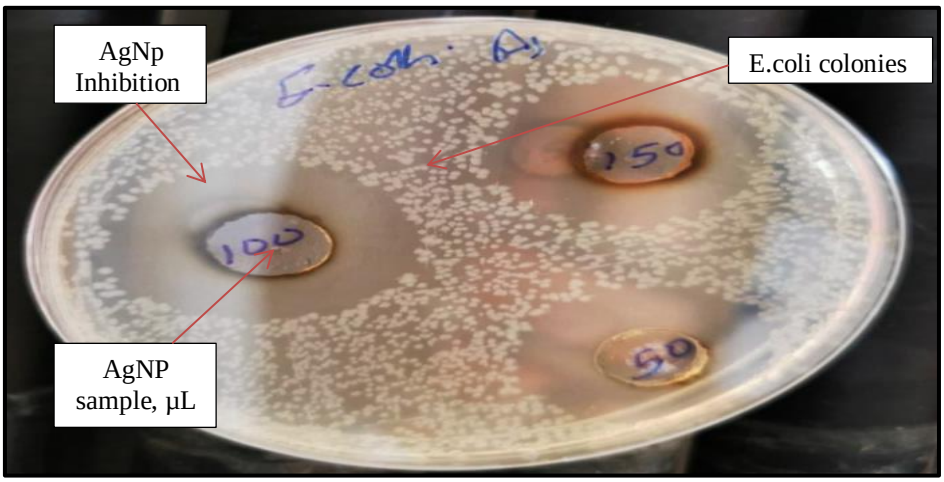

Fig. 4.7: The inhibition zones of AgNP in well diffusion method.

4.3.2 Disk diffusion

The results of disk diffusion test are shown in Fig. 4.8. Around uncoated membrane there was growth of Escherichia coli (E. coli) observed and no zone of inhibition formed for high E.coli concentration used in the test . However, there was clear zone of inhibition around three piece of impregnated membrane with three different $AgNO_3$ concentration (0.001, 0.002, and 0.003 M). The largest zone of inhibition (10mm) resulted in the highest $AgNO_3$ concentration, while, smallest zone of inhibition (6mm) resulted in the lowest $AgNO_3$ concentration . The piece of coated membrane with 0.002M of $AgNO_3$ concentration has (9mm) of inhibition zone. A clear zone of inhibition around impregnated membranes was an indication of the antimicrobial effect. This showed

that the antibacterial action was purely due to the AgNPs imbedded in the PVC membrane and not to the membrane itself. Other investigations had come to the same conclusion, conducted by Dankovich, 2011; Achisa et al., 2014

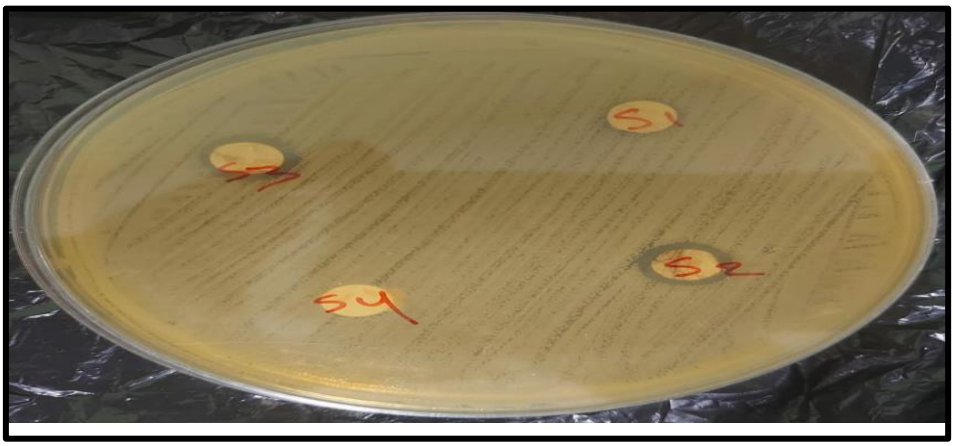

Fig 4.8: Represented to disk diffusion test with different $AgNO_3$ concentration (s_1=0.001M; S_2=0.002M; S_3= 0.003M; S_4= uncoated membrane).

4.3.3 Removal efficiency

Experiments were conducted to quantify the deactivation of E. coli in relation to different PVC concentrations. E. coli was chosen as a model for the reduction of bacterial pathogens in water. 55000 CFU/100 mL of E.coli concentrations were employed for this test using synthetic feed. Water samples were also collected in sterile glass bottles, to conduct the microbiological analyses in order to determine the number of E. coli bacteria before and after disinfection.

Fig. 4.9 shows that PVC micro filtration membranes in different concentration are highly effective against waterborne pathogen bacteria (E.coli). Removal efficiency for coated membranes pv_1, pv_2, pv_3, pv_4 and pv_5 was (88.8%, 90.1%, 90.9%, 91.9% and 94.1%) respectively.

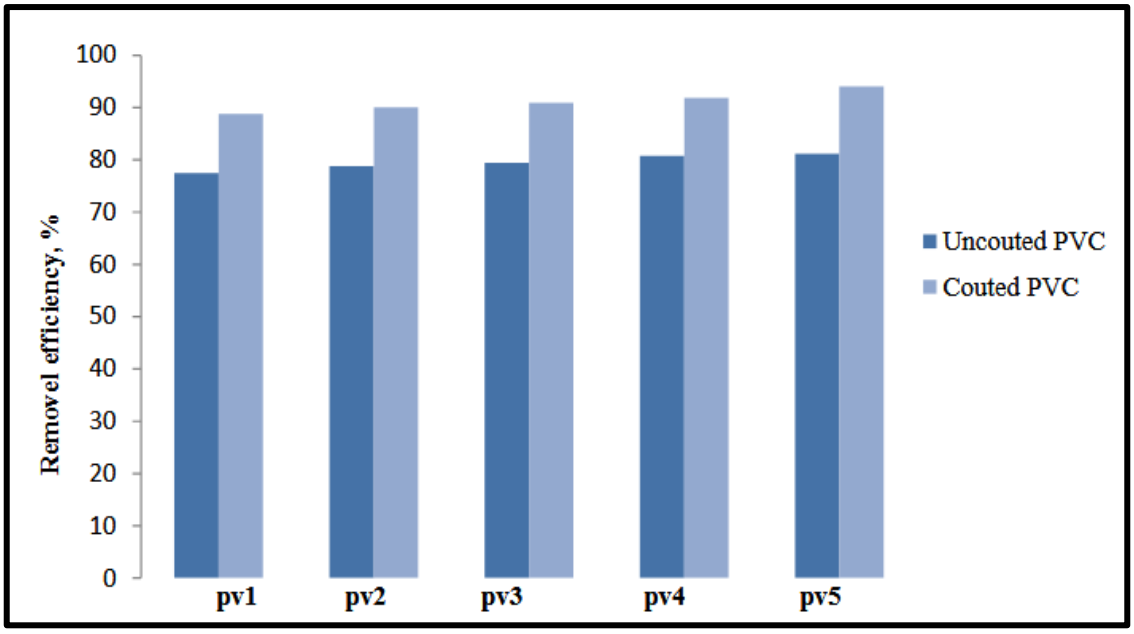

Fig. 4.9: The removal efficiency of un coated and coated PVC membrane.

The removal efficiency for uncoated was less than the removal efficiency for coated as shown in Fig. 4.9, which indicate that colloidal silver reduces bacterial contamination as it kills bacteria by inactivating their metabolic enzymes or by attaching to the cellular membrane, and because the silver has bacteriostatic properties and inactivates bacteria by disrupting the desulphated bonds of proteins in the cell membrane or by inhibiting DNA replication.

The reality is that all correctly manufactured filters reduce microbiological contaminants significantly, and that silver is a necessary additive to the membrane to prevent bacterial growth in the filter itself. Pv_5 membrane (3.5 % PVC; 21.5 % DMAS) was chosen due to its efficiency in removing E.coli.

4.4 Turbidity

Turbidity is the suspension of particles in water that obstructs the transmission of light. Turbidity is the measurement of water clarity,

caused by a wide spectrum of suspended matter, ranging in size from colloidal to coarse dispersion depending on the degree of turbulence, and ranging from pure inorganic to highly organic compounds. The results from the filtration using both the uncoated and coated filters (PV_5) are shown in Fig. 4.10.

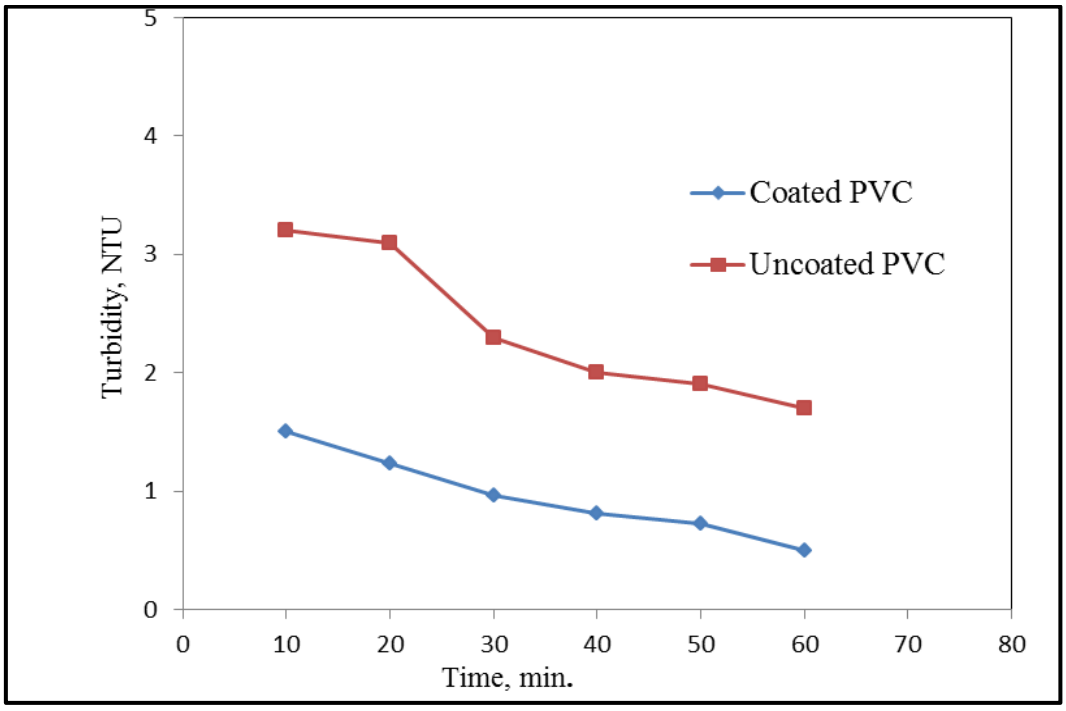

Fig. 4.10: Average permeate turbidities for river water (60 NTU) using uncoated and coated membrane.

As shown in Fig. 4.10, AgNPs/PVC microfiltration membrane reduced the turbidity of water sample to 0.5 NTU over time. The turbidity of the permeate from both the uncoated and coated filters was generally less than 1 NTU, and so met the specified requirements for potable water [WHO, 2017]. PVC membrane filtration are highly effective at reducing turbidity provided that the membranes are intact. In general, microfiltration process achieve filtered water turbidity of less than 1

NTU. This finding was agreed with the other studies conducted by Laine et al., 2000; AWWA, 2005; and Guo et al., 2010.

Membrane filtration is an absolute barrier to remove any particle that is larger than the exclusion characteristic of the membrane system. However, any breach in the integrity of a membrane or leak in the system could allow particulate matter into the filtrate and therefore increase the turbidity. The ability of turbidity monitoring to detect breaches can vary significantly.

4.5 Effect of time on silver elution from AgNPs coated materials

Silver nanoparticles may leach into drinking water filtration systems when polymeric materials incorporating silver nanoparticles are used. Deionized water were filtered with system test over period 2 h at 1 bar to investigate the evolution of silver elution over time and investigation of the effect of permeate flow rate on silver leaching. The silver content of the filtered water analysis after every 15min was measured by using an Atomic Absorption Spectrophotometer as shown in Fig. 4.11.

The silver elution is mainly caused by weak adhesion forces between AgNPs and the pvc membrane, as well as nanosilver dissolution in water, which leads to the release of silver ions. As shown in Figs. 4.11 and 4.12, silver elution decreased significantly of continuous filtration (the Ag^{+} concentration in the filtrate decreased as more water was filtered). The biggest part of silver release occurs at the beginning of immersion in the water bath. This fast decrease in the release of silver is qualitatively. This results was similar to other results conducted by, Dong et al., 2017; Aline et al., 2020.

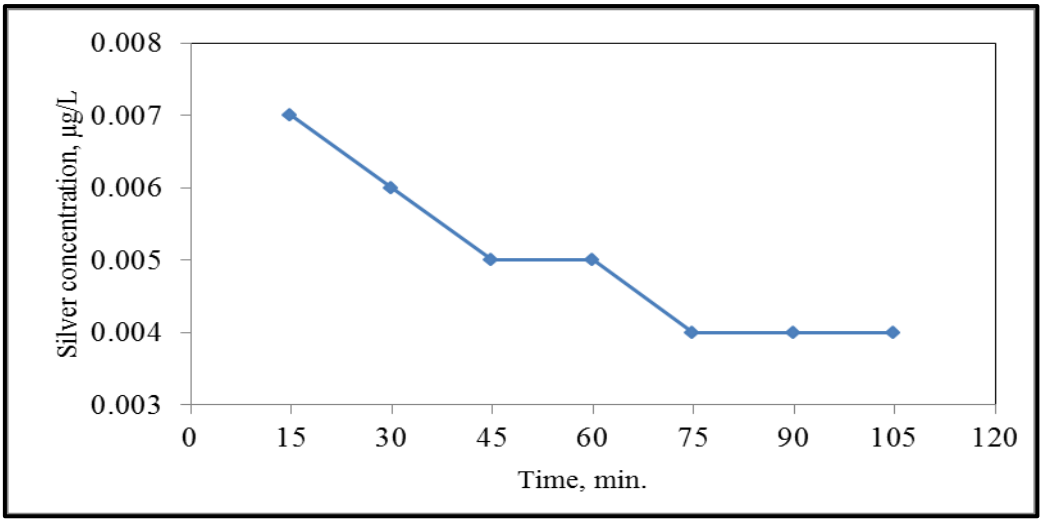

Fig. 4.11: Silver concentration in permeate over time.

The leaching process can be caused by physical damage or improper nanoparticles embedding techniques, [Ng et al., 2013]. The major causes of silver elution include weak adhesion forces between AgNPs and the pvc membrane, as well as nanosilver dissolution in water, which results in the release of silver ions, [Achisa, 2014].

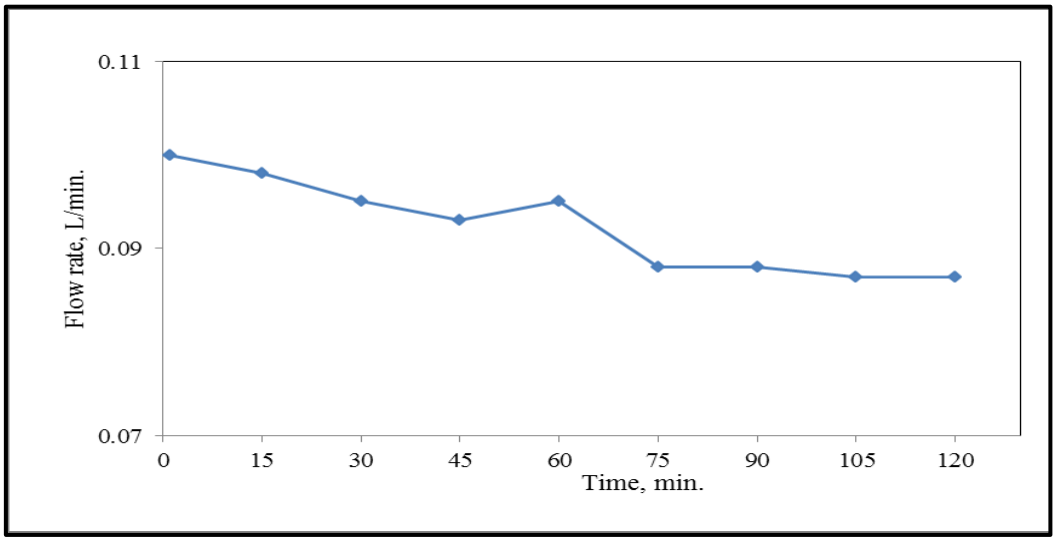

Fig. 4.12: Permeate flow rate over time.

