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Evaluating the potential of the membrane technology for copper recovery from effluents and wastewater generated at copper mines and processing facilities in South Africa

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A dissertation presented to the University of Venda's Department of Chemistry in fulfillment of the qualifications for the degree of Master of Science in Chemistry

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Abstract

Membrane separation is a well-known and widely used method in water treatment. It finds applications in mining and metallurgical processes and offers many potential benefits to the mining industry, such as significant water recovery from mine wastewater, excellent metal upgrades, and reagent recycling from process streams.

This study evaluated membrane technology for the recovery of copper and recycling clean water from an aqueous effluent stream generated from copper mines. The copper content in the test work was 639 mg/L copper (Cu) in a synthetic solution and 427 mg/L copper in a real solution. Seven commercial flat sheets (FS) membranes were tested at a laboratory scale, and at the pilot scale, one spiral-wound membrane was tested. The performance of membranes was assessed, as well as the effect of various process parameters.

It was demonstrated that nanofiltration (NF) technology could be effectively used to treat wastewater generated by copper mines. Five of seven evaluated membranes (AMS A3011, A3012, A3014, B4021, and DOW N90) were found to reject >90% of copper into the concentrate at operating pressure of 20, 30, and 40 bar at ambient temperatures. In all the evaluated membranes the following was observed;

- An increase in the operational pressure increased operational flux;
- However, as pressure and temperature increased, the rejection of copper and other metals decreased.

During the optimisation of DOW N90 operational parameters, the following trends were identified:

- Operational pressure is required as it improved operational flux, increased the rejection of copper, and minimized flux depreciation with time.
- The temperature had a negative impact on flux; however, the optimum operating temperature has to be found because copper rejection can be compromised at higher temperatures.

The DOW NF90, which was tested on a pilot rig, was also found to be suitable for treatments of the diluted copper solution, with a high copper rejection achieved. And a permeate recovery of 53.64% was achieved, but this value can be improved by increasing copper in the concentrate for further recovery.

Keywords: Copper, Effluent; Membranes; Removal; Recycle.

Acknowledgments

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Declaration

Mpho Ramabulana (11575992), declares that this research dissertation was not submitted for a degree at any other university or institution. The dissertation does not include any writing from other people unless it is explicitly acknowledged and properly referenced.

Signed (Student): ________________ Date: 22/ 05 /2023

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List of abbreviations

AMS	Advance membrane separation
CF	Concentration factor
CIP	Cleaning in place
CP	Concentration polarization
Da	Dalton
DOW	Chemical Company
ED	Electrodialysis
FS	Flat sheet
ICP-OES	Inductively coupled plasma optical emission spectroscopy
ISA	Integrally skinned asymmetric
J	Flux
LMH	Liters per meter squared per hour
m^2	Meter squared
MF	Microfiltration
mg	Milligram
mg/L	Milligram per liter
µ	Microns
MWCO	Molecular weight cut off
°C	Degree celsius
NF	Nano-filtration
PE	Polyethylene
pH	Potential of hydrogen ion concentration
PTFE	Polytetrafluoroethylene
R	Rejection rate
RO	Reverse osmosis
SMBS	Sodium metabisulphite
UF	Ultra-filtration

CHAPTER 1

1.1 Background information and an introduction

South Africa has a severe water shortage and is under increasing pressure to find environmentally and economically sustainable water resources. Acid Mine Drainage (AMD) is particularly detrimental to water quality in the mining sector (Nathoo et al., 2017). Hazardous metals are important pollutants today, and their disposal in waste streams must be minimized (Yasser & Ahmed, 2012). The most prevalent heavy metals include uranium, nickel, zinc, silver, lead, iron, chromium, copper, arsenic, and cadmium which are frequently found in industrial wastewater. However, in the construction, transportation, and electrical industries, copper is considered to be one of the most valuable and widely utilized all around the world (Al-Saydeh et al., 2017).

This study's main objective is on streams with copper contamination, copper is a dangerous element even at low concentrations, hence contaminated wastewater must be treated before being released into the environment. Copper removal from industrial wastewater has been tackled in a variety of ways during the past few years (Al-Saydeh et al., 2017), including chemical precipitation (Hu et al., 2017), adsorption (Alcaraz et al., 2020), electrochemical (Caprarescu et al., 2014), and membrane filtration (Ab Hamid et al., 2022). Membrane separation processes have progressed from basic laboratory equipment to industrial products with substantial technological as well as commercial significance (Nath, 2008). The aim of membrane separation technologies, especially NF, is to displace more common separation techniques to lower capital and operating costs (Mortazavi, 2008). The membrane technology offers many potential benefits to the mining industry, for instance:

- To recover and subsequently purify water to regulatorily standards, and this applies to any metallurgical process (Mortazavi, 2008).
- Recovery and recycling of reagents such as sulphuric acid from base metals process solutions; therefore, minimising the consumption of neutralising reagents is required (minimises lime consumption) (Fornarelli & Mullett, 2014) (Archer et al., 2014);
- Metal separation and concentration, separation of copper from cyanide-containing solutions with an upgrade of the latter (Lien, 2008);

Membrane technology is now widely used in industrial applications, because of the minimal pollutants it produces. As a result, the Best Available Technologies (BAT) manual for wastewater treatment encourages the use of membranes. There has been a rise in the use of membranes as a result of the development of new membrane processes and new membrane materials that are tailored to specific process specifications (Staszak & Karolina, 2023).

This study's objectives are to evaluate the efficiency of NF membranes for recovering clean water for reuse while eliminating copper from wastewater for environmental reasons.

1.2 Problem statement

Effluents and wastewater from copper mines and processing plants contain varying amounts of copper. To comply with environmental regulations and reclaim copper as a valuable metal that can be sold for additional revenue, waste should be treated for copper removal. To remove heavy metals from water, particularly copper, more efficient and affordable technologies must be developed.

Water filtration using membrane technology performed incredibly well, and during the past ten years, several installations have been made. Due to recent advancements, membranes can now be employed in harsh mining and metallurgical environments (low pH, high concentrations). It is anticipated that good membrane material performance and stability will lead to the implementation of separation, concentration, and purification steps of metallurgical flowsheets that aim to recover valuable metals from mine effluent streams.

1.3 Aim and objectives

The purpose of this study was to develop a treatment protocol for copper removal from dilute streams using NF membranes to reduce environmental impact. To achieve this goal, the following specific aim was undertaken:

- Test work on synthetic and real solutions for evaluation and optimisation of NF membranes process for copper removal including;
- Performance of different membranes,
- Solution composition,
- Operating parameters,
- Evaluation of the need and ways for a polishing step to produce clean water
- Mitigation of scaling,

1.4 Outline of the dissertation

Chapter 1

The introduction, background, problem statement, aim & objectives, and research hypothesis are all covered in this chapter.

Chapter 2

A literature review is presented in this chapter on membrane technology, the application of membranes in the mining industry, copper chemistry and copper mines in South Africa, and the environmental impact.

Chapter 3

This chapter discusses the experimental component of the research that was done using both synthetic and real solutions.

Chapter 4

This chapter presents the findings and analysis of the synthetic and real solutions screening test work and optimisation tests with a real solution.

Chapter 5

This chapter was comparing the performance of NF tested with the solution as is and after is treated with an ultrafiltration membrane looking at the pre-treatment impact.

Chapter 6

This chapter outlines the results and discussion obtained from the pilot run with a real solution using the DOW N90 membrane.

Chapter 7

This chapter highlights the conclusions, and recommendations of this study.

References and Appendix

References of all cited studies from the introduction and literature review. Appendix of all the conducted tests data, results, and mass balance

CHAPTER 2

2.1 Introduction

Understanding the principles of membrane technology is the major objective of this study because its use must process streams in the mining industry. Understanding membrane technologies and their capabilities enables one to foresee a variety of prospective uses for the technology, including the expansion into new and enhanced metallurgical processing or the improvement of existing processes that provide treatment problems to process and metallurgical engineers. The following topics for membrane technology were covered in the study.

2.1.1 Membrane filtration process

The following definitions provide an overview of the important concepts used in the membrane process:

- **Permeate**- a stream that contains penetrants or solvents that have left a membrane module.
- **Concentrate/reject** - a stream that has been stripped of any dissolved substances that downstream exit the membrane units without passing through the membrane.
- **Flow through a membrane**, Q- Feed flow is the rate at which feed solution is fed to the membrane system, and is typically measured in m^3/h. Concentrate flow and product flow are the rates of flow of non-permeated concentrate and permeated product leaving the membrane system, both measured in m^3/h.
- **Flux**, J - the rate of permeate carried per unit of membrane area, often measured in L/h.m^2

$$J = Q/A \qquad \text{Equation 1}$$

Critical flux is the maximum flux that can continuously be maintained without causing permanent fouling.

- **Permeability (P)**, the flow rate per membrane area per unit pressure difference, L/($m^{2\cdot}$h.bar)

$$P = \frac{Q}{A \cdot \Delta P} \qquad \text{Equation 2}$$

- **Recovery** is the amount of the membrane system's feed that is recovered or recovered as a product or permeate.

$$Rec = \frac{Q_p}{Q_f} \cdot 100 \qquad \text{Equation 3}$$

- **Rejection/retention**, Rej, which is expressed as a proportion of the solute concentration removed by the membrane from the system feed, describes the membrane's capacity to prevent some substances from going through.

$$Rej = (1 - \frac{C_p}{C_f}) \cdot 100 \qquad \text{Equation 4}$$

$$Rej = (1 - \frac{C_p}{C_r}) \cdot 100 \qquad \text{Equation 5}$$

Where

Component concentrations in permeate and feed are expressed as C_p and C_f, respectively, in milligrams per liter (mg/L). C_r: The component's concentration in retentate, expressed in mg/L. Selectivity of separation of component an over component b, S_{ab}:

$$S_{ab} = \frac{Rej_a}{Rej_b} \qquad \text{Equation 6}$$

Where

Rej_a = Rejection of component a

Rej_b = Rejection of component b

Figure 2.1 shows how the feed solution was separated into the permeate and retentate products (Vermaak et al., 2021). During the filtration, the material that the membrane rejected is what makes up the retentate, whereas the substance that passed through the membrane pores is what makes up the permeate.

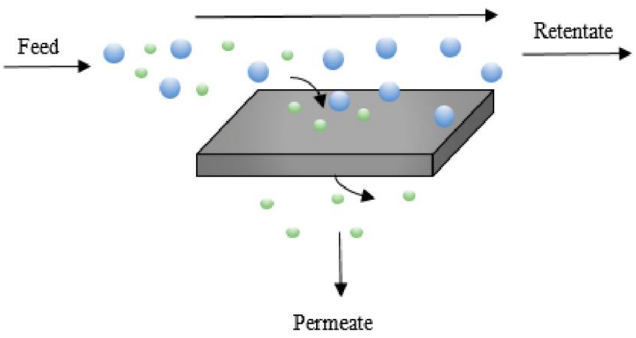

Figure 2.1: A straightforward membrane separation process

The permitted species is transported across the membrane matrix with the use of a driving force across the membrane forming the basis for categorising the membrane separation process. This classification is based on the type of force that propels mass transfer across the membrane which can be mechanical pressure, chemical concentration potential, temperature, or electrical potential according to Mortazavi, 2008.

2.1.2 Pressure-driven membrane processes

Figure 2.2 illustrates the four primary pressure-driven membrane filtration techniques in decreasing the order of pore size (Selatile et al., 2018). The pressure-driven membranes UF, NF, and RO are the most widely used membrane filtration types and are of interest for hydrometallurgy (Al-Saydeh et al., 2017)

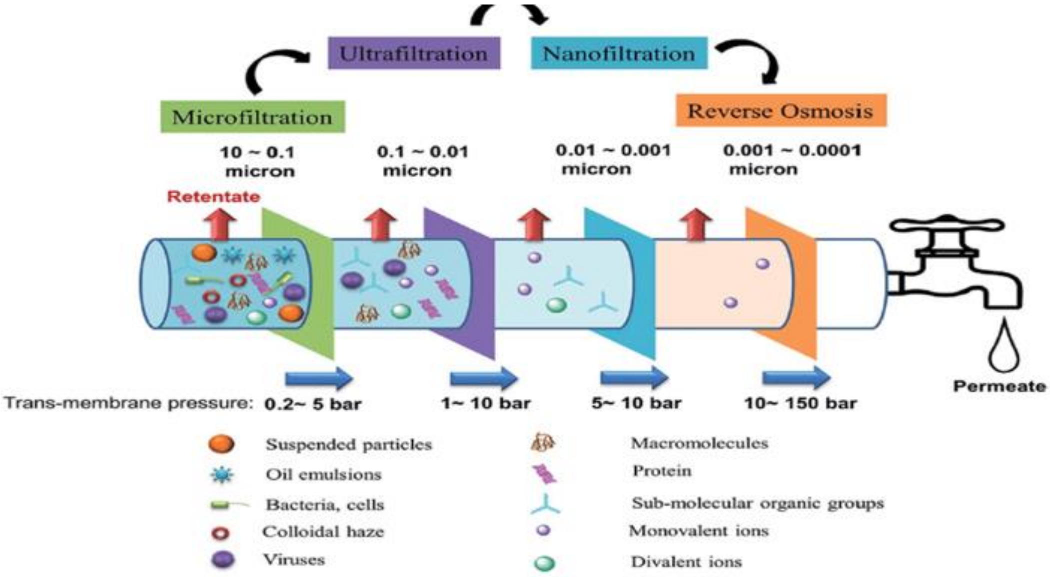

Figure 2.2: Type of pressure driven membranes

- **Microfiltration (MF)**

The pore diameters of MF membranes range from 0.1-10 microns (µ). The molecular weight cut-off (MWCO) of these membranes is larger than 1,000,000 daltons (Da). Hydraulic pressures used by MF range from about 100 to 400 KPa (1-4 bar). Sand, silt, clays, algae, and several bacterial species are among the substances that MF rejects (Mortazavi, 2008). MF can be used as a pre-treatment, with a typical flow of 200 L/h.m^2 or more for NF/RO membranes to lower the possibility of fouling (Marriott, 2011).

- **Ultrafiltration (UF)**

The MWCO between 10,000 and 100,000 Da are characteristics of UF membranes. The UF membrane maintains the mineral content in water input while acting as an efficient barrier for suspended particles, colloids, and pathogens because of its small pore size. (Aryanti et al., 2018). It has been demonstrated that when the metal concentration is between 10 and 112 mg/L, the pH is between 5 and 9.5, and the pressure is between 2 and 5 bar, UF can remove copper with an efficiency of more than 90%, depending on the membrane properties. (Gunatilake, 2015).

Since UF membranes are less dense than RO and NF membranes and thus more prone to fouling and pore-clogging, they operate at lower pressures of between 100 and 500 KPa (1-5 bar), with an average flow of between 2 and 200 L/h.m^2 (Marriott, 2011).

- **Nanofiltration (NF)**

Monovalent ions can pass through NF membranes (Ahmad et al., 2010) and the operating pressure can reach 40 bar with pores as small as 0.001 microns (Marriott, 2011). The NF membrane has many advantages, including low operating pressure, high flux, and high retention of multivalent anion salts and organic molecules greater than 300 Da. These advantages have increased NF applications worldwide (Hilal et al., 2004). Because the MWCO value is determined by rejection experiments, this characteristic is highly dependent on the solute and solvent properties, as well as the test operating condition (Patrizia et al., 2014).

- **Reverse Osmosis (RO)**

Water is the only substance that passes through the membrane during reverse osmosis (RO), which is designed to separate ionic solutes, metals, and macromolecules. The operating pressure of RO is normally between 15 and 150 bar, depending on the osmotic pressure of the solution (Lyndsey & Elke, 2018). Numerous researchers examined the effectiveness of the RO method for removing copper, and they discovered that high separation efficiency could be attained between 70 and 99.9% (Al-Saydeh et al., 2017). Table 2.1 summarises the characteristics of different membranes.

Table 2.1: Characteristics of different membrane types. (Van der Bruggen et al., 2003)

Membrane type	**Size exclusion,** nm	**Molecular weight cut-off**, Da	**Pressure range**, bar	**Flux,** L/(h.m^2)	**Permeability,** L/(h.m^2·bar)
MF	>100	>1000000	0.1-2	100-200	>1000
UF	5-50	1000-300 000	05-Jan	50-100	10-1000
NF	10-Jan	200 - 10000	20-Mar	15-30	1.5-30
RO	0.1-1	<200	5-120	15-30	0.05-1.5

2.1.3 Membrane materials manufacture and preparation

The majority of membranes were created using synthetic organic polymers (Sagle & Freeman, 2015). Although the same material is commonly used to make both MF and UF created under different conditions, leading to various pore diameters. Typical membrane materials for MF and UF include polyvinylidene fluoride, polysulphone, polyacrylonitrile, and polyacrylonitrile-polyvinyl chloride copolymers. Typically, RO membranes are either polysulphone covered with aromatic polyamides or cellulose acetate mixes (Sagle & Freeman, 2015). NF membranes can be produced from both polymeric and inorganic materials, but to produce membranes with a long lifespan, these materials must possess strong mechanical, chemical, and thermal stability (Patrizia et al., 2014).

- **Polymeric membranes** (Patrizia et al., 2014)

To ensure mechanical stability, the majority of polymeric membranes are produced on a nonwoven backing material. Both the Thin Film Composite (TFC) and Integrally Skinned Asymmetric (ISA) membranes are the two primary varieties of polymeric membranes, and they are both seen in Figure 3 (Marchetti et al., 2014). A skin layer is found on top of a more porous sublayer in ISA membranes (Figure 2.3, a). The underlying support layer and upper skin layer are both developed simultaneously. The thin skin layer affects how the membrane ultimately performs, or its selectivity and permeance.

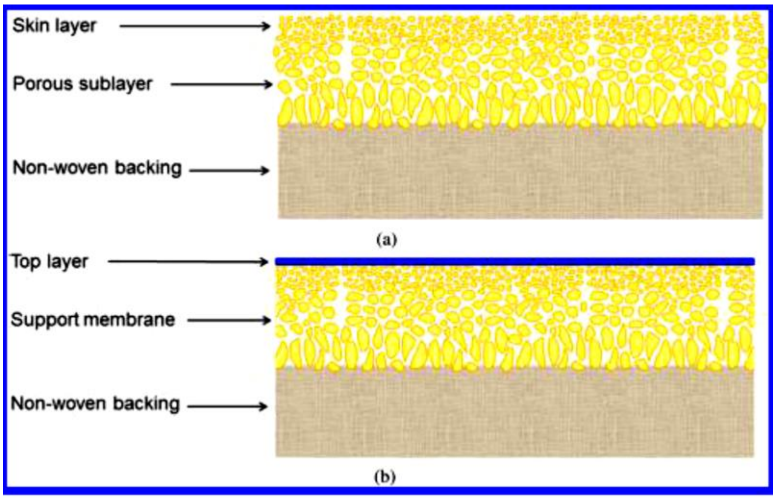

Figure 2.3: (a) ISA membrane and (b) TFC membrane schematics

A very thin "separating layer" is cast on a porous surface substrate with a unique chemical composition to create TFC membranes (Figure 2.3, b) The membrane has a particular layered structure that makes it feasible to independently modify the porous support's chemistry as well as its effectiveness to enhance the membrane's overall performance (Patrizia et al., 2014).

- **Mixed Matrix Membranes** (MMM) (Patrizia et al., 2014).

Mixed Matrix Membranes are organic-inorganic hybrid polymers created to combine the advantages of both polymeric and inorganic materials. ISA or TFC membranes can be used to produce MMMs. Three alternative techniques can be utilized to change membranes using nanoparticles:

- before the phase inversion procedure, nanoparticles are added to the casting solution;
- nanoparticles are deposited on the membrane's surface; and
- Inserting nanoparticles into the polymeric membrane's pores.

Adding nanoparticles to membranes often results in higher flow rates and mechanical stability without lowering rejection. However, time and stress can affect permeance.

- **Ceramic membranes** (Patrizia et al., 2014).

The majority of ceramic NF membranes on the market are composed of metal oxides including alumina, zirconia, titania, or a combination of oxides. By using suspension coating, a thin layer is placed on a porous ceramic support, possibly with one or more intermediate layers. The porous inorganic support determines the mechanical stability and outward shape of the membrane. The most tightly packed hydrophilic NF ceramic membrane available today has an MWCO of 450 g/mol and is constructed of TiO_2 with 0.9 nm pores (obtained in water). Figure 2.4 illustrates two possible membrane configurations: flat sheet and tubular (Drioli et al., 2006). There are three types of tubular membranes: hollow fibers (fiber diameter 0.5 mm), capillary (0.5-10 mm), and tubular (>10 mm). (Drioli et al., 2006).

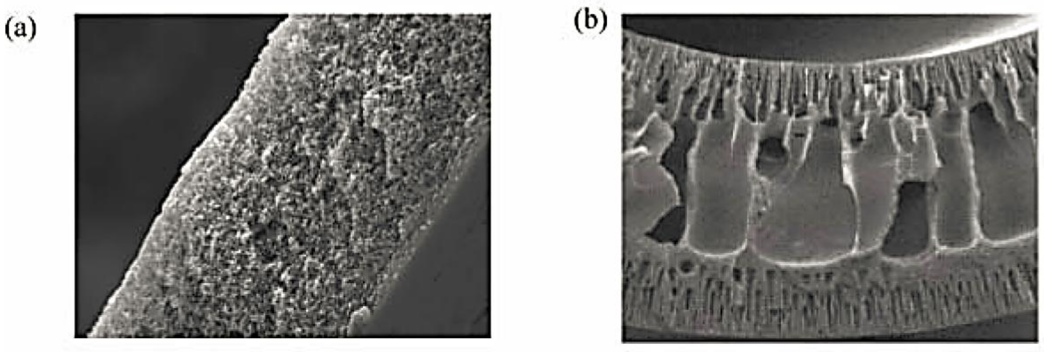

Figure 2.4: Images from scanning electron microscopy (SEM) of a flat sheet (a) and a hollow fiber (b) membrane cross section

2.1.4 Membrane modules

The membrane filtering system's performance is greatly influenced by the configuration of the membrane modules since it affects the packing density and feed flow patterns (Barambu et al., 2021). A module is the smallest component of a membrane unit, consisting of a specified membrane surface area housed in a device with a filtrate output structure. Modules are classified into four categories:

- Plate and frame
- Spiral wound
- Tubular
- Capillary
- Hollow fibre

The fundamental characteristics of various module configurations are listed in Table 2.2. Using a dead-end filtration stirred cell and a spiral-wound Kivu membrane pilot unit, the flat sheet membranes (plate and frame) and spiral wound were studied.

Table 2.2: Properties of different module configurations (Darunee et al., 2002), (Brouckaert & Buckley, 1992).

Properties	**Plate and frame**	**Spiral wound**	**Tubular**	**Capillary**	**Hollow fiber**
Packing density, m^2/m^3	100-400	300-1000	<300	600-1200	up to 30 000
Specific surface area, m^2/m^3	-[1]	1000	300	-	15 000
Inside diameter or spread, mm	-	4-20	20-50	-	0.5-2
Flux, $L/m^2/day$	-	300-1000	300-1000	-	30-100
Production, m^3/m^3 per module & day	-	300-1000	100-1000	-	450-1500
Space velocity, cm/s	-	25-50	100-500	-	0.5
Pressure loss, bar	-	1-2	2-3	-	0.3
Pre-treatment	-	medium	simple	-	high
Replacement	-	difficult	easy	-	impossible
Fouling tendency	low to moderate	med-high	low	high	very high
Ease of cleaning	good	poor to good	good to excellent	poor	poor
CAPEX	high	med-high	high	low	low
OPEX	high	moderate	high	low	low

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[1] - Not provided

2.1.5 Operating configuration of membrane filtration units

Figure 2.5 illustrates schematically the numerous ways that a filtration process can be operated (Munir, 2006).

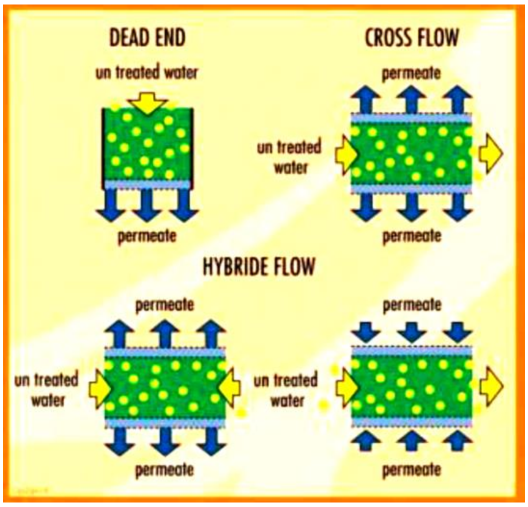

Figure 2.5: Representation of various configurations for operation of membrane filtration

- **Dead end filtration**

The most fundamental type of filtration is dead-end filtration. Dead-end filtration's primary goal is to have the feed flow direction parallel to the membrane surface (Marriott, 2011). When the concentration of particles to be removed is minimal or the tendency of the filtered material to pack compactly prevents a significant pressure drop across the filter media, this works well. Clogging is a problem that frequently arises with dead-end filtration. When molecules bind to the membrane surface and increase the operating pressure, they block the flow and reduce flux because they are larger than the membrane pores (Darunee et al., 2002).

- **Cross-flow filtration** (Basile & Nunes, 2011)

Many different process streams contain significant amounts of particles or macromolecules. These process streams might contain cells, proteins, and precipitates. During dead-end filtering, the particles or macromolecules condense on the filter surface. The filtration rate thus falls sharply and rises to an unacceptable level. In these circumstances, you can maintain constant filtration rates thanks to a crossflow membrane system. By sustaining a constant turbulent flow along the membrane surface, cross-flow filtration prevents materials from building up on the membrane surface. The design of a crossflow system depends on choosing a membrane geometry that corresponds to the physical characteristics of the process fluid. There are several different designs of crossflow membranes, including hollow fiber, flat sheet, spiral wound, and tubular, each of which offers certain benefits.

- **Hybrid flow filtration** (Basile & Nunes, 2011)

The cross-flow and dead-end principles are combined in the hybrid flow process. Tubular membranes are utilized with the filtering layer on the inside of the walls, just like in cross-flow filtration. The filtration process has two stages: production and flushing. Throughout the production phase, the tubes are closed on one side and a dead-end filtration is carried out. When the tube is open on both sides, the fraction that did not pass through the membrane is eliminated during the flushing phase, just like in cross-flow filtration. This filtration method is particularly effective at processing water streams that have modest quantities of suspended particles.

- **Submerged filtration** (Basile & Nunes, 2011)

As presented in Figure 2.6, the membranes are immersed in the liquid that needs to be filtered (Triqua International bv, n.d.).

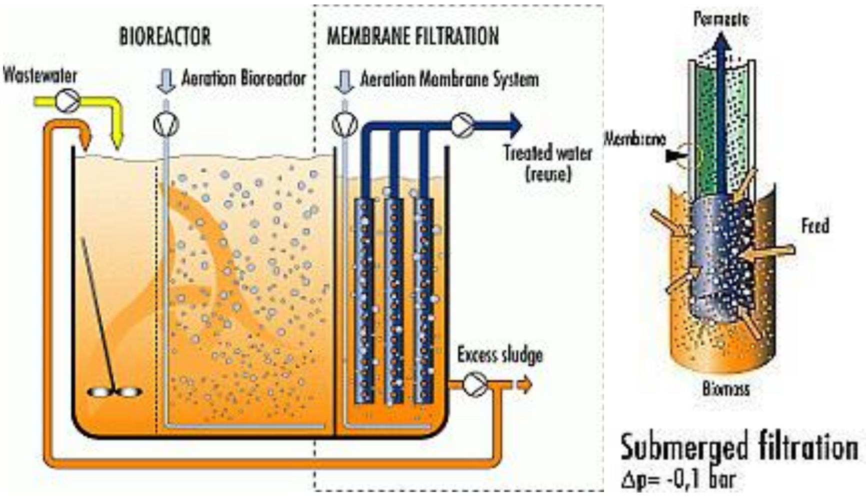

Figure 2.6: Submerged membrane filtration

The membrane's exterior and inside are used for the filtration process. Shear forces are produced along the membrane by the surface movement of air bubbles. The airlift concept can occasionally cause a liquid flow in addition to the airflow. A vacuum that is applied to the membrane's inner side acts as the driving force.

2.1.6 Transfer through membranes and Mechanisms of separation

According to the solute's and membrane's physicochemical characteristics, charge repulsion, dielectric exclusion, and solution diffusion, separation can be achieved using one or more techniques, such as sieving. These mechanisms are the basis for numerous models which are widely used to predict membranes performance.