Silver ion concentrations in the permeate were very low in filtration testing, with less than 0.01 µg/L, which satisfies with the United States Environmental Protection Agency's (US-EPA) drinking water

guideline (less than 0.1 mg/L). This was related to the silver nanoparticles' stability in the filters. From this viewpoint, employing silver immobilized membranes for membranes is unlikely to cause any health risks, as the Ag released was significantly lower than the WHO standard.

4.6 Effect of permeate flow rate on leaching of silver

To investigated the effect of permeate flow rates on the leaching of silver from polymer by using pump, the filter was run at different operating pressure in order to obtain difference in permeate flow rates for 1 day. The leaching of Ag^+ was confirmed by Atomic Absorption Spectrophotometer (AAS) analyses, the leaching value is 0.005 µg/L at 20 kPa and 0.009 µg/L at 45 kPa after continuous use for a period of 1day. The Ag^+ concentration in the filtrate decreased as more water was filtered. This study concluded that a higher operating pressure does not release the silver impregnations from the polymer, which means the silver embedded into the filter is held very strongly by PVC polymer.

4.7 Disinfection efficacy over time

The current study endeavored to test the performance of the coated filters without formation of the cake layer by using synthetic feed over time. 20 L synthetic feed (66000 CFU/100mL) was filtered and 100 mL of permeate was collected randomly into a sterile glass bottle and analyzed for the presence of E. coli and investigated for silver.

4.7.1 Effect of silver leaching on the disinfection efficacy

The present study attempted to investigate the relationship between the elution of silver from the coated filter and the disinfection efficacy achieved over time. Figs. 4.13 show the effect of time on permeate flux .

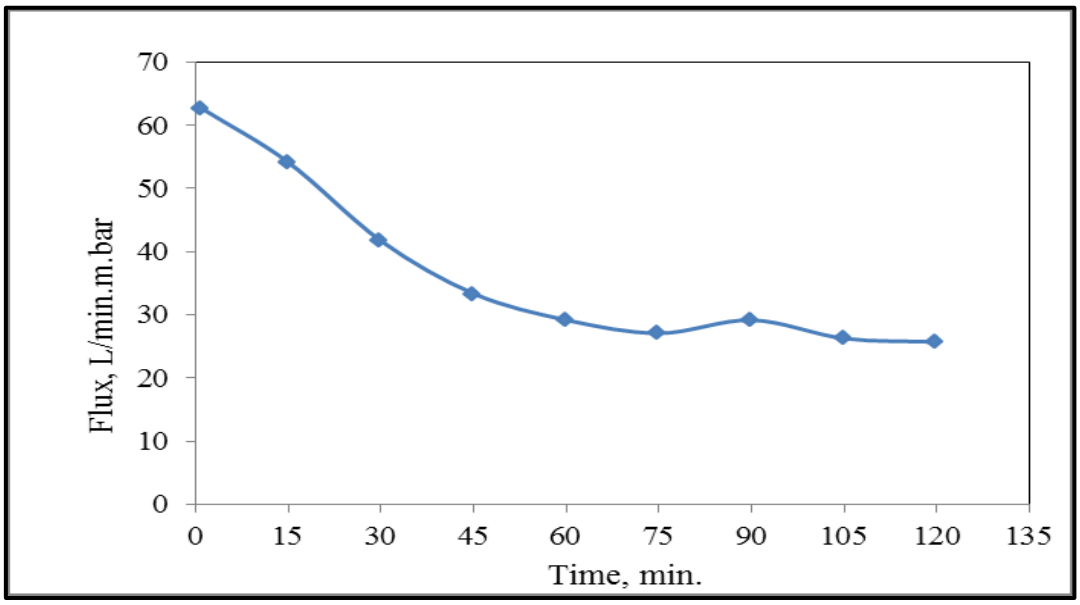

Fig. 4.13: Permeation flux from the membrane with time.

Decrease in flow rate over time is because the particles of the component(E.coli) being rejected by the membrane and killed by Ag^{+} ions accumulate on the membrane surface and obstructs the passage of the solvent through the membrane. If the process is allowed to continue to run, the rejected layer on the membrane surface grows thicker and becomes more and more resistant to solvent flow and this result in the flux dropping (Initial flux is a term used mostly with constant pressure systems, initial flux is the flux at the beginning of filtration and is usually high because at this stage the membrane is clean and flux is affected mainly by four factors: pressure, concentration, temperature and turbulence adjacent to membrane surface). Fig. 4.13 shows the silver elution findings from the filters. Silver leaching decreased with time, most likely due to decreased silver concentration on the filters. This agree

with [Zodrow et al, 2009], they were reported that as more water was filtered, the silver concentration in the filtrate was observed to drop. They are observed that when 10% of the silver put on the UF polysulfone membranes was lost, the antibacterial and antiviral properties of the coated membranes were significantly reduced.

In this study the term disinfection refers to both physical removal of E.coli due to size exclusion by filtration and inactivation by AgNPs. The efficiency of E. coli removal above 99.8 % (Fig. 4.14) . Moreover, the performance of the silver nanoparticle-coated PVC membrane was evaluated in terms of silver in the effluent and compliance with the drinking-water quality standards. This clearly demonstrates that PVC membrane embedded with AgNPs had good antimicrobial activity against E. coli. E. coli colony forming units (CFU) per 100 mL should be zero in drinking water and in municipal water filtration, and LRV of 4 or 5 is recommended, as cited by Baker and Richard, 2004. From Fig. 4.15 the results do not match these specifications. [WHO, 2003] categorizes the risk of poor water quality as “low” if there are 1–10 CFU per 100 mL, “moderate” for values between 11 and 100, and “high” for levels greater than 100.

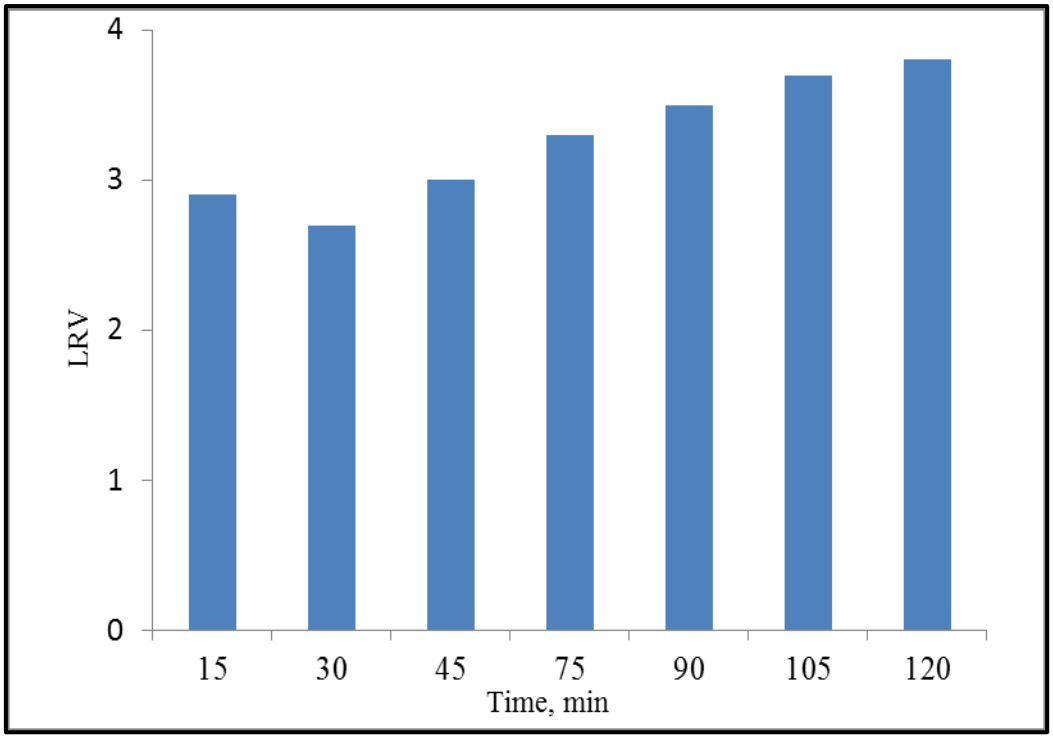

Fig. 4.14: Effect of sample collection time on the disinfection efficacy for synthetic feed of (66000 CFU/ 100 mL).

It was however noted that the removal efficiency remained high despite the decreasing silver leaching was below 0.004 mg/L. Pore blockage by E. coli itself may be responsible for the improved rejection in the synthetic feed water. Aside from pore blockage, another mechanism that could contribute to E. coli rejection in synthetic feed water is E. coli's release of sticky biofilm after death. This biofilm totally closes the pores of the membrane, according to the findings of the membrane bioreactor by Simon, 2010, because it coats the membrane's surface and is usually very sticky. These results suggest that Ag^{+} was the main antimicrobial agent.

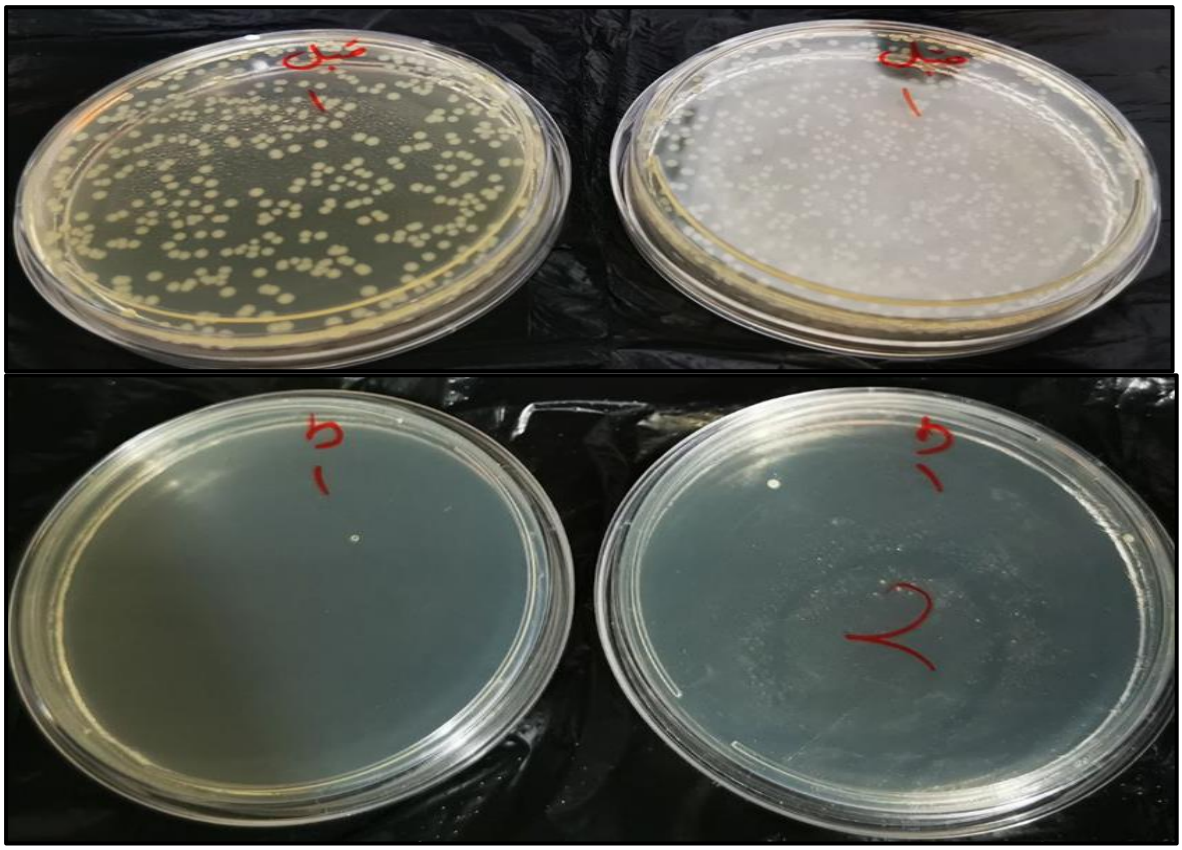

Fig. 4.15: Colony of bacteria formed: a) before percolation through uncoated PVC membrane . b)After percolation through coated PVC membrane.

The antibacterial mechanism of AgNP, as reported in previous literature, is the release of silver ions (Ag+) that can induce cell membrane damage, promote generation of Reactive Oxygen Species (ROS) and Disrupt Adenosine Triphosphate (ATP) production and DNA replication, ultimately causing the death of bacteria. This finding was agree with the finding conducted by [Qi et al., 2018] .

4.7.2 Effect of leaching rate on the disinfection efficiency

Samples of permeate from the filters from the disinfection performance were collected randomly and investigated for silver leaching

using Atomic Absorption Spectrometer (AAS). Fig. 4.16 shows the silver elution findings from the PV_5. Silver leaching decreased with time, most likely due to decreased silver concentration on the filters. This agree with [Zodrow et al, 2009], who reported that as more water was filtered, the silver concentration in the filtrate was observed to drop. They were observed that when 10% of the silver put on the UF polysulfone membranes was lost, the antibacterial and antiviral properties of the coated membranes were significantly reduced.

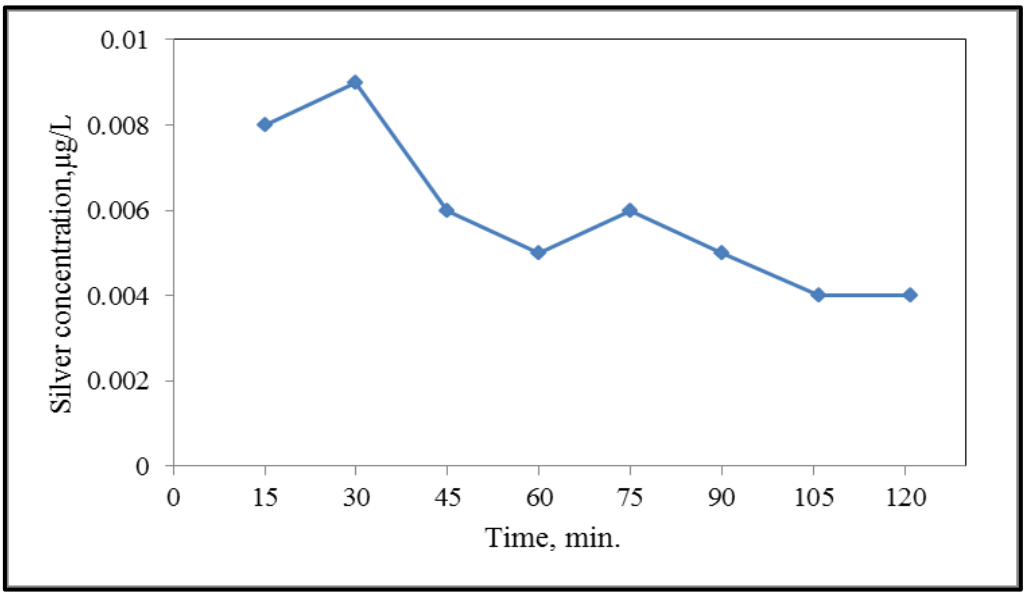

Fig. 4.16: Silver concentration from the membrane with time at PV_5.

Although silver elution contributes to the disinfection efficacy, it also reduces the amount of silver on the membranes, potentially reducing the filter's effectiveness. Bacterial removal effectiveness improves with membrane usage and increased filtration time. This can be attributed to the biological layer maturing as a result of greater membrane usage. The biological layer is also responsible for the decrease in flow rate when the pores become clogged due to dirt collection, which lengthens the contact period between membrane and the biological layer, which agree with the results Achisa, 2014.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

CHAPTER FIVE
CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter contains the concluding remarks, obtained from this study. It also provides suggested recommendations, that could be valuable in upcoming works.

5.2 Conclusions

The following conclusions were formed based on the results obtained:

1. The chemical reduction of $AgNO_3$ using cloves extract as a reducing agent produced spherical silver nanoparticles that were efficiently disseminated and stabilized on Polyvinyl chloride PVC polymer, and can successfully embed silver nanoparticles into PVC membrane.
2. The flow rates were high in the early stages of filters use and operation and decreased with an increase in time and the volume of water filtered through.
3. The Poly Polyvinyl chloride vinyl chloride micro filtration membrane can produce enough drinking and cooking water for a family of small members due to their flow rates. These filters may be considered for treating contaminated water at household scale in places where water is taken directly from the source without treatment.
4. The membrane characterization analysis revealed that increasing the PVC percentage in the dope solution reduced the size of macro voids and revealed sponge-like elements in the reported SEM images. The roughness of the PVC membrane decreased after the addition of AgNP. Furthermore, the contact angle of the PVC membrane was clearly seen to decrease with the addition of AgNP.

5. The turbidity of the permeate from both the uncoated and coated filters was generally less than 1 NTU, and so met the specified requirements for potable water.

6. The results show that, porosity will decrease with the increase of polymer concentration .

7. The results show that, it is possible to conclude that the PVC microfiltration membrane that prepared from (14 PVC wt.% and 86 wt.% DMAS) with lower porosity were found to be have the better removal efficiency (94.1%).

8. Using Polyvinyl chloride micro filtration membrane to treat water eliminates the need to add chemicals to the water, avoiding chemical taste and odor issues as well as the formation of disinfection by-products, many of which are toxic (carcinogenic) over time. This therapeutic strategy is suitable for long-term use, especially in the context of development.

9. Polyvinyl chloride microfiltration membrane simple to apply and to use, no need of high-skill labor and low level of training requested.

10. The amount of silver leaching from the PVC membrane was very low, therefore the silver content in the effluent meets the 0.1 mg/L drinking water limits set by the Environmental Protection Agency (EPA) and the World Health Organization (WHO). Therefore the system can be used for potable water treatment without risk to human health resulting from high silver concentrations in treated water.

5.3 Recommendations for future work

The following recommendations are suggested for future work:-

1. Studying other types of materials to be embedded with AgNPs for the purpose of water disinfection.
2. Investigating the impact of organic and inorganic components found in natural water on the performance of AgNPs, coated membrane.
3. Assessing the expulsion productivity of AgNPs membrane for different kinds of microbes present in water that could have health impact.
4. Studying the relationship between particle sizes formed and removal efficiency.
5. Investigate how the lifespan can be increased and how silver elution can be controlled.
6. Develop a feasibility study to find out the cost of this treatment.

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APPENDICES

APPENDIX

A

APPENDIX – A

A1: Granularity AFM Normal Distribution Report And Chart Before Coating with AgNPs.

Sample:Sample Name	Code:Sample Code
Line No.:lineno	Grain No.:802
Instrument:CSPM	Date:2021-07-05

Avg. Diameter:204.71 nm	<=10% Diameter:80.00 nm
<=50% Diameter:180.00 nm	<=90% Diameter:320.00 nm

Diameter(nm)<	Volume(%)	Normal(%)	Diameter(nm)<	Volume(%)	Normal(%)	Diameter(nm)<	Volume(%)	Normal(%)
20.00	0.12	1.37	240.00	7.61	83.56	460.00	0.37	4.11
40.00	0.62	6.85	260.00	6.98	76.71	480.00	0.25	2.74
60.00	2.74	30.14	280.00	4.61	50.68	500.00	0.12	1.37
80.00	5.36	58.90	300.00	4.36	47.95	520.00	0.12	1.37
100.00	5.99	65.75	320.00	4.24	46.58	540.00	0.37	4.11
120.00	6.98	76.71	340.00	2.74	30.14	580.00	0.12	1.37
140.00	5.86	64.38	360.00	2.24	24.66	600.00	0.12	1.37
160.00	8.85	97.26	380.00	2.24	24.66	640.00	0.25	2.74
180.00	9.10	100.00	400.00	1.75	19.18	680.00	0.12	1.37
200.00	7.48	82.19	420.00	0.87	9.59			
220.00	6.61	72.60	440.00	0.75	8.22			

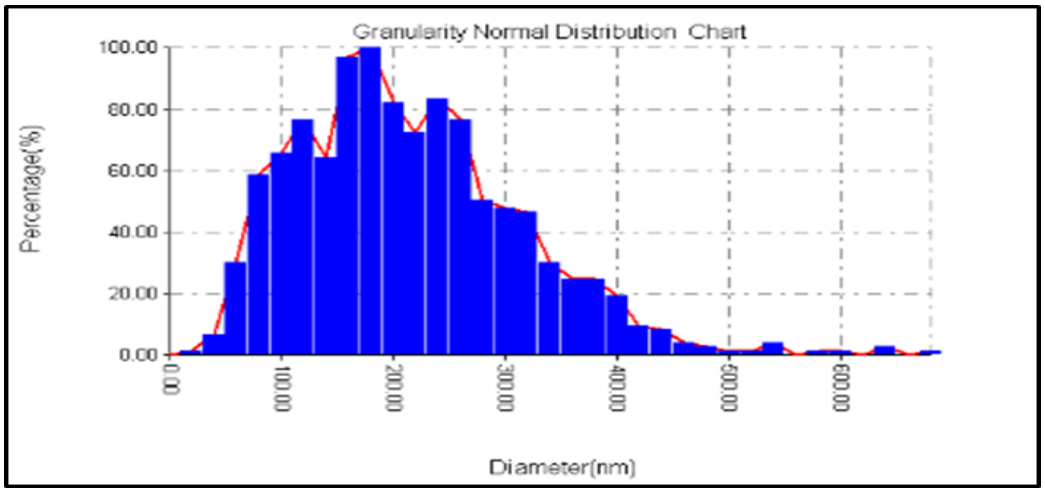


Fig. A1.1: PV_1 granularity AFM normal distribution report and chart before coating with AgNPs

Sample: Sample Name	**Code:**Sample Code
Line No.:lineno	**Grain No.:**327
Instrument:CSPM	**Date:**2021-07-05

Avg. Diameter:308.53 nm	**<=10% Diameter:80.00 nm**
<=50% Diameter:260.00 nm	**<=90% Diameter:560.00 nm**

Diameter(nm)<	Volume(%)	Normal(%)	Diameter(nm)<	Volume(%)	Normal(%)	Diameter(nm)<	Volume(%)	Normal(%)
20.00	0.31	5.00	320.00	3.06	50.00	620.00	1.53	25.00
40.00	1.22	20.00	340.00	3.36	55.00	640.00	1.83	30.00
60.00	3.36	55.00	360.00	2.45	40.00	660.00	0.31	5.00
80.00	3.06	50.00	380.00	1.83	30.00	680.00	1.22	20.00
100.00	2.45	40.00	400.00	2.75	45.00	700.00	0.92	15.00
120.00	3.98	65.00	420.00	4.59	75.00	720.00	0.61	10.00
140.00	2.75	45.00	440.00	3.36	55.00	740.00	0.31	5.00
160.00	4.28	70.00	460.00	1.53	25.00	760.00	0.61	10.00
180.00	6.12	100.00	480.00	3.36	55.00	780.00	0.61	10.00
200.00	4.28	70.00	500.00	3.36	55.00	800.00	0.31	5.00
220.00	4.89	80.00	520.00	1.53	25.00	840.00	0.31	5.00
240.00	4.28	70.00	540.00	0.92	15.00	860.00	0.31	5.00
260.00	6.12	100.00	560.00	0.31	5.00	1060.00	0.31	5.00
280.00	6.12	100.00	580.00	0.92	15.00			
300.00	3.67	60.00	600.00	0.61	10.00			

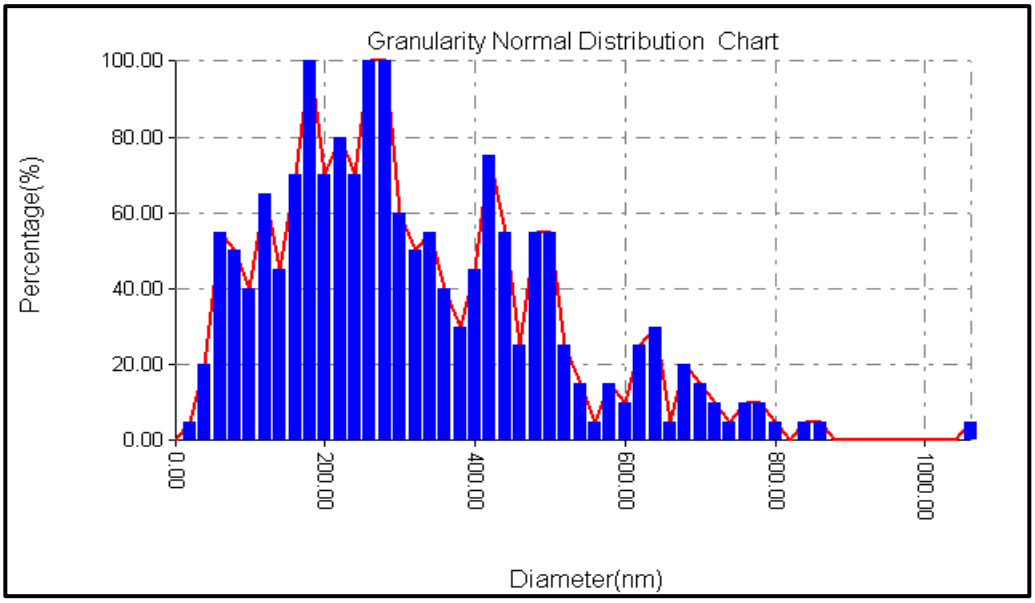


Fig. A1.2: PV_2 granularity AFM normal distribution report and chart before coating with AgNPs.

Sample: Sample Name	**Code:**Sample Code
Line No.:lineno	**Grain No.:**479
Instrument:CSPM	**Date:**2021-07-05

Avg. Diameter:259.28 nm	**<=10% Diameter:100.00 nm**
<=50% Diameter:220.00 nm	**<=90% Diameter:460.00 nm**

Diameter(nm)<	Volume(%)	Normal(%)	Diameter(nm)<	Volume(%)	Normal(%)	Diameter(nm)<	Volume(%)	Normal(%)
40.00	0.63	7.89	280.00	4.59	57.89	520.00	1.67	21.05
60.00	1.46	18.42	300.00	3.55	44.74	540.00	1.25	15.79
80.00	3.13	39.47	320.00	5.64	71.05	560.00	0.63	7.89
100.00	3.76	47.37	340.00	3.13	39.47	580.00	1.67	21.05
120.00	6.05	76.32	360.00	3.55	44.74	600.00	0.42	5.26
140.00	5.64	71.05	380.00	2.30	28.95	620.00	0.21	2.63
160.00	6.26	78.95	400.00	1.88	23.68	640.00	0.42	5.26
180.00	6.05	76.32	420.00	2.51	31.58	660.00	1.04	13.16
200.00	7.93	100.00	440.00	2.09	26.32	700.00	0.21	2.63
220.00	6.47	81.58	460.00	0.84	10.53	740.00	0.21	2.63
240.00	6.47	81.58	480.00	1.67	21.05	760.00	0.42	5.26
260.00	5.43	68.42	500.00	0.63	7.89	780.00	0.21	2.63

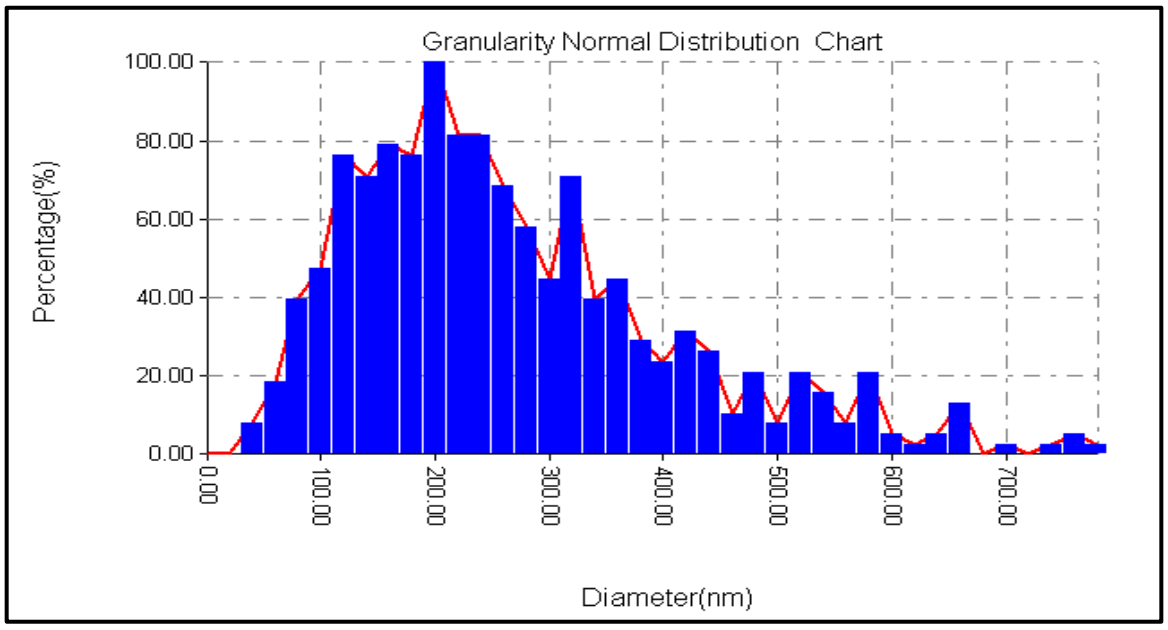


Fig. A1.3: PV_3 granularity AFM normal distribution report and chart before coating with AgNPs.

Sample: Sample Name	**Code:**Sample Code
Line No.:lineno	**Grain No.:**150
Instrument:CSPM	**Date:**2021-07-05

Avg. Diameter:462.63 nm	**<=10% Diameter:150.00 nm**
<=50% Diameter:350.00 nm	**<=90% Diameter:800.00 nm**

Diameter(nm)<	Volume(%)	Normal(%)	Diameter(nm)<	Volume(%)	Normal(%)	Diameter(nm)<	Volume(%)	Normal(%)
50.00	2.00	15.00	500.00	6.67	50.00	950.00	0.67	5.00
100.00	1.33	10.00	550.00	4.67	35.00	1000.00	2.67	20.00
150.00	3.33	25.00	600.00	4.67	35.00	1100.00	0.67	5.00
200.00	5.33	40.00	650.00	7.33	55.00	1150.00	0.67	5.00
250.00	10.00	75.00	700.00	4.67	35.00	1250.00	0.67	5.00
300.00	6.00	45.00	750.00	0.67	5.00	1350.00	0.67	5.00
350.00	13.33	100.00	800.00	5.33	40.00	1400.00	0.67	5.00
400.00	9.33	70.00	850.00	2.67	20.00			
450.00	5.33	40.00	900.00	0.67	5.00			

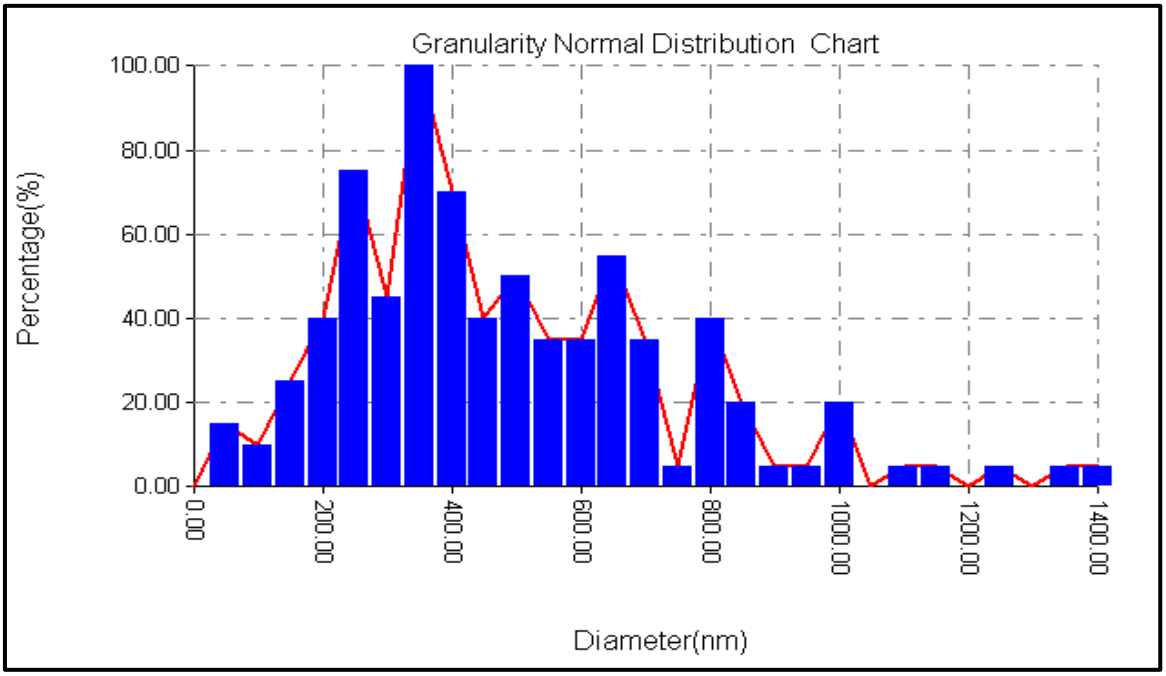


Fig. A1.4: PV_4 granularity AFM normal distribution report and chart before coating with AgNPs.