- **Sieve mechanism**

According to the sieve's working principle, a particle will pass through a pore if its diameter is less than that of the pore itself. The membrane delays the particle blocks the pore and increases the membrane's hydrodynamic resistance if the particle diameter is greater than the pore diameter. A membrane will easily allow particles smaller than its pores to pass through. Uncharged molecules are retained mainly by the sieving process, and they are transported across the membrane via diffusion and convection due to concentration gradients and pressure differences, respectively (Starov et al., 2002).

- **Solution diffusion mechanism**

The accepted mechanism of transport through membranes is called the solution diffusion model. The solution diffusion model is the widely accepted mechanism of membrane transport. Solutes permeate the membrane by dissolving in the membrane material and diffusing down a concentration gradient (Baker, 2004), as illustrated in Figure 2.7 (http://molit.concord.org). The difference in solubility and mobility of different solutes in the membrane causes separation. Because certain molecules are soluble in the membrane material, they pass through it. Other molecules are not (or are less) soluble and are retained (or concentrated) on the membrane's upstream side (Baker, 2004).

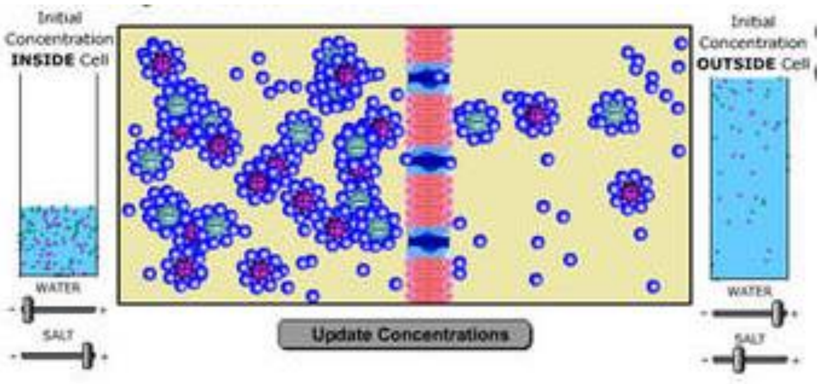

Figure 2.7: Solution diffusion mechanism

- **Exclusion mechanisms in NF**

The mechanisms of transport and exclusion in NF are more complex than in other types of filtration. The majority of NF membranes are electrically charged. As a result, their separation mechanisms include not only size exclusion but also electrostatic effects, as shown in Figure 2.8 (https://encyclopedia.pub).

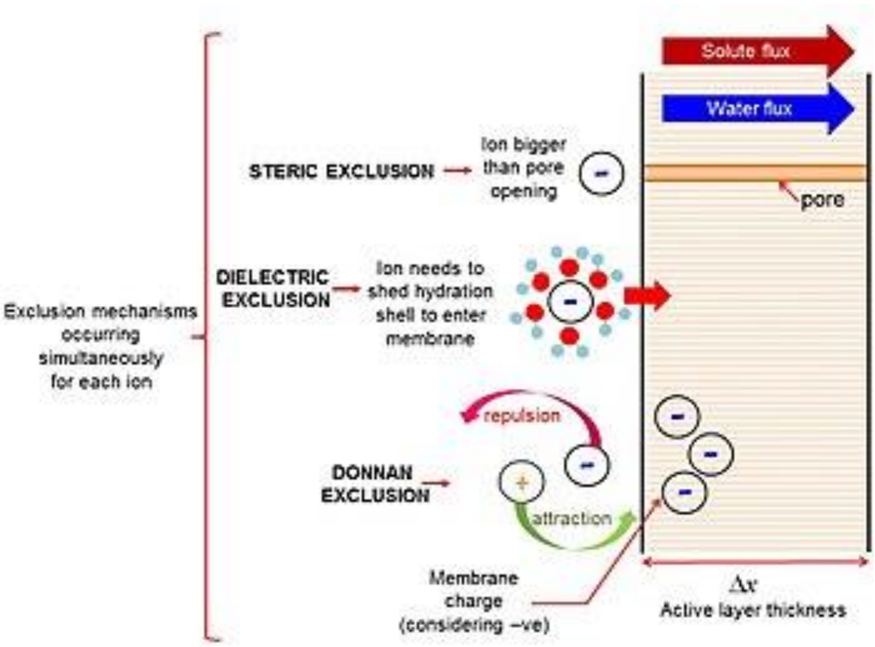

Figure 2.8: NF exclusion mechanisms

The effects of hydration should also be considered, in which molecules in solution have a solvation shell of surrounding water molecules. The exclusion caused by hydration is known as dielectric exclusion because the dielectric constant of the solvent changes as it moves from the solution to the membrane phase. Higher hydration energy ions are more retained because it takes more energy to extract these ions and push them into the pores than lower hydration energy ions. An electrostatic interaction occurs between the charged component and the membrane (Tu, 2013).

The Donnan exclusion mechanism of NF membranes allows for the rejection of charged solutes with diameters much smaller than the pores. This charging action can be used, in particular, to separate ions according to their ionic valences and remove ions from wastewater. According to the Donnan steric pore-flow model, Figure 2.9 shows two typical membrane rejection profiles: one for uncharged solutes and the other for membranes with uniform pore sizes (rp between 0.75 and 1.5 nm). The solid line represents the desired rejection profile, while the dotted lines were obtained through simulation. Optimal rejection patterns include an acute distinct line with a sharp change in rejection or a broad curve with a gradual increase in rejection across a wide range of solute sizes (light blue line) (dark blue line) (Patrizia et al., 2014).

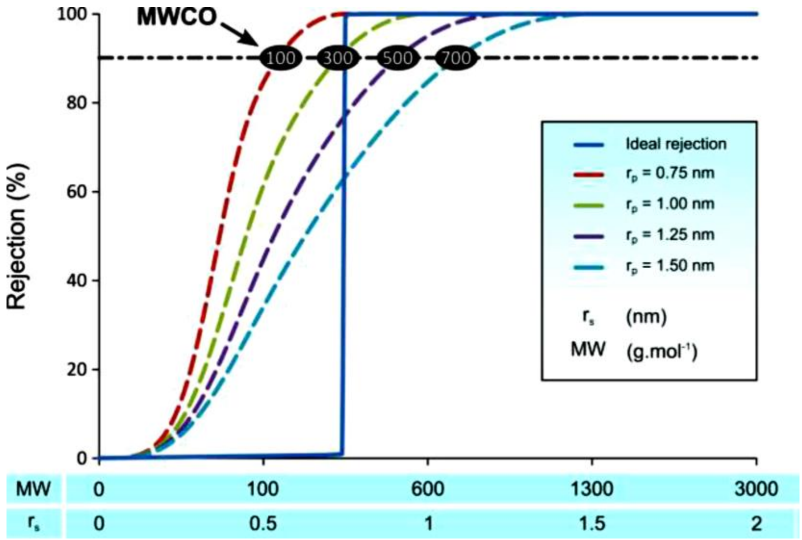

Figure 2.9: Diagram showing the rejection profile for uncharged solutes

- **Concentration polarisation**

A significant phenomenon in membrane science and technology is concentration polarisation. It refers to the reversible formation of concentration gradients at the membrane/solution interface brought on by the selective translocation of certain species under the control of transmembrane driving forces. At the upstream membrane surface, the concentration of retained species rises while that of transported species falls. As a result of competition between the convective transport of solute towards the membrane and the diffusive transport away from the membrane, an area near the membrane with a higher concentration of solute develops at a steady state Figure 2.10 (Luis, 2018).

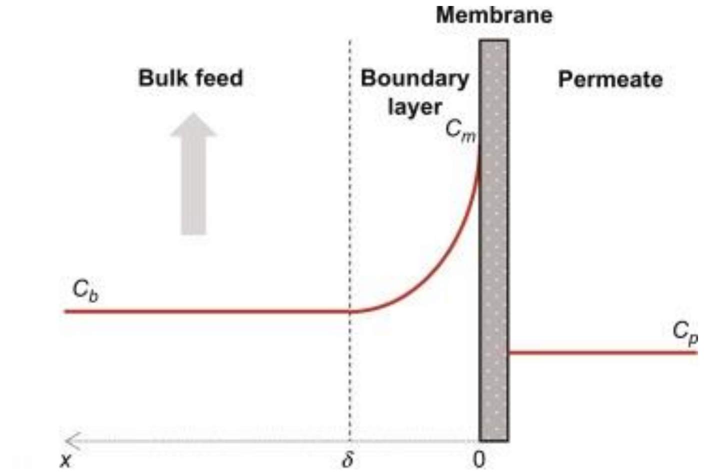

Figure 2.10: Concentration polarisation

Concentration polarisation has a significant impact on the performance of separation processes. It reduces the driving force within the membrane, thereby lowering the useful flux/rate of separation. The osmotic pressure gradient in the membrane increases as a result of this phenomenon, which reduces the net driving pressure gradient in pressure-driven processes. More power is consumed when the separation rate is lower under the same external driving force. Furthermore, concentration polarisation increases salt leakage through the membrane, decreasing selectivity and increasing the likelihood of scaling/fouling (Bhattacharjee, 2017).

2.1.7 The performance of NF membranes is affected by certain factors

Some operational conditions must be considered when designing an NF process. The key operational factors influencing NF membrane performance are as follows. The material of the membrane is one of the factors influencing its performance. The material determines membrane stability (thermal, mechanical, and chemical), pore size, membrane charge, hydrophobicity, roughness, concentration polarization at the membrane face, and fouling.

- **Membrane properties**

Their performance is significantly influenced by the type of membrane used and the size of the pores. Some critical parameters, such as membrane charge along the surface and through the pores, are involved in the transport mechanism via the NF membrane. Several mechanisms can be used to charge membranes. These mechanisms may include functional group dissociation, ion adsorption from solution, polyelectrolytes, ionic surfactants, and charged macromolecule adsorption. This charging mechanism can occur on both the exterior and interior pore surfaces of the membrane. Due to the system's electroneutrality requirement, these surface charges influence the distribution of ions in the solution. This results in the formation of an electrical double layer composed of a charged surface and a counter-ion-neutralizing excess in the adjacent solution (Tu, 2013).

- **Pressure**

NF process is driven by pressure difference. At net pressures of 10 bars and above, the NF offers strong separation because the effective driving pressure is equivalent to the hydraulic pressure far less than the osmotic pressure the solutes impose on the membrane (Abhang et al., 2013).

- **Temperature**

Because of the decrease in solution viscosity, raising the process temperature raises the flux through the NF membrane. The process temperature does not, however, have a significant effect on NF membrane rejection (Abhang et al., 2013).

- **Cross-flow velocity**

Increasing the cross-flow velocity in an NF membrane process may improve the average flux due to the efficient removal of the fouling layer from the membrane surface. However, the membrane's mechanical strength, along with the hardware design of the component and system, will dictate the highest cross-flow velocity that may be used. An NF membrane may fail early if it is operated at an excessively high cross-flow velocity (Abhang et al., 2013).

- **pH**

The pH could have multiple effects on how well NF membranes work. The charged sites on the NF membrane surface (carboxylic and sulfonic groups) are negatively charged at neutral pH or higher but become neutral at acidic pH. As a result, it is possible to assert that most NF and RO membranes reject less at low pH or after an acid rinse. However, because different membrane manufacturers use different chemistries to create their thin film composite layer, it is important to note that the pH dependency of a membrane should be established for each membrane type. Aside from its effect on the membrane, pH can also change the composition of the feed solution, affecting the membrane's performance (Abhang et al., 2013).

- **Ionic strength**

As the ionic strength of the surrounding liquid increases, a charged pore's effective pore radius grows. When their concentration in the feed solution increases, monovalent ions will consequently be rejected less frequently. Although there may be a few minor adverse effects, divalent ions may still be rejected (Abhang et al., 2013).

2.1.8 Membranes fouling

Fouling is the deposition of trapped particles, colloids, macromolecules, salts, and other substances on the membrane surface and/or aggregation in the pores, which leads to a partial or complete blockage of the pores and a steady decrease in flow (Macedo et al., 2018). Due to the elevated salt concentration in the vicinity of the membrane brought on by concentration polarisation, scaling always takes place at the membrane surface. In addition to being crucial for metallurgical applications, this kind of fouling is a key challenge for RO and NF membranes. Figure 2.11 illustrates how, in a concentrated state, ions, and cations are drawn toward one another and begin to take on shapes as they get closer to one another physically (Stephen et al., 2016).

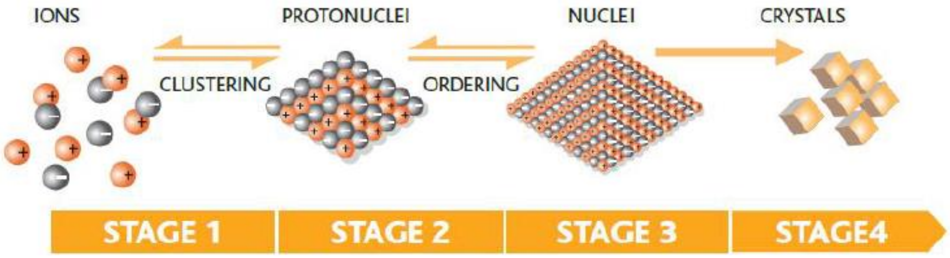

Figure 2.11: Scaling process

Membrane composition and characteristics can affect membrane fouling. In general, fouling may be less likely on membranes with smoother, more hydrophilic surfaces. The higher roughness of these membranes is principally responsible for the more severe fouling (Qianhong et al. 2016). Fouling is an irreversible process and it is important to minimize and/or delay the process. Methods that are used to control fouling fall into three broad categories:

- Pre-treat or customize membranes
- Change operation parameters and
- Modify or pre-treat the feed solution

2.2 Applications of NF in the mining industry: case studies

Numerous case studies involving membrane separation procedures in the mining industry have been published in the past 10 to 15 years. Below is a brief discussion of a few of them.

2.2.1 Acid purification

Acids have been recovered from hydrometallurgical streams using methods such as distillation, ion exchange (IX), solvent extraction (SX), and NF. When compared to other techniques, NF offers several favourable features, including the recovery of pure acid, less water usage, separation, and concentration of commodity metals (Mullet & Fornarelli, 2014).

By recovering a pure acid solution, acid recovery strives to recycle and reuse acids throughout the extraction process. Because it has a low acid rejection, usually 10%, and a high rejection of multivalent cations, NF is suitable for acid purification (Manis et al., 2003). The benefits and drawbacks of using NF membranes to recover acid from different acidic streams are summarized in Table 2.3.

Table 2.3: Advantages and disadvantages of using NF membranes for acid recovery (Mullet & Fornarelli, 2014)

Advantages	**Disadvantages**
Recovery of purified acid at full acid strength enabling direct recycling to leach or elution	Metals are not selectively recovered in the concentrate
Separation and concentration of commodity metals	Limited by osmotic pressure (concentration of metals)
Reduced water consumption and downstream capital	Flux decay, membrane fouling potential
Versatile membrane options: effective in both ionic as well as molecular filtration	Need to use acid resistant/ stable membranes
Low acid rejection (<10%) enables a high mass flow to the permeate	Extensive Pre-treating is required to remove suspended particles

2.2.2 Copper recovery from sulphuric acid

Australian Nuclear Science & Technology Organisation (ANSTO) investigated the NF method for copper removal from sulphuric acid (0.002 to 2 M). Experiments on synthetic solutions were carried out using a cross-flow membrane filtering device. The evaluation of two acid-resistant flat sheet NF membranes revealed that copper retention decreased with increasing acid concentration due to membrane charge effects. The permeate flux decreased as the feed acid concentration increased due to an increase in solution viscosity. These membranes' lifespans are reduced at acidic conditions, as demonstrated by membrane stability studies, and neither membrane is likely to be able to support applications where (H_2SO_4) ≥ 2 M (Manis et al., 2003).

2.2.3 Membrane technology being used in a base metal refinery (Nel et al., 2013)

Spent nickel electrolyte with a composition of 50-60 g/L nickel (Ni) and 25-40 g/L sulphuric acid (H_2SO_4) was subjected to NF testing for treatment before being recycled into the leach circuit. According to the current process configuration, which is shown in Figure 2.12, the used nickel electrolyte is treated before being recycled back into the leaching circuit, and this process comprises four main process units. The existing process' principal flaw is the substantial amount of caustic soda that is required to produce a sodium sulphate by-product that is economically priced. The benefits of the current method include the efficient removal of excess sulphur in the form of sodium sulphate and the removal of water (Nel et al., 2013).

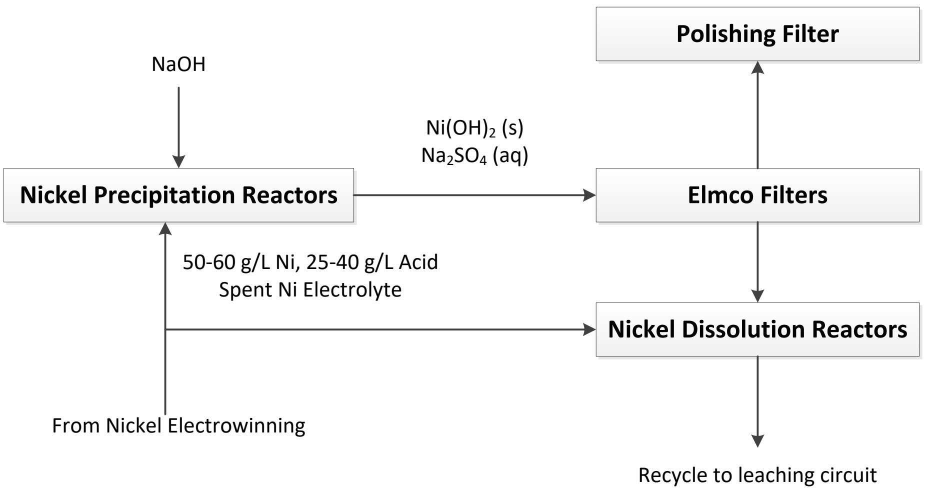

Figure 2.12: Nickel recovery section at base metals refinery

As shown in Figure 2.13, one NF unit substitutes the four processes that are now required for nickel concentration and recovery in the alternative process for nickel recovery from the used electrolyte (Nel et al., 2013). While the permeate is recycled back to the leaching circuit to reduce the overall sulphuric acid consumption of the base metal refinery, the concentrated nickel in the retentate stream is recycled back to the nickel electrowinning tank house along with the sodium sulphate to ensure conductivity within the electrowinning cells.

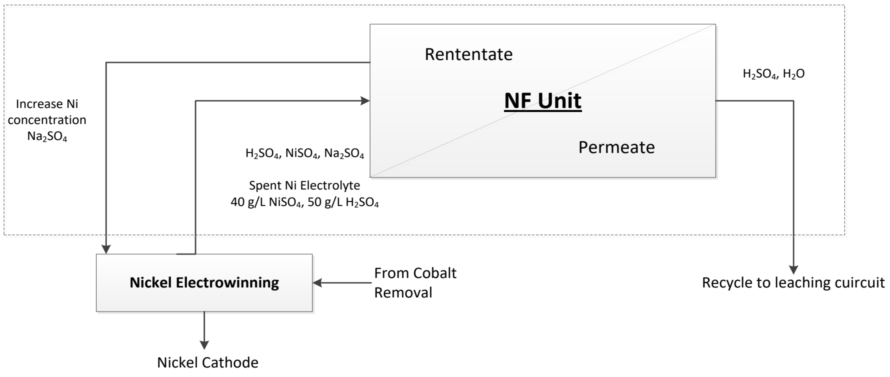

Figure 2.13: Alternative flowsheet with NF

According to this investigation, the following rejections can be accomplished at 2.5 m/s cross-flow velocity and 50 g/L sodium sulphate content in the feed solution (Nel et al., 2013):

- Nickel - between 54.4% and 98.2%;
- Acid - between -5.9% and 21.8%;
- Sodium - between 16.6% and 72.4%.

Nickel, sodium, and acid ions were more strongly rejected by a rise in transmembrane pressure than they were by an increase in sodium sulphate concentration. It was discovered that the total permeate flux rose with rising transmembrane pressure and fell with rising sodium sulphate concentration.

Nickel, sodium, acid ions, and the overall permeate flow rejection were both unaffected by the cross-flow velocity. Although there was no economic analysis provided, the performance of NF in this particular application appeared to be promising (Nel et al., 2013).

2.2.4 Membrane filtration performance in copper-gold cyanide systems

The successful use of membrane technology for the recovery of cyanide and copper cyanide from gold leach solutions was reported by HW Process Technology Inc. (HWPT) in 2008. (Lien, 2008). Figure 2.14 illustrates the separation principle (Lien, 2008).

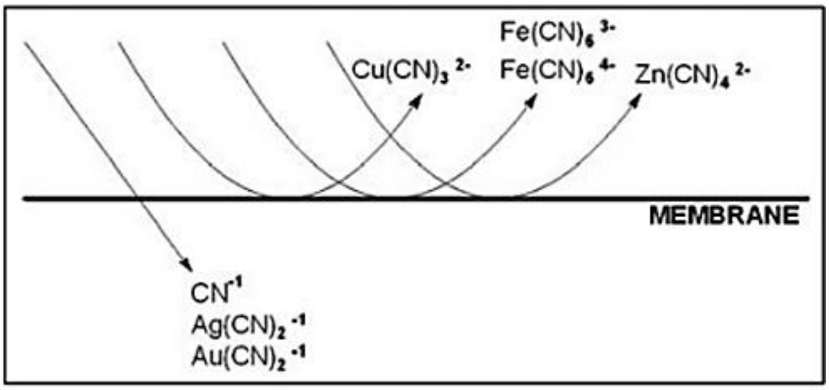

Figure 2.14: HWPT copper-gold membrane split

They recommended incorporating the EMS® or Engineered Membrane Separation method into a typical flow sheet for recovering gold from ores with significant copper content, as presented in Figure 2.15 (Lien, 2008).

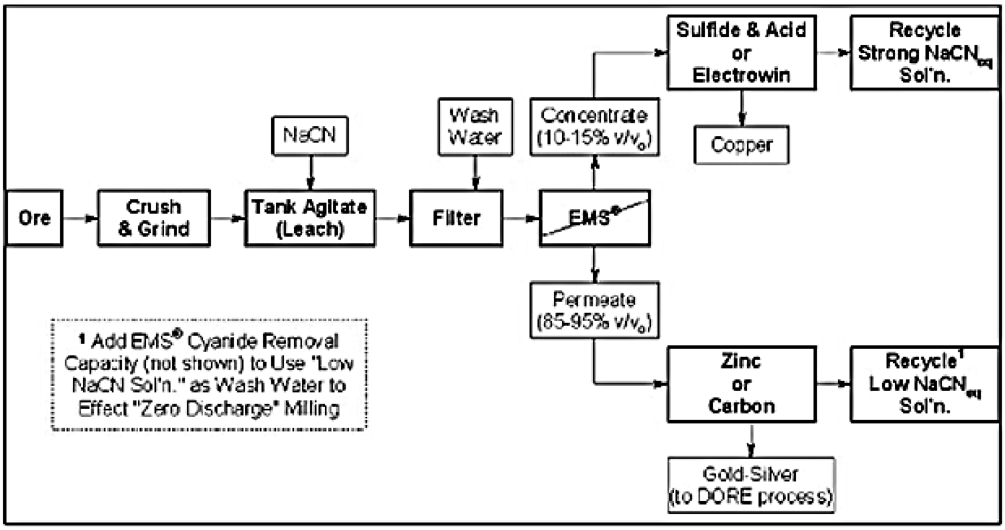

Figure 2.15: Typical EMS® copper-gold flowsheet

The EMS® method typically yields a 90% by-volume gold-silver free cyanide carrying permeate and a 10% by-volume cyanide salt concentrate. In South Africa, NanoReTech Systems (Pty) Ltd is actively promoting a similar idea for the treatment of dumps located in Sub-Saharan Africa that contain base metals and Au/PGMs (NanoReTech Systems (Pty) Ltd, 2014).

2.3 Copper chemistry, extraction, and pollution

This chapter concentrated on copper chemistry in mining, the environmental damage caused by copper pollution, and South Africa's major primary copper mines. The mining industry frequently uses water from rivers, lakes, boreholes, or pipelines for ore transportation and processing, and the industry also generates aqueous waste streams contaminated with heavy metal ions (Ibrahim & Mohamed, 2012).

2.3.1 Copper's physical and chemical characteristics

The chemical element copper has an atomic weight of 63.54 g/mol, an atomic number of 29, and a density of 8.94 g/cm^3. The natural abundances of the two stable isotopes of copper, 63 copper, and 65 copper, are 69.2% and 30.8%. (Nordberg et al., 2007).

As presented in Figure 2.16 (Gambino et al., 2008) copper can be found in oxidation states +1, +2, +3, and Cu (0), which is relatively stable but can dissolve in both sulphuric and nitric acids. When exposed to oxidizing conditions, the cuprous Cu (I) ion becomes unstable. In hydrophilic and oxidizing conditions, Cu (II) is the most prevalent oxidation state and is stable in most situations. Cu (III) has relatively little biological importance and is highly unstable (Nordberg et al., 2007).

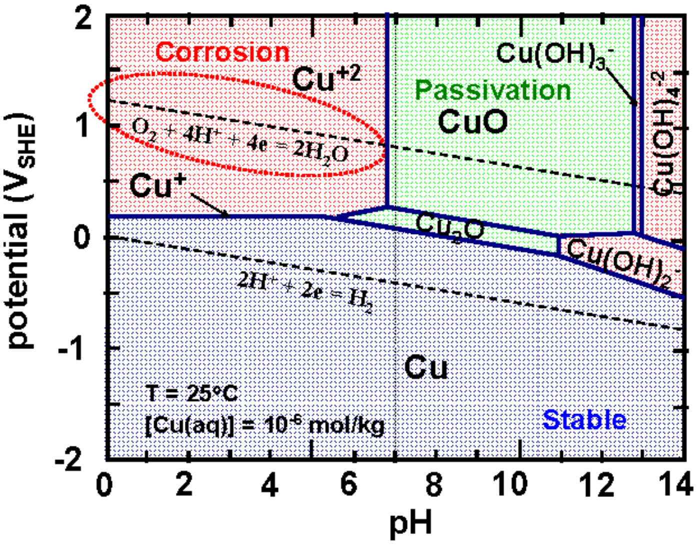

Figure 2.16: Pourbaix diagram for copper at 25°C

2.3.2 *Copper processing*

It takes two types of ores to produce 99.99% copper compounds which include oxide and sulphide. The production starts mining the ore with less than 1% copper content and comes to an end with 99.99% copper. Copper is recovered from the ores using a variety of techniques depending on the chemistry of the ore. Low-grade copper is treated by hydrometallurgy (Stanley et al., 2015). These processes involve four primary phases of aqueous solution extraction and purification of copper:

- Metals are taken out of the environment by leaching (L),
- Copper is upgraded through ion exchange (IX) and solvent extraction (SX),
- A type of electrolysis known as electrowinning (EW) helps produce copper that is 99.99% pure

A simplified diagram of the hydrometallurgical treatment of copper oxide ore is presented in Figure 2.17 (Savov et al., 2012).

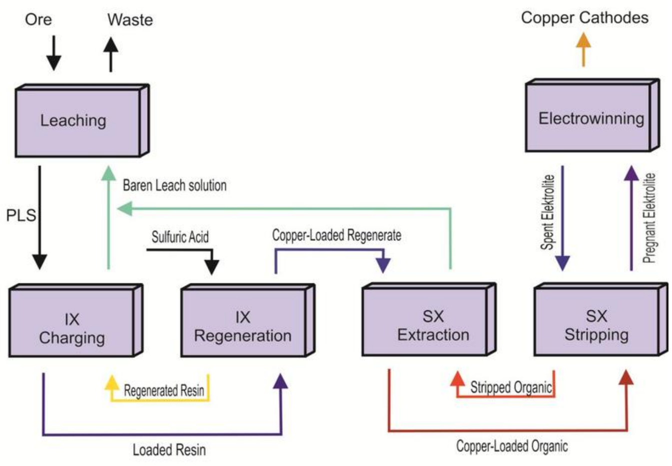

Figure 2.17: L/IX/SX/EW simplified process flowsheet for oxide ore

On the other hand, sulphide ore with greater copper contents present in the form of chalcocite (Cu_2S) chalcopyrite ($CuFeS_2$), and covellite (CuS) are typically processed using the pyrometallurgy process (Stanley et al., 2015). Figure 2.18 schematically shows how to extract copper from Cu-Fe-S ores using the typical pyrometallurgical method (Sohn, 2014).

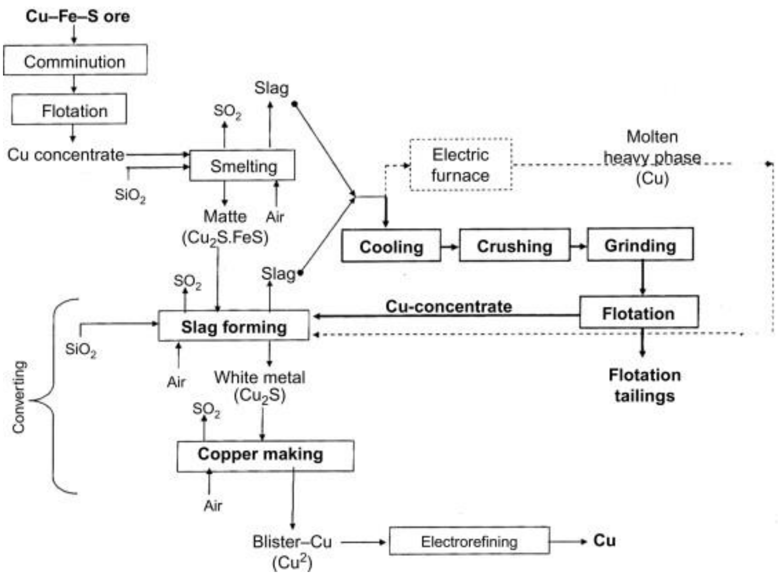

Figure 2.18: Typical pyrometallurgical process for extracting copper

The pyrometallurgical process involves mining, crushing, grinding, concentrating, smelting, and refining copper ore. In the ore, copper minerals are separated from the gangue particles which may contain 0.5% copper in the concentrating operations to create a concentrate that contains 27% to 36% copper. During the smelting process, the copper and iron sulphides are heated to high temperatures and oxidized producing impure molten metallic copper (97-99%). The iron oxide is subsequently disposed of as slag after the impure copper has been electrolytically cleaned to 99.99% purity (William, 2001). Impure copper anodes high-grade copper cathodes and a copper (II) sulphate electrolyte are all used in the purifying process

An electrolytic copper refining cell is presented in Figure 2.19 (Rajan & Rahul, n.d.). At the anode, one copper ion enters the solution for everyone that is deposited at the cathode. The cathode swells and the anode breaks down as more pure copper is provided. It isn't quite as simple in reality because of the pollutants involved (Jim, 2019).

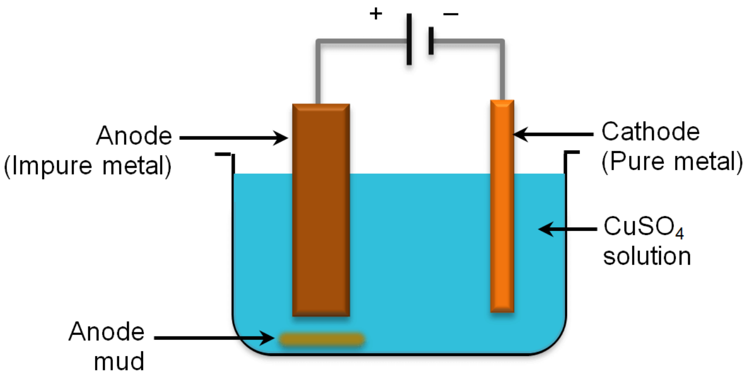

Figure 2.19: Electrolytic copper refining cell

2.3.3 Copper waste, pollution, and toxicity

The ecosystem in the mining area may be negatively impacted by mine wastewater and tailings resulting in contamination of soil, water, and air. Acid mine drainage (AMD) occurs when sulphides in mining waste react with oxygen and water, creating an acidic environment. The acid produced may dissolve minerals from the waste that contain hazardous metals, including copper (Larsson et al., 2018). Figure 2.20 illustrates the significant environmental impact of copper contamination (Belema, 2017).

Figure 2.20: Environmental effect of copper pollution

Figure 2.21 (Belema, 2017), illustrates copper's bio-toxic effects on human health and related concerns of water and soil contamination by heavy metals like copper (Singo, 2013).

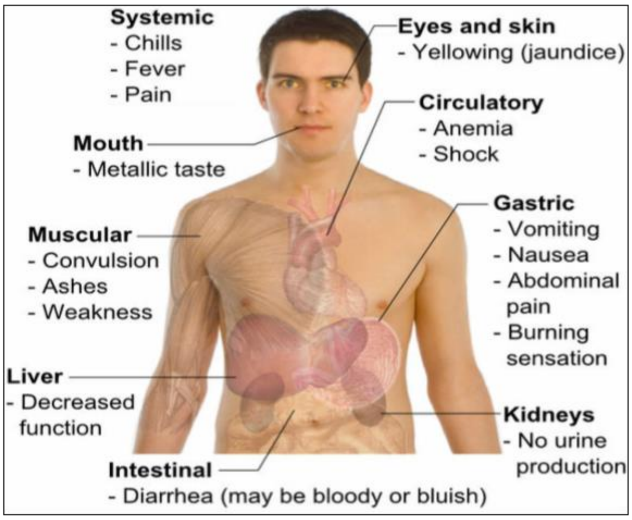

Figure 2.21: The most severe symptoms of copper poisoning in humans

The toxicity of copper can harm fish, invertebrates, plants, and amphibians. When an organism is subjected to chronic toxicity, its chances of survival, reproduction, and growth may be compromised (EPA, 2008). The maximum permitted concentration of a copper ion in drinking water, according to the World Health Organization (WHO) and Environmental Protection Agency (EPA) standards, is 1.3

mg/L (U.S, 2004). Table 2.4 lists the restrictions for a copper pollutant under the laws of South Africa (SANS-241-1:2015) and Mozambique (DM-180/2004) (Verlicchi & Vittoria, 2020).

Table 2.4: Guidelines for copper in drinking

Contaminant	Unit	South Africa	Mozambique
Copper	µg/L	≤ 2000	1000
pH (25°C)		5-9.7	6.5-8.5

In 2019, Health Canada issued new maximum acceptable concentrations (MAC) for copper in drinking water. They also changed the sampling protocols and moved the compliance point from the drinking water distribution system to the customer's faucet. A new MAC of 2 mg/L (2000 µg/L) for copper was introduced, and the aesthetic objective (AO) of 1 mg/L (1000 µg/L) was reaffirmed (novascotia, 2022).

2.4 Copper mines in RSA mining industries

2.4.1 The major primary copper producers in South Africa

- **Musina copper mine**

The Artonvilla, Spence, Messina, Harper, and Western Campbell mines are five distinct mines that were scattered along an East-Northeast trending line near Musina, Limpopo. The Musina plant produced 10,000 tonnes of copper per year. The ore was processed using the flotation technique, currently, the mine is not in operation (Figure 2.22) (Wilson et al., 2018). Musina's abandoned copper tailings disposal site has been subjected to weathering for the past 25 years (Wilson et al., 2018).

Research on the abandoned Musina Copper Mine tailings revealed significant concentrations of readily extractable copper, indicating that exposure to the tailings could endanger human health and the environment (Gitari et al., 2018).

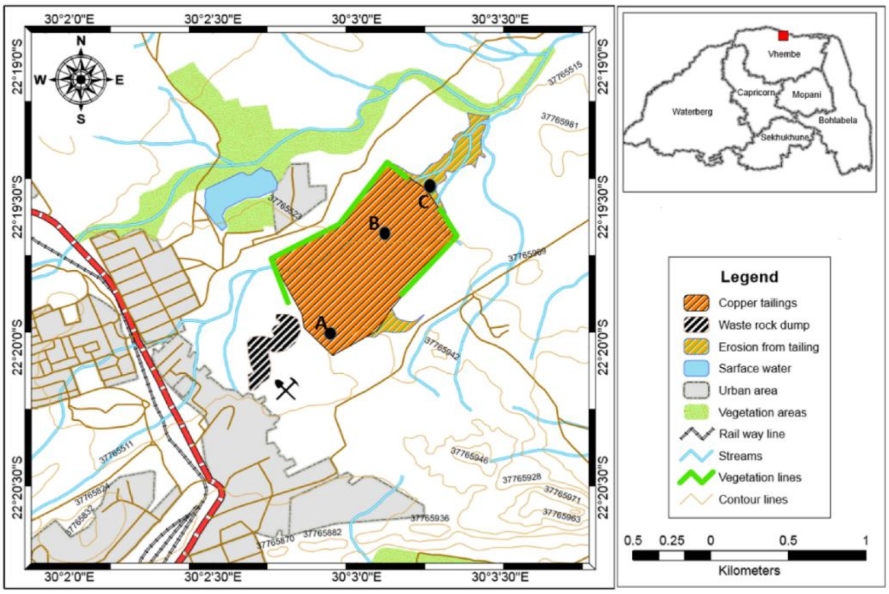

Figure 2.22: Musina location of abandoned copper tailings dumps

Ogola and Sebola found the highest concentrations of 32.9 mg/kg lead (Pb), 2.52 mg/kg zinc (Zn), 12.59 mg/kg copper, 5.19 mg/kg iron, and 1.61 mg/kg. Cadmium was found in mine waste and soil inside and near the Musina copper mine tailings dump. Copper values increased significantly in the west, from 4.27 mg/kg to 12.59 mg/kg, approximately 400 m away from the dam, however, the distribution of copper varied in different directions (Ogola & Sebola, 2010).

- **Orion Minerals**

The Prieska Copper-Zinc mine operated between the 1970s and 1990s, producing about 430k tonnes of copper and 1 million tonnes (Mt) of zinc from 46.8 Mt of milled sulphide ore. Orion is now involved in the development of the Deep Sulphide Resource, which consists of 28.73 Mt at 1.2% copper and 3.8% zinc and served as the foundation for an extremely successful revised Bankable Feasibility Study (BFS) finished in May 2020. (Orionminerals, Prieska Copper-Zinc Project, 2020). In its ten-year foundation phase, the $378 million project is anticipated to produce 189000 t of copper and 580000 t of zinc at a rate of 2.4 Mt per year. The Prieska project anticipates producing 88000 t/y of concentrate zinc and 23000 t/y of copper at its peak. (Orionminerals, Prieska Copper-Zinc Project, 2020).

Studies on environmental effects are a component of the current BFS for the possible project. (Prieska, 2019). Prieska mine (Orion plant), is considering membrane technology (RO) to treat wastewater containing copper. A 5m^3 per hour test water treatment facility has been constructed and is now operational. To measure and test critical design parameters, the plant combines chemical treatment, precipitation, UF, and RO purification (http://www.miningnewspro.com, 2020).

This is how the water treatment flowsheet is set up see Figure 2.23 and mobilization of the pilot facility for water treatment, starting up the pilot water treatment plant's reverse osmosis, filtration, and chemical treatment units. Figure 2.24 shows how this unit is set up to handle 5 m^3/hr of feed water. Feed water from the mine is pumped into the aeration tank to oxidize dissolved metals and other oxidisable ions (Orionminerals, 2019).

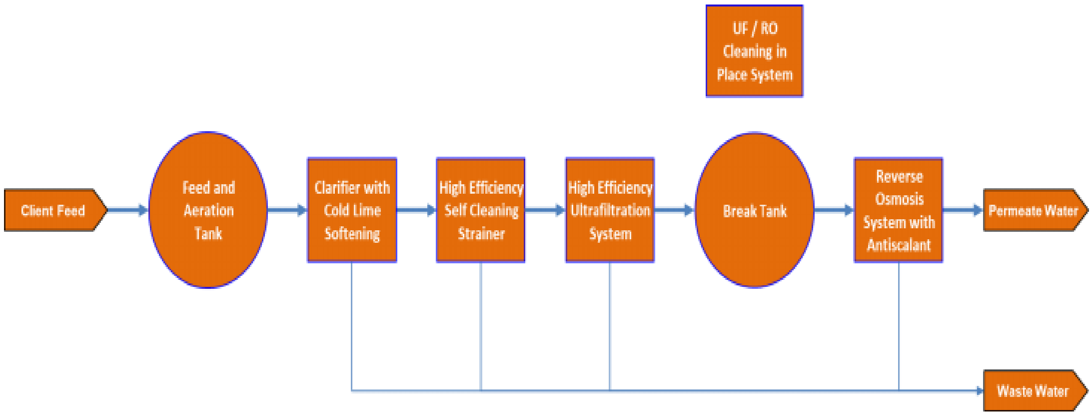

Figure 2.23: Flowchart of a Water Treatment Plant

Figure 2.24: Water treatment pilot plant mobilisation

- **Black Mountain Mining (BMM)**

Vedanta owns 69.6% of BBM, Exxaro owns 24.4%, and the BMM employee share ownership plan owns 6% of the company which is based in the Northern Cape Province mining town of Aggeneys. Figure 2.25 depicts the BBM flow diagram for a metal-in-concentrate production capacity of 90000 tonnes per annum (t/pa) of zinc, lead, silver, and copper by hoisting 17 million tonnes of ore per annum (mt/pa) from the two underground shafts that comprise this structure are Deeps and Swartberg (Vedanta, 2021).

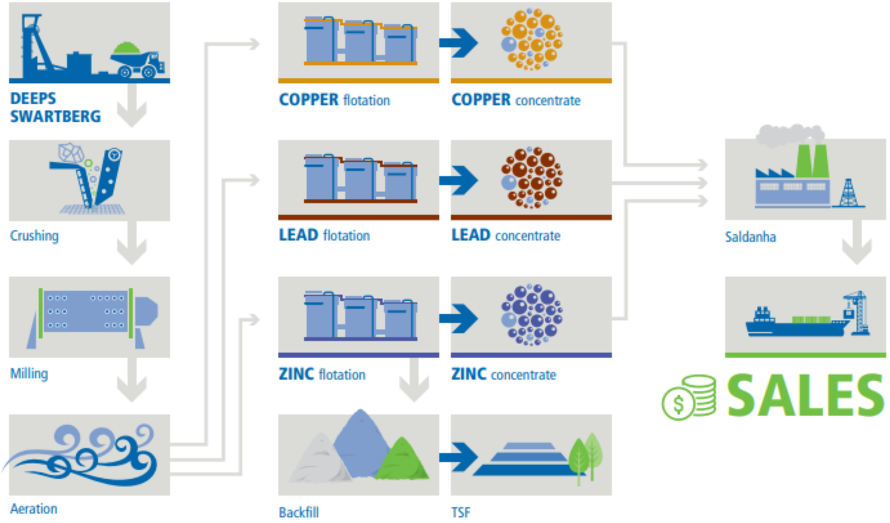

Figure 2.25: BBM flow chart

Plans to deepen Swartberg are well underway, and if successful, they will increase production to 1.6Mtpa (million tons per annum) of copper and lead ore Future ramp-up will raise the production of copper and lead ore above the 2Mtpa limit (Vedanta, 2021).

BMM is a responsible mining company in terms of wastewater output. The mine's main water supply comes from the Orange River, a large river with varying water levels throughout the year and a history of flooding in upper catchments during the wet season (Vedanta, 2013-14).

The mine activities used 1,584,394 m^3 (cubic meters) of water throughout the reporting period. 359,148 m^3 of processed water was recycled at the plants, accounting for 14% of all water consumed. Water used for sanitation is recycled separately. To maximize water recycling, underground dams, and settling ponds were constructed. There are no discharges outside of the operational boundaries because BMM has a zero-discharge policy (Vedanta, 2013-14).

- **Palabora copper mine**

Palabora mine is o (PMC) one of the biggest and deepest open-pit copper mines in the world and is situated in Limpopo Province, South Africa. Palabora mine produced roughly 80,000 tons of copper annually until recently (Network, 2013). The Palabora facilities featured a smelter, a copper electro-refinery, as well as some auxiliary factories that dealt with by-products (Rodney & Phillip, 2015).

- **Copalcor-Germiston smelter**

The biggest secondary copper smelter in South Africa is Copalcor-Germiston, which produces copper, brass, and alloy numerous copper and brass goods are produced there. The induction furnaces used for scrap melting provide molten metal for slab casting, hot rolling, and extrusion.

Three furnaces at Copalcor can melt more than 400 tons of non-ferrous alloys per month or around 5000 tons per year. (Rodney & Phillip, 2015).

- **O'oKiep copper mine**

The O'okiep copper mine, which was shut down in 2004, is situated in Springbok, Northern Cape, South Africa. It began operating there in the 1930s and was originally managed by Newmont Mining, then by the defunct Gold Fields of South Africa, and ultimately by a specialized small mining business called Metorex (Brendan, 2015). A deal between Handa Mining and the copper mines O'okiep and SHIP calls for funding and building a copper processing facility. An old waste pile of copper oxide and copper carbonate minerals from prior mining is present there (Sahris, 2019), the copper leached from oxide ore would be refined by solvent extraction, then recovered by electrowinning.

A dry residue cake would be created for upcoming brick manufacturing from the process's tailings after dewatering. Phase 2 of the project would involve stockpiling screen oversize (>1mm) for potential later processing. To test its appropriateness for drinking and irrigation, Erdogan et al., 2020 evaluated the seasonal variation of the open-pit groundwater (OPGW) quality near a closed metalliferous mine in O'oKiep (South Africa). With an average pH of 4.9 and 3.7, the copper content is high during the dry season at roughly 628 mg/L and lower during the wet season at about 447 mg/L.

This amount of copper in wastewater might harm the ecology and the local communities if it is released into the environment. Although the OPGW was effective for irrigation in both seasons, prolonged use could be detrimental to the land. The findings also revealed that the groundwater was highly salinized and moderately acidic throughout both the dry and wet seasons. These results back up the advice to install a water treatment system at O'oKiep to address the contaminated OPGW. (Erdogan et al., 2020).

2.5 Conclusion

Membrane separation technology has the potential to compete with current separation methods since it is adaptable, wastes, energy, and cost-efficient. The growth potential is still significant even though there have been a lot of studies done on membranes since the field's inception and the benefits of membrane filtration over traditional methods in terms of safety, environmental impact, and cost-effectiveness. To get industries to make significant changes to the current procedures, a few concerns must be resolved.

During the last decade, interest in the use of membrane technology, particularly NF, has grown in a variety of industries due to a combination of factors such as:

- increasing demand for high-quality water,

- increasing pressure to reuse wastewater and reagents,
- improved reliability and integrity of the membranes,
- lower membrane prices due to increased use, and
- more stringent standards (Van der Bruggen et al., 2008)

With the negative impact that heavy metals have on both human health and the environment's living things, it is crucial that heavy metals, particularly copper, are removed from industrial effluents. It is important to remember that choosing the best approach depends on several factors, including economics (*i.e*., operational costs), environmental impact, and technical performance. A promising solution for the treatment of diluted streams is membrane technology.

Membrane technology for mine wastewater is a relatively recent procedure in South African copper mines, and literature research information in this field is scarce. More research on testing, evaluation of various products, and optimisation of working conditions are required for the successful application of membrane filtering.

CHAPTER 3

3. Methodology

3.1 Introduction

Experiments were conducted using a synthetic and real solution to evaluate and recommend suitable membranes for water recycling and copper recovery. Commercial available NF membranes were evaluated using a dead-cell and pilot rig. The experimental part explained how the laboratory and pilot tests were conducted.

3.2 Experimental part

An initial flat-sheet membrane screening study was performed to evaluate the flux, passage, and rejection of potentially viable NF membranes. The test work was executed on a dead-end filtration unit at various temperature and pressure conditions to provide data for feasibility studies. The results gave a good indication of the minimum flux a membrane would produce over a range of operating conditions.

3.2.1 Membranes tested

In this study, flat-sheet membranes were evaluated using a dead-end cell. The physical properties of the membranes that were evaluated are listed in Table 3.1.

Table 3.1: Properties of the commercial membranes evaluated

Name	**Company**	**pH range**	**Max temperature** (°C)	**Max pressure** (bar)	**MCOW** (Da)
A3011	AMS	0-12	80	70	100
A3012	AMS	0-12	80	70	200
A3014	AMS	0-12	80	40	400
B4021	AMS	3-14	80	60	100
NF90	Dow	2-11	45	41	100-150
NF245	Dow	3-10	50	54.8	200-400
A-U301	AMS	0-12	50	40	2500

3.2.2 Synthetic feed preparation and chemical characterisation

Membrane screening tests were carried out using a representative copper synthetic solution. It was prepared based on the composition of open-pit groundwater from O'okiep copper in the dry season. 5000mL copper solution was prepared using deionised (DI) water and salts specified in Table 3.2.

Table 3.2: Chemical used for synthetic solution preparation

Chemical name	Chemical formula
Aluminium chloride hexahydrate	$AlCl_3 \cdot 6H_2O$
Calcium chloride hexahydrate	$CaCl_2 \cdot 6H_2O$
Magnesium sulphate heptahydrate	$MgSO_4 \cdot 7H_2O$
Sodium fluoride	NaF
Copper (II) sulphate pentahydrate	$CuSO_4 \cdot 5H_2O$
Ferric Sulphate hydrate	$Fe_2(SO_4)_3 \cdot XH_2O$
Manganese (II) chloride tetrahydrate	$MnCl_2 \cdot 4H_2O$
Nickel (II) chloride hexahydrate	$NiCl_2 \cdot 6H_2O$
Potassium chloride	KC
Sodium chloride	$NaCl$
Sodium sulphate	Na_2SO_4

After adding the required mass of slats the solution was magnetically stirred in a hotplate until all the salts dissolved. A summary of the analytical results for the synthetic solution is shown in **Error! Reference source not found.**. The prepared solution was stored in a volumetric flask and used immediately in the membrane screening tests.

Table 3.3: Physical and chemical composition of synthetic copper solution

	Dry season	**Synthetic feed**
Physical parameters		
pH at 25 °C	4.9	2.75
Parameters for cations and anion mg/L		
Ca	600	269
Na	492.8	501.67
Mg	544	556
K	34.9	70.77
F^-	6.8	-[2]
Cl^-	686.8	-
SO_4^{2-}	4830	4621
NH_3	1	-
N	10	-
Ortho-phosphate (P)	3.6	-
Elemental parameters mg/L		
Al	38.8	35.7
Sb	0.02	-
As	0.01	3.2
Cd	0.07	<2
Cr	0.08	<2
Co	1.54	<2
Cu	**628**	**639**
Fe	79.5	292
Mn	39	5.6
Hg	6	-
Ni	9.9	11.4
Se	0.04	-
V	0.06	0.04
Zn	0.02	0.52
CN^-	0.3	-[3]

---

[2] - Not detected (F^-,Cl^-, NH_3,P, Sb, Hg, Se)
[3] - Not analysed

3.2.3 Chemical analyses

The analytical methods used during the test work program and their respective detection limits are given in Table 3.4.

Table 3.4: Analytical techniques and detection limits

Method	Elements	Detection limit
Inductively Coupled Plasma Optical-Emission Spectroscopy (ICP-OES) (base metals)	Mg, Al, Si, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Pb, Mo, SO_4^{2-},	2 mg/L for all elements, except for SO_4^{2-} which is 5 mg/L
Potentiometric titration	H_2SO_4	1 g/L
Wet Chemistry	SO_4^{2-}, Cl, F	1 mg/kg, 0.03% - 50%, 0.01 – 30%
Atomic adsorption spectroscopy (AAS)	Na, Cu, Ca, and K	2ppm except for Ca = 10ppm

3.2.4 Set-up and procedure

A dead-end filtration stirred cell, as illustrated in Figure 3.1, was used for laboratory scale studies. Table 3.5 lists the cell's technical parameters.

Table 3.5: Stirred cell characteristics and technical specs

Parameter	Units	
Membrane size(diameter)	mm	53
Active membrane area	cm^2	13
Processing volume	mL	150
Maximum pressure	Bar	69
Maximum temperature	-[4]	Membrane dependant
Cell body	-	Hastelloy
O-rings	-	EPDM
Gaskets	-	EPDM
Stir bar	-	Teflon
Dimensions: Cell Height	cm	19.8
Cell Diameter	cm	4.8

This device has one membrane module that functions in the 1 to 69 bar pressure range and has an effective membrane area of 13 cm^2. A 150 mL feed tank, pressure gauges, and a permeate outlet were all parts of the apparatus.

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[4] -Not provided

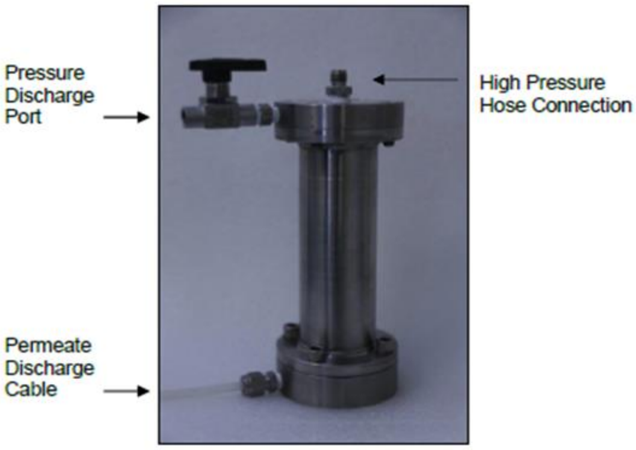

Figure 3.1: Laboratory apparatus for NF filtration processes

The experiments were conducted in the dead-end cell. The unit reservoir was filled with 100 mL of feed solution. Following that, the unit was tightly sealed to prevent pressure loss during filtration. The unit was pressurized with nitrogen gas, and the solutions were constantly stirred at 750 rpm to homogenize the feed samples. After collecting 80% of the volume into permeate and recording time, pH, and Oxidation/Reduction Potential (Eh), the tests were stopped and the concentrate (retentate) was removed. The concentration of the concentrate stream was determined, and the sample was sent for analysis. Figure 3.2 shows the Metrohm 877 Titrino Plus used to titrate the acid in the samples.

Figure 3.2: Metrohm 877 Titrino Plus

After completing a test, the membrane was removed from the module and rinsed with deionised water. Figure 3.3 shows the different solutions before and after filtration.

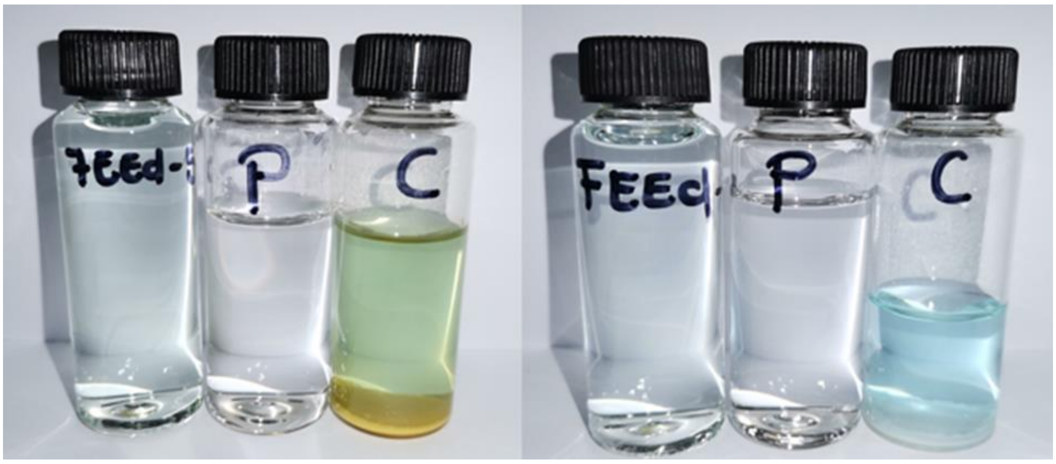

Figure 3.3: Synthetic (greenish) and Real (blue) solutions generated during filtration

3.3 Experimental pilot testing

3.3.1 *Materials*

In this study, commercial NF spiral-wound membranes produced by DOW were tested. The physical properties of the membrane are given in Table 3.6.

Table 3.6: Properties of the commercial spiral-wound NF membrane evaluated

Name	**NF90-2540**
Supplier	DOW
Membrane type	Polyamide Thin-Film Composite
Molecular cut-off weight (Da)	200
Stabilized salt rejection (%)	>97.0
pH	2-11
Temperature	45°C
Maximum Pressure (Bar)	41
Active Area (m^2)	2.6

It should be noted that the membranes were previously used for cold commissioning of the membrane rig using deionised water. The main objective of this study was for practical purposes to understand the operational conditions of membrane rigs prior to a real solution. The membrane was stored in 1% (w/v) SMBS for preservation.

3.3.2 Experimental set-up for continuous run

The spiral-wound Kivu membrane Pilot Unit 2.5 was used for the filtering studies (2540). In Figure 3.4 a picture of the experimental unit is presented. The device is made up of a feed tank, two membrane cells, a variable-speed high-pressure pump, a buster pump, pressure gauges, digital flow meters, and a needle valve at the concentrate line. It also has a series of valves that allow direct solutions in different configurations. The test work was set in such a way that two membranes were run in parallel and the valves were in the positions stipulated in Appendix A.

Figure 3.4: Pilot plant apparatus for membrane filtration processes

Before testing the real solution, the permeability of pure water was determined by passing water through the system at various pressures and measuring flows. The copper sample was then placed in the tank and pumped into the filtration unit, where it separated the concentrate and permeated.