Sample: Sample Name	**Code:**Sample Code
Line No.:lineno	**Grain No.:**303
Instrument:CSPM	**Date:**2021-07-05

Avg. Diameter:322.67 nm	**<=10% Diameter:100.00 nm**
<=50% Diameter:300.00 nm	**<=90% Diameter:560.00 nm**

Diameter(nm)<	Volume(%)	Normal(%)	Diameter(nm)<	Volume(%)	Normal(%)	Diameter(nm)<	Volume(%)	Normal(%)
40.00	0.66	10.53	320.00	6.27	100.00	600.00	0.33	5.26
60.00	2.97	47.37	340.00	3.30	52.63	620.00	1.65	26.32
80.00	2.31	36.84	360.00	2.97	47.37	640.00	0.33	5.26
100.00	3.30	52.63	380.00	4.95	78.95	660.00	0.66	10.53
120.00	2.97	47.37	400.00	3.63	57.89	680.00	1.65	26.32
140.00	4.62	73.68	420.00	2.31	36.84	700.00	0.99	15.79
160.00	5.61	89.47	440.00	2.64	42.11	720.00	0.33	5.26
180.00	4.29	68.42	460.00	2.97	47.37	760.00	0.33	5.26
200.00	3.30	52.63	480.00	2.97	47.37	780.00	0.33	5.26
220.00	4.29	68.42	500.00	2.97	47.37	800.00	0.66	10.53
240.00	3.63	57.89	520.00	0.99	15.79	820.00	0.33	5.26
260.00	3.63	57.89	540.00	1.98	31.58	840.00	0.99	15.79
280.00	4.95	78.95	560.00	1.65	26.32	940.00	0.33	5.26
300.00	2.64	42.11	580.00	1.98	31.58	960.00	0.33	5.26

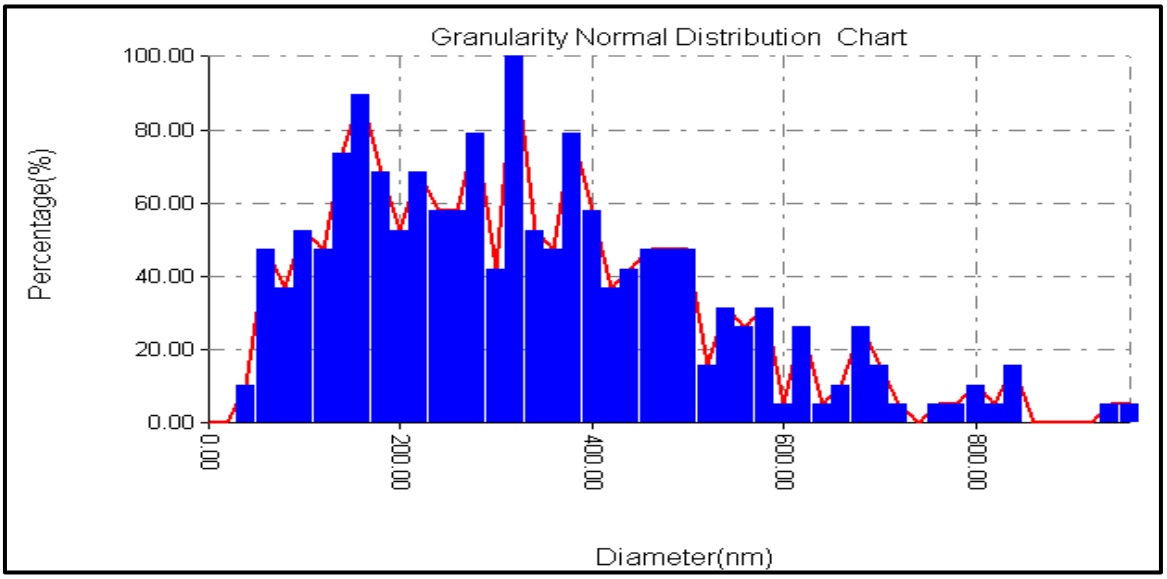


Fig. A1.5: PV_5 granularity AFM normal distribution report and chart before coating with AgNPs.

A2: Granularity AFM Normal Distribution Report And Chart After Coating with AgNPs.

Sample: Sample Name	**Code:**Sample Code
Line No.:lineno	**Grain No.:**345
Instrument:CSPM	**Date:**2021-07-07

Avg. Diameter:298.24 nm	**<=10% Diameter:80.00 nm**
<=50% Diameter:260.00 nm	**<=90% Diameter:540.00 nm**

Diameter(nm)<	Volume(%)	Normal(%)	Diameter(nm)<	Volume(%)	Normal(%)	Diameter(nm)<	Volume(%)	Normal(%)
40.00	0.87	15.00	320.00	3.77	65.00	600.00	1.45	25.00
60.00	2.03	35.00	340.00	4.35	75.00	620.00	0.58	10.00
80.00	2.90	50.00	360.00	3.19	55.00	640.00	1.16	20.00
100.00	5.22	90.00	380.00	4.06	70.00	660.00	1.45	25.00
120.00	4.64	80.00	400.00	2.32	40.00	680.00	0.58	10.00
140.00	4.93	85.00	420.00	1.16	20.00	700.00	0.58	10.00
160.00	4.06	70.00	440.00	1.74	30.00	740.00	0.29	5.00
180.00	3.77	65.00	460.00	2.61	45.00	760.00	0.58	10.00
200.00	4.93	85.00	480.00	2.03	35.00	800.00	0.29	5.00
220.00	5.51	95.00	500.00	2.03	35.00	840.00	0.29	5.00
240.00	5.22	90.00	520.00	1.74	30.00	900.00	0.29	5.00
260.00	4.93	85.00	540.00	1.45	25.00	1080.00	0.29	5.00
280.00	3.77	65.00	560.00	1.16	20.00	1200.00	0.29	5.00
300.00	5.80	100.00	580.00	1.74	30.00			

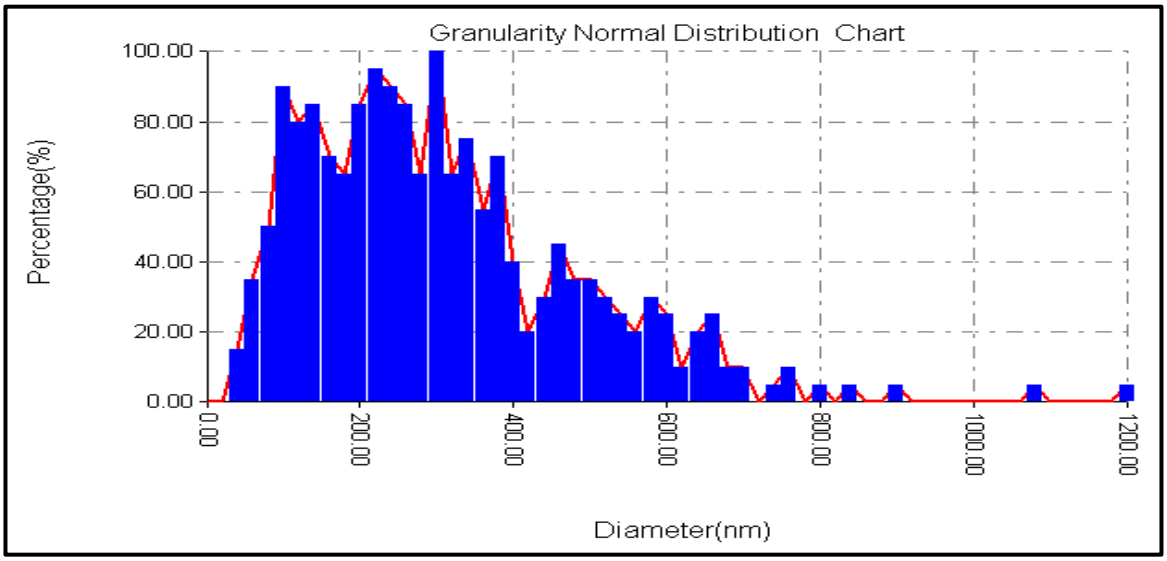


Fig. A2.1: PV_1 granularity AFM normal distribution report and chart after coating with AgNPs.

Sample: Sample Name	**Code:**Sample Code
Line No.:lineno	**Grain No.:**313
Instrument:CSPM	**Date:**2021-07-05

Avg. Diameter:273.76 nm	**<=10% Diameter:100.00 nm**
<=50% Diameter:260.00 nm	**<=90% Diameter:440.00 nm**

Diameter(nm)<	Volume(%)	Normal(%)	Diameter(nm)<	Volume(%)	Normal(%)	Diameter(nm)<	Volume(%)	Normal(%)
40.00	0.96	14.29	260.00	4.15	61.90	480.00	1.60	23.81
60.00	2.24	33.33	280.00	5.75	85.71	500.00	0.64	9.52
80.00	1.60	23.81	300.00	6.07	90.48	520.00	1.92	28.57
100.00	4.47	66.67	320.00	6.07	90.48	540.00	0.96	14.29
120.00	3.19	47.62	340.00	4.15	61.90	560.00	1.92	28.57
140.00	3.51	52.38	360.00	4.79	71.43	580.00	0.32	4.76
160.00	4.47	66.67	380.00	5.43	80.95	600.00	1.28	19.05
180.00	6.71	100.00	400.00	3.83	57.14	620.00	0.96	14.29
200.00	5.43	80.95	420.00	2.24	33.33	700.00	0.32	4.76
220.00	6.71	100.00	440.00	1.28	19.05			
240.00	5.11	76.19	460.00	1.92	28.57			

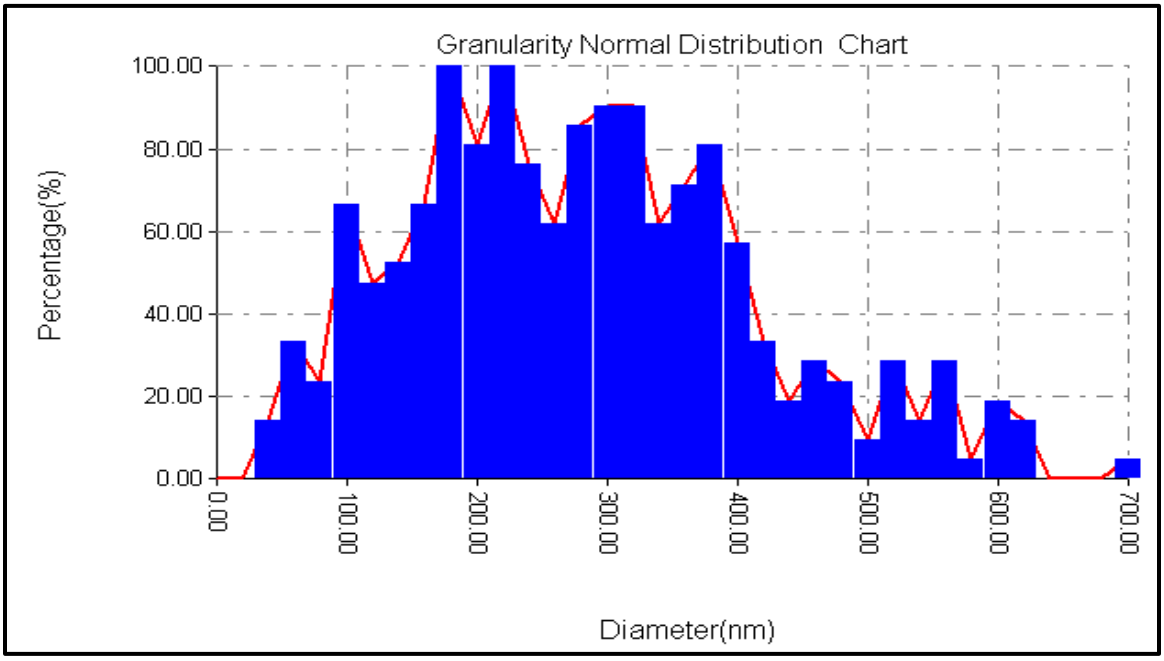


Fig. A2.2: PV_2 granularity AFM normal distribution report and chart after coating with AgNPs.

Sample: Sample Name	**Code:**Sample Code
Line No.:lineno	**Grain No.:**403
Instrument:CSPM	**Date:**2021-07-05

Avg. Diameter:281.14 nm	**<=10% Diameter:80.00 nm**
<=50% Diameter:240.00 nm	**<=90% Diameter:480.00 nm**

Diameter(nm)<	Volume(%)	Normal(%)	Diameter(nm)<	Volume(%)	Normal(%)	Diameter(nm)<	Volume(%)	Normal(%)
20.00	0.25	3.03	300.00	3.97	48.48	580.00	0.99	12.12
40.00	0.25	3.03	320.00	4.96	60.61	600.00	0.99	12.12
60.00	3.47	42.42	340.00	3.47	42.42	620.00	0.50	6.06
80.00	2.98	36.36	360.00	4.71	57.58	640.00	0.99	12.12
100.00	3.97	48.48	380.00	3.23	39.39	660.00	0.50	6.06
120.00	4.22	51.52	400.00	3.47	42.42	680.00	0.50	6.06
140.00	4.22	51.52	420.00	2.48	30.30	700.00	0.25	3.03
160.00	5.21	63.64	440.00	1.74	21.21	720.00	0.74	9.09
180.00	4.47	54.55	460.00	1.24	15.15	760.00	0.25	3.03
200.00	5.21	63.64	480.00	2.98	36.36	780.00	0.25	3.03
220.00	5.21	63.64	500.00	1.99	24.24	800.00	0.25	3.03
240.00	8.19	100.00	520.00	1.49	18.18	920.00	0.25	3.03
260.00	5.46	66.67	540.00	1.49	18.18			
280.00	2.98	36.36	560.00	0.25	3.03			

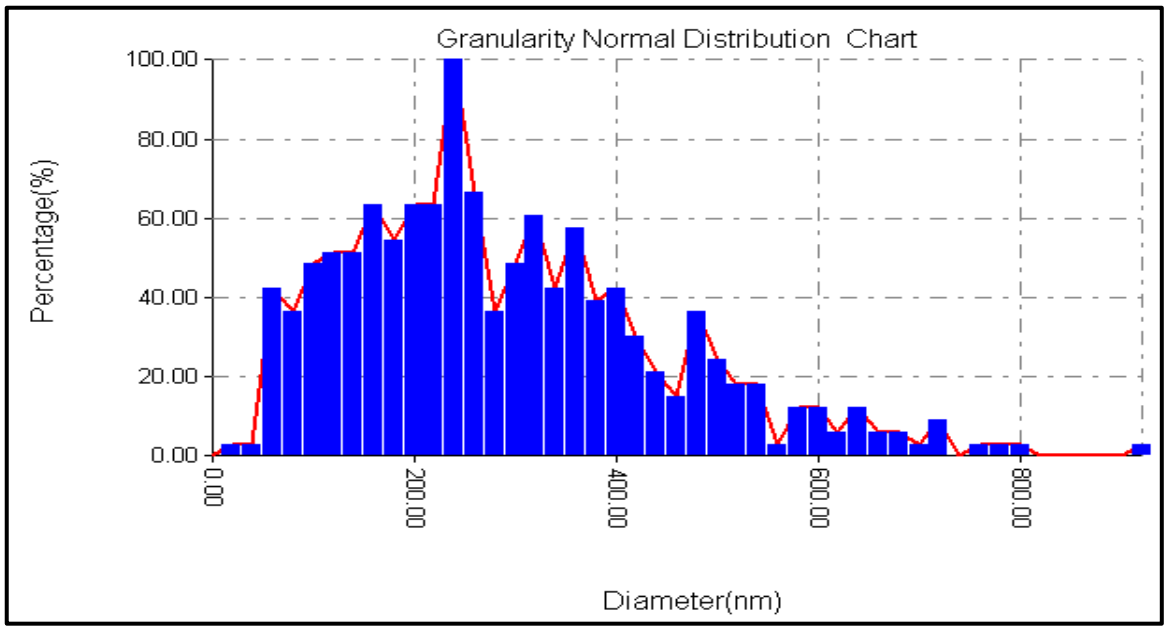


Fig. A2.3: PV_3 granularity AFM normal distribution report and chart after coating with AgNPs.

Sample: Sample Name	**Code:**Sample Code
Line No.:lineno	**Grain No.:**762
Instrument:CSPM	**Date:**2021-07-05

Avg. Diameter:206.41 nm	**<=10% Diameter:60.00 nm**
<=50% Diameter:180.00 nm	**<=90% Diameter:340.00 nm**

Diameter(nm)<	Volume(%)	Normal(%)	Diameter(nm)<	Volume(%)	Normal(%)	Diameter(nm)<	Volume(%)	Normal(%)
20.00	0.13	1.75	240.00	6.17	82.46	460.00	0.79	10.53
40.00	1.44	19.30	260.00	5.64	75.44	480.00	0.13	1.75
60.00	4.72	63.16	280.00	4.20	56.14	500.00	0.13	1.75
80.00	6.04	80.70	300.00	5.38	71.93	520.00	0.66	8.77
100.00	5.91	78.95	320.00	4.46	59.65	540.00	0.26	3.51
120.00	5.25	70.18	340.00	3.15	42.11	560.00	0.26	3.51
140.00	7.35	98.25	360.00	2.23	29.82	580.00	0.26	3.51
160.00	7.48	100.00	380.00	2.36	31.58	600.00	0.13	1.75
180.00	7.35	98.25	400.00	1.57	21.05	640.00	0.13	1.75
200.00	6.69	89.47	420.00	1.44	19.30	660.00	0.13	1.75
220.00	7.09	94.74	440.00	1.05	14.04			

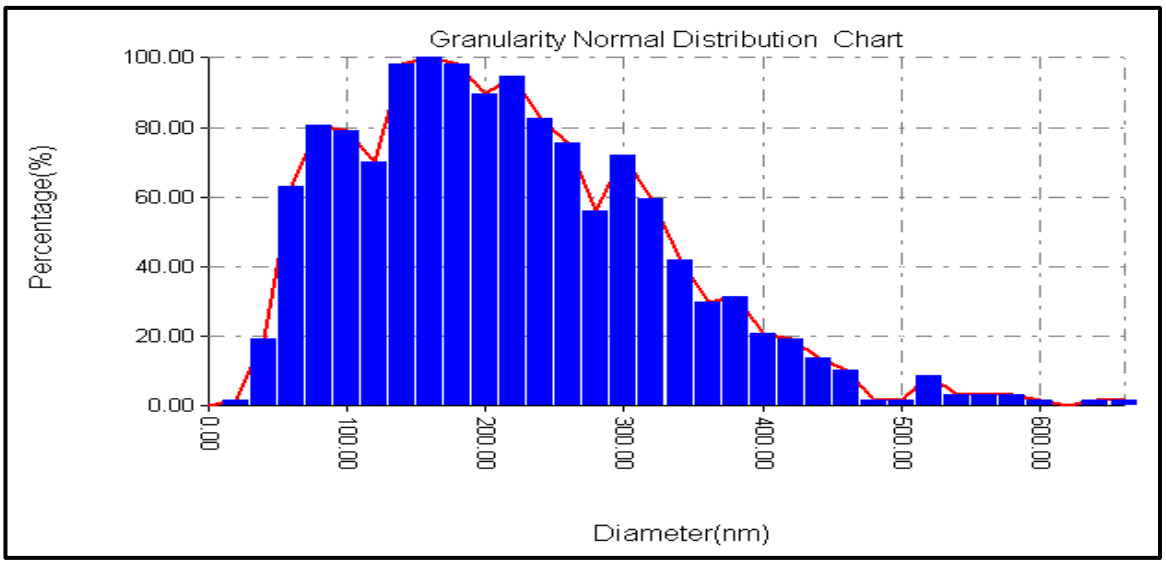


Fig. A2.4: PV_4 granularity AFM normal distribution report and chart after coating with AgNPs.

Sample: Sample Name	**Code:**Sample Code
Line No.:lineno	**Grain No.:**429
Instrument:CSPM	**Date:**2021-07-05

Avg. Diameter:278.08 nm	**<=10% Diameter:100.00 nm**
<=50% Diameter:260.00 nm	**<=90% Diameter:460.00 nm**

Diameter(nm)<	Volume(%)	Normal(%)	Diameter(nm)<	Volume(%)	Normal(%)	Diameter(nm)<	Volume(%)	Normal(%)
40.00	0.93	11.11	300.00	7.23	86.11	560.00	2.33	27.78
60.00	1.63	19.44	320.00	8.39	100.00	580.00	0.23	2.78
80.00	2.80	33.33	340.00	3.50	41.67	600.00	0.23	2.78
100.00	4.20	50.00	360.00	4.66	55.56	620.00	0.47	5.56
120.00	3.96	47.22	380.00	2.56	30.56	640.00	0.47	5.56
140.00	4.90	58.33	400.00	2.33	27.78	660.00	0.23	2.78
160.00	4.20	50.00	420.00	2.56	30.56	680.00	0.23	2.78
180.00	5.83	69.44	440.00	3.26	38.89	700.00	0.23	2.78
200.00	5.36	63.89	460.00	1.86	22.22	720.00	0.23	2.78
220.00	5.13	61.11	480.00	3.50	41.67	800.00	0.23	2.78
240.00	3.73	44.44	500.00	0.93	11.11	820.00	0.23	2.78
260.00	4.90	58.33	520.00	1.40	16.67			
280.00	3.96	47.22	540.00	1.17	13.89			

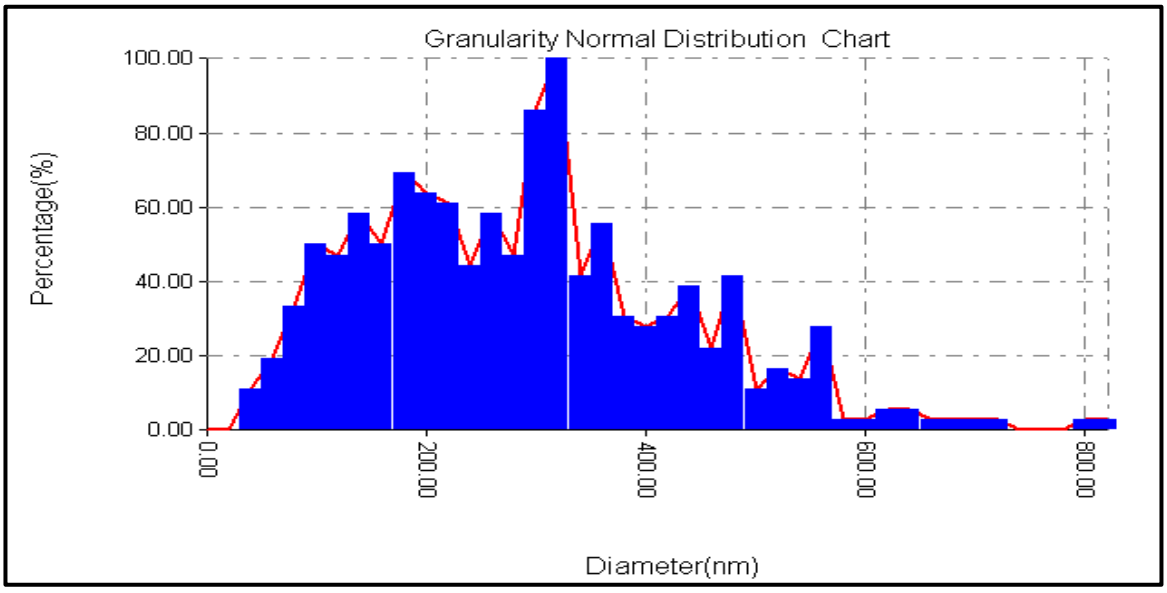
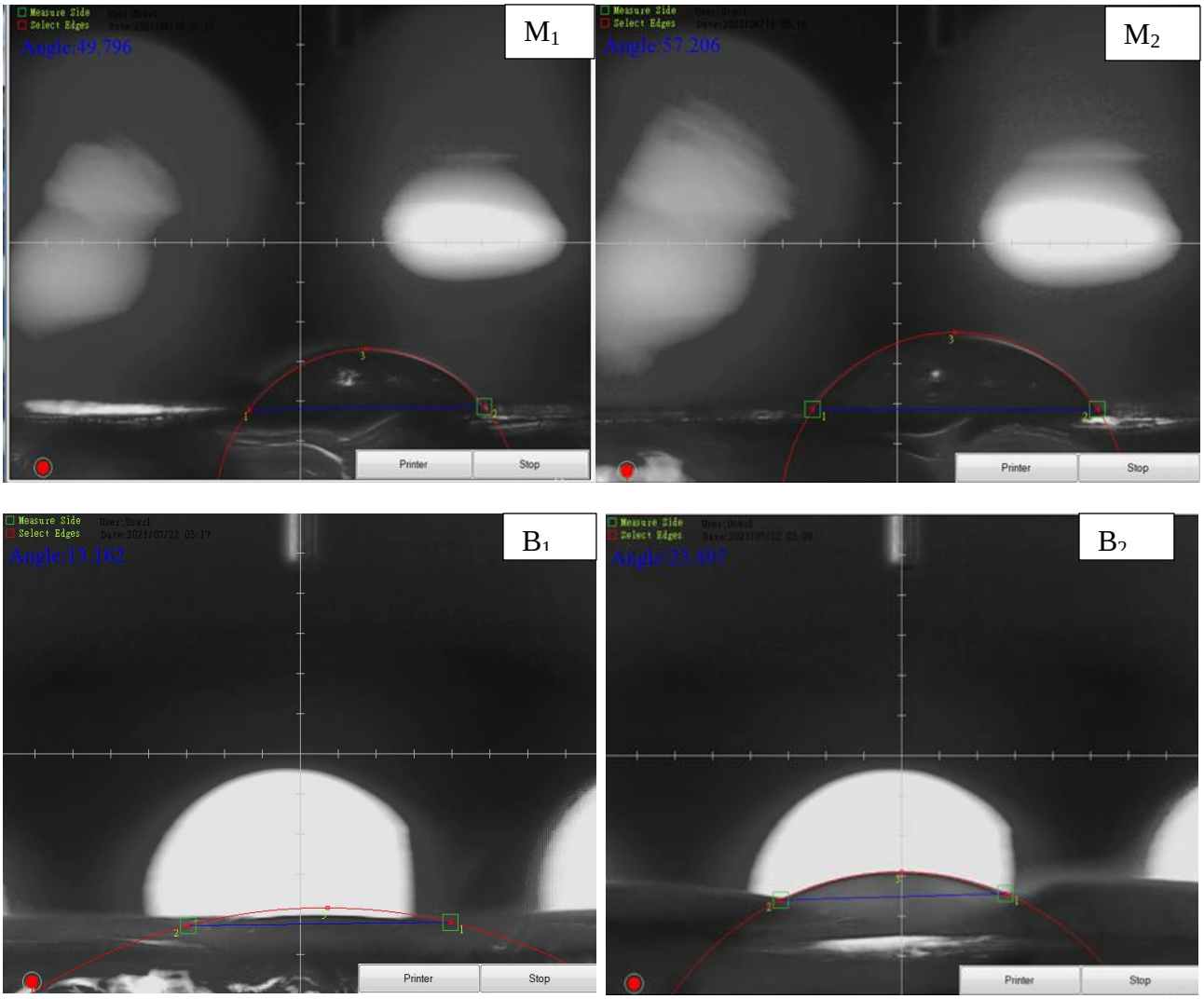


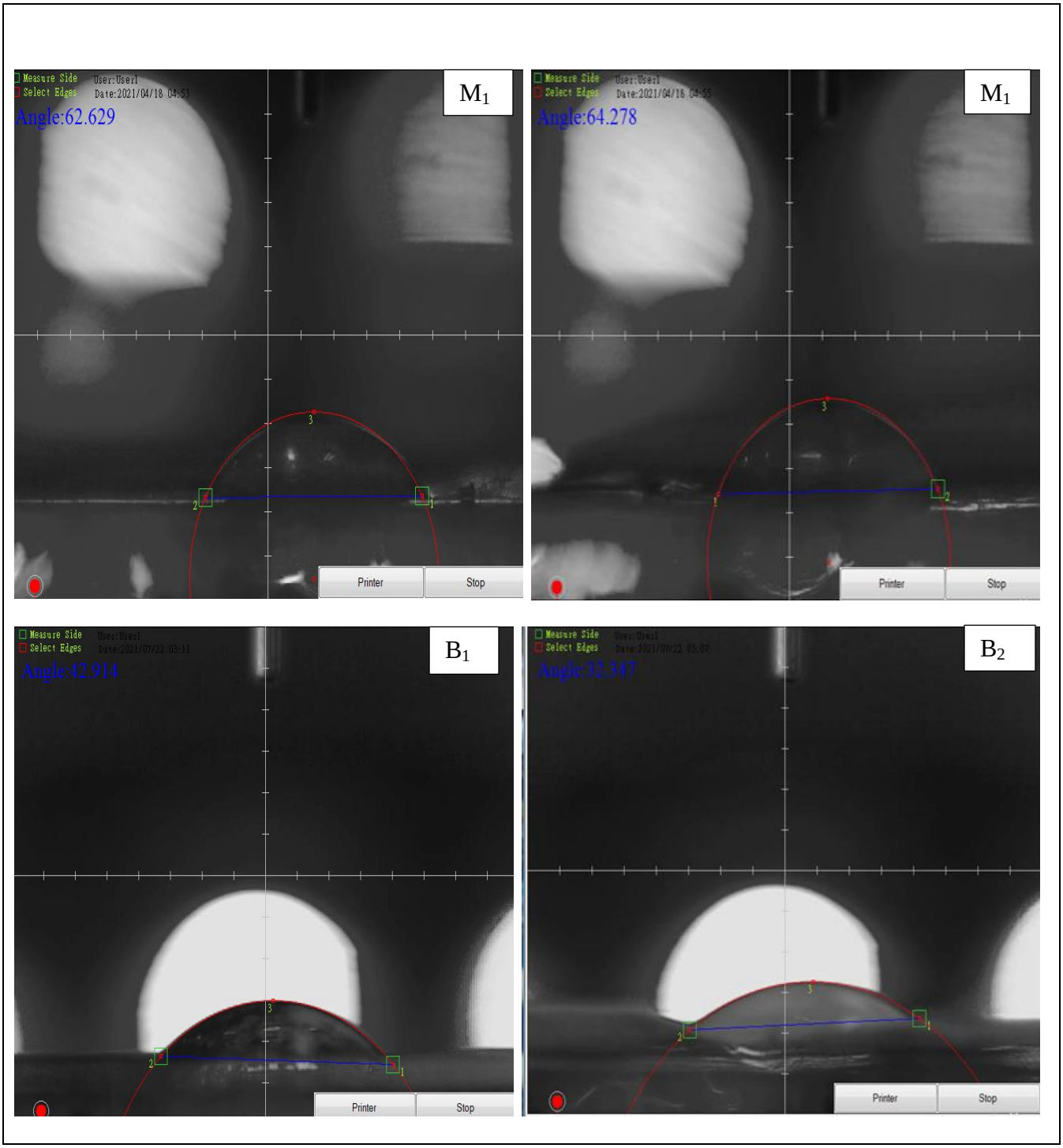
Fig. A2.5: PV_5 granularity AFM normal distribution report and chart after coating with AgNPs.

P1: Water droplets on the surfaces of the uncoated and coated membranes.