Two tests were conducted. In the case of test 1, both flows were recirculated to the feed tank evaluating optimal operating pressure. The test was run for 1h40 min at ambient temperature while increasing the pressure by 5 bars every 5 min until 40 bars and the samples were collected every 10 min, data in Appendix B.

Test 2 was conducted using optimum conditions obtained from test 1. The unit was run with the same feed flow and optimum pressures of 40 bar at room temperature but recycling concentrate to the feed tank. The experiment was carried out continuously, with pressure, temperature, and stream flows recorded. Test 2 was run for 70 min to reach 40 bar and was left to run for 60 min at targeted pressure, the samples were collected every 30 sec, and data are reported in Appendix C

CHAPTER 4

4. Results and Discussion of synthetic and real solutions

4.1 Introduction

Six NF membranes and one UF membrane with characteristics given in Table 3.1 were evaluated. NF screening tests were done to identify the best-performing membrane(s). The NF membrane performance was characterized by two factors, the permeate flux, and copper rejection. A high flux rate and copper rejection of >90% were required.

The UF membrane can be used as either a pre-filtration option before NF filtration or as the stand-alone membrane in acid purification and metal concentration. The experimental conditions of all the tests were kept similar while varying the operational pressure at 20, 30, and 40 bar. The copper concentration in the feed solutions was 639 mg/L for a synthetic solution and 427 mg/L for a real solution, respectively. The acid concentration in the synthetic and real feed solutions was 2.92 g/L and 0.93 g/L. The tests were conducted at ambient temperature and the cell was agitated at 750 rpm during filtration.

4.2 NF screening tests conducted on a synthetic solution

Using a synthetic copper solution at operating pressures of 20, 30, and 40 bars, the performance of various membranes was compared. Appendix D contains detailed information on the tests performed on membranes. Equation 1 was used to calculate the permeate flux, Figure 4.1-4.3 show the permeate flux profiles generated during the evaluation of membrane performance at 20, 30, and 40 bars:

- A decrease in flux over time;
- An increase in copper concentration in the permeate collected with time;

The decrease in membrane performance was most likely caused by fouling of the membrane and has to be accounted for during the comparison of various products. However, increasing the operating pressure improved membrane performance in terms of flux rate.

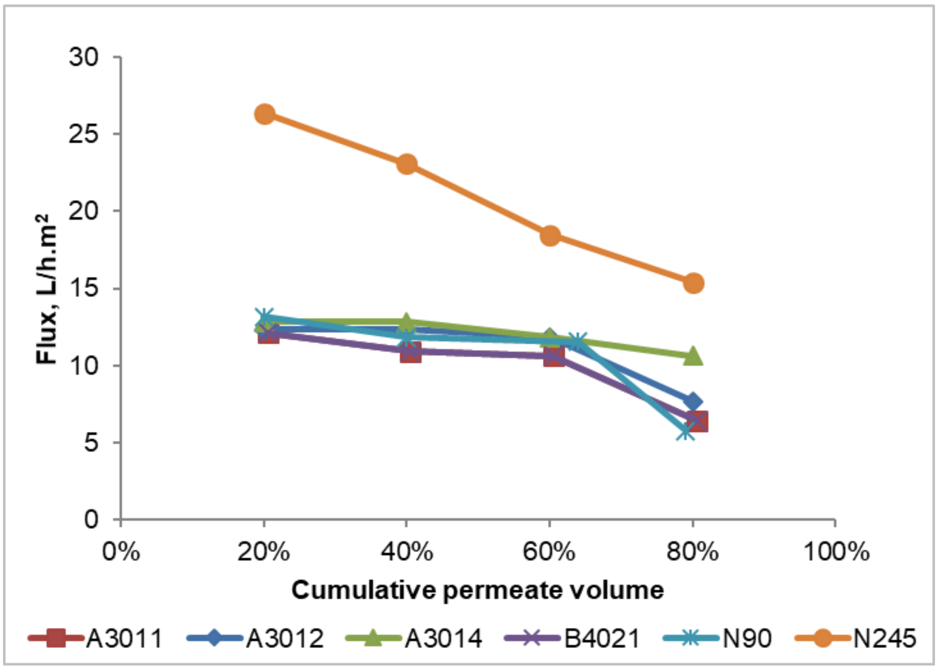

Figure 4.1: NF membrane synthetic solution permeate flux profiles at 20 bar

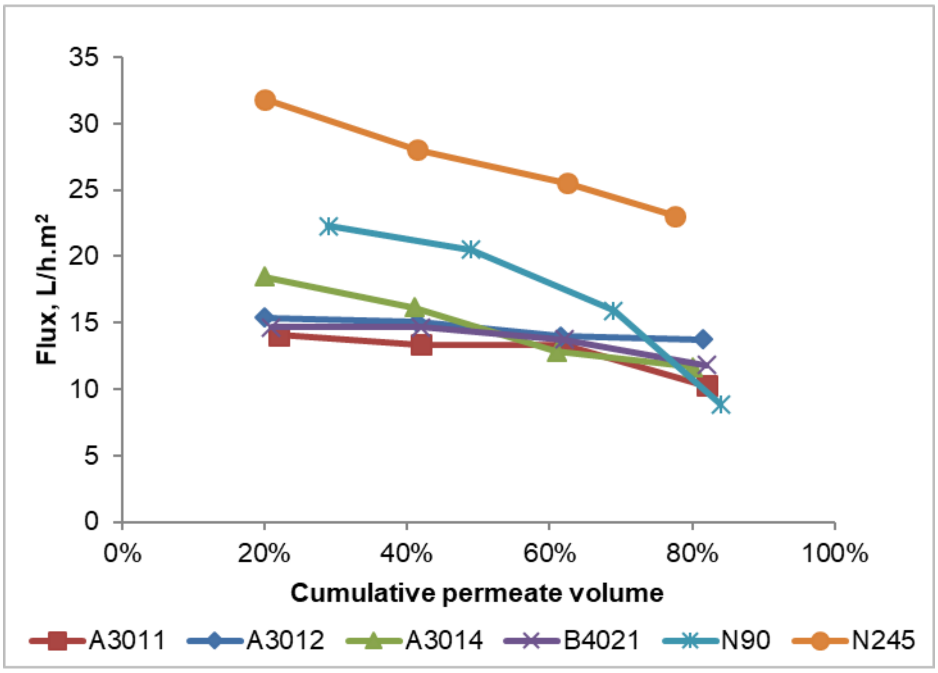

Figure 4.2: NF membrane synthetic solution permeate flux profiles at 30 bar

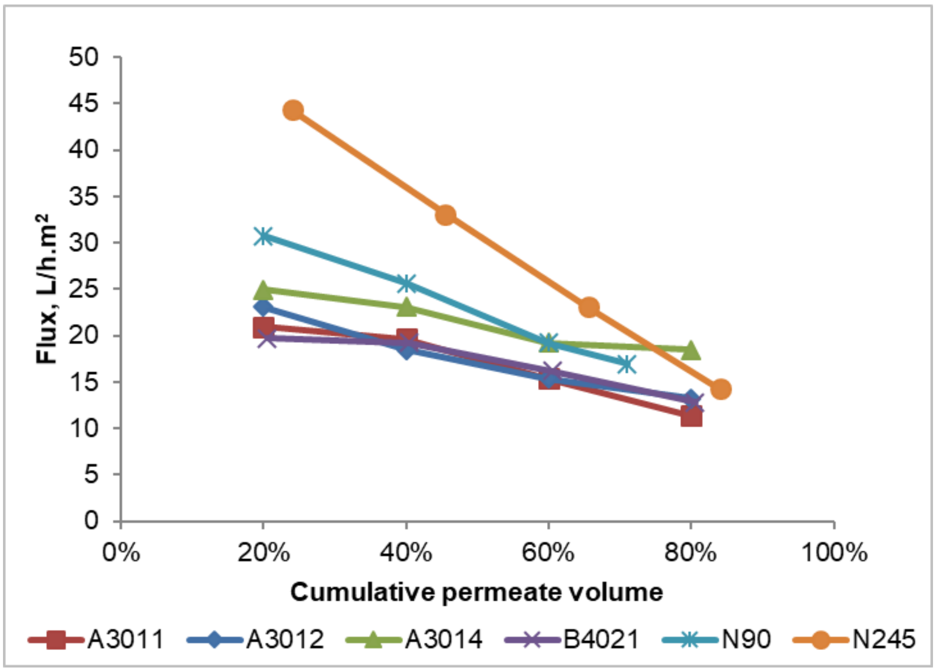

Figure 4.3: NF membrane synthetic solution permeate flux profiles at 40 bar

In all the cases, the permeate flux decreased with the volume passed through the membrane. The fastest flux drop was seen in DOW N245 and N90 membranes, compared to all other NF membranes that were investigated. AMS membranes showed a gradual slow decrease in flux. This decrease in flux may have been caused by the first deposition of the contaminants on the membrane surface or fouling, although significant fouling was not observed when membranes were removed from filtration equipment. Further decline in flux could be due to increased concentration of copper and other cations and anions in the concentrated phase as the filtration progressed.

The rate of the flux decrease can characterise the susceptibility of a membrane to degradation or fouling. However, a long-term evaluation in real conditions is required to confirm this suspicion. For direct comparison of different membranes operated at various pressure, the permeate flux was calculated for the time required to collect ~80% of the feed into the permeate stream. The flux of the various membranes at 20, 30, and 40 bars is presented graphically in Figure 4.4.

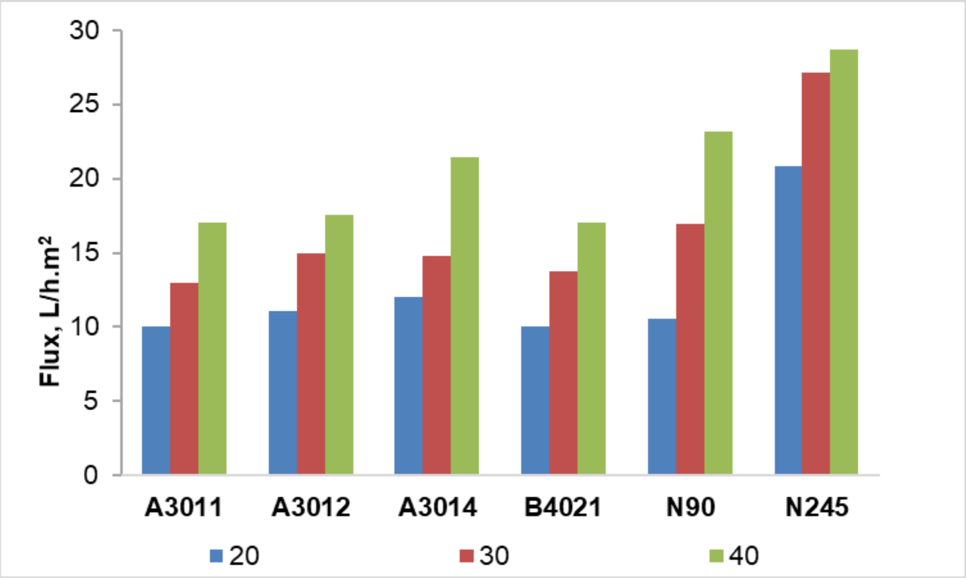

Figure 4.4: Synthetic solution permeate flux of the NF membranes at various operational pressures

It was observed that for all membranes evaluated, an increase in operational pressure resulted in higher flux. Dow NF245 membrane had the highest permeate flux of the membranes tested at the pressure of 20, 30, and 40 bar. A water test was conducted before and after each membrane test. It provides an indication of membrane flux in general and helps to monitor membrane fouling/scaling. Figure 4.5-4.7 show the water flux of the tested membranes, membranes produced by Dow (N245 and N90) had higher water flux determined before the test in comparison to AMS membranes. If comparing two Dow products, N245 with a higher MCOW value had a higher flux than N90. AMS membranes A3011 and B4021 series with different MCOWs had similar initial water flux.

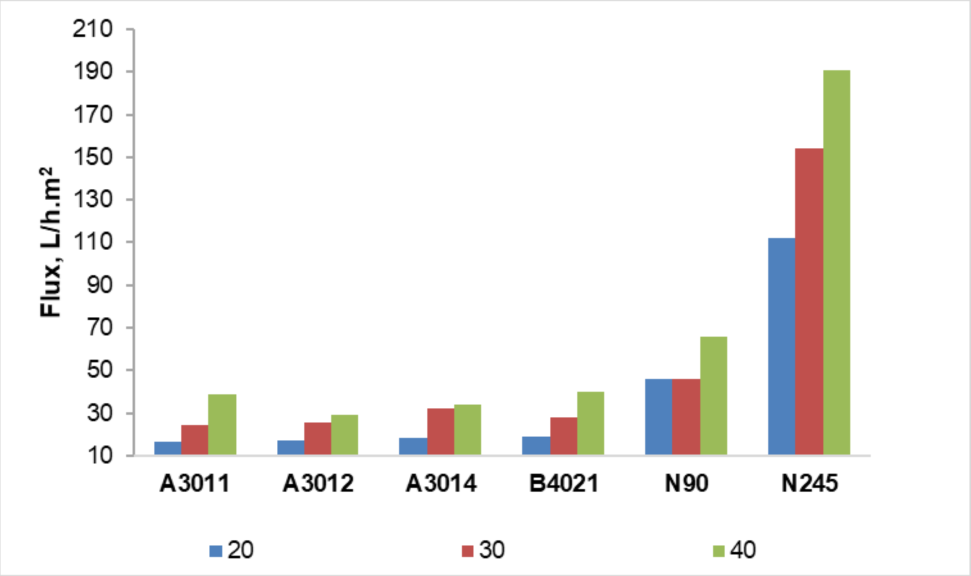

Figure 4.5: Water flux before passing feed solution separation

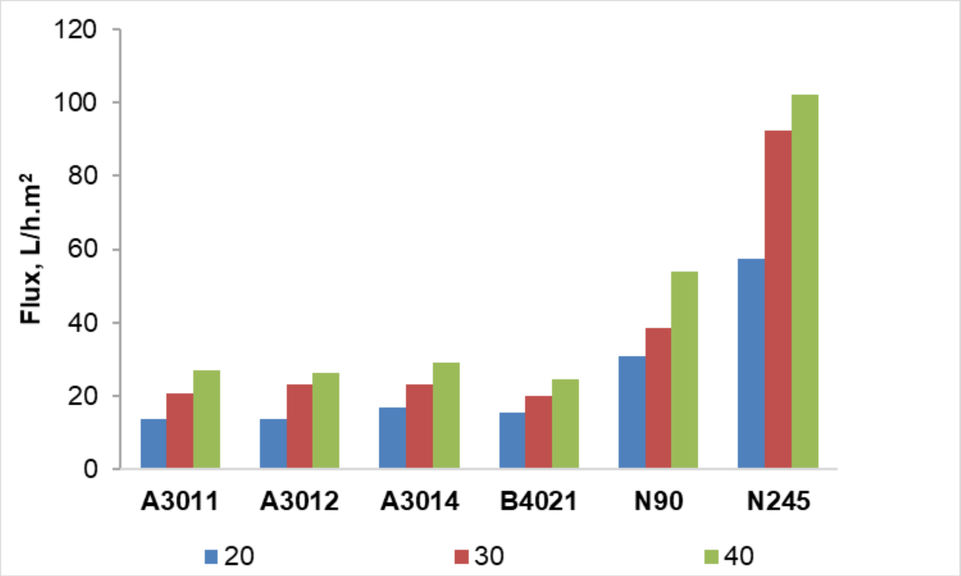

Figure 4.6: Water flux after passing feed solution

Water flux measured after treating the solution decreased slightly for both membranes due to pore blockage after passing the feed solution. Another factor used to characterize membrane performance was copper rejection by the membrane and it was calculated using Equation 4. The copper rejection into retentate was obtained after passing 80% feed solution through the membrane. Figure 4.7 shows the copper rejections achieved with various membranes tested.

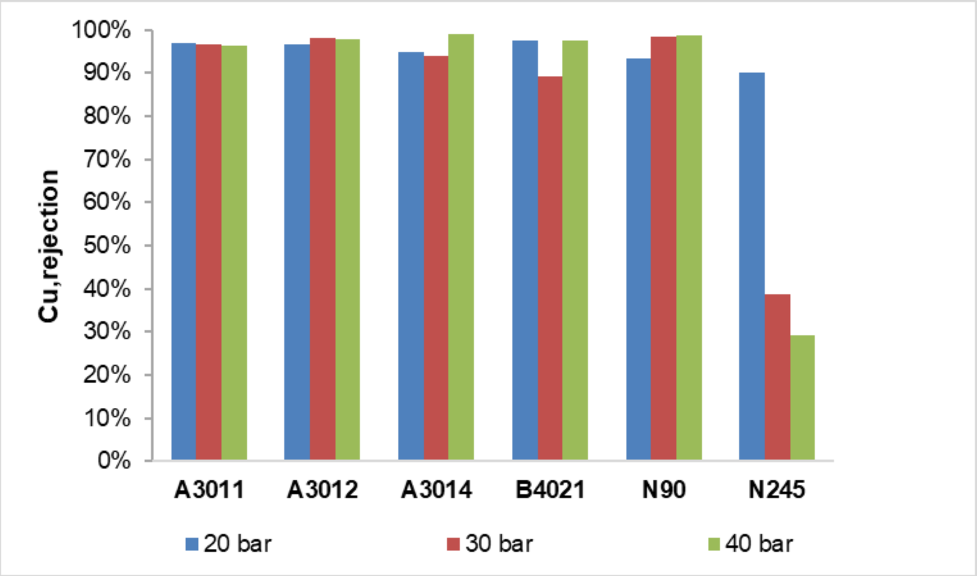

Figure 4.7: Synthetic solution copper rejection at 80% permeate recovery for various operational pressure

DOW N245 rejected around 90% copper at 20 bars, but copper rejection dropped to 29-39% at 30 and 40 bars. Other membranes showed good performance by rejecting >90% of copper at different operating pressures tested. Figure 4.8-4.10 characterise the copper concentration profiles in the permeate collected.

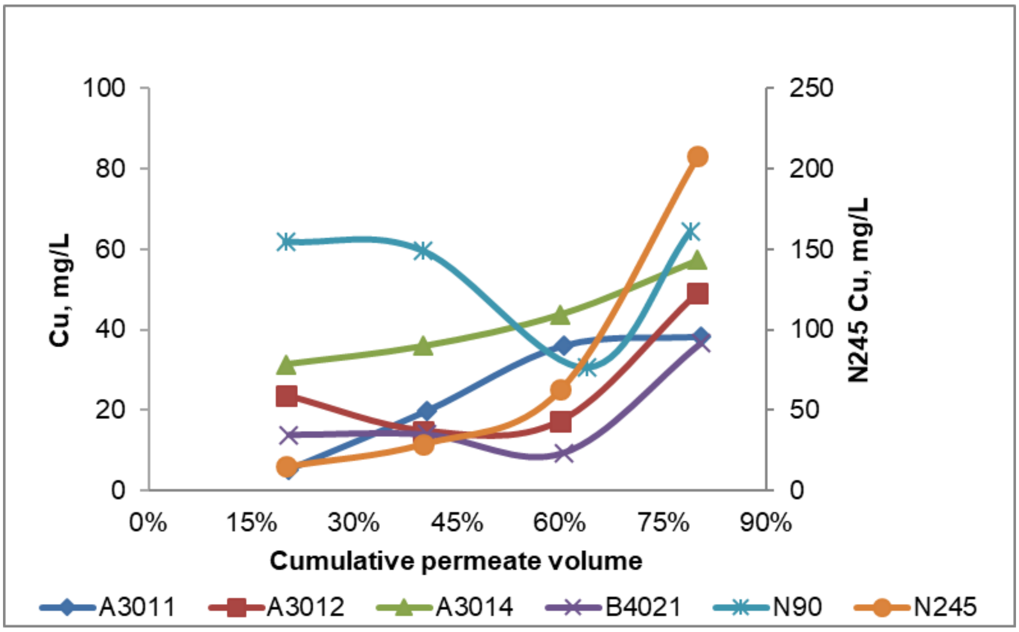

Figure 4.8: Synthetic solution copper concentration profile at 20 bar

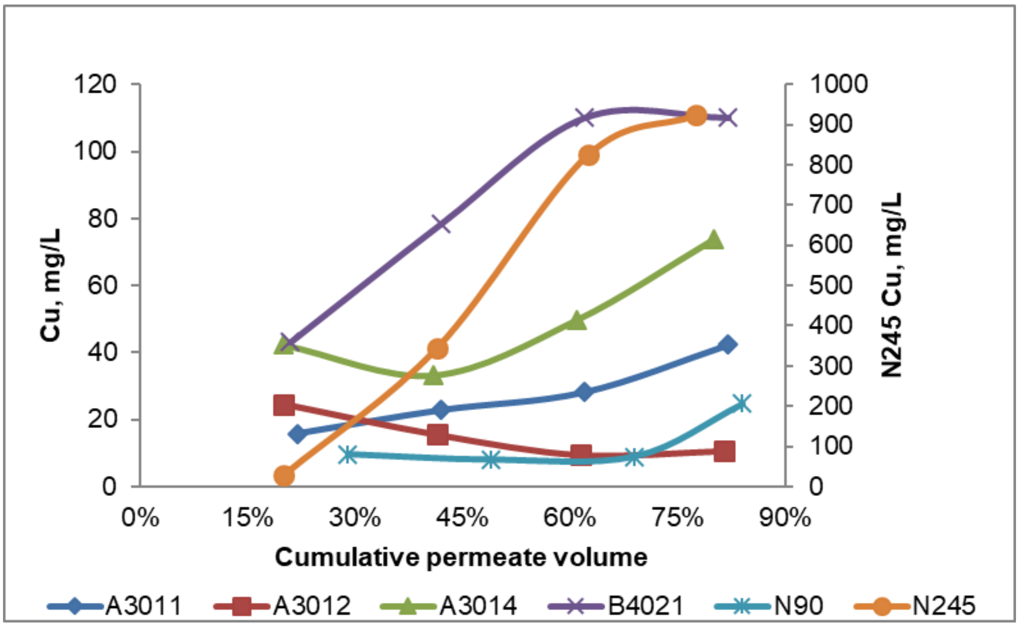

Figure 4.9: Synthetic solution copper concentration profile at 30 bar

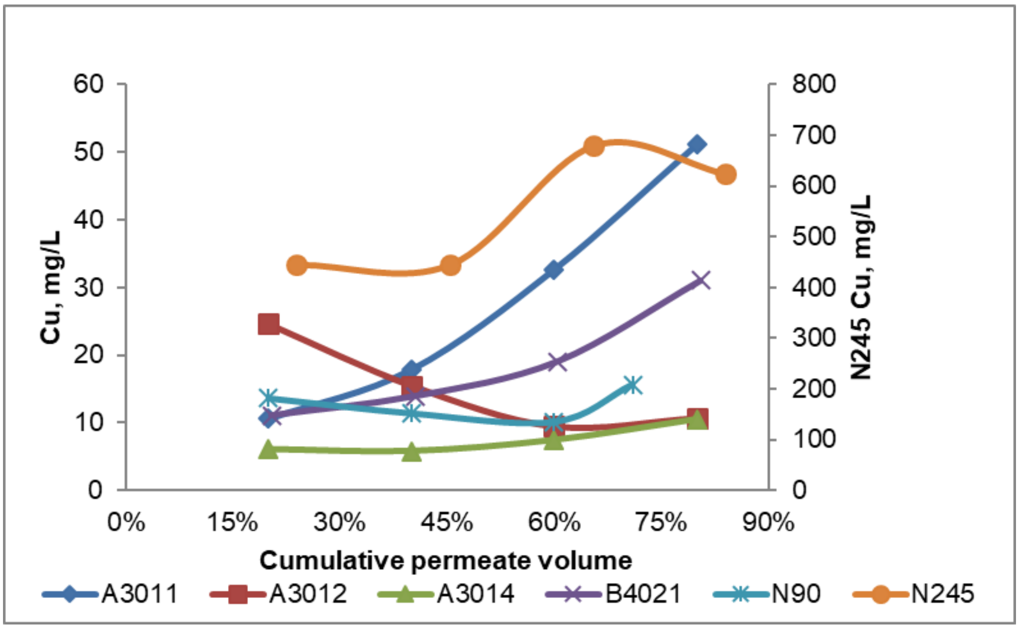

Figure 4.10: Synthetic solution copper concentration profile at 40 bar

The AMS B4021 membrane outperformed all other membranes at 20 bar for copper rejection into the retentate, while the DOW NF90 membrane had a good performance at 30 bar. It was expected that a membrane with a smaller pore size (A3011 and B4021) would reject copper better than the membranes with a larger pore size (AMS A3014).

Nanofiltration in general combines molecular sieving of uncharged molecules and retention based on charge. The most dominant separation characteristic for ionic compounds in nanofiltration is the Donnan effect. The difference in membrane behavior observed can be due to the difference in the charge on the membrane surface due to the different composites used for the production of these membranes. Dow membranes are reported to be polyamide with positively charged functional groups. AMS does not disclose the composition of its products.

In the case of AMS A3011, operating pressure did not affect copper rejection. For AMS A3012, A3014, and DOW N90 an increase in pressure resulted in decreases in the amount of copper passing through the membrane. Overall, the permeate flux and copper rejection can be enhanced by increasing the operational pressure. However, an increase in operating pressure can result in membrane damage (if the increase certain level determined by the producer) and would require higher power consumption for filtration.

The summary of NF membrane screening tests at tested pressures is given in Table 4.1. All evaluated membranes recovered more than 80% permeate except for AMS B4021 with 90% copper rejection into the concentrate. These membranes are suitable for treating copper dilute streams, however for environmental disposal generated permeate stream needs to be passed in a second membrane to decrease the copper concentration in the stream.

Table 4.1: Synthetic solution summary of NF membrane screening tests at tested pressures

Membranes	Recovery permeate	Flux permeate L/h.m^2	combined permeate copper mg/L	Upgrade copper g/L	Retentate copper mg/L	Copper rejection
20 bar						
A3011	81%	10	24.67	3.6	2320	97%
A3012	80%	11	26.23	4.2	2690	97%
A3014	80%	12	42.08	3.6	2330	95%
B4021	77%	10	18.4	2.6	1630	98%
N90	79%	11	52.29	4	2570	94%
N245	80%	21	78.63	4.6	2930	90%
30 bar						
A3011	86%	13	26.95	4.5	2880	97%
A3012	82%	15	15.51	4.8	3050	98%
A3014	81%	15	38.65	4	2540	94%
B4021	82%	14	18.4	2.6	1690	89%
N90	84%	17	11.74	5.1	3230	98%
N245	78%	27	504.63	1.6	1030	39%
40 bar						
A3011	80%	17	28.07	4.5	2876	96%
A3012	80%	18	16.44	4.4	2820	98%
A3014	80%	21	7.45	4	2580	99%
B4021	81%	17	18.73	2.6	1640	98%
N90	71%	23	12.32	3.2	2020	99%
N245	84%	29	539.38	1.6	1020	29%

Detailed solutions analysis was also conducted for the tested membrane Figure 4.11-4.13 shows rejections of different metals. It was found that cations present in the solution were efficiently rejected. Rejection for most of the elements was > 90% except for N245 at 30 and 40 bar. For other membranes, pressure had a negligible effect on their performance. Sodium (Na) and manganese (Mn) had a lower rejection capacity on all membranes.