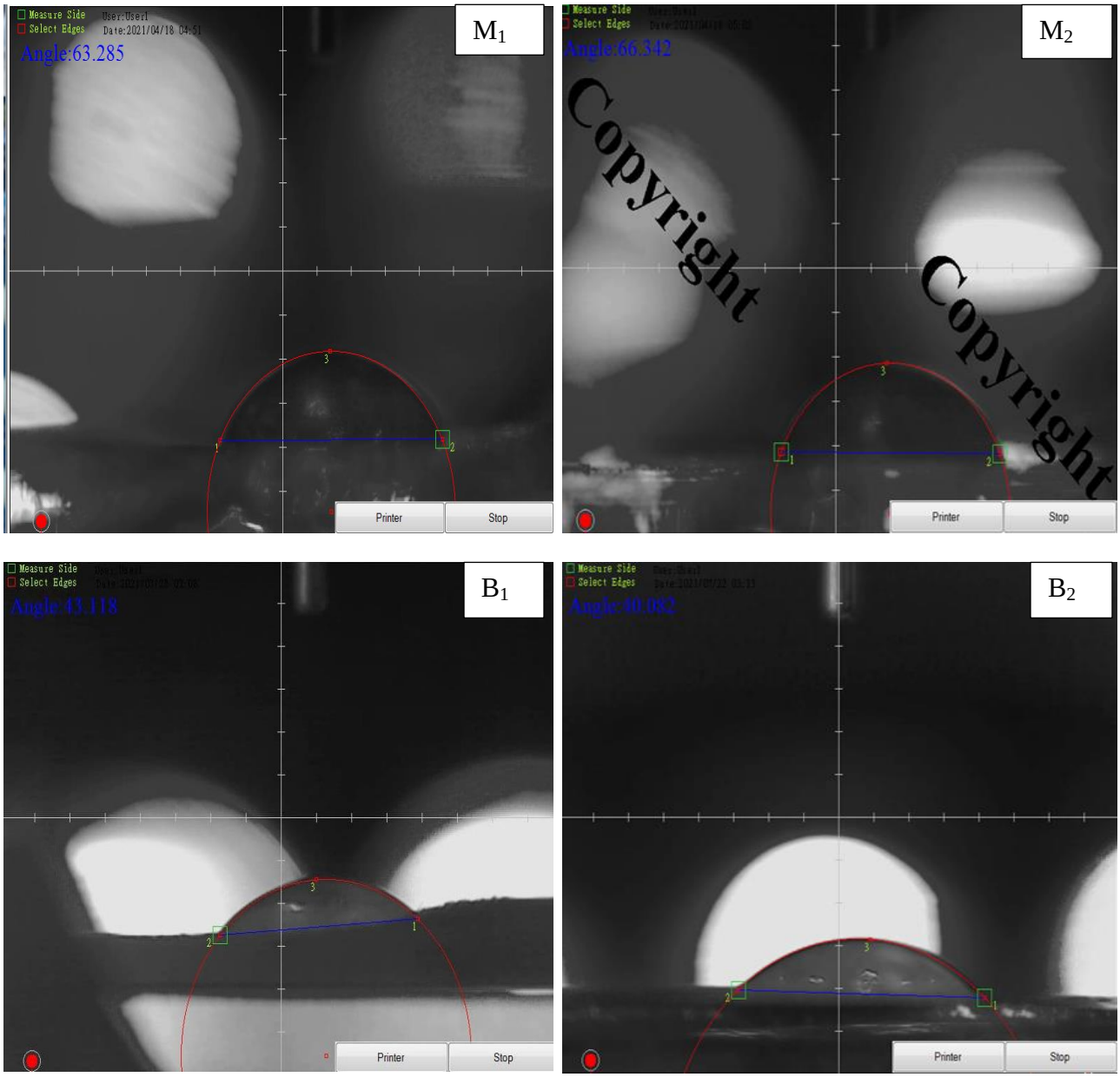
Photographs of water droplets on the surfaces of the uncoated and coated membranes are shown in Figures below:



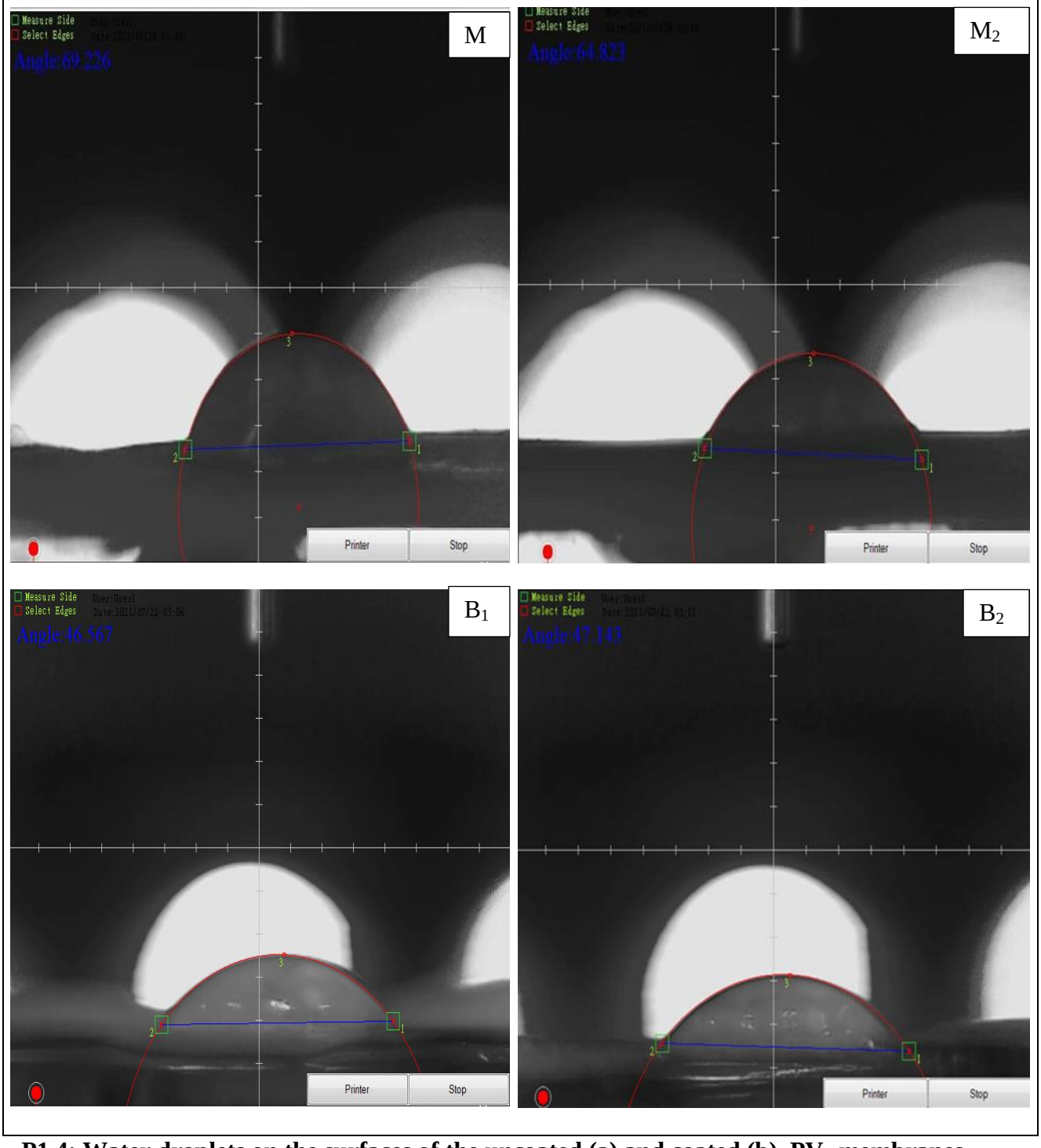
P1.1: Water droplets on the surfaces of the uncoated (a) and coated (b) PV_1 membranes.



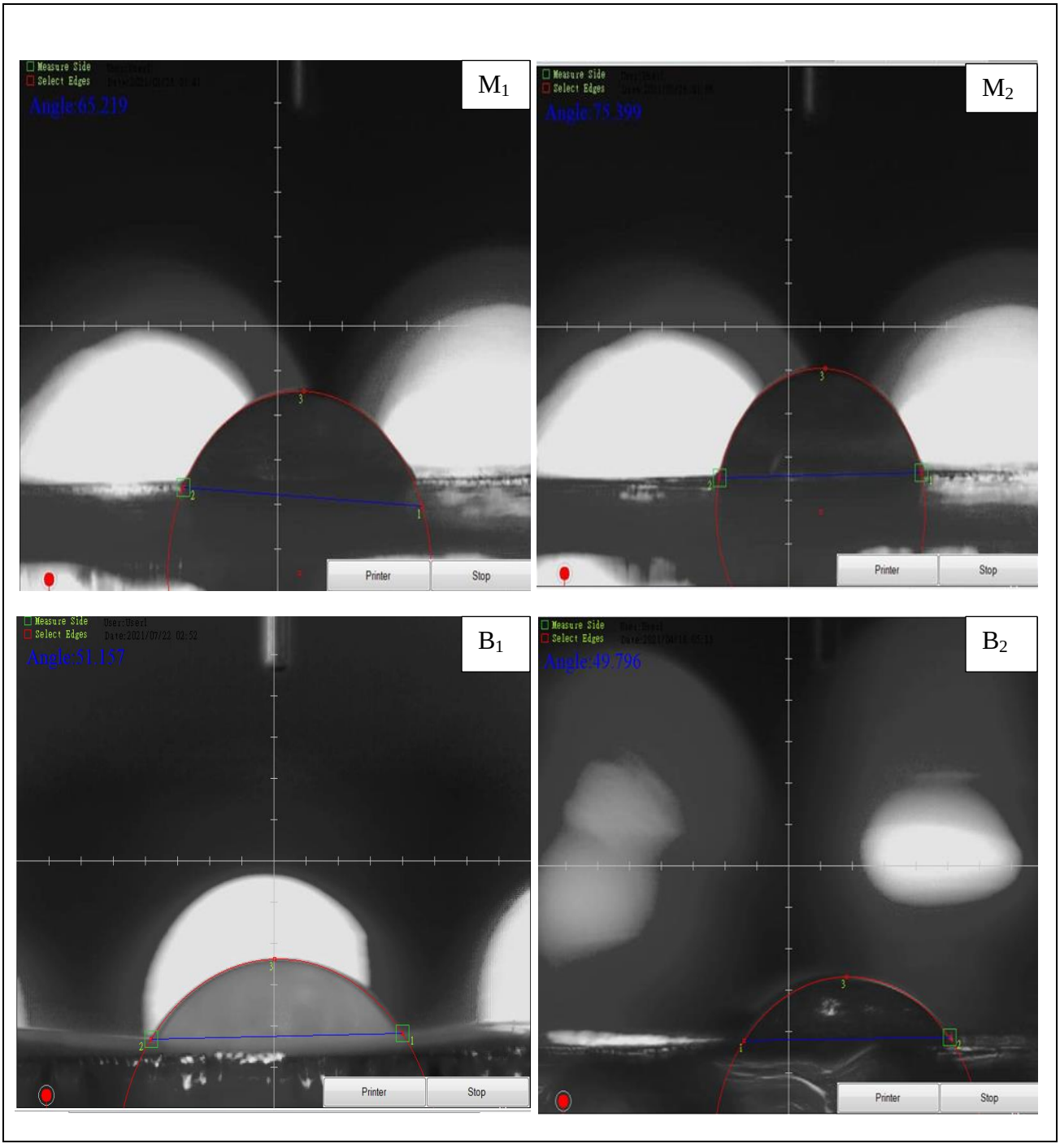
P1.2: Water droplets on the surfaces of the uncoated (a) and coated (b) PV_2 membranes.



P1.3: Water droplets on the surfaces of the uncoated (a) and coated (b) PV_3 membranes.



P1.4: Water droplets on the surfaces of the uncoated (a) and coated (b) PV_4 membranes.



P1.5: Water droplets on the surfaces of the uncoated (a) and coated (b) PV_5 membranes.

APPENDIX

B

APPENDIX – B
DRINKING WATRE GUIDELINES

Table B.1: World Health Organization Guideline values for bacteriological quality.

Organisms	Guideline value
All water intended for drinking	
E. coli or thermotolerant coliform bacteria[b,c]	Must not be detectable in any 100-ml sample
Treated water entering the distribution system	
E. coli or thermotolerant coliform bacteria[b]	Must not be detectable in any 100-ml sample
Total coliform bacteria	Must not be detectable in any 100-ml sample
Treated water in the distribution system	
E. coli or thermotolerant coliform bacteria[b]	Must not be detectable in any 100-ml sample
Total coliform bacteria	Must not be detectable in any 100-ml sample. In the case of large supplies, where sufficient samples are examined, must not be present in 95% of samples taken throughout any 12-month period

Table B.2: US Environmental Protection Agency Drinking Water Standards and Health Advisories.

Chemicals	CASRN Number	Standards			Status HA Document	Health Advisories						Cancer Descriptor[1]
						10-kg Child						
		Status Reg.	MCLG (mg/L)	MCL (mg/L)		One-day (mg/L)	Ten-day (mg/L)	RfD (mg/kg/day)	DWEL (mg/L)	Life-time (mg/L)	mg/L at 10^{-4} Cancer Risk	
ORGANICS												
Acenaphthene	83-32-9	-	-	-	-	-	-	0.06	2	-	-	-
Acifluorfen (sodium)	62476-59-9		-	-	F '88	2	2	0.01	0.4	-	0.1	*L/N*
Acrylamide	79-06-1	F	zero	TT[2]	F '87	1.5	0.3	**0.002**	0.07	-	-	L
Acrylonitrile	107-13-1		-	-	-	-	-	-	-	-	0.006	B1
Alachlor	15972-60-8	F	zero	0.002	F '88	0.1	0.1	0.01	0.4	-	***0.04***	***B2***
Aldicarb[3]	116-06-3	F[4]	0.001	0.003	F '95	0.01	0.01	0.001	0.035	0.007	-	D
Aldicarb sulfone[3]	1646-88-4	F[4]	0.001	0.002	F '95	0.01	0.01	0.001	0.035	0.007	-	D
Aldicarb sulfoxide[3]	1646-87-3	F[4]	0.001	0.004	F '95	0.01	0.01	0.001	0.035	0.007	-	D
Aldrin	309-00-2	-	-	-	F '92	0.0003	0.0003	0.00003	0.001	-	0.0002	B2
Ametryn	834-12-8	-	-	-	F '88	9	9	0.009	0.3	0.06	-	D
Ammonium sulfamate	7773-06-0	-	-	-	F '88	20	20	0.2	8	2	-	D
Anthracene (PAH)[5]	120-12-7	-	-	-	-	-	-	0.3	10	-	-	D
Atrazine	1912-24-9	F	0.003	0.003	F '88	-	-	***0.02***	0.7	-	-	*N*
Baygon	114-26-1	-	-	-	F '88	0.04	0.04	0.004	0.1	0.003	-	C
Bentazon	25057-89-0	-	-	-	F '99	0.3	0.3	0.03	1	0.2	-	E
Benz[a]anthracene (PAH)	56-55-3	-	-	-	-	-	-	-	-	-	-	B2
Benzene	71-43-2	F	zero	0.005	F '87	0.2	0.2	**0.004**	0.1	**0.003**	**1 to 10**	**H**
Benzo[a]pyrene (PAH)	50-32-8	F	zero	0.0002	-	-	-	-	-	-	0.0005	B2
Benzo[b]fluoranthene (PAH)	205-99-2	-	-	-	-	-	-	-	-	-	-	B2
Benzo[g,h,i]perylene (PAH)	191-24-2	-	-	-	-	-	-	-	-	-	-	D
Benzo[k]fluoranthene (PAH)	207-08-9	-	-	-	-	-	-	-	-	-	-	B2
Bis(2-chloro-1-methylethyl) ether	108-60-1	-	-	-	F '89	4	4	**0.04**	1	0.3	-	-
Bromacil	314-40-9	-	-	-	F '88	5	5	***0.1***	3.5	0.07	-	C
Bromobenzene	108-86-1	-	-	-	D '86	4	4	**0.008**	0.3	**0.06**	-	I

[1]Chemicals evaluated under the 2005 Cancer Guidelines or the 1996 or 1999 drafts are demoted by an abbreviation for their weight-of-the-evidence descriptor (see page iii). If the agency has not completed a new assessment for the chemical, the 1986 Guidelines Group designation (see page iii) is given in the Cancer Descriptor column.

[2] When Acrylamide is used in drinking water systems, the combination (or product) of dose and monomer level shall not exceed that equivalent to a polyacrylamide polymer containing 0.05% monomer dosed at 1 mg/L.

[3] The MCL value for any combination of two or more of these three chemicals should not exceed 0.007 mg/L because of a similar mode of action.

[4] Administrative stay of the effective date.

[5] PAH = Polycyclic aromatic hydrocarbon.

- Continued

Chemicals	CASRN Number	Standards			Status HA Document	Health Advisories						Cancer Descriptor
						10-kg Child						
		Status Reg.	MCLG (mg/L)	MCL (mg/L)		One-day (mg/L)	Ten-day (mg/L)	RfD (mg/kg/day)	DWEL (mg/L)	Life-time (mg/L)	mg/L at 10^{-4} Cancer Risk	
Bromochloromethane	74-97-5	-	-	-	F '89	50	1	0.01	0.5	0.09	-	D
Bromodichloromethane (THM)	75-27-4	F	zero	0.08[1]	-	1	0.6	0.003	0.1	-	0.1	L
Bromoform (THM)	75-25-2	F	zero	0.08[1]	-	5	0.2	0.03	1	-	0.8	L
Bromomethane	74-83-9	-	-	-	D '89	0.1	0.1	0.001	0.05	0.01	-	D
Butyl benzyl phthalate	85-68-7	-	-	-	-	-	-	0.2	7	-	-	C
Butylate	2008-41-5	-	-	-	F '89	2	2	0.05	2	0.4	-	D
Carbaryl	63-25-2	-	-	-	F '88	1	1	***0.01***	0.4	-	4	***L***
Carbofuran	1563-66-2	F	0.04	0.04	F '87	-	-	***0.00006***	-	-	-	***N***
Carbon tetrachloride	56-23-5	F	zero	0.005	F '87	4	0.2	**0.004**	0.1	**0.03**	**0.05**	L
Carboxin	5234-68-4	-	-	-	F '88	1	1	0.1	3.5	0.7	-	D
Chloramben	133-90-4	-	-	-	F '88	3	3	0.015	0.5	0.1	-	D
Chlordane	12798-03-6	F	zero	0.002	F '87	0.06	0.06	**0.0005**	0.02	**0.004**	**0.01**	B2
Chloroform (THM)	67-66-3	F	0.07	0.08[1]	-	4	4	**0.01**	0.35	0.07	-	L/***N***
Chloromethane	74-87-3	-	-	-	F '89	9	0.4	-	-	-	-	I
Chlorophenol (2-)	95-57-8	-	-	-	D '94	0.5	0.5	0.005	0.2	0.04	-	D
Chlorothalonil	1897-45-6	-	-	-	F '88	0.2	0.2	0.015	0.5	-	0.15	B2
Chlorotoluene o-	95-49-8	-	-	-	F '89	2	2	0.02	0.7	0.1	-	D
Chlorotoluene p-	106-43-4	-	-	-	F '89	2	2	0.02	0.7	0.1	-	D
Chlorpyrifos	2921-88-2	-	-	-	F '92	0.03	0.03	***0.0003***	0.01	0.002	-	***D***
Chrysene (PAH)	218-01-9	-	-	-	-	-	-	-	-	-	-	B2
Cyanazine	21725-46-2	-	-	-	D '96	0.1	0.1	0.002	0.07	0.001	-	

[1] 1998 Final Rule for Disinfectants and Disinfection By-products: The total for trihalomethanes (THM) is 0.08 mg/L

- Continued

Chemicals	CASRN Number	Standards			Status HA Document	Health Advisories						Cancer Descriptor
						10-kg Child						
		Status Reg.	MCLG (mg/L)	MCL (mg/L)		One-day (mg/L)	Ten-day (mg/L)	RfD (mg/kg/day)	DWEL (mg/L)	Life-time (mg/L)	mg/L at 10^{-4} Cancer Risk	
Cyanogen chloride[1]	506-77-4	-	-	-	-	0.05	0.05	0.05	2	-	-	D
2,4-D (2,4-dichlorophenoxyacetic acid)	94-75-7	F	0.07	0.07	F '87	1	0.3	***0.005***	0.2	-	-	***D***
DCPA (Dacthal)	1861-32-1	-	-	-	F '08	2	2	***0.01***	0.35	0.07	-	***C***
Dalapon (sodium salt)	75-99-0	F	0.2	0.2	F '89	3	3	0.03	0.9	0.2	-	D
Di(2-ethylhexyl)adipate	103-23-1	F	0.4	0.4	-	20	20	0.6	20	0.4	3	C
Di(2-ethylhexyl)phthalate	117-81-7	F	zero	0.006	-	-	-	0.02	0.7	-	0.3	B2
Diazinon	333-41-5	-	-	-	F '88	0.02	0.02	***0.0002***	0.007	0.001	-	***E***
Dibromochloromethane (THM)	124-48-1	F	0.06	0.08[2]	-	0.6	0.6	0.02	0.7	0.06	0.08	S
Dibromochloropropane (DBCP)	96-12-8	F	zero	0.0002	F '87	0.2	0.05	-	-	-	0.003	B2
Dibutyl phthalate	84-74-2	-	-	-	-	-	-	**0.1**	4	-	-	D
Dicamba	1918-00-9	-	-	-	F '88	-	-	***0.5***	18	4	-	***N***
Dichloroacetic acid	76-43-6	F	zero	0.06[3]	-	**3**	**3**	**0.004**	0.1	**0.03**	**0.07**	**L**
Dichlorobenzene o-	95-50-1	F	0.6	0.6	F '87	9	9	0.09	3	0.6	-	D
Dichlorobenzene — [4]	541-73-1	-	-	-	F '87	9	9	0.09	3	0.6	-	D
Dichlorobenzene p-	106-46-7	F	0.075	0.075	F '87	11	11	0.1	4	0.075	-	C
Dichlorodifluoromethane	75-71-8	-	-	-	F '89	40	40	0.2	5	1	-	D
Dichloroethane (1,2-)	107-06-2	F	zero	0.005	F '87	0.7	0.7	-	-	-	0.04	B2
Dichloroethylene (1,1-)	75-35-4	F	0.007	0.007	F '87	2	1	**0.05**	2	**0.4**	**0.006**	**S**
Dichloroethylene (cis-1,2-)	156-59-2	F	0.07	0.07	F '90	4	**3**	**0.002**	0.07	**0.01**	-	**I**
Dichloroethylene (trans-1,2-)	156-60-5	F	0.1	0.1	F '87	20	**2**	**0.02**	0.7	0.1	-	**I**
Dichloromethane	75-09-2	F	zero	0.005	D '93	10	2	0.06	2	**0.2**	0.5	**L**
Dichlorophenol (2,4-)	120-83-2	-	-	-	D '94	0.03	0.03	0.003	0.1	0.02	-	E
Dichloropropane (1,2-)	78-87-5	F	zero	0.005	F '87	-	0.09	-	-	-	0.06	B2
Dichloropropene (1,3-)	542-75-6	-	-	-	F '88	0.03	0.03	**0.03**	1	-	**0.04**	**L**
Dieldrin	60-57-1	-	-	-	F '88	0.0005	0.0005	0.00005	0.002	-	0.0002	B2
Diethyl phthalate	84-66-2	-	-	-	-	-	-	0.8	30	-	-	D

[1] Under review.
[2] 1998 Final Rule for Disinfectants and Disinfection By-products: The total for trihalomethanes is 0.08 mg/L.
[3] 1998 Final Rule for Disinfectants and Disinfection By-products: The total for five haloacetic acids is 0.06 mg/L.
[4] The values for m-dichlorobenzene are based on data for o-dichlorobenzene.

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Chemicals	CASRN Number	Standards			Status HA Document	Health Advisories						Cancer Descriptor
						10-kg Child						
		Status Reg.	MCLG (mg/L)	MCL (mg/L)		One-day (mg/L)	Ten-day (mg/L)	RfD (mg/kg/day)	DWEL (mg/L)	Life-time (mg/L)	mg/L at 10^{-4} Cancer Risk	
Diisopropylmethylphosphonate	1445-75-6	-	-	-	F '89	8	8	0.08	3	0.6	-	D
Dimethrin	70-38-2	-	-	-	F '88	10	10	0.3	10	2	-	D
Dimethyl methylphosphonate	756-79-6	-	-	-	F '92	2	2	0.2	7	0.1	0.7	C
Dimethyl phthalate	131-11-3	-	-	-	-	-	-	-	-	-	-	D
Dinitrobenzene (1,3-)	99-65-0	-	-	-	F '91	0.04	0.04	0.0001	0.005	0.001	-	D
Dinitrotoluene (2,4-)	121-14-2	-	-	-	F '08	1	1	0.002	0.1	-	0.005	L
Dinitrotoluene (2,6-)	606-20-2	-	-	-	F '08	0.4	0.04	0.001	0.04	-	0.005	L
Dinitrotoluene (2,6 & 2,4)[1]		-	-	-	F '92	-	-	-	-	-	0.005	B2
Dinoseb	88-85-7	F	0.007	0.007	F '88	0.3	0.3	0.001	0.035	0.007	-	D
Dioxane p-	123-91-1	-	-	-	F '87	4	0.4	**0.03**	1	0.2	**0.035**	L
Diphenamid	957-51-7	-	-	-	F '88	0.3	0.3	0.03	1	0.2	-	D
Diquat	85-00-7	F	0.02	0.02	-	-	-	***0.005***	0.02	-	-	***E***
Disulfoton	298-04-4	-	-	-	F '88	0.01	0.01	***0.0001***	0.0035	0.0007	-	***E***
Dithiane (1,4-)	505-29-3	-	-	-	F '92	0.4	0.4	0.01	0.4	0.08	-	D
Diuron	330-54-1	-	-	-	F '88	1	1	***0.003***	0.1	-	***0.2***	***L***
Endothall	145-73-3	F	0.1	0.1	F '88	0.8	0.8	***0.007***	0.25	0.05	-	***N***
Endrin	72-20-8	F	0.002	0.002	F '87	0.02	0.005	**0.0003**	0.01	0.002	-	I
Epichlorohydrin	106-89-8	F	zero	TT[2]	F '87	0.1	0.1	0.002	0.07	-	**0.3**	B2
Ethylbenzene	100-41-4	F	0.7	0.7	F '87	30	3	0.1	3	0.7	-	D
Ethylene dibromide (EDB)[3]	106-93-4	F	zero	0.00005	F '87	0.008	0.008	**0.009**	0.3	-	**0.002**	L
Ethylene glycol	107-21-1	-	-	-	F '87	20	6	**2**	70	14	-	D
Ethylene Thiourea (ETU)	96-45-7	-	-	-	F '88	0.3	0.3	***0.0002***	0.007	-	***0.06***	B2
Fenamiphos	22224-92-6	-	-	-	F '88	0.009	0.009	***0.0001***	0.0035	0.0007	-	***E***

[1] Technical grade.
[2] When epichlorohydrin is used in drinking water systems, the combination (or product) of dose and monomer level shall not exceed that equivalent to an epichlorohydrin-based polymer containing 0.01% monomer dosed at 20 mg/L.
[3] 1,2-dibromoethane.

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Chemicals	CAS Number	Standards			Status HA Standards	Health Advisories						Cancer Descriptor
						10-kg Child						
		Status Reg.	MCLG (mg/L)	MCL (mg/L)		One-day (mg/L)	Ten-day (mg/L)	RfD (mg/kg/day)	DWEL (mg/L)	Life-time (mg/L)	mg/L at 10^{-4} Cancer Risk	
Fluometuron	2164-17-2	-	-	-	F '88	2	2	0.01	0.5	0.09		D
Fluorene (PAH)	86-73-7	-	-	-	-	-	-	0.04	1	-	-	D
Fonofos	944-22-9	-	-	-	F '88	0.02	0.02	0.002	0.07	0.01	-	D
Formaldehyde	50-00-0	-	-	-	D '93	10	5	0.2	7	1	-	B1[1]
Glyphosate	1071-83-6	F	0.7	0.7	F '88	20	20	2	70	-	-	D
Heptachlor	76-44-8	F	zero	0.0004	F '87	0.01	0.01	0.0005	0.02	-	0.0008	B2
Heptachlor epoxide	1024-57-3	F	zero	0.0002	F '87	0.01	-	0.00001	0.0004	-	0.0004	B2
Hexachlorobenzene	118-74-1	F	zero	0.001	F '87	0.05	0.05	0.0008	0.03	-	0.002	B2
Hexachlorobutadiene[2]	87-68-3	-	-	-	-	0.3	0.3	0.0003	0.01	-	0.09	L
Hexachlorocyclopentadiene	77-47-4	F	0.05	0.05	-	-	-	0.006	0.2	-	-	N
Hexachloroethane	67-72-1	-	-	-	F '91	5	5	0.001	0.04	0.001	0.3	C
Hexane (n-)	110-54-3	-	-	-	F '87	10	4	-	-	-	-	I
Hexazinone	51235-04-2	-	-	-	F '96	3	2	0.05	2	0.4	-	D
HMX[3]	2691-41-0	-	-	-	F '88	5	5	0.05	2	0.4	-	D
Indeno[1,2,3,-c,d]pyrene (PAH)	193-39-5	-	-	-	-	-	-	-	-	-	-	B2
Isophorone	78-59-1	-	-	-	F '92	15	15	0.2	7	0.1	4	C
Isopropyl methylphosphonate	1832-54-8	-	-	-	F '92	30	30	0.1	3.5	0.7	-	D
Isopropylbenzene (cumene)	98-82-8	-	-	-	D '87	11	11	0.1	4	-	-	D
Lindane[4]	58-89-9	F	0.0002	0.0002	F '87	1	1	0.005	0.2	-	-	S
Malathion	121-75-5	-	-	-	F '92	0.2	0.2	0.07	2	0.5	-	S
Maleic hydrazide	123-33-1	-	-	-	F '88	10	10	0.5	20	4	-	D
MCPA[5]	94-74-6	-	-	-	F '88	0.1	0.1	0.004	0.14	0.03	-	N
Methomyl	16752-77-5	-	-	-	F '88	0.3	0.3	0.025	0.9	0.2	-	E
Methoxychlor	72-43-5	F	0.04	0.04	F '87	0.05	0.05	0.005	0.2	0.04	-	D
Methyl ethyl ketone	78-93-3	-	-	-	F '87	75	7.5	0.6	20	4	-	D
Methyl parathion	298-00-0	-	-	-	F '88	0.3	0.3	0.0002	0.007	0.001	-	N

[1] Carcinogenicity based on inhalation exposure.
[2] Regulatory Determination Health Effects Support Document for Hexachlorobutadiene (http://www.epa.gov/safewater/ccl/pdfs/reg_determine1/support_cc1_hexachlorobutadiene_healtheffects.pdf).
[3] HMX = octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine.
[4] Lindane = γ – hexachlorocyclohexane.
[5] MCPA = 4 (chloro-2-methoxyphenoxy) acetic acid.

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Chemicals	CASRN Number	Standards			Status HA Document	Health Advisories						Cancer Descriptor
						10-kg Child						
		Status Reg.	MCLG (mg/L)	MCL (mg/L)		One-day (mg/L)	Ten-day (mg/L)	RfD (mg/kg/day)	DWEL (mg/L)	Life-time (mg/L)	mg/L at 10^{-4} Cancer Risk	
Metolachlor	51218-45-2	-	-	-	F '88	2	2	***0.1***	3.5	0.7	-	***C***
Metribuzin	21087-64-9	-	-	-	F '88	5	5	***0.01***	0.35	0.07	-	***D***
Monochloroacetic acid	79-11-8	F	0.07	0.06[1]	-	0.2	0.2	0.01	0.35	0.07	-	I
Monochlorobenzene	108-90-7	F	0.1	0.1	F '87	4	4	**0.02**	0.7	0.1	-	D
Naphthalene	91-20-3	-	-	-	F '90	0.5	0.5	**0.02**	0.7	0.1	-	I
Nitrocellulose[2]	9004-70-0	-	-	-	F '88	-	-	-	-	-	-	-
Nitroguanidine	556-88-7	-	-	-	F '90	10	10	0.1	3.5	0.7	-	D
Nitrophenol p-	100-02-7	-	-	-	F '92	0.8	0.8	0.008	0.3	0.06	-	D
N-nitrosodimethylamine		-	-	-	-	-	-	-	-	-	**0.00007**	**B2**
Oxamyl (Vydate)	23135-22-0	F	0.2	0.2	F '05	0.01	0.01	0.001	0.035		-	N
Paraquat	1910-42-5	-	-	-	F '88	0.1	0.1	***0.0045***	0.2	0.03	-	***E***
Pentachlorophenol	87-86-5	F	zero	0.001	F '87	1	0.3	**0.005**	0.2	0.04	**0.009**	**L**
PFOA	335-67-1	-	-	-	F '16	-	-	2×10^{-5}	3.7×10^{-4}	7×10^{-5}	5×10^{-2}	S
PFOS	1763-23-1	-	-	-	F '16	-	-	2×10^{-5}	3.7×10^{-4}	7×10^{-5}	-	S
Phenanthrene (PAH)	85-01-8	-	-	-	-	-	-	-	-	-	-	D
Phenol	108-95-2	-	-	-	D '92	6	6	**0.3**	11	2	-	D
Picloram	1918-02-1	F	0.5	0.5	F '88	20	20	***0.02***	0.7	-	-	D
Polychlorinated biphenyls (PCBs)	1336-36-3	F	zero	0.0005	D '93	-	-	-	-	-	0.01	B2
Prometon	1610-18-0	-	-	-	F '88	0.2	0.2	***0.05***	2	0.4	-	***N***
Pronamide	23950-58-5	-	-	-	F '88	0.8	0.8	***0.08***	3	-	***0.1***	***B2***
Propachlor	1918-16-7	-	-	-	F '88	0.5	0.5	***0.05***	2	-	0.1	***L***
Propazine	139-40-2	-	-	-	F '88	-	-	***0.02***	0.7	0.01	-	***N***
Propham	122-42-9	-	-	-	F '88	5	5	0.02	0.6	0.1	-	D
Pyrene (PAH)	129-00-0	-	-	-	-	-	-	0.03	-	-	-	D
RDX[3]	121-82-4	-	-	-	F '88	0.1	0.1	0.003	0.1	0.002	0.03	C
Simazine	122-34-9	F	0.004	0.004	F '88	-	-	***0.02***	0.7	-	-	***N***
Styrene	100-42-5	F	0.1	0.1	F '87	20	2	0.2	7	0.1	-	C
2,4,5-T (Trichlorophenoxy-acetic acid)	93-76-5	-	-	-	F '88	0.8	0.8	0.01	0.35	0.07	-	D

[1]1998 Final Rule for Disinfectants and Disinfection By-products: the total for five haloacetic acids is 0.06 mg/L.
[2] The Health Advisory Document for nitrocellulose does not include HA values and describes this compound as relatively nontoxic.
[3] RDX = hexahydro -1,3,5-trinitro-1,3,5-triazine.