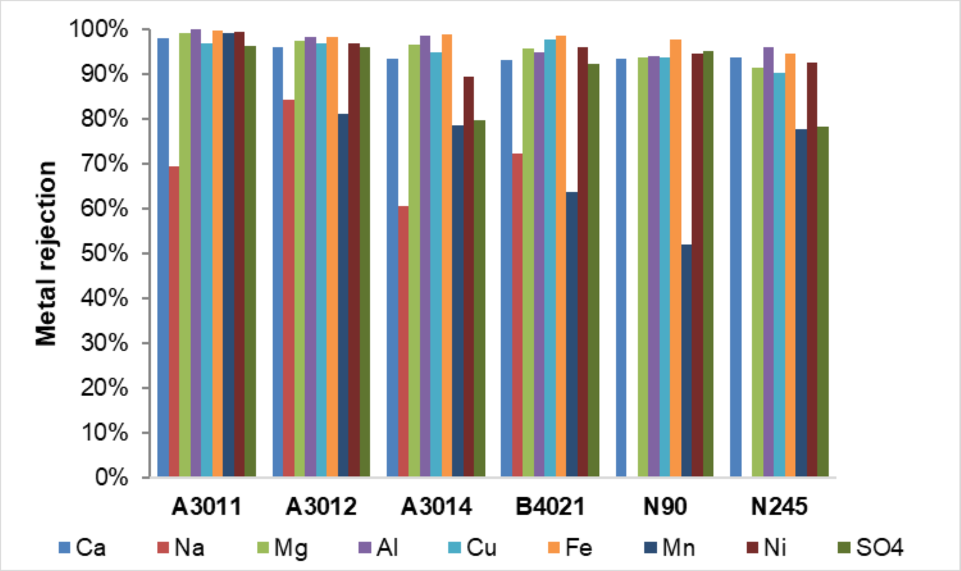

Figure 4.11: Synthetic solution metal rejection at 20 bar

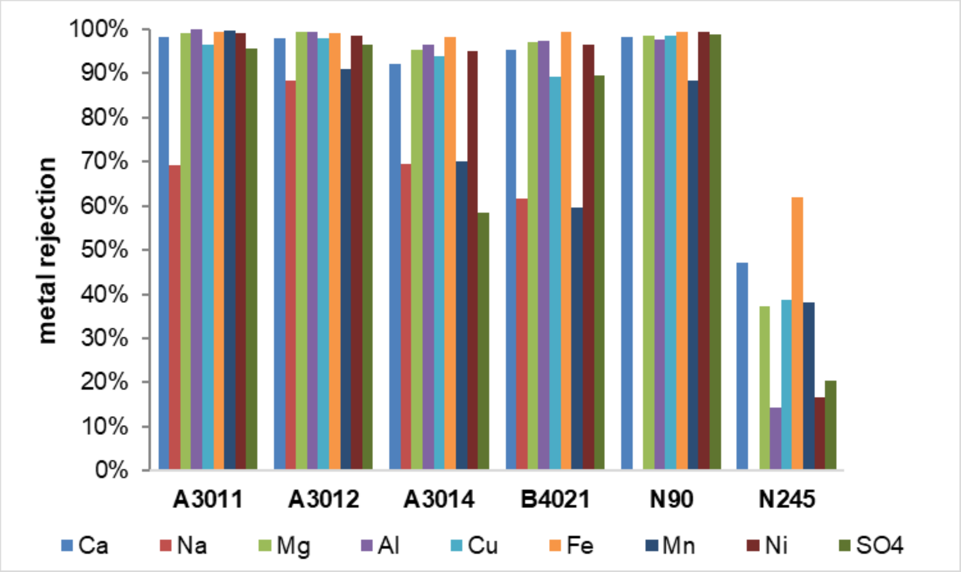

Figure 4.12: Synthetic solution metal rejection at 30 bar

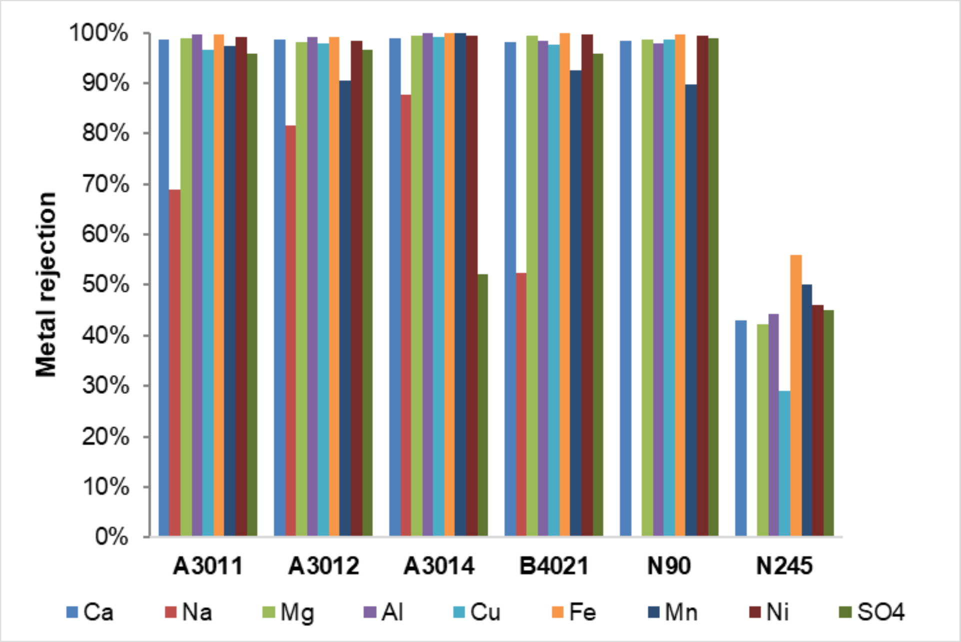

Figure 4.13: Synthetic solution metal rejection at 40 bar

4.3 NF screening tests conducted on a real solution

A similar screening test work was conducted using a real solution. The chemical composition of the real copper solution obtained from an open-pit mine is given in Table 4.2. The solution had a pH of 3.87 and contained 427 mg/L copper. Calcium (Ca), magnesium (Mg), and Sulphate (SO_4^{2-}) were found in the solution at a relatively high level. Traces of Aluminium (Al), Cobalt (Co), Iron (Fe), Manganese (Mn), Nickel (Ni), Silicon (Si), and Zinc (Zn) were also analysed using ICP-OES.

Table 4.2: Real solution composition

pH (25°C)	3.87
Elements	mg/L
K	31.4
Na	454
Al	8.6
As	3.33
Ca	343.75
Cd	<2
Co	1.37
Cr	<2
Cu	426.72
Fe	<2
Li	<2
Mg	441.1
Mn	14
Mo	<2
Ni	5.65
Pb	<2
S	966.5
Si	21.7
Ti	<2
V	<2
Zn	<2
SO_4^{2-}	3121.34

The permeate flux profiles generated during the evaluation of membrane performance at 20, 30, and 40 bar is presented in Figure 4.14-4.16. Detailed information about tests performed on membranes can be found in Appendix E.

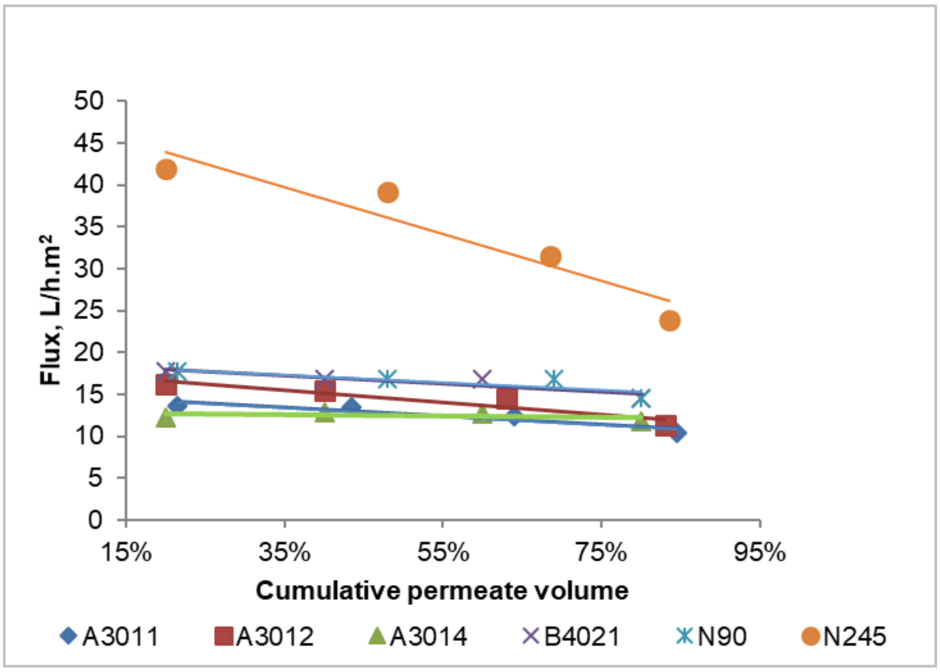

Figure 4.14: NF membrane real solution permeate flux profiles at 20 bar

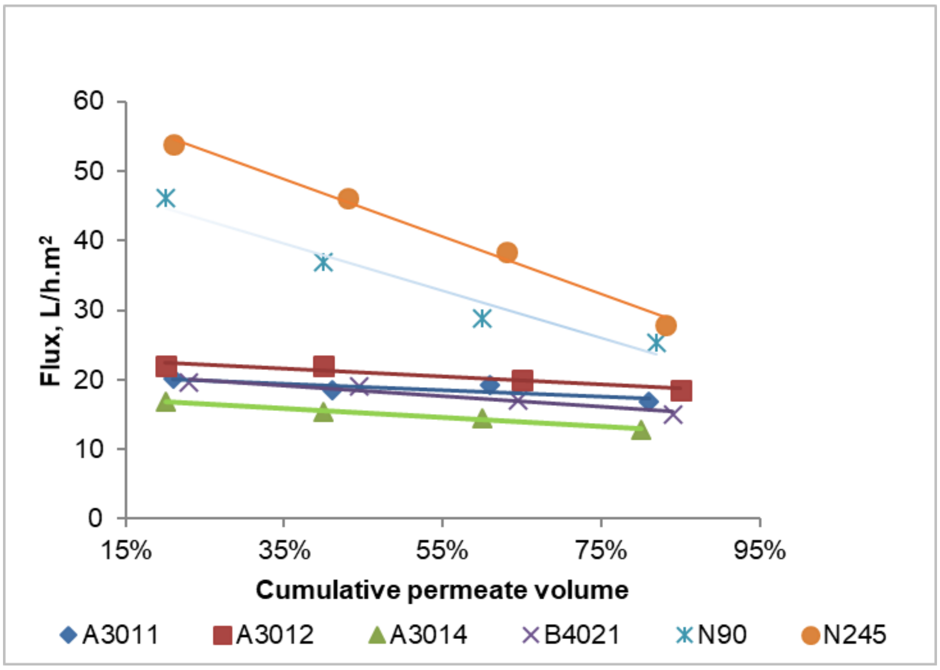

Figure 4.15: NF membrane real solution permeate flux profiles at 30 bar

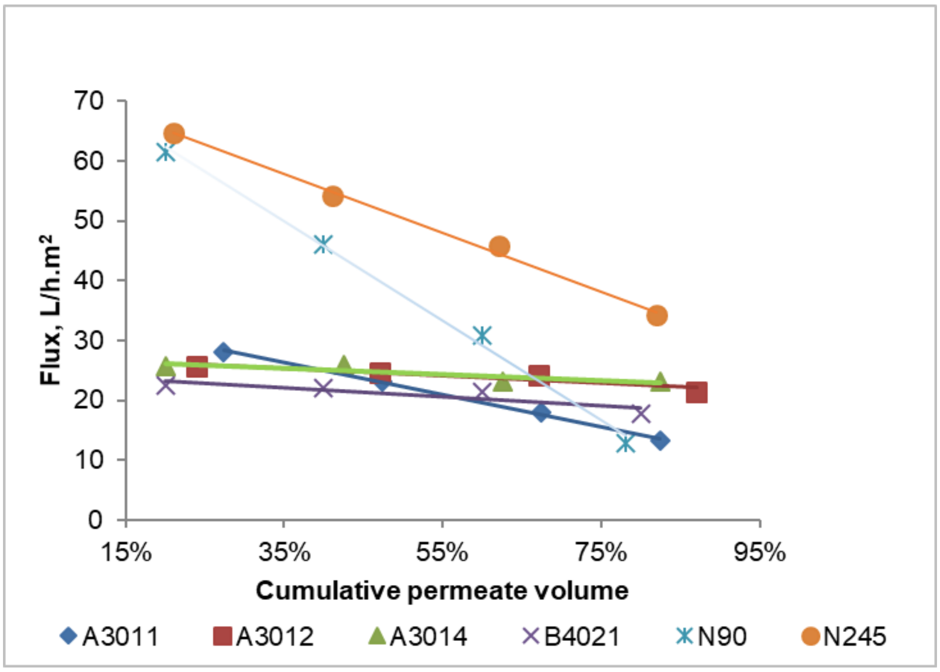

Figure 4.16: NF membrane real solution permeate flux profiles at 40 bar

For all tests with synthetic and real solutions, the permeate flux decreased with the volume of the solution passed through the membrane. Similar observations were tested conducted on synthetic solutions (Section 4.2). A sharp decline in flux was reported for Dow N245 and N90 membranes. In the case of the real solution, the formation of precipitation was reported in the concentrated phase as shown in Figure 4.17.

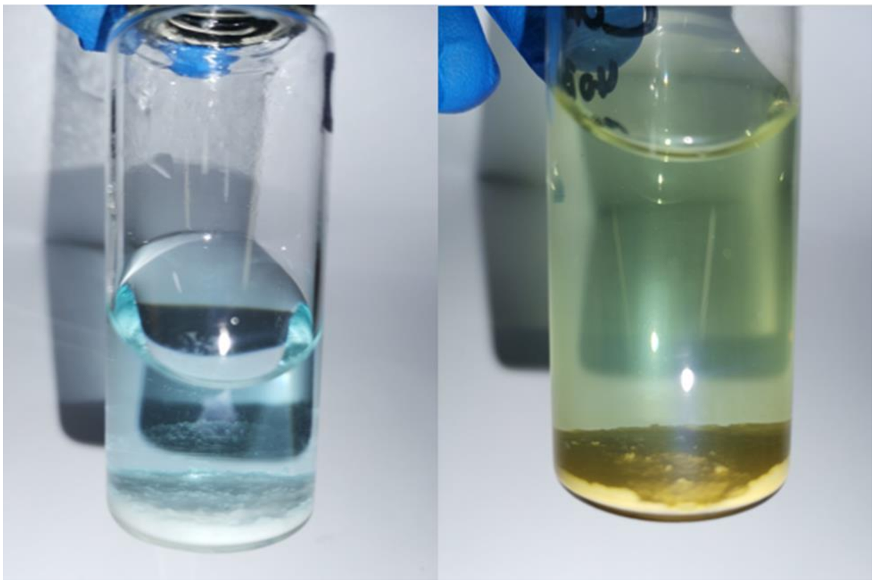

Figure 4.17: Precipitation formed during filtration processes

For comparison of various membranes, permeate flux corresponded to the time required to collect ~80% of the feed volume into the permeate was used. The flux of the various membranes at 20, 30, and 40 bars is presented graphically in Figure 4.18.

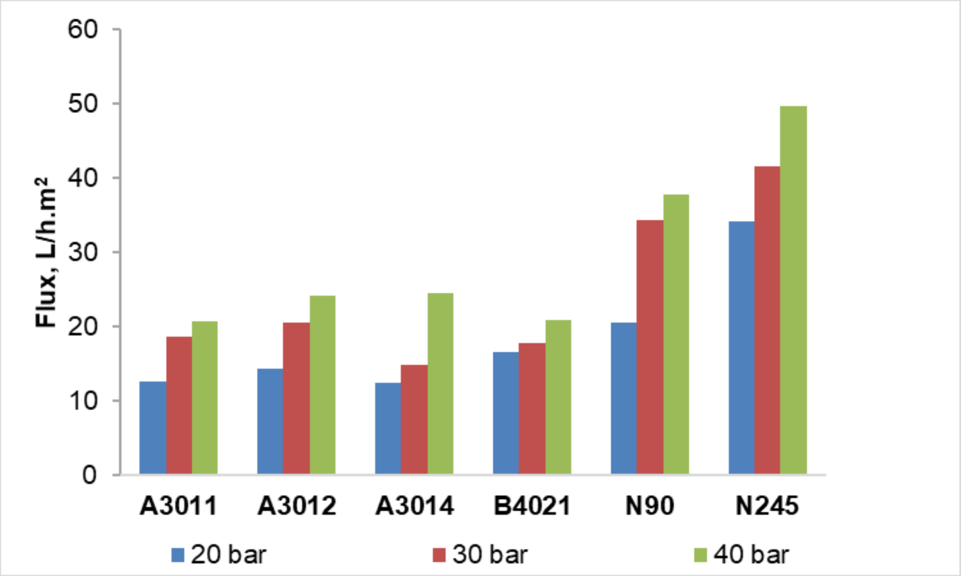

Figure 4.18: Real solution permeate flux of the NF membranes at various operational pressures

An increase in operating pressure improved the efficiency of the NF membranes. DOW NF245 membrane had the highest permeate flux of the membranes tested. Figure 4.19 shows the copper rejections achieved with various membranes tested and Figure 4.18-4.20 characterise the copper concentration profile in the permeate collected.

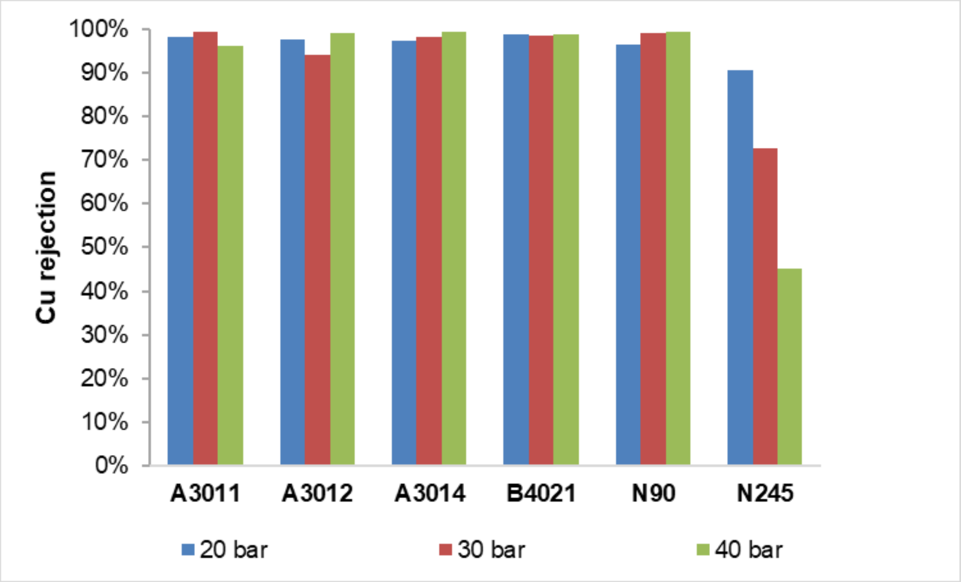

Figure 4.19: Real solution copper rejection at 80% permeate recovery for various operational pressure

The rejection of copper and other metals for a real solution was not impacted by the increase of pressure for AMS A3011, A3012, A3014, B4021, and DOW N90. Monovalent cations (Na) had a lower rejection capacity on all membranes as compared to divalent and trivalent cations. DOW N245 had poor rejection of copper and other elements at increased pressure.

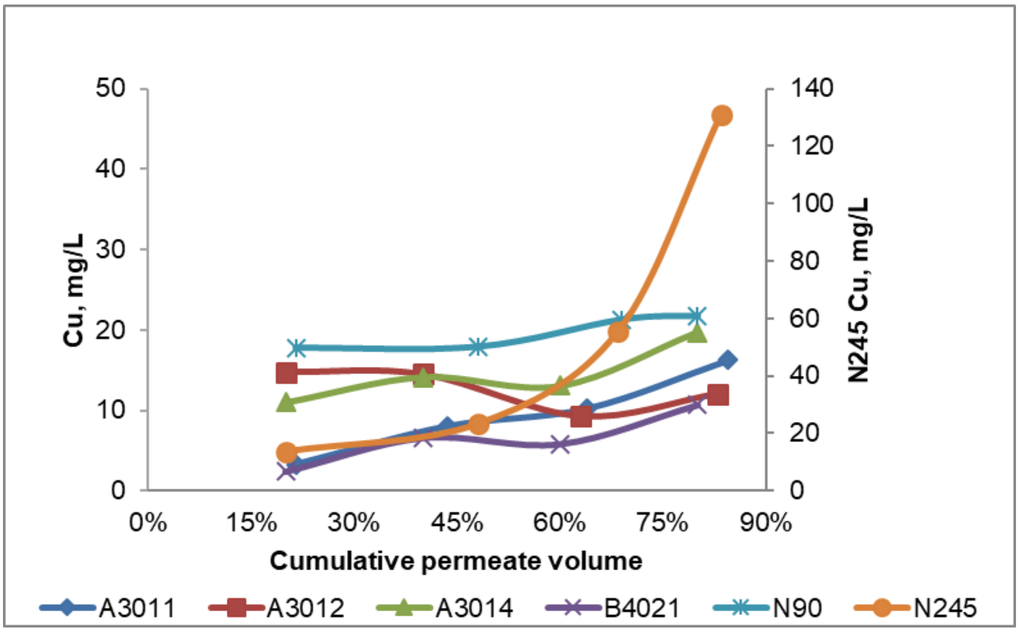

Figure 4.20: Real solution copper concentration profile at 20 bar

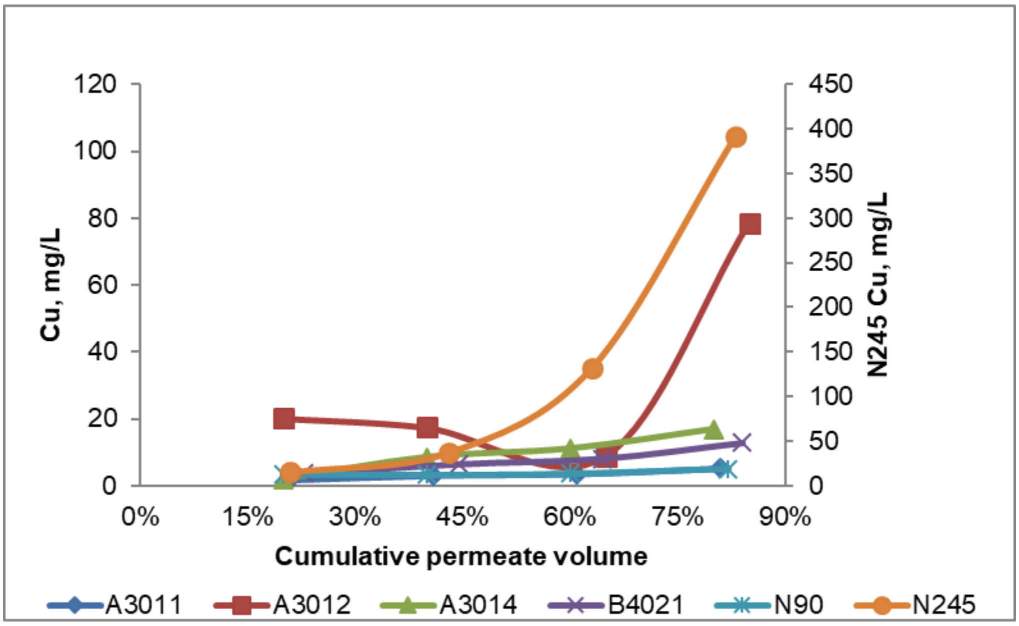

Figure 4.21: Real solution copper concentration profile at 30 bar

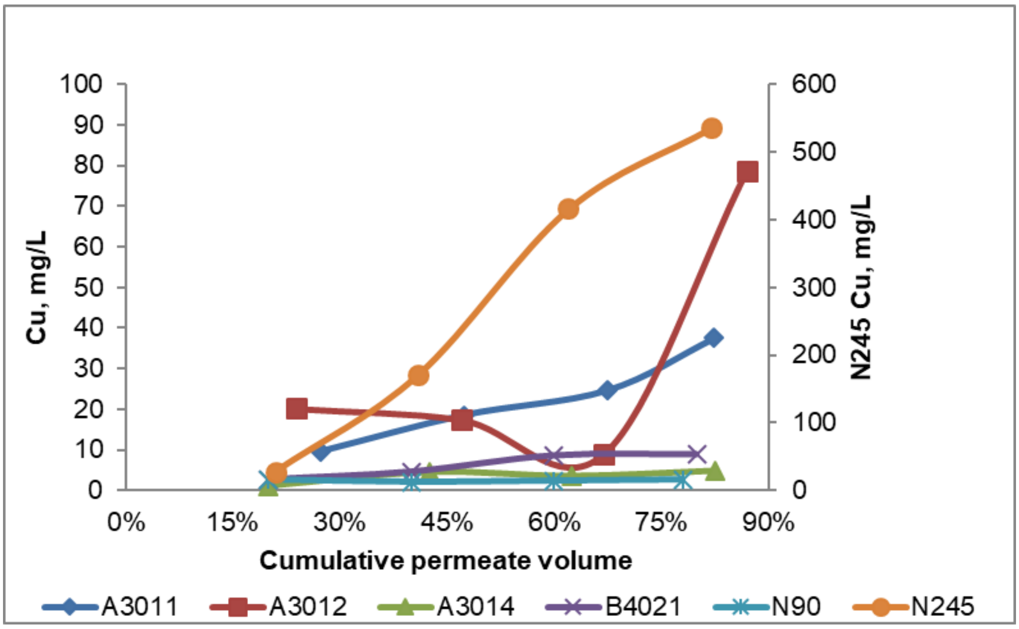

Figure 4.22: Real solution copper concentration profile at 40 bar

The AMS B4021 membrane outperformed all other membranes in terms of copper rejection at different conditions. The summary of NF membrane screening tests at tested pressures is given in Table 4.3. All evaluated membranes recovered > 80% permeate except for AMS B4021 with 90% copper rejection into the concentrate. These membranes are suitable for treating copper dilute streams, however for environmental disposal generated permeate stream needs to be passed in a second membrane to decrease the copper concentration in the stream.

Table 4.3: Real solution summary of NF membrane screening tests at tested pressures

Membranes	Recovery Permeate	Flux Permeate L/h.m^2	Combined permeate copper mg/L	Upgrade copper g/L	Retentate copper mg/L	Copper rejection
20 bar						
A3011	85%	12	9.34	4.3	1820	98%
A3012	83%	14	12.18	4.2	1780	98%
A3014	80%	12	14.46	3.5	1510	97%
B4021	77%	16	6.37	4.3	1830	99%
N90	80%	21	19.32	3.7	1600	96%
N245	84%	34	24.72	4.3	1840	91%
30 bar						
A3011	86%	19	3.38	4	1710	99%
A3012	82%	21	29.8	3.8	1610	94%
A3014	81%	15	9.64	3.7	1560	98%
B4021	82%	18	7.6	4.3	1830	99%
N90	84%	34	3.94	4.9	2100	99%
N245	78%	42	139.7	3.5	1510	73%
40 bar						
A3011	80%	21	20.46	3.9	1660	96%
A3012	80%	24	4.93	4.8	2050	99%
A3014	80%	24	3.53	4.1	1740	99%
B4021	81%	21	6.27	5.7	2450	99%
N90	71%	38	2.42	4.8	2035	100%
N245	84%	50	286.12	1.6	703	45%

One membrane was selected to conduct an optimisation test DOW N90 at optimum pressure 40 bar with high flux 38 L/h.m^2 and less than 3 mg/L copper passing through the membrane will 100% copper rejection. The additional reason for using the DOW N90 membrane is also its availability in different configurations.

4.4 Optimisation of DOW N90 membrane

The effectiveness of membrane separation operations is influenced by the operating conditions as well as the chemical characteristics of the membrane (Nel et al., 2013). For this reason, additional tests were conducted to ascertain the effects of temperature, pressure, pH, and the rate of agitation inside the cell to support final recommendations for the operation of the laboratory membrane testing unit (which operates in the dead-end configuration mode, see Figure 3.1). Several operational conditions must be considered when constructing an NF process. The following are the primary operational elements that affect NF membrane performance.

4.4.1 Agitation inside the cell

For the purpose of the laboratory tests, the cell was stirred to minimise the effect of concentration polarisation that occurs during dead-end filtration. On a commercial scale, cross-flow filtration would be employed and this parameter will not be relevant. The effects of stirring on the permeate flux and copper rejection were evaluated by varying the agitation speed. The following speeds were tested: 250, 500, and 750 rpm. This NF test was done at ambient temperature and a pressure of 40 bar; the feed solution containing 427 mg/L copper was passed through the membrane until collecting 80% feed solution. The effect of stirring on the permeate flux is shown graphically in Figure 4.23. Detailed information about tests performed on membranes can be found in Appendix F.