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Chemicals	CASRN Number	Standards			Status HA Document	Health Advisories						Cancer Descriptor
						10-kg Child						
		Status Reg.	MCLG (mg/L)	MCL (mg/L)		One-day (mg/L)	Ten-day (mg/L)	RfD (mg/kg/day)	DWEL (mg/L)	Life-time (mg/L)	mg/L at 10^{-4} Cancer Risk	
2,3,7,8-TCDD (Dioxin)	1746-01-6	F	zero	3E-08	F '87	1E-06	1E-07	1E-09	4E-08	-	2E-08	B2
Tebuthiuron	34014-18-1	-	-	-	F '88	3	3	0.07	2	0.5	-	D
Terbacil	5902-51-2	-	-	-	F '88	0.3	0.3	0.01	0.4	0.09	-	E
Terbufos	13071-79-9	-	-	-	F '88	0.005	0.005	*0.00005*	0.002	0.0004	-	D
Tetrachloroethane (1,1,1,2-)	630-20-6	-	-	-	F '89	2	2	0.03	1	0.07	0.1	C
Tetrachloroethane (1,1,2,2-)	79-34-5	-	-	-	F '08	3	3	0.01	0.4	-	0.04	L
Tetrachloroethylene[1]	127-18-4	F	zero	0.005	F '87	2	2	0.01	0.5	0.01	-	-
Tetrachloroterephthalic acid	236-79-0	-	-	-	F '08	100	100	-	-	-	-	I
Trichlorofluoromethane	75-69-4	-	-	-	F '89	7	7	0.3	10	2	-	D
Toluene	108-88-3	F	1	1	D '93	20	2	**0.08**	3	-	-	I
Toxaphene	8001-35-2	F	zero	0.003	F '96	0.004	0.004	0.0004	0.01	-	0.003	B2
2,4,5-TP (Silvex)	93-72-1	F	0.05	0.05	F '88	0.2	0.2	0.008	0.3	0.05	-	D
Trichloroacetic acid	76-03-9	F	0.02	0.06[2]	-	3	3	0.03	1	0.02	-	S
Trichlorobenzene (1,2,4-)	120-82-1	F	0.07	0.07	F '89	0.1	0.1	**0.01**	0.35	0.07	-	D
Trichlorobenzene (1,3,5-)	108-70-3	-	-	-	F '89	0.6	0.6	0.006	0.2	0.04	-	D
Trichloroethane (1,1,1-)	71-55-6	F	0.2	0.2	F '87	100	40	**2**	70	-	-	I
Trichloroethane (1,1,2-)	79-00-5	F	0.003	0.005	F '89	0.6	0.4	0.004	0.1	0.003	0.06	C
Trichloroethylene [1]	79-01-6	F	zero	0.005	F '87	-	-	0.007	0.2	-	0.3	B2
Trichlorophenol (2,4,6-)	88-06-2	-	-	-	D '94	0.03	0.03	0.0003	0.01	-	0.3	B2
Trichloropropane (1,2,3-)	96-18-4	-	-	-	F '89	0.6	0.6	**0.004**	0.1	-	-	L
Trifluralin	1582-09-8	-	-	-	F '90	0.08	0.08	***0.02***	0.7	0.01	0.4	***C***
Trimethylbenzene (1,2,4-)	95-63-6	-	-	-	D '87	-	-	-	-	-	-	D
Trimethylbenzene (1,3,5-)	108-67-8	-	-	-	D '87	10	-	-	-	-	-	D
Trinitroglycerol	55-63-0	-	-	-	F '87	0.005	0.005	-	-	0.005	0.2	-
Trinitrotoluene (2,4,6-)	118-96-7	-	-	-	F '89	0.02	0.02	0.0005	0.02	0.002	0.1	C
Vinyl chloride	75-01-4	F	zero	0.002	F '87	3	3	**0.003**	0.1	-	**0.002**	H
Xylenes	1330-20-7	F	10	10	D '93	40	40	**0.2**	7	-	-	I

[1] Under review.
[2] 1998 Final Rule for Disinfectants and Disinfection By-products: The total for five haloacetic acids is 0.06 mg/L.

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Chemicals	CASRN Number	Standards			Status HA Document	Health Advisories						Cancer Descriptor
						10-kg Child						
		Status Reg.	MCLG (mg/L)	MCL (mg/L)		One-day (mg/L)	Ten-day (mg/L)	RfD (mg/kg/day)	DWEL (mg/L)	Life-time (mg/L)	mg/L at 10^{-4} Cancer Risk	
INORGANICS												
Ammonia	7664-41-7	-	-	-	D '92	-	-	-	-	30	-	D
Antimony	7440-36-0	F	0.006	0.006	F '92	0.01	0.01	0.0004	0.01	0.006	-	D
Arsenic	7440-38-2	F	zero	0.01	-	-	-	**0.0003**	0.01	-	**0.002**	A
Asbestos (fibers/l >10Fm length)	1332-21-4	F	7 MFL[1]	7 MFL	-	-	-	-	-	-	700-MFL	A[2]
Barium	7440-39-3	F	2	2	D '93	0.7	0.7	**0.2**	7	-	-	N
Beryllium	7440-41-7	F	0.004	0.004	F '92	30	30	**0.002**	0.07	-	-	-
Boron	7440-42-8	-	-	-	F '08	3	3	**0.2**	7	6	-	I
Bromate	7789-38-0	F	zero	0.01	D '98	0.2	-	**0.004**	0.14	-	0.005	B2
Cadmium	7440-43-9	F	0.005	0.005	F '87	0.04	0.04	0.0005	0.02	0.005	-	D
Chloramine[3]	10599-90-3	F	4[4]	4[4]	D '95	-	-	0.1	3.5	3.0	-	-
Chlorine	7782-50-5	F	4[4]	4[4]	D '95	3	3	0.1	5	4	-	D
Chlorine dioxide	10049-04-4	F	0.8[4]	0.8[4]	D '98	0.8	0.8	0.03	1	0.8	-	D
Chlorite	7758-19-2	F	0.8	1	D '98	0.8	0.8	0.03	1	0.8	-	D
Chromium (total)	7440-47-3	F	0.1	0.1	F '87	1	1	**0.003**[5]	0.1	-	-	D
Copper (at tap)	7440-50-8	F	1.3	TT[6]	D '98	-	-	-	-	-	-	D
Cyanide	143-33-9	F	0.2	0.2	F '87	0.2	0.2	**0.0006**[7]	-	-	-	I
Fluoride	7681-49-4	F	4	4	-	-[8]	-	**0.06**[9]	-	-	-	-
Lead (at tap)	7439-92-1	F	zero	TT[6]	-	-	-	-	-	-	-	B2
Manganese	7439-96-5	-	-	-	F'04	1	1	0.14[10]	1.6	0.3	-	D
Mercury (inorganic)	7487-94-7	F	0.002	0.002	F '87	0.002	0.002	**0.0003**	0.01	0.002	-	D
Molybdenum	7439-98-7	-	-	-	D '93	0.08	0.08	0.005	0.2	0.04	-	D
Nickel	7440-02-0	F	-	-	F '95	1	1	0.02	0.7	0.1	-	-

[1] MFL = million fibers per liter.
[2] Carcinogenicity based on inhalation exposure.
[3] Monochloramine; measured as free chlorine.
[4] 1998 Final Rule for Disinfectants and Disinfection By-products: MRDLG=Maximum Residual Disinfection Level Goal; and MRDL=Maximum Residual Disinfection Level.
[5] IRIS value for chromium VI.
[6] Copper action level 1.3 mg/L; lead action level 0.015 mg/L.
[7] This RfD is for hydrogen cyanide.
[8] In case of overfeed of the fluoridation chemical see CDC Guidelines in Engineering and Administrative Recommendations on Water Fluoridation www.cdc.gov/mmwr/preview/mmwrhtml/00039178.htm. Elevated F levels ≥ 10mg/L require action by the water system operator.
[9] Based on dental fluorosis in children, a cosmetic effect. MCLG based on skeletal fluorosis. 10 Dietary manganese. The lifetime health advisory includes a 3 fold modifying factor to account for increased bioavailability from drinking water.

- Continued

Chemicals	CASRN Number	Standards			Status HA Document	Health Advisories						Cancer Descriptor
						10-kg Child						
		Status Reg.	MCLG (mg/L)	MCL (mg/L)		One-day (mg/L)	Ten-day (mg/L)	RfD (mg/kg/day)	DWEL (mg/L)	Life- time (mg/L)	mg/L at 10^{-4} Cancer Risk	
Nitrate (as N)	14797-55-8	F	10	10	D '93	10[1]	10[1]	1.6	-	-	-	-
Nitrite (as N)	14797-65-0	F	1	1	D '93	1[1]	1[1]	0.16	-	-	-	-
Nitrate + Nitrite (both as N)		F	10	10	D '93	-	-	-	-	-	-	-
Perchlorate[2]	14797-73-0	-	-	-	I '08	-	-	0.007	0.025	0.015	-	L/N
Selenium	7782-49-2	F	0.05	0.05	-	-	-	0.005	0.2	0.05	-	D
Silver	7440-22-4	-	0.1	0.1	F '92	0.2	0.2	0.005[3]	0.2	0.1[3]	-	D
Strontium	7440-24-6	-	-	-	D '93	25	25	0.6	20	4	-	D
Thallium	7440-28-0	F	0.0005	0.002	F '92	0.007	0.007	-	-	-	-	I
White phosphorous	7723-14-0	-	-	-	F '90	-	-	0.00002	0.0005	0.0001		D
Zinc	7440-66-6	-	-	-	D '93	6	6	0.3	10	2	-	I
RADIONUCLIDES												
Beta particle and photon activity (formerly man-made radionuclides)		F	zero	4 mrem/yr	-	-	-	-	-		4 mrem/yr	A
Gross alpha particle activity		F	zero	15 pCi/L	-	-	-	-	-	-	15 pCi/L	A
Combined Radium 226 & 228	7440-14-4	F	zero	5 pCi/L	-	-	-	-	-	-	-	A
Radon	10043-92-2	P	zero	300 pCi/L AMCL[4] 4000 pCi/L	-	-	-	-	-	-	150 pCi/L	A
Uranium	7440-61-1	F	zero	0.03	-	-	-	0.0006[5]	0.02	-	-	A

[1] These values are calculated for a 4-kg infant and are protective for all age groups.
[2] Subchronic value for pregnant women.
[3] Based on a cosmetic effect.
[4] AMCL = Alternative Maximum Contaminant Level.
[5] Soluble uranium salts. Radionuclide Rule.

Table B.3: Microbiology

	Status Reg.	Status HA Document	MCLG	MCL	Treatment Technique
Cryptosporidium	F	F 01	zero	TT	Systems that filter must remove 99% of *Cryptosporidium*
Cylindrospermosin	-	F 15	-	-	-
Cyanobacterial Microcystin Toxins	-	F 15	-	-	-
Giardia lamblia	F	F 98	zero	TT	99.9% killed/inactivated
Legionella	F[1]	F 01	zero	TT	No limit; EPA believes that if *Giardia* and viruses are inactivated, *Legionella* will also be controlled
Heterotrophic Plate Count (HPC)	F[1]	-	NA	TT	No more than 500 bacterial colonies per milliliter.
Mycobacteria	-	F 99	-	-	-
Total Coliforms	F	-	zero	5%	No more than 5.0% samples total coliform-positive in a month. Every sample that has total coliforms must be analyzed for fecal coliforms; no fecal coliforms are allowed.
Turbidity	F	-	NA	TT	At no time can turbidity go above 5 NTU (nephelometric turbidity units)
Viruses	F[1]	-	zero	TT	99.99% killed/inactivated

الخلاصة

يوجد عدد من أنظمة معالجة المياه المنزلية في الاسواق وبكثره. وهي تختلف بشكل رئيسي في طريقة التصنيع والأليات المستخدمة في تنقية المياه. ان معظم هذه الاجهزة المتاحة مكلفة وبالتالي هناك حاجة إلى ابتكار تقنيات معالجة رخيصة وبأسعار معقولة. تعرض هذه الدراسة التضمين الموضعي لجزيئات الفضة النانوية في فلاتر معالجة مياه منزلية فعالة ومقبولة من حيث التكلفة باستخدام مواد صديقة للبيئة مثل بولي (كلوريد الفينيل) باستخدام مستخلص القرنفل العطري كعامل مختزل ومثبت.

تم تحضير أغشية الألواح المسطحة من بوليمير البولي (كلوريد الفينيل) وبأبسط التقنيات لتحضير الأغشية باستخدام طريقة انعكاس الطور بتركيزات مختلفة من المحاليل في المذيبات (N، N ثنائي ميثيل أسيتاميد (DMAc). تم فحص نشاط الغشاء المطلي بالفضة النانوية المضاد للبكتريا باستخدام بكتريا الأشريكية القولونية وبطرق فحص مختلفة فأعطيت الفضة النانوية مناطق تثبيط عالية كلما زاد تركيز نترات الفضة حيث تم ترشيح الماء خلال الفلتر المطلي بجزيئات الفضة النانوية فلوحظ ان أغشية الترشيح الدقيق بولي (كلوريد الفينيل) وبتركيزات مختلفة تتميز بفاعلية عالية ضد البكتيريا المسببة للأمراض المنقولة بالمياه (الإشريكية القولونية). كانت كفاءة الإزالة للأغشية المطلية (10٪ ، 11٪ ، 12٪ ، 13٪ و 14٪) بولي (كلوريد الفينيل) (88.8٪ ، 90.1٪ ، 90.9٪ ، 91.9٪ ، 94.1٪) على التوالي.

الفلتر بتركيز (2.5٪ من البولي (كلوريد الفينيل) و 22.5٪ من DMAS) كان الاعلى كفائه في ازالة بكتريا الاشريكية القولونية التي وصلت الى99.8 ٪ عند تمرير الماء الملوث بالبكتريا خلال ساعتين وبدرجة عكوره اقل من NTU1 وبمعدل جريان عالي. بالأخذ بنظر الاعتبار لمحددات نوعية مياه الشرب، تم تحليل المياه بعد الترشيح خلال الفلتر المضمن بدقائق الفضة النانوية بواسطة التحليل الطيفي للامتصاص الذري، حيث وجد ان جميع التراكيز تنطبق مع محددات منظمة الصحة العالمية ووكالة حماية البيئة الامريكية والتي تنص على ان لا يزيد تركيز الفضة في مياه الشرب عن 0.1ملغم\التر.

تم استخدام المسح المجهري الإلكتروني (SEM) ، والفحص المجهري للقوة الذرية AFM ، وزاوية التلامس ، وحيود الأشعة السينية ، والتحليل الطيفي للأشعة المرئية وفوق البنفسجية لتحليل بنية وحجم حبيبات الجزيئات والأغشية المنتجة. اظهرت دراسة SEM انه لا يوجد فرق كبير في

شكل الاغشية غير المطلية والمطلية ومع ذلك، تم التعرف على بعض المواد الموجودة على سطح الفلتر المطلي على انها فضه نانوية. أظهرت نتائج خشونة سطح الأغشية المحسوبة من AFM انخفض متوسط قيم زاوية التلامس لغشاء PVC مع إضافة الفضة النانوية لأن إضافة الفضة النانوية قد أدت إلى تحسين قابلية الغشاء للماء. الغشاء بتركيز ٪ 14 كانت أعلى قيمة زاوية تلامس (70.3) والتي قلت الى (50.40) بعد اضافة الفضة النانوية. كان التبلور وموضع المستوى البلوري للجسيمات المنتجة مشابهًا لنمط الفضة النانوية القياسي ، وكان متوسط حجم الجسيمات النانوية 46.99 نانومتر ، كما هو محدد في نمط XRD. في التحليل الطيفي للأشعة المرئية وفوق البنفسجية ، يُظهر طيف امتصاص الغرويات الفضية ذات اللون الأصفر والبني الشاحب نطاق امتصاص البلازمون السطحي بطول موجي أقصى يبلغ 435 نانومتر.

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أغشية الترشيح الدقيق كنقطة استخدام لتكنولوجيا معالجة المياه

رسالة

مقدمة الى كلية الهندسة –جامعة بابل

كجزء من متطلبات نيل درجة ماجستير في الهندسة/ هندسة البيئة

من قبل

أسماء ناظم هادي كاظم

اشراف

أ. د .علاء حسين الفتلاوي

شوال، ١٤٤٣ هـ **ايار، ٢٠٢٢م**