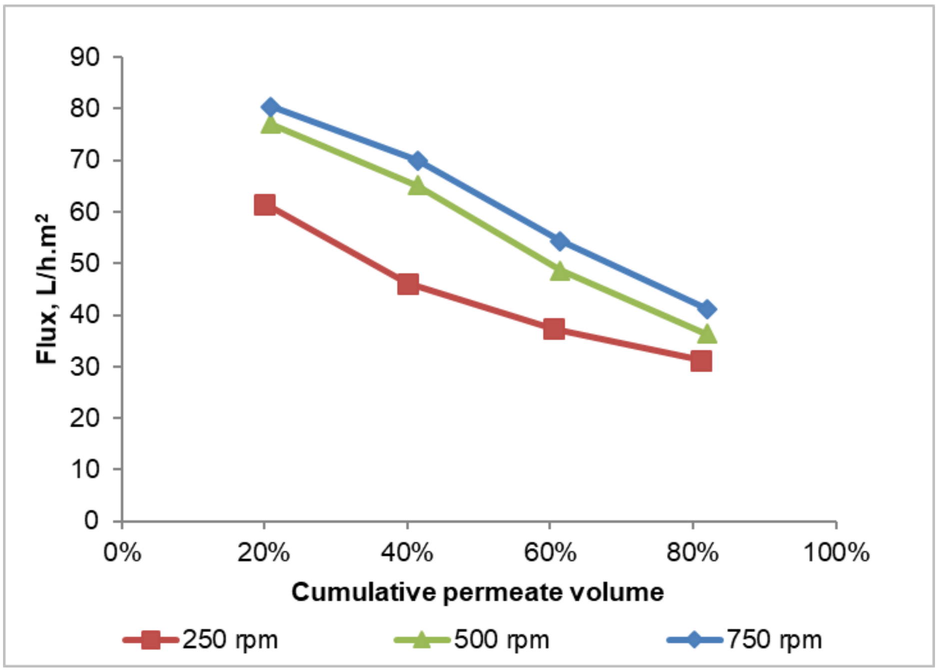

Figure 4.23: Flux as a function of agitation speed at 40 bar DOW N90

An increase in agitation speed improved overall permeate flux with time, stirring rate leads does have a positive impact on a decrease in the rate of fouling. Because in the dead-end filtration configuration, the permeate solution moves perpendicular to the membrane, and with time the membrane pores clog (effect from concentration polarisation). Mixing the solution during filtration can reduce the amount of blockage improving NF separation. Figure 4.24 shows the copper passing through the membrane at different agitation speeds. At 250 rpm the combined copper leakage into the permeate was 4 mg/L, at 500 rpm 1.97 mg/L, and at 750 rpm 1.85 mg/L. An increase in agitation speed does minimise the leakage of copper, in this case, and the optimum agitation speed for the operation of the membrane test cell was found to be 750 rpm.

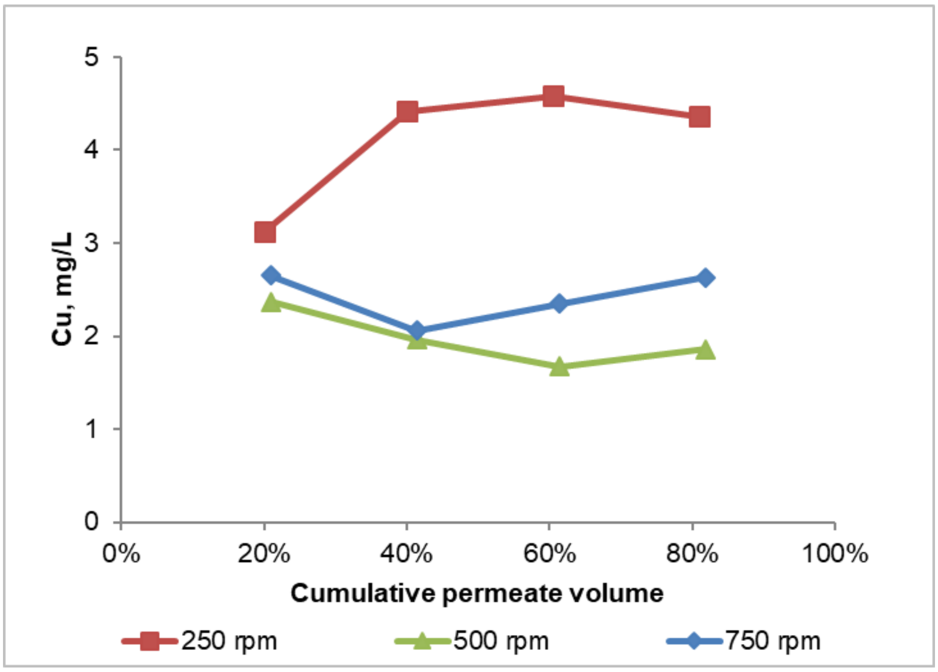

Figure 4.24: Copper deportment into the permeate as a function of agitation speed at 40

Figure 4.25 shows the copper rejection for D0W N90 at 250, 500, and 750 rpm, and more than 98% of copper was rejected.

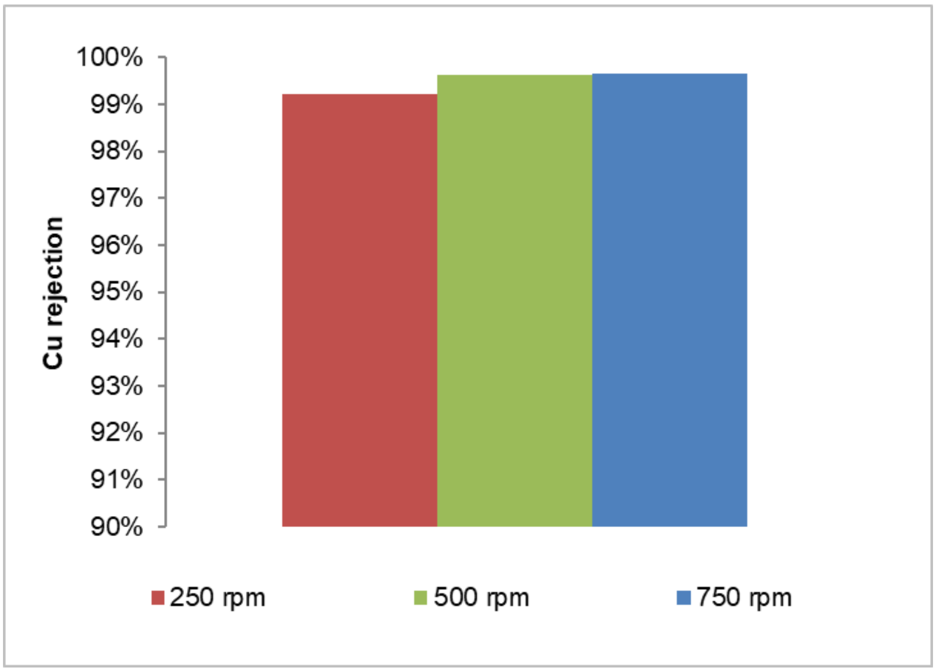

Figure 4.25: The copper rejection of 250, 500, and 750 rpm

4.4.2 Operating pressure

The operational pressure was varied at 10, 15, 20, 25, 30, 35, and 40 bar to determine its impact on the permeate flux and copper rejection. All other parameters were kept constant. Figure 4.26 and Figure 4.27 show that the permeate flux and copper rejection into retentate increased linearly with pressure. Detailed information about tests performed on membranes can be found in Appendix G.

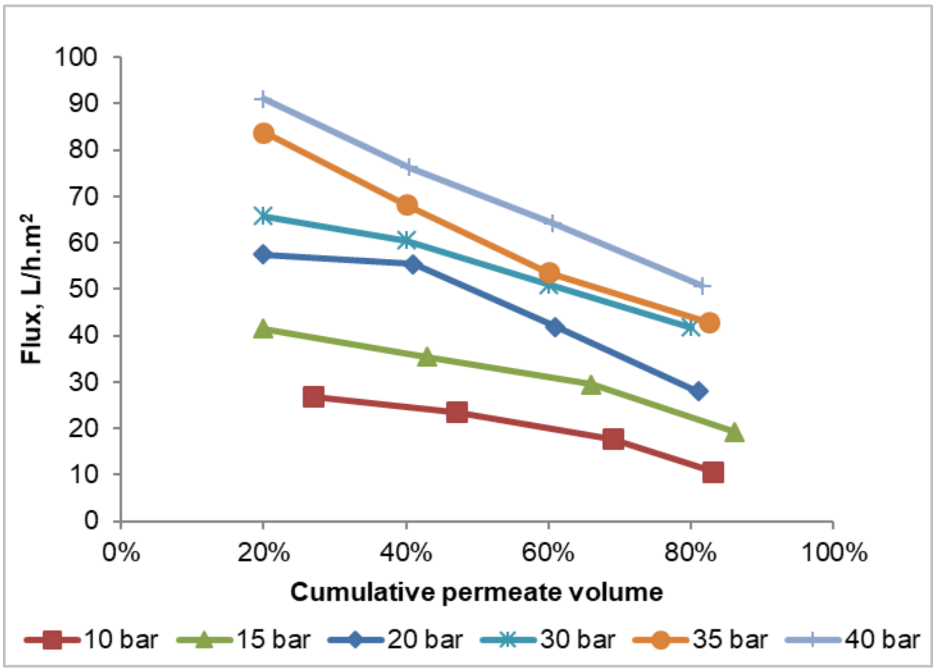

Figure 4.26: Pressure's impact on permeate flow

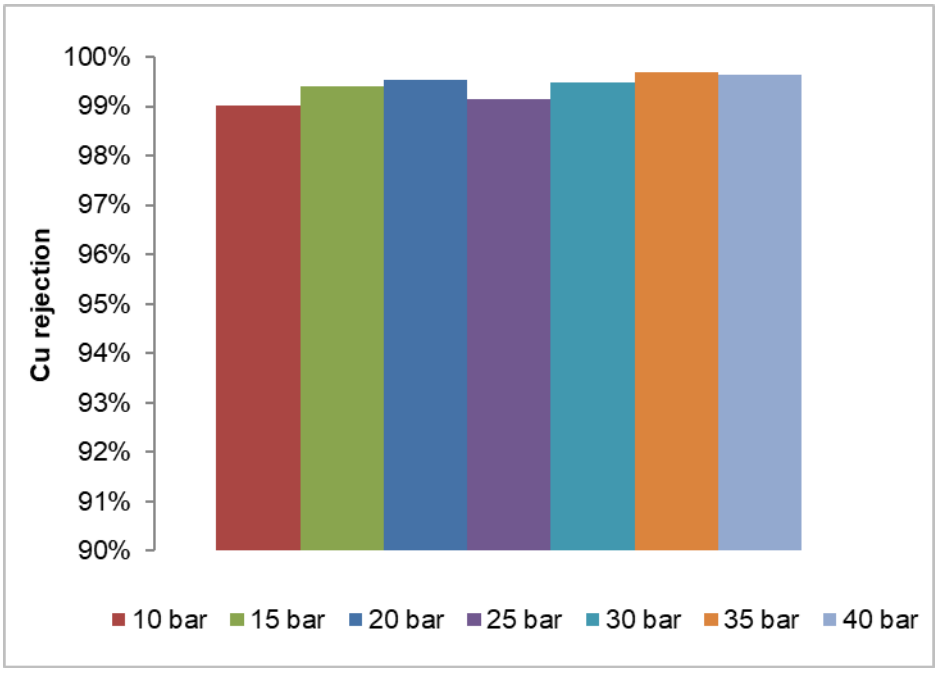

Figure 4.27: Pressure's Impact on copper rejection

As stated by Bastos et al. in 2009, at lower operational pressures, a diffusive transport of metal is responsible for the reduced rejections, but at higher pressures, convective transport of salts through the membrane takes control. This study found that, despite a change in the transport mechanism across the membrane DOW N90, there was an increase in copper rejection into retentate at lower operational pressures.

4.4.3 Temperature

The impact of temperature on the flux and copper rejection in a range of 25, 30, 35, and 45°C for DOW N90 is shown in Figure 4.28 The operational pressure and agitation were kept constant at 40 bar and 750 rpm, respectively. Detailed information about tests performed on membranes can be found in Appendix H.

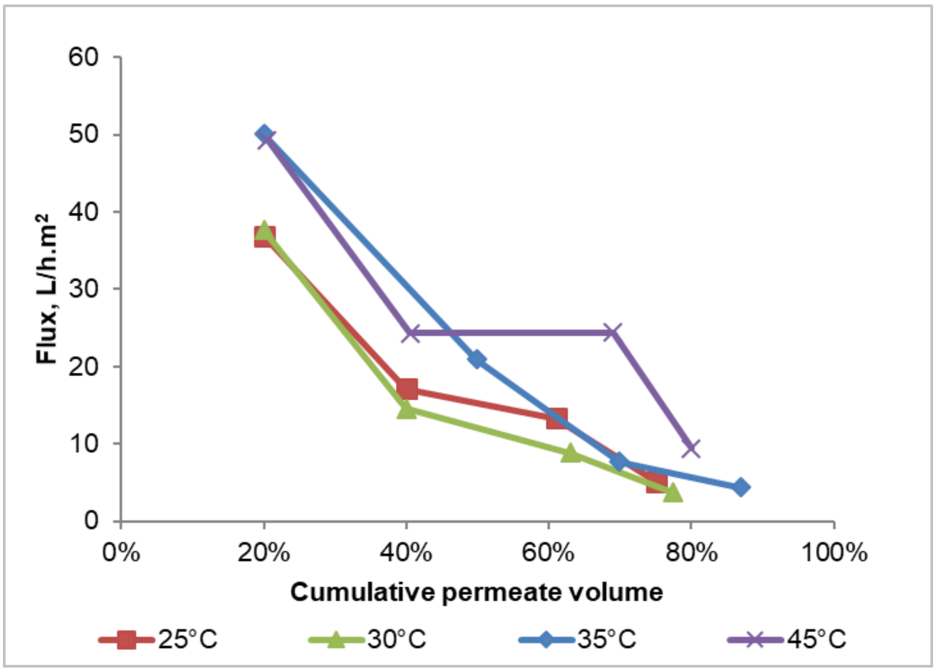

Figure 4.28: Effects of temperature on permeate flux

The permeate flux increased with temperature, which was most likely due to a decrease in viscosity of the liquor at temperature and a faster diffusion rate of feed solution through the membrane pores. The increase in flux may also indicate membrane pore expansion due to temperature increase (Mattheus et al., 2002). However, the process temperature has no significant impact on the mental rejection of NF membranes (Abhang et al., 2013). Figure 4.29 represents the profiles of copper concentrations detected in the permeate at various temperatures.

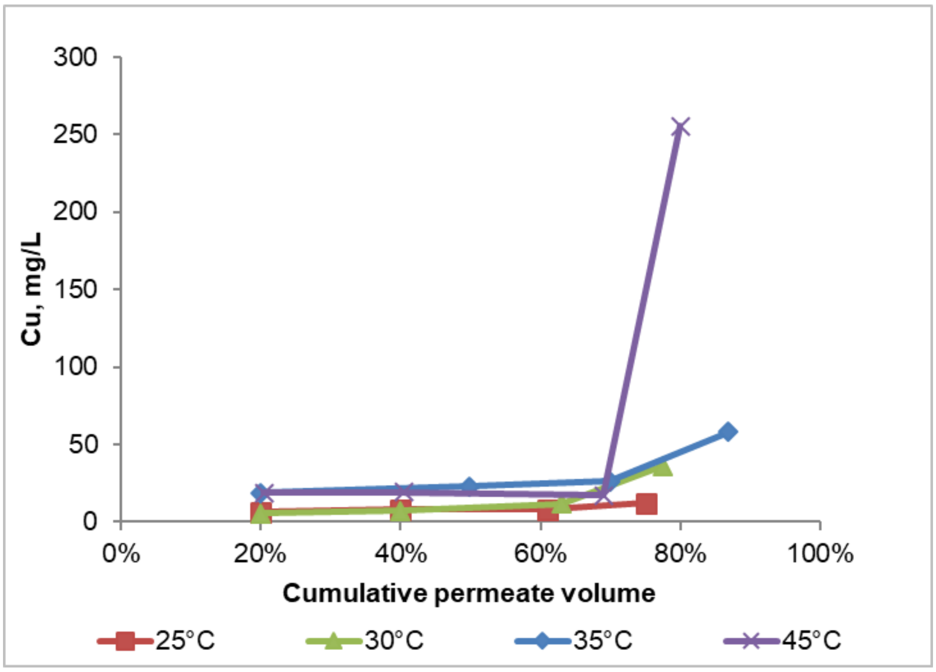

Figure 4.29: Copper leakage into permeate at various temperatures

The temperature was found to be another important parameter affecting the concentration of copper in permeate. An increase in temperature increases the amount of copper passing through the membrane, at 25°C combined permeate passing was 8.31 mg/L, at 30°C 13.49 mg/L, at 35°C 29.60 mg/L, and at 45°C 50.84 mg/L. An increase in temperature also impacted copper rejection negatively increasing the amount of copper passing through the membranes. The effect of copper rejection at the tested temperature is shown in Figure 4.30.

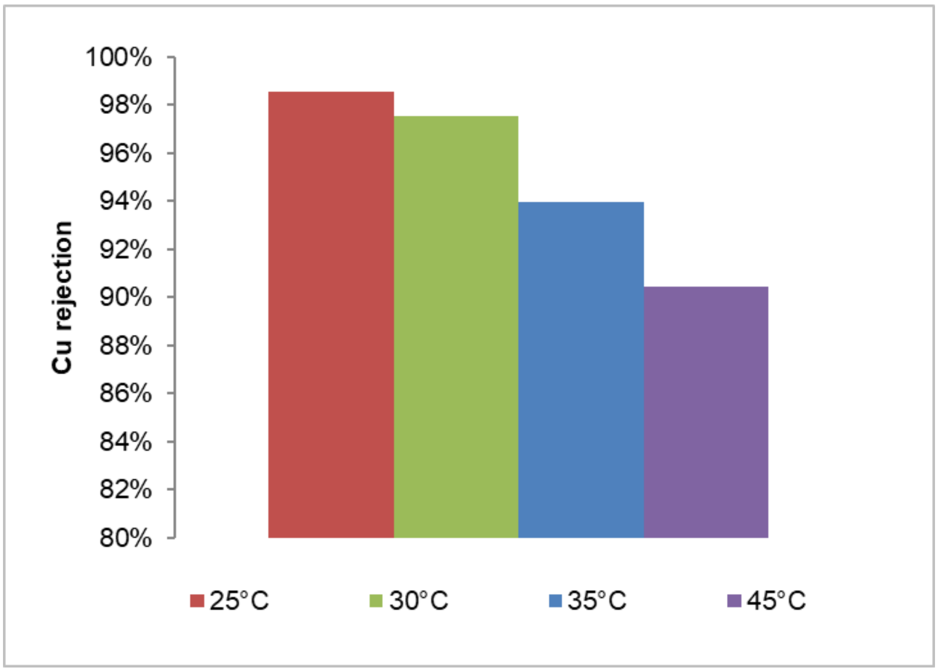

Figure 4.30: Effects of temperature copper rejection

Copper rejection into the retentate decreased from 98% at 25°C to 90% at 45 °C. A decrease in copper rejection was most likely caused by an increase in the rate of copper diffusion through the membrane pores. This could be because pore size changed as the temperature rose. At the conditions tested, the optimum temperature for the separation of water and copper was determined to be 25°C.

4.4.4 Impact of pH on copper rejection and permeate flux

The removal and recovery of copper are significantly influenced by the pH of the sample. To examine the differences in permeate flux at various pH ranges, the input parameters are kept constant at a feed concentration of 427 mg/L, operating pressure of 40 bar, and speed of 750 rpm.1 M NaOH (sodium hydroxide) was used to adjust the pH. Detailed information about tests performed on membranes can be found in Appendix I. Shown in Figure 4.31 are the pH solutions evaluated and Figure 4.32 is the copper speciation in the solution at different pHs (Anurag et al., 2017).

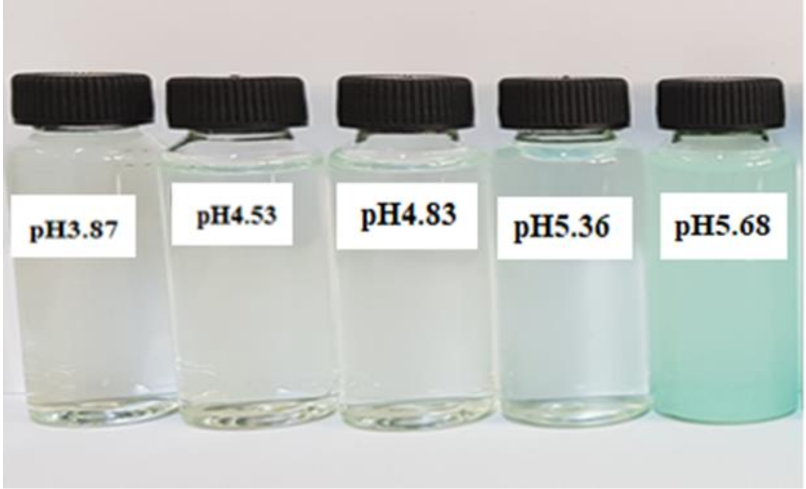

Figure 4.31: pH-adjusted feed solution

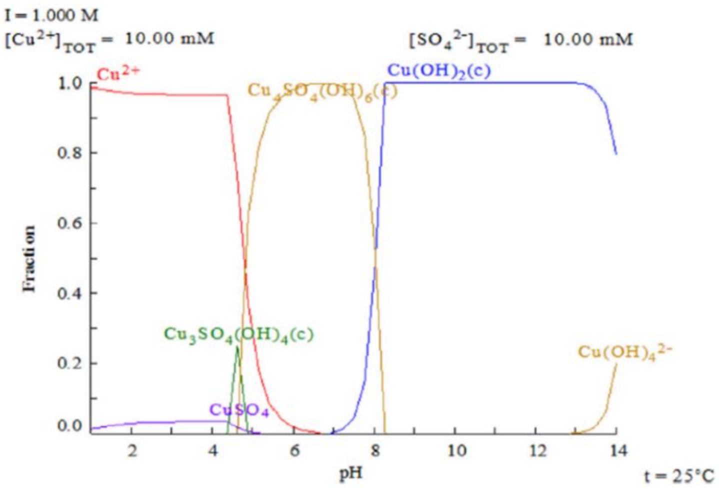

Figure 4.32: Impact of pH on the ion species of copper and the complex formation

The permeated flux is shown in Figure 4.33. The highest permeated flux was observed at pH 3.87. At higher pH, permeate flux was affected by the precipitates formed during the pH adjustment.

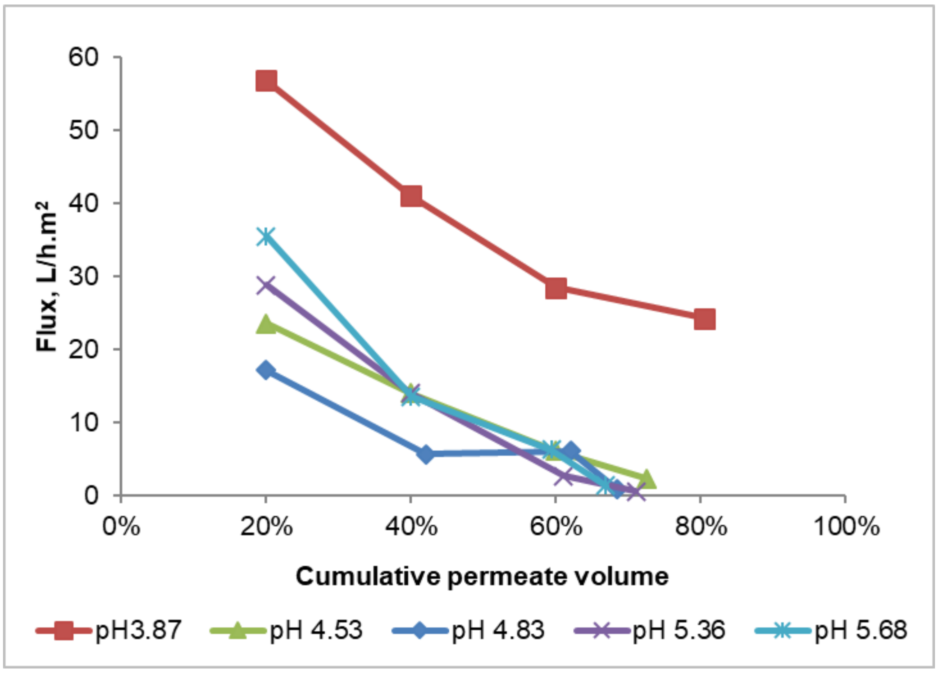

Figure 4.33: The effect of pH on permeated flux at 40 bar

The profiles of the copper concentration detected in the permeate at various pH are presented in Figure 4.34. It can be seen that the copper concertation in permeate increased initially (when pH increased from 3.87 to 5.36) and then dropped to very low concentrations at pH 5.68 at which the copper hydrolyses with the formation of $Cu(OH)_2$ precipitate. Higher copper in permeate and lower Cu rejection at pH 5.36 can be due to this pH corresponding to the isoelectric point of the membrane.

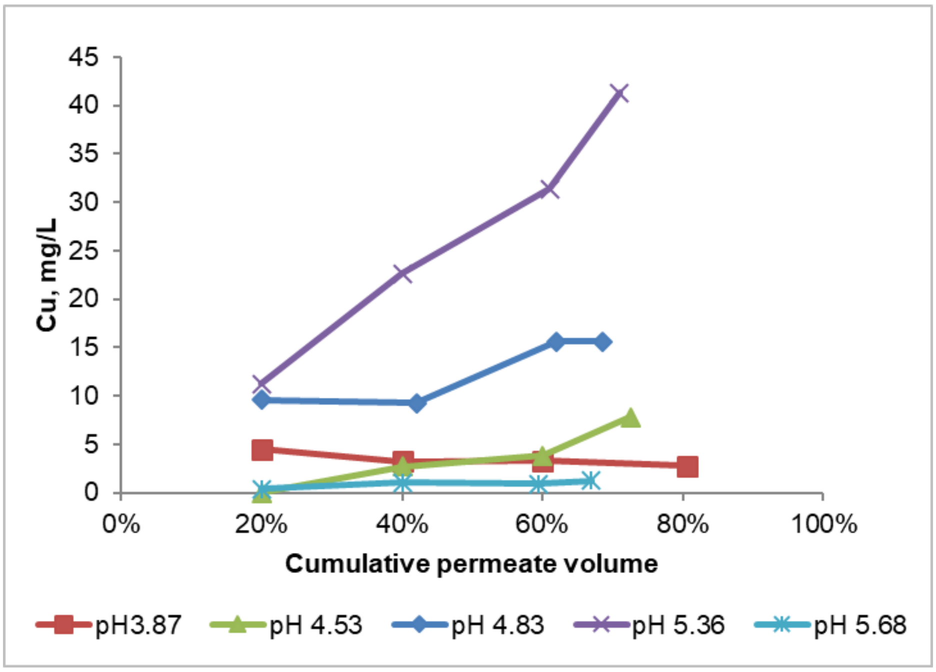

Figure 4.34: Copper concentration detected in the permeate at various pH

Thin-film polyamide membranes (NF90) with an isoelectric point between pH 3.5 and 5.0 have amphoteric properties. As a result, for pH values below the isoelectric point, the membranes have a positive charge due to the protonation of amine groups, whereas for pH values above the isoelectric point, the membranes have a negative charge due to deprotonation of carboxyl groups, and the zeta potential becomes more negative as the pH rises.

This amphoteric property of membranes plays a significant part in NF-promoting electrostatic interactions with ionisable solutes like atenolol, for example, which can lead to drastically different performances in terms of permeate flux or rejection depending on the pH range of the stream being treated (Soares et al., 2021). Figure 4.35 shows the rejection of copper at various pHs, more than 97% of copper was rejected with the higher copper rejection at pH 5.68.

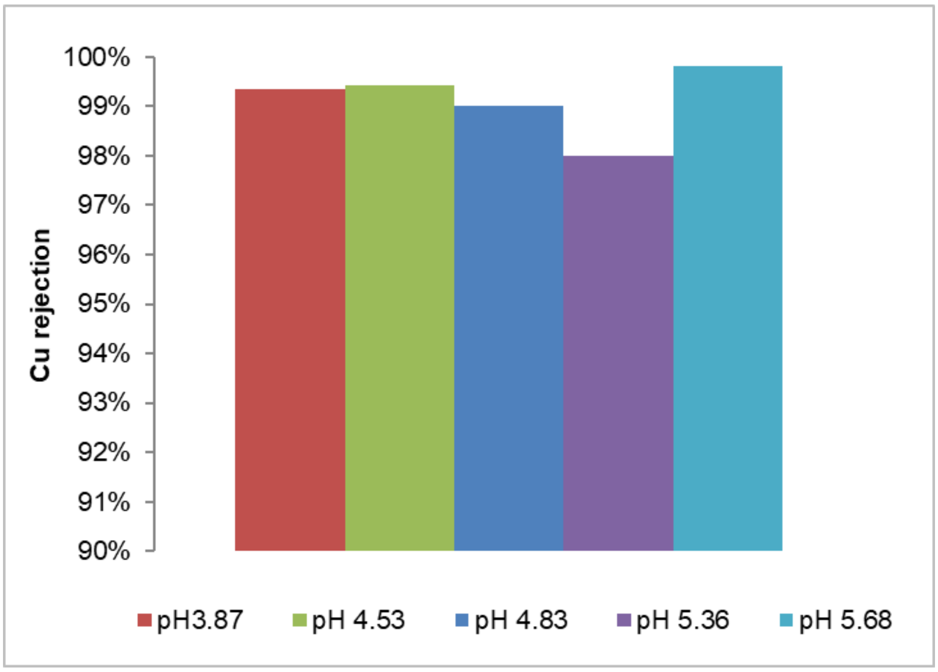

Figure 4.35: Copper rejection at various pH

4.5 NF fouling/ scaling test

The lifespan of the DOW N90 membrane was examined using a real solution at 40 bar. Five tests were conducted using one FS membrane evaluating the performance of membrane reuse. The permeate flux and copper rejection of Test 1-5 are shown in Figure 4.36. Throughout the test, flux decrease is less noticeable after five tests, after the initial decline, flux stabilised and only slightly changed during subsequent cycles. Probably cake layer was formed on the surface of the membrane and the solution was filtered through this layer. Detailed information about tests performed on membranes can be found in Appendix J.

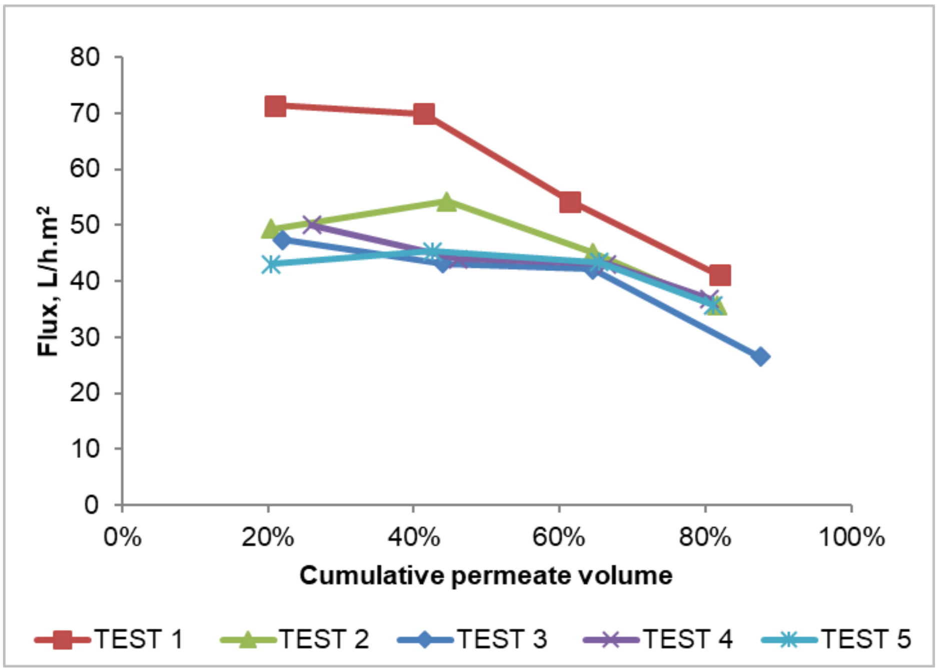

Figure 4.36: Flux Test 1-5 using one FS membrane (DOW N90)

There was no loss of copper rejection in the course of Test 1-5, Figure 4.37 shows a stable rejection at the beginning of the test until Test 5, and in Figure 4.38 copper passes through the membrane. The results for Test 1 until Test 5 show a stable rejection during the filtration tests. In all the tests the rejection of copper was more than 95%. DOW N90 membrane at ambient temperature performed well while being reused, however for more accuracy more tests should be conducted for better conclusions concerning its life span and at different conditions

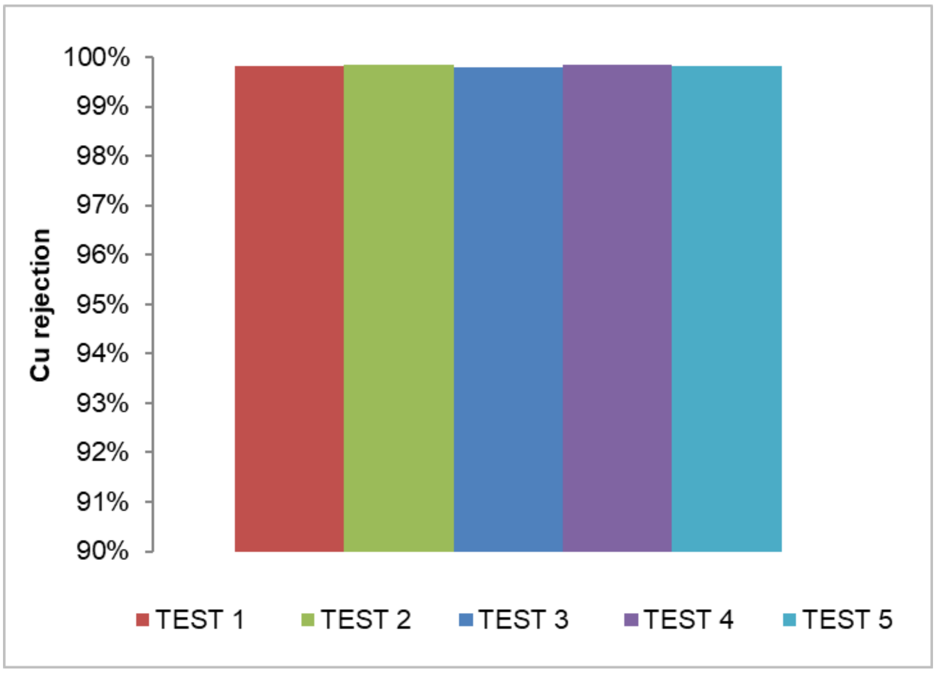

Figure 4.37: Test 1-5 copper rejection

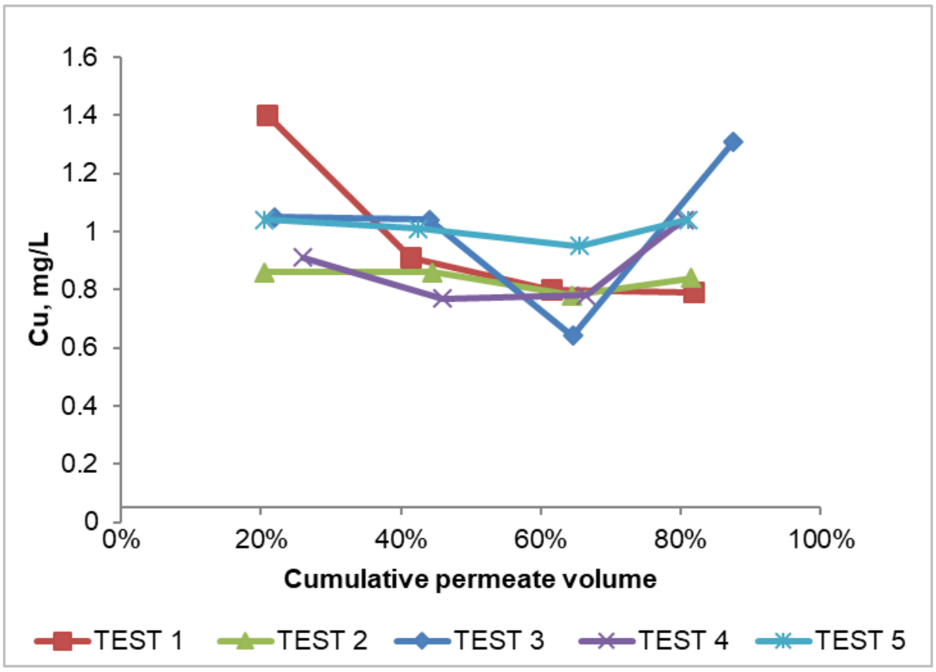

Figure 4.38: Copper concentration detected in the permeate at Test 1-5

CHAPTER 5

5. UF Filtration Results and Discussion

5.1 Introduction

As stated by the supplier AMS A-U301 membrane has long-term performance with high and stable fluxes in a very acidic environment, featuring high pressure and temperature compatibility. AMS A-U301 can either be used for pre-filtration before NF or as stand-alone membranes in acid purification and metal concentration. Synthetic and real feed solutions were pre-treated using UF membrane (AMS A-U301), to minimise potential fouling of NF membrane.

5.2 UF pre-treatment

The schematic diagram of the conducted test using AMS A-U301 and DOW N90 is shown in Figure 5.1 for a synthetic and real solution. Detailed information about tests performed on membranes can be found in Appendix K and Appendix L.

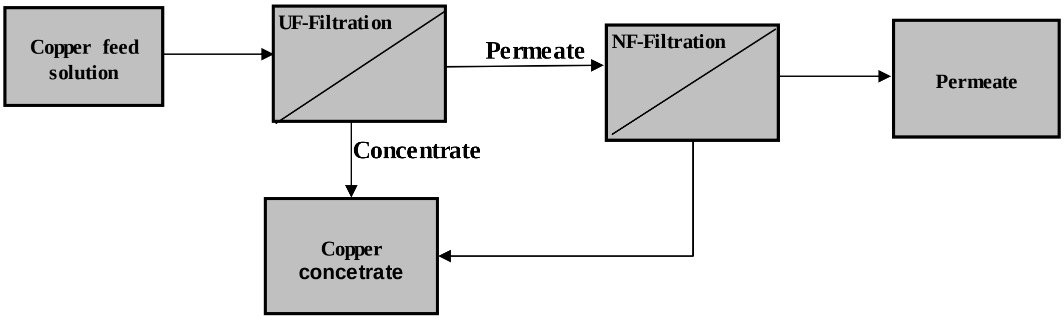

Figure 5.1: Schematic block diagram for UF-pretreatment

5.2.1. UF filtration

The experiments were run in a dead-end cell (see Figure 3.1), with 150 mL of feed solution added to the cell reservoir. Following that, 20 mL permeate samples were collected, and the tests were stopped after collecting 80% of the volume into the permeate. Figure 5.2 and Figure 5.3 show the change in flux and metal rejection at 40 bars. The A-U301 flux was slightly decreasing with time for both evaluated solutions, with poor metal rejection into retentate. Copper rejections achieved with the tested UF membrane were 75% for the synthetic solution and 65% for the real solution. UF alone cannot effectively remove copper from effluent streams.

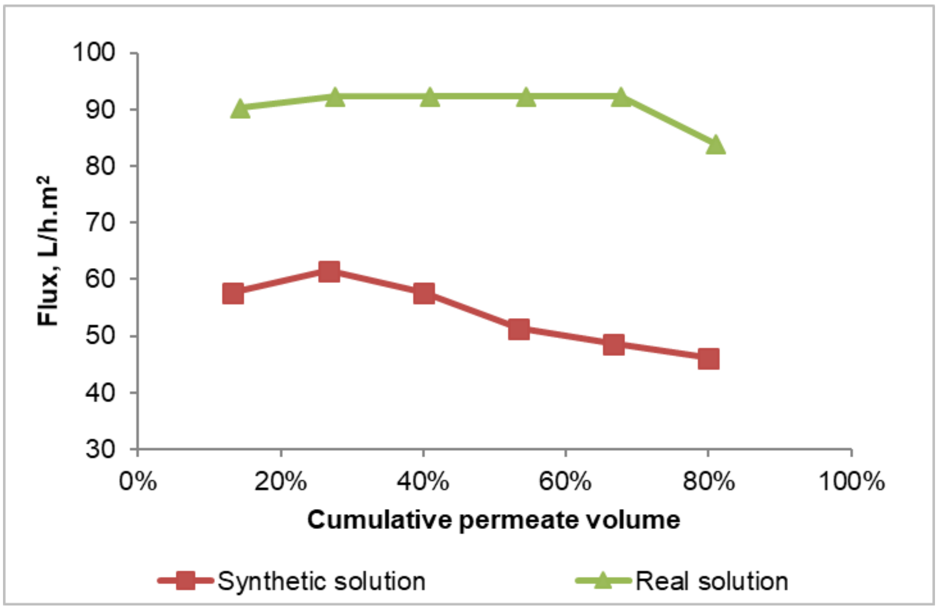

Figure 5.2: UF flux for a synthetic and real solution

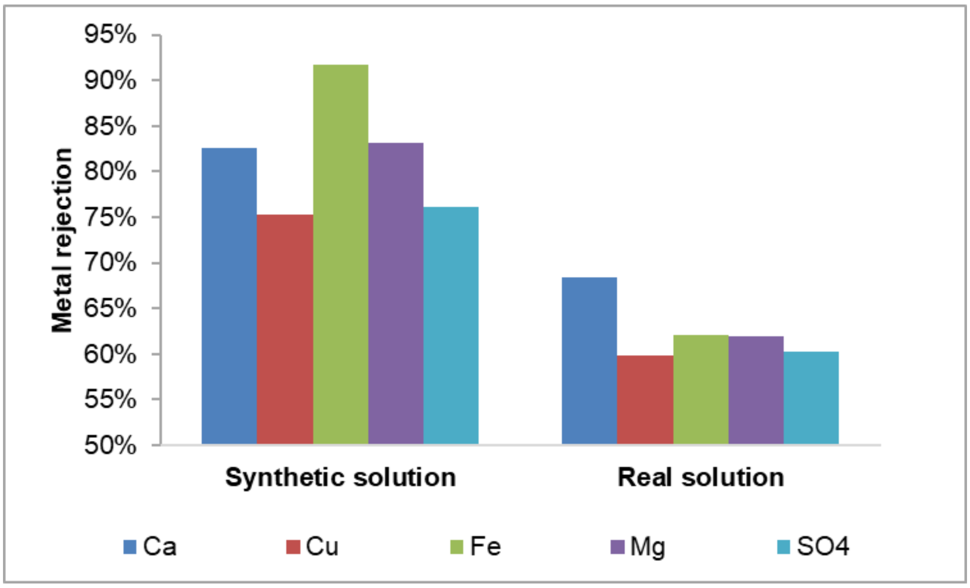

Figure 5.3: UF copper rejection for a synthetic and real solution

Table 5.1 shows the copper concentration in the feed, the UF permeates and concentrates C-1 after AMS A-U301.

Table 5.1: Feed as is and UF treated for tested solutions

Elements	Synthetic as is mg/L	Synthetic permeate mg/L	Synthetic C-1 mg/L	Real as is mg/L	Real permeate mg/L	Real C-1 mg/L
Al	34.7	3.82	177	9.26	3.04	25.5
As	<2	<2	<2	<2	<2	<2
Ca	398	86.6	505	289	114	522
Cd	<2	<2	<2	<2	<2	<2
Co	<2	<2	<2	<2	<2	4.91
Cr	<2	<2	<2	<2	<2	<2
Cu	639	197	1430	427.7	215	966
Fe	172	17.8	792	1,9	1	5
Li	<2	3.22	3.27	<2	3.45	3.91
Mg	571	120	2410	416	198	1240
Mn	37.9	<2	21.8	29.6	15.5	84.3
Mo	<2	<2	<2	<2	<2	<2
Ni	10.6	2.67	46.2	8.24	4.39	24.8
Pb	<2	<2	<2	<2	<2	<2
S	1630	487	6210	1020	506	2720
Si		<2	8.93	15.6	13.6	22
Ti	<2	<2	<2	<2	<2	<2
V	<2	<2	<2	<2	<2	<2
Zn	<2	<2	<2	4.63	2.89	11.2

The permeates had lower copper concentrations than corresponding feed solutions with 197 mg/L analysed in the permeate obtained from synthetic feed, and 217 mg/L copper reported in the permeate generated from the real solution and concentrates had 1430 mg/L synthetic copper and 966 mg/L real copper.

5.2.2. UF permeate filtration followed by DOW N90 filtration

The second test was conducted using the real solution as is and treated with UF. The solution was passed through DOW N90 at 40 bar ambient temperature to see the impact of the UF pre-treatment. The permeate flux for filtering of solutions as is and treated with UF are presented graphically in Figure 5.4. Pre-treatment with UF increased the flux.

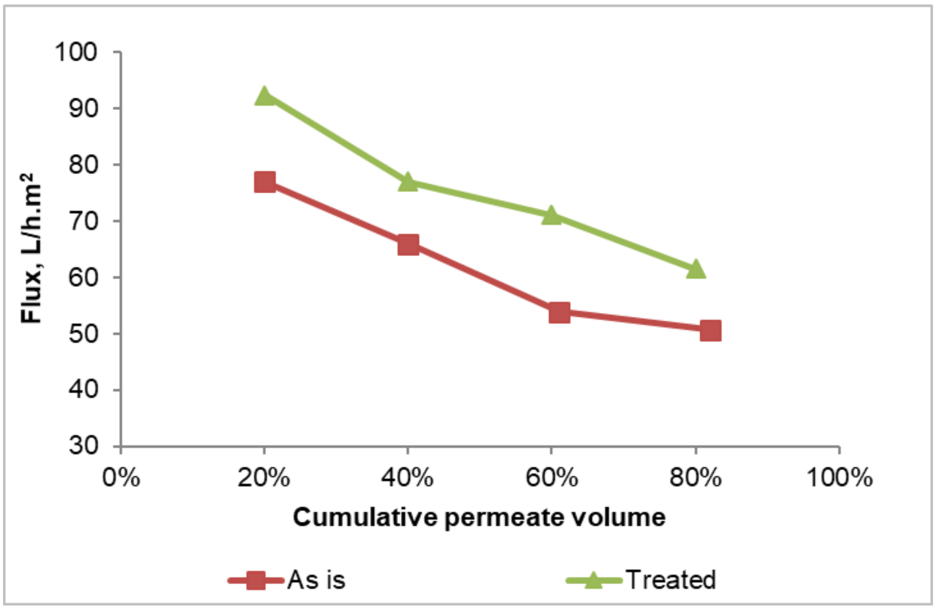

Figure 5.4: DOW N90 flux as is and treated

Figure 5.5 shows the copper concentration in the permeates collected for DOW N90 membranes. In the case of the untreated solution, NF permeate had a higher copper concentration, whereas, in the UF-treated solution, the copper concentration in NF permeate was less than 2 mg/L.

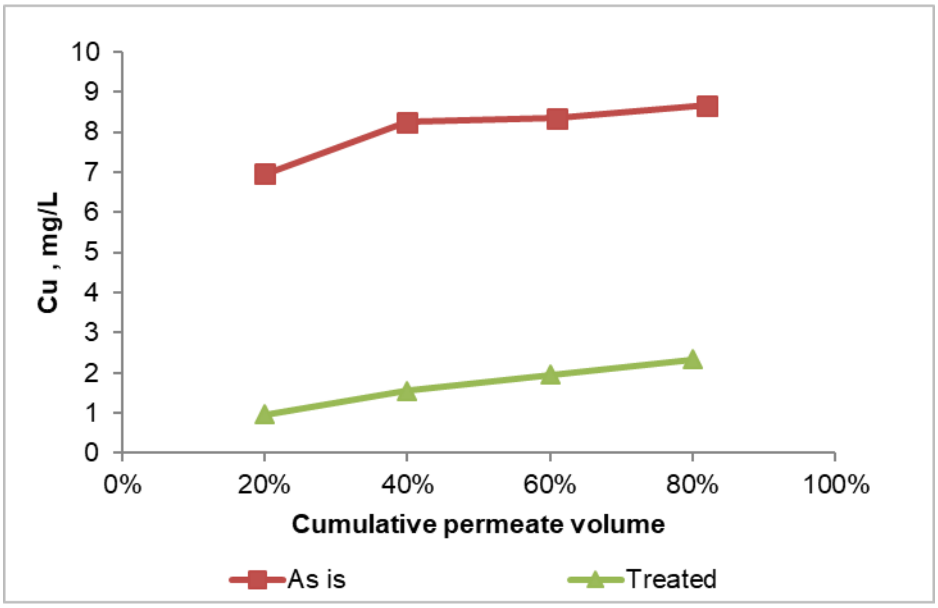

Figure 5.5: Copper passing for DOW N90 as is and treated

The metals rejected into permeate are shown in Figure 5.6. The rejections of copper in both solutions were > 90%. It should be noted that the analysis of iron may be erratic for streams generated using real feed due to the very low iron concentration there.

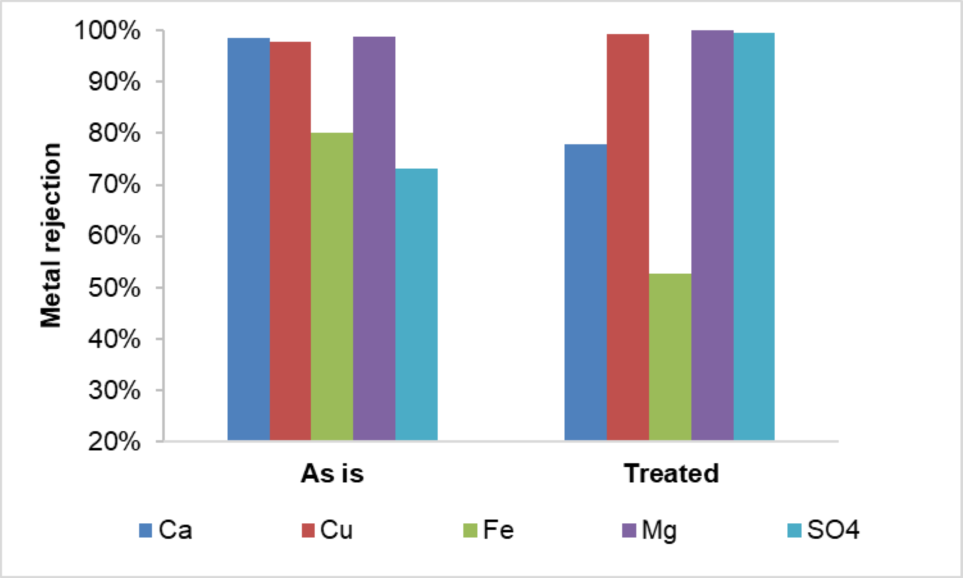

Figure 5.6: DOW N90 metal rejected as is and treated

CHAPTER 6

6. Results and Discussion of Pilot Run

6.1 Introduction

The pilot test is the next step after the laboratory scale test. During piloting, an entire process is evaluated in real-time. The real feed solution with a composition reported in Table 4.2 was used to evaluate the feasibility of using DOW N90 membrane technology to remove copper and produce purified water/acid.

6.2 Water test

In this test, the feed was deionised water, and the measurements for the penetrated water flow rate at the matching hydraulic pressure readings were made directly. Equation 1 was used to calculate the experimental values of water flux through the membrane, which were then evaluated by dividing the permeate water flow rate by the membrane area. The trans-membrane hydraulic pressure differential was then divided by water flux to determine the experimental pure water permeability.

Results of tests conducted at an average feed flow rate of 17.2 L/h.m^2 are shown in Figure 6.1 and Figure 6.2. It can be seen that at applied pressure below 5 bar, it was no water flow through the membrane. A minimal flux rate was obtained at 8.8 bar pressure and was 15.5 L/h.m^2. This increase was linear up to the pressure of 18 bar, and after this flux did not change significantly. Pure water permeability was between 3 and 5 L/h.m^2.bar.

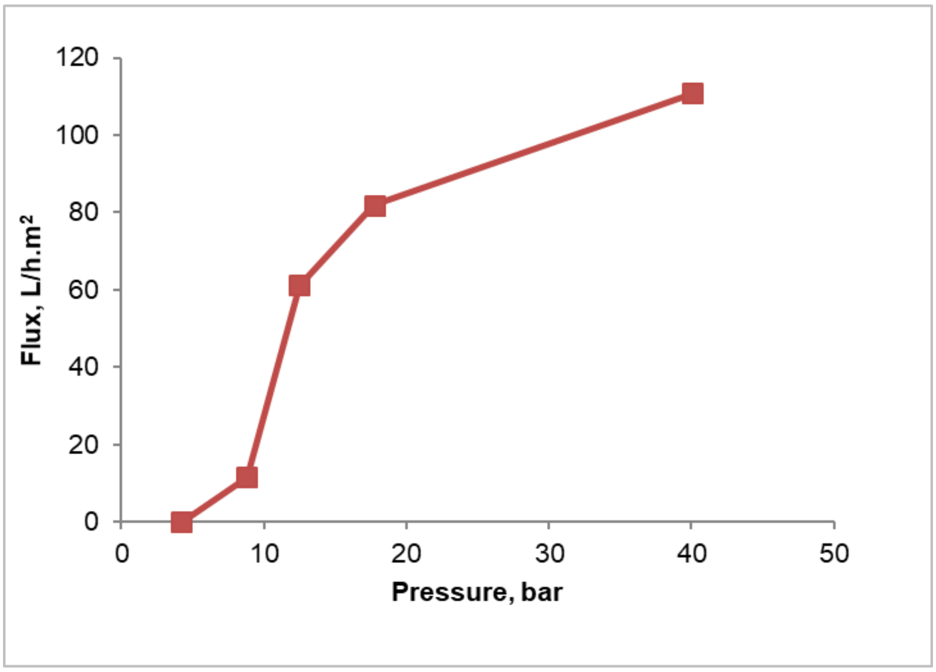

Figure 6.1: Flux of water test

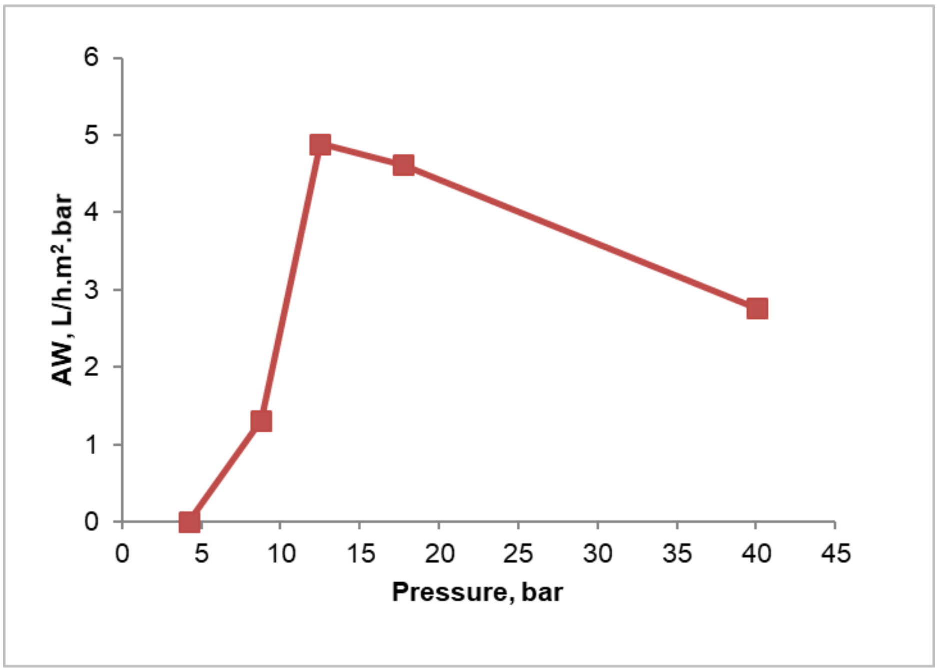

Figure 6.2: Results of the water test

6.3 Copper solution: Test 1. Pressure optimisation

The objective of the test work was to evaluate the possibility and optimal conditions for the removal of copper using the NF membrane tested. Test work was conducted at different applied pressure. Figure 6.3 shows that pure water flux was much higher than permeate flux obtained for a copper solution at similar pressure values.

The minimal flux rate for a copper solution was obtained at 15.3 bar pressure and was 13.8 L/h.m^2. Permeate flux increased with pressure linearly up to the pressure of 30 bar, then was declining slowly. This might be because of fouling or a phenomenon called concentration polarisation, which happens when more ions are trapped on the membrane's surface and reduce its rejection and permeability as a result of rising osmotic pressure on the feed side (Ambiado et al., 2017).

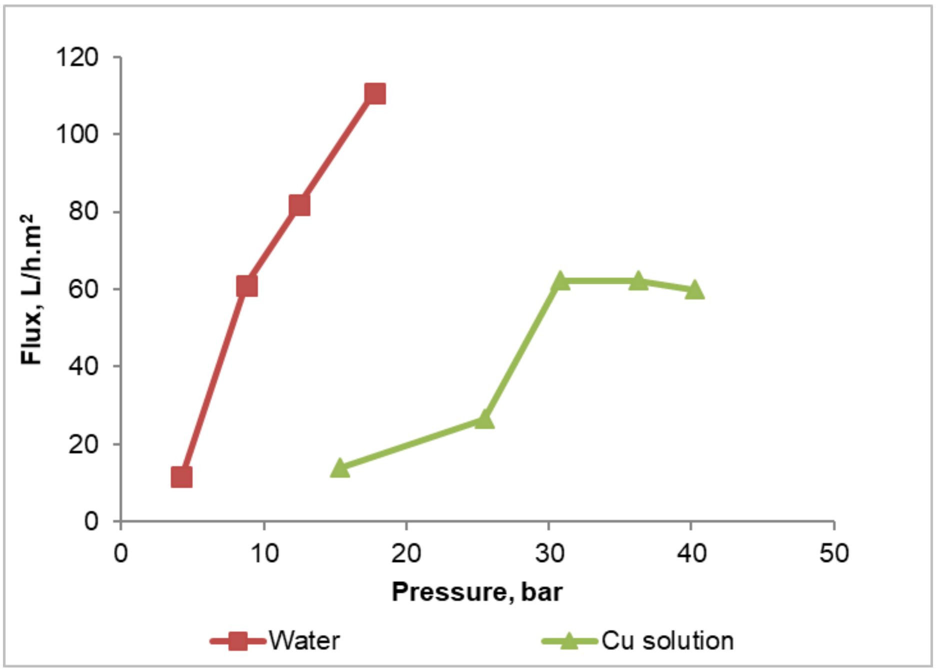

Figure 6.3: Flux vs pressure. Test 1

The water recovery rate (WRR) was calculated as per the equation below:

$$\mathrm{WRR} = {}^{\mathrm{Qp}}/_{\mathrm{Q_f}} * 100 \qquad \text{Equation 6}$$

Where: Q_p is the permeate volumetric flow rate;$\frac{L}{hr}$, Q_f is the feed volumetric flow rate;$\frac{L}{hr}$

Figure 6.4 shows that the water recovery rate increased proportionally to applied pressure and a maximal 30% WRR was reported at a pressure of 30 bar, then WRR stabilised.

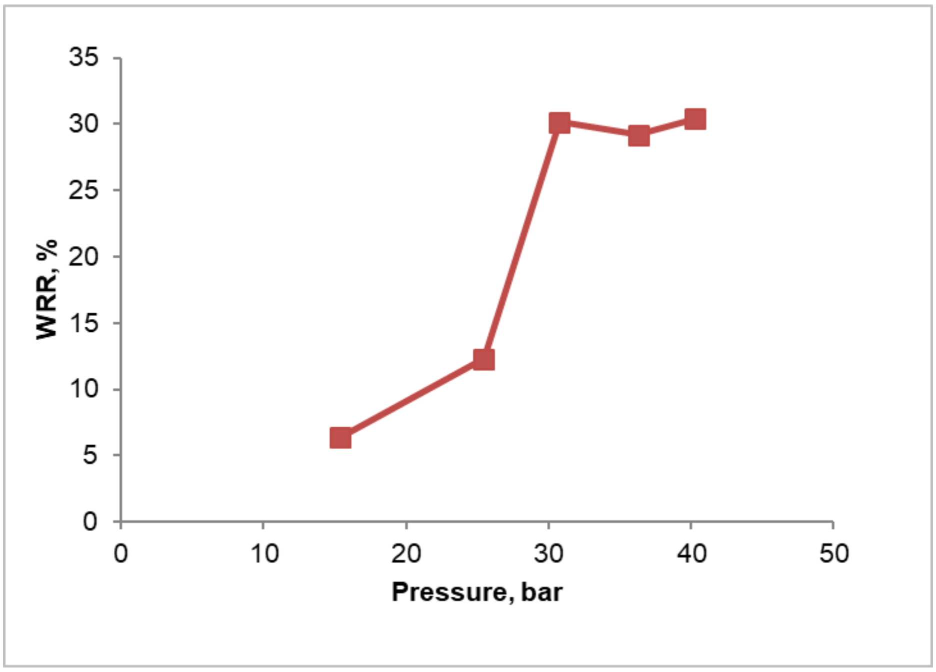

Figure 6.4: Water recovery rate vs pressure. Test 1

Permeate quality remained constant till pressure increased to 40 bar (Figure 6.5), however, there was a spike in metal concentrations reported at 35 bar. The reason for this is unknown pH of permeate ranged between 4.0 and 5.7. These numbers are higher than the feed's pH. (3.9). The flow of protons through the membrane can be inferred from differences in permeate pH compared to feed pH. The isoelectric point of the DOW NF90 membrane is 5.3 (Shashank et al., 2016); (Alice et al., 2016) Protons are electrostatically attracted to the positively charged membrane surface when the feed pH is 3.9, which makes it difficult for protons to move through the NF membrane.

Permeates analysis showed that elements of interest were at a very low level (3-6 mg/L Cu, Ca, Mg, and Si, other elements were below the detection limit). However, permeate sample collected at 60 bar had 3-5 times higher metal concentrations.

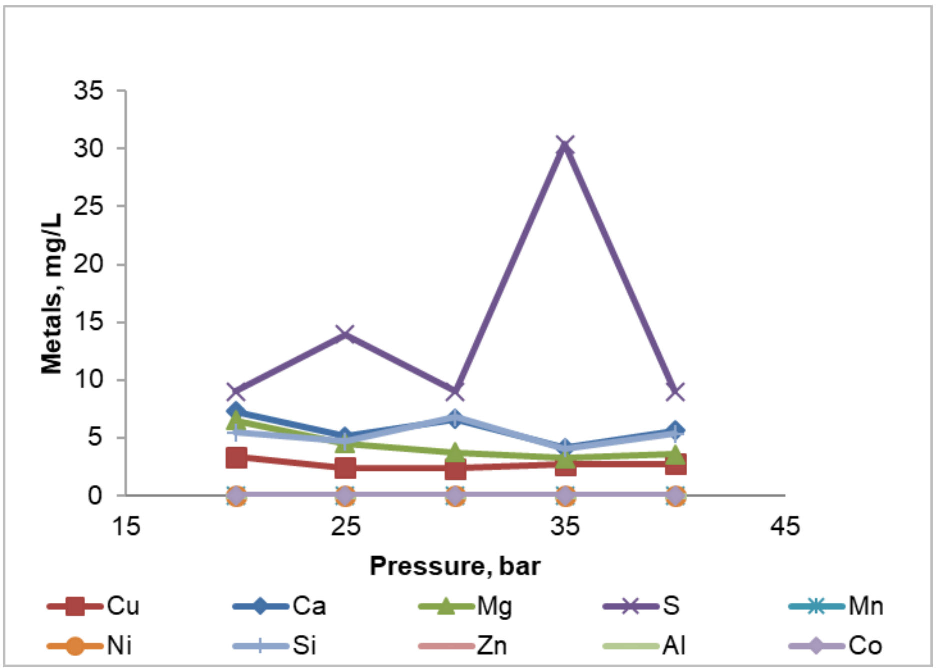

Figure 6.5: Metals content in permeate. Test 1

Figure 6.6 shows metal rejection obtained during Test 1. It should be noted that rejections for different pressure were similar. NF membrane tested showed good performance rejecting 99% Cu and >98% Ca and Mg. The efficient rejection of cations by the DOW NF90 membrane is due to the pore size of the membrane and the electrostatic repulsion discussed above. Sulphate and silicate rejection could be explained by counter-ions retained by the membrane to maintain the electro-neutrality of the solution.

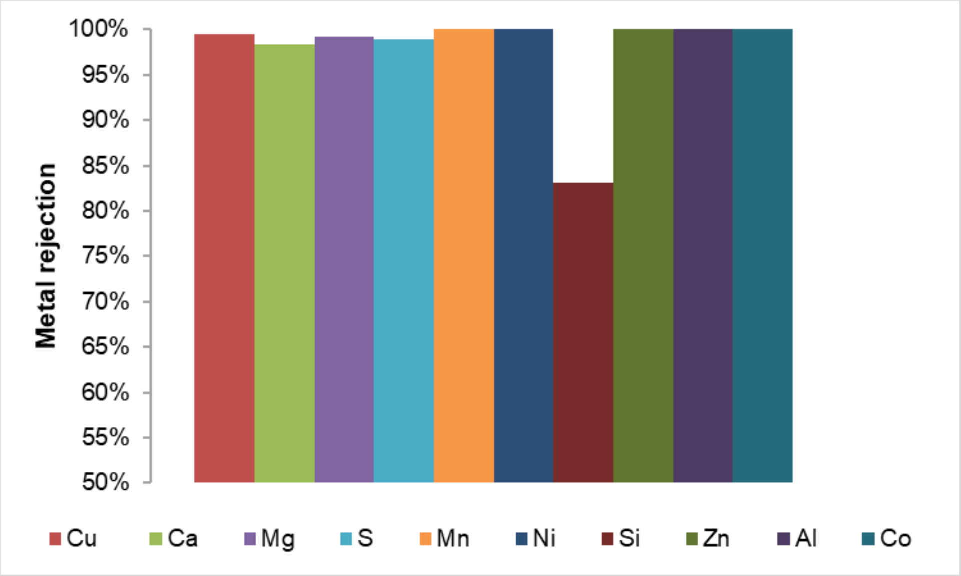

Figure 6.6: Metals rejection in permeate Test 1

The pH of the concentrate produced ranged between 3.24 and 3.64. Concentrations produced at different pressures were analysed and results are reported in Figure 6.7. For most of the elements analysed increase of feed pressure from 15 to 25 bar resulted in the increase of concentration in the concentrate stream, then their concentrations were stable for pressure up to 30-40 bar. In the case of calcium and sulphur, a decrease in their concentrations in the concentrate stream was observed. It was reported by Al-Rashdi et al., 2013 that increasing the pressure increases concentration polarization which result affects rejection negatively.

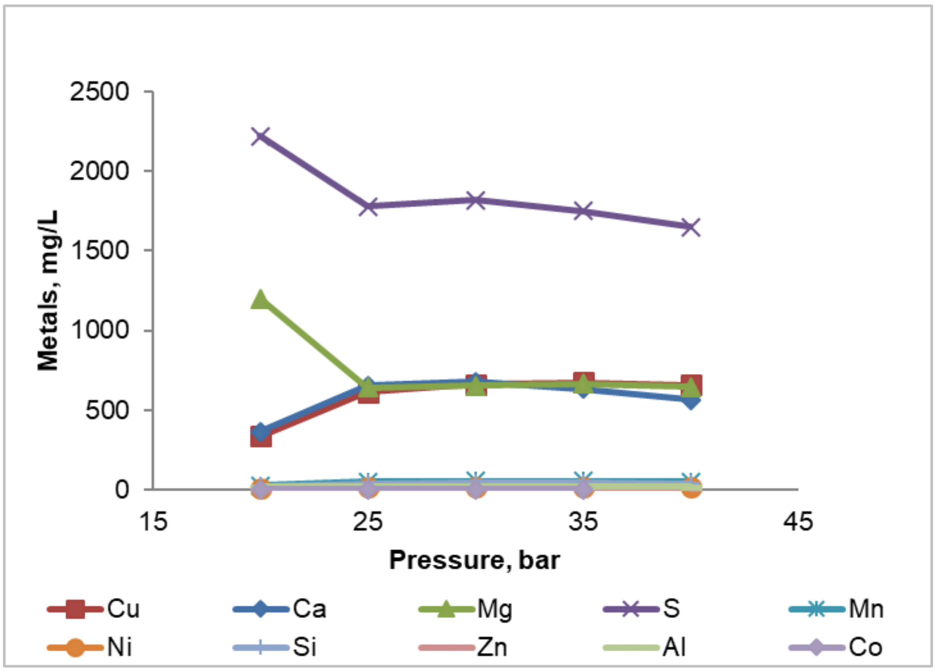

Figure 6.7: Metals content in concentrate. Test 1

The concentration factor (CF) was calculated as

$$\mathrm{CF} = \frac{\mathrm{Cc}}{\mathrm{Cf}} \qquad \text{Equation 7}$$

Where *Cc* is the concentration of solute in the concentrate, mg/L;

Cf is the concentration *of* solute concentration in the feed, mg/L.

In the case of copper, the concentration factor (CF) was~1.4 for different pressures tested. Other elements had similar CF. Based on the results of Test 1, the operating pressure of 40 bar was selected for Test 2.

6.4 Copper solution: Test 2. Recycling of the concentrate

The feed was reanalysed before Test 2 and the results are presented in Table 6.1. A slight increase in feed concentration was observed compared to Test 1. This could be due to evaporation and sampling.

Table 6.1: Feed for Test 2

Element	**Feed Test 2 (mg/L)**
Al	16.4
As	<2
Ca	544
Cd	<2
Co	<2
Cr	<2
Cu	505
Fe	<2
Li	<2
Mg	495
Mn	42.4
Mo	<2
Ni	12
Pb	<2
S	1480
Si	35.4
Ti	<2
V	<2
Zn	5.93

Permeate flow rate was measured during gradual pressure increase in Test 2 and the corresponding flux was calculated. Figure 6.8 shows that the performance of the membrane did not change.

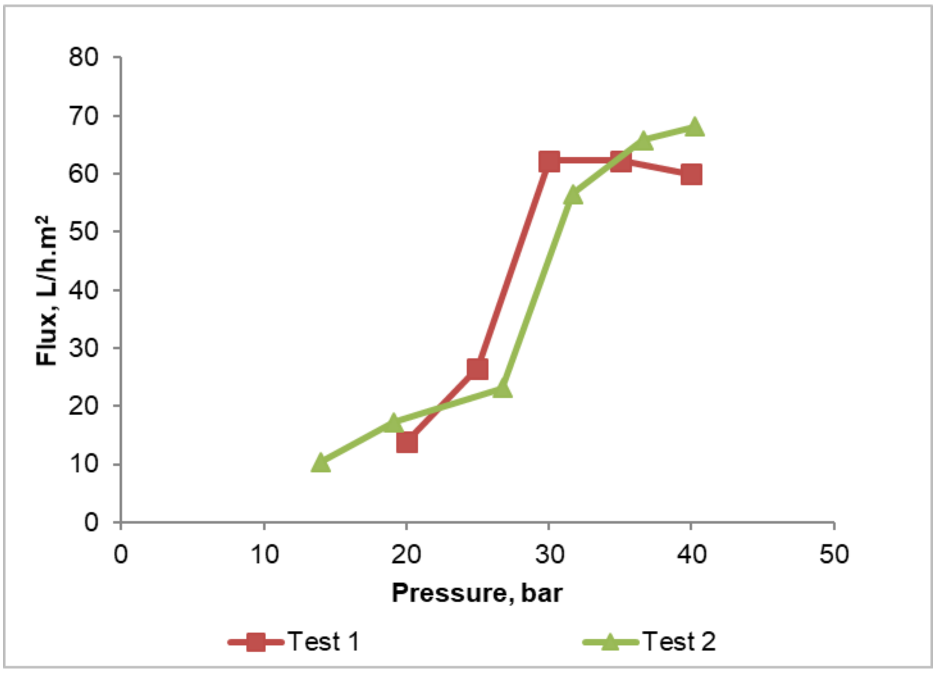

Figure 6.8: Flux vs pressure Test 2

After the pressure reached 40 bar, the test started with permeate collected in portions of 2.95 L corresponding to 5.36% of feed volume, and the concentrate was recycled to the feed tank. The test aimed to simulate higher permeate recovery and improved CF. The maximal permeate recovery achieved in Test 2 was 53.64% which is almost double compared to Test 1. It should be noted that no further increase of permeate recovery was done as the feed tank volume reached a minimal value allowing safe operation of the unit. Flux vs pressure test 2.

Figure 6.9 showed that permeate had higher pH than concentrate and feed indicating that H^+ was retained by the membrane. However, the pH of the permeate (and concentrate) did not remain stable slowly decreasing as the test progressed.

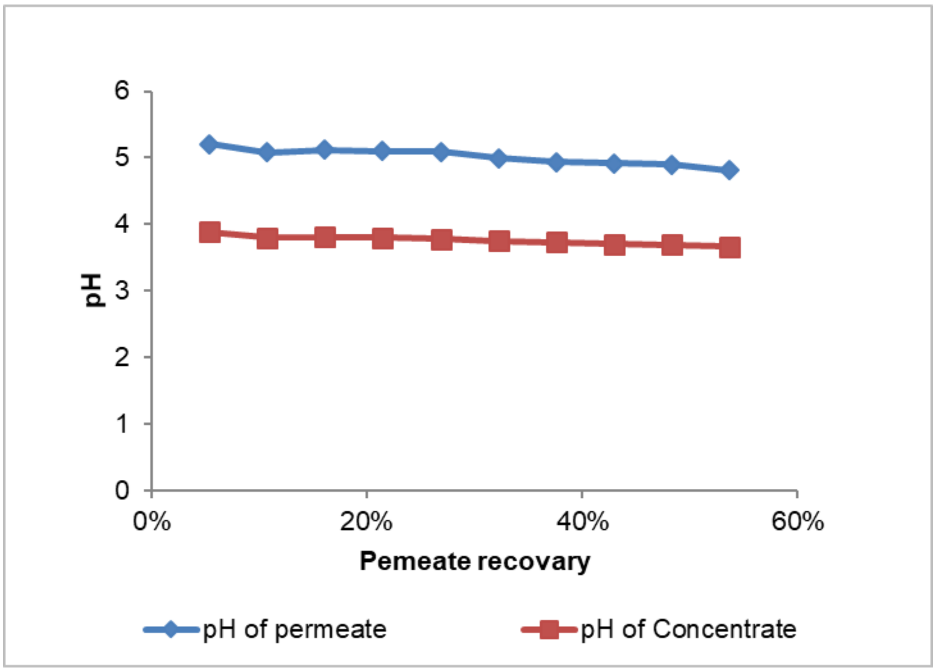

Figure 6.9: Test 2 pH measurement

Permeate generated during the test was analyses and the results are shown in Figure 6.10. It can be seen that calcium and silica in the permeate were fluctuating around the average value of 5-6 mg/L during the test, while copper and magnesium concentrations slowly increased from 2.5 to 6 mg/L and from 3 to 7 mg/L, respectively. The reason for this could be increased concentrations of solutes in the feed (after concentrate recycling). Nevertheless, the quality of the permeate generated at maximal permeate recovery was acceptable.

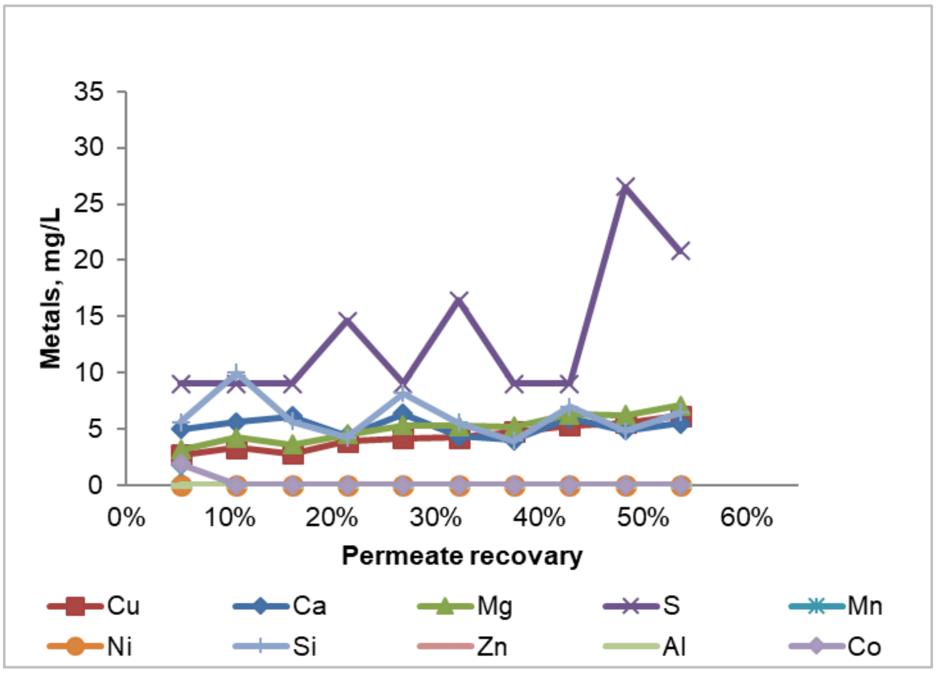

Figure 6.10: Metals content in permeate. Test 2

Rejection for most elements of interest was high, above 98%. A slow decrease in rejection was observed with the increase in permeate volume collected, see Figure 6.11.

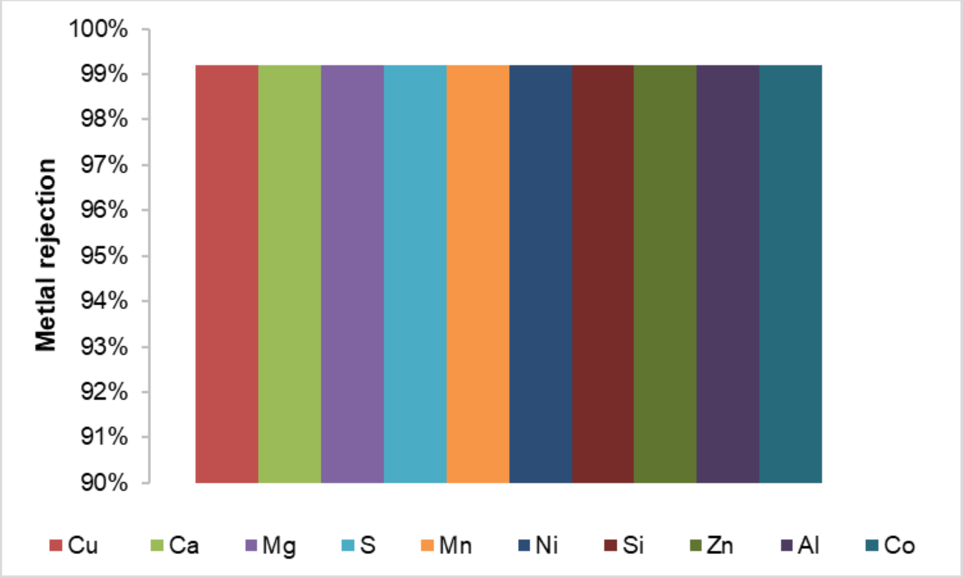

Figure 6.11: Metals rejection in permeate Test 2

Figure 6.12 shows the concentration of various elements in the concentrate collected. An increase in concentrations was observed due to the recycling of the concentrate.

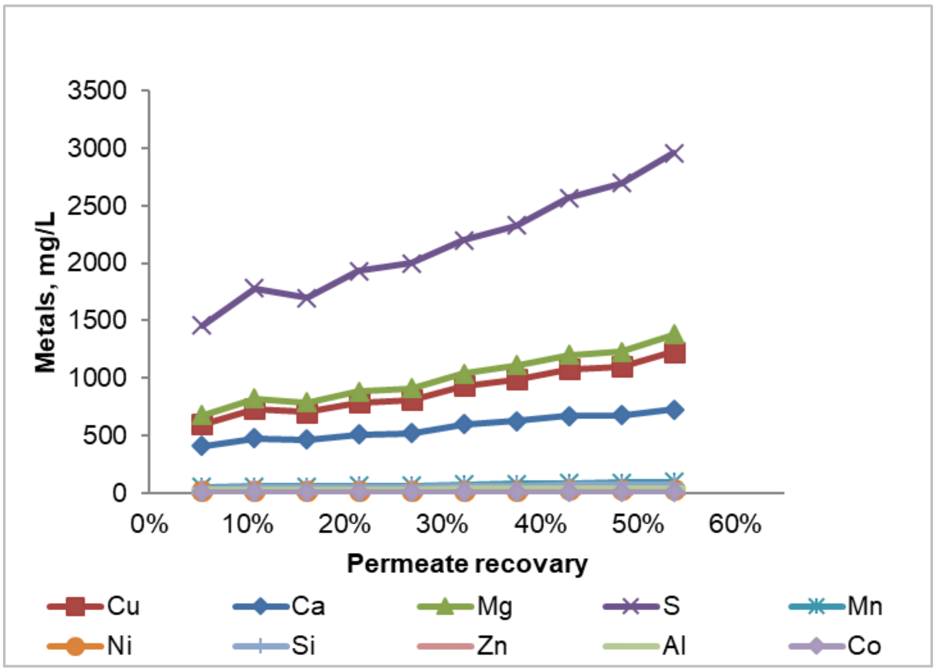

Figure 6.12: Metals content in concentrate. Test 2

The picture of the feed, permeate, and concentrate streams is shown in Figure 6.13. It could be seen that permeate produced is clear while the concentrate had a more intensive blue colour than the feed.

Figure 6.13: Solutions generated during filtration

The final concentrate produced was analysed and the results are reported in Table 6.2. An upgrade in a solute concentration of about 2 times was achieved. It was noticed that the Ca upgrade was lower than expected and accountability for Ca was quite low, at 62%. This is probably due to $CaSO_4$ precipitation as its saturation level exceeded during the run.

Table 6.2: Concentrate from Test 2

Elements	Final concentrate, mg/L	CF (mg/L)
Al	38	2.32
As	<2	n/a
Ca	718	1.32
Cd	<2	n/a
Co	4.41	n/a
Cr	<2	n/a
Cu	1140	2.26
Fe	2.25	n/a
Li	<2	n/a
Mg	1270	2.57
Mn	95.5	2.25
Mo	<2	n/a
Ni	25.5	2.13
Pb	<2	n/a
S	3110	2.1
Si	67.9	1.92
Ti	<2	n/a
V	<2	n/a
Zn	11.8	1.99

CHAPTER 7

7. Conclusion

Membrane systems provide opportunities to treat dilute streams and recover water in the copper mines. This process provides benefits not only from an economic point of view but also in terms of environmental factors such as reduced quantities of waste from neutralisation.

7.1 Laboratory test work

The performance of six commercially available NF membranes was assessed for the treatment of a copper dilute stream generated in a copper mine. Synthetic and real solutions were used throughout the test work. Membranes from two different producers namely; AMS and Dow were evaluated. The results confirmed that NF can be used for the treatment of dilute copper solution to recover copper and clean solution. The evaluated membranes were found to reject 80-99% of copper into the concentrate with > 80% of permeate at an operating pressure of 20, 30, and 40 bar at room temperature. Pressure optimisation tests are required to find the optimum conditions for the membrane operation point of view since the energy requirements of the NF process are directly linked to operational pressure. Of all the evaluated membranes:

- An increase in the operational pressure increased operational flux;
- However, an increase in pressure and temperature decreases the rejection of copper and other metals.
- During the optimisation of the DOW N90 parameters, the following was observed: high flux values with high copper rejection >90% for both synthetic and real solutions at 40 bar ambient temperature.

7.2 Pilot test work

DOW N90 was found to be suitable for treatments of diluted copper solution with a high rejection of copper achieved. Another advantage of the utilisation of this membrane was the simultaneous rejection of H^+ and other impurities. Permeate produced would only require a slight pH adjustment (to the value above 5.5) before discharge into a municipal sewer.

Permeate recovery of 53.64% was achieved but this value can potentially be improved with a simultaneous increase of copper in the concentrate for further recovery. $CaSO_4$ precipitation and membrane scaling are a limitation of the technology. However, this problem may be addressed by adding an antiscalant (Louise, 2020) or gypsum removal from the concentrate stream (Z haoyi, et al. 2022).

7.3 Future work

Membrane technology is gradually emerging for hydrometallurgical wastewater treatment and my future research studies should focus on membrane development for wastewater treatment generated during hydrometallurgical processes. The main goal will be to develop eco-friendly, cost-effective, and sustainable membranes, and developing suitable membranes will help make the process more viable for large-scale applications. Because membrane fouling and high energy demand are still major issues in pressure-driven processes, ongoing research is required to find a long-term solution

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Appendix A. VALVES

Valve Tag	Connection	FILLING FEED TANK/RECYCLING OF CONCENTRATE AND PERMEATE/FLUSH (recycle)/CIP	OPERATION IN SERIES	OPERATION IN PARALLEL	FLUSH (out)	SHUT-DOWN
BV-01	Feed pump PC-01 to feed tank TK-01	open	open	open	open	**closed**
BV-02	feed tank TK-01 to buster pump PC-02	open	open	open	open	**closed**
BV-03	feed tank TK-01 to drain	**closed**	**closed**	**closed**	**closed**	**closed**
BV-04	buster pump PC-02 to cartridge filter CF-01	open	open	open	open	**closed**
BV-05	cartridge filter CF-01 to heat exchanger HX-01	open	open	open	open	**closed**
BV-06	heat exchanger HX-01 to feed tank TK-01	**closed**	**closed**	**closed**	**closed**	**closed**
BV-07	heat exchanger HX-01 to pressure pump PC-03	open	open	open	open	**closed**
BV-08	pressure pump PC-03 to membranes	open	open	open	open	**closed**
BV-09	Valve BV-08 to membrane PV-01	open	open	open	open	**closed**
BV-10	Valve BW-08 to membrane PV-02	open	**closed**	open	open	**closed**
BV-11	Membrane PV-01 to membrane PV-02 (conc from membrane 1 to membrane 2)	**closed**	open	**closed**	**closed**	**closed**
BV-12	Membrane PV-01 to sampling point SP-02 (conc from membrane 1 to combined conc stream)	open	**closed**	open	open	**closed**
BV-13	Membrane PV-02 to sampling point SP-02 (conc from membrane 2 to combined conc stream)	open	open	open	open	**closed**
BV-14	Membrane PV-01 to sampling point SP-01 (perm from membrane 1 to combined perm stream)	open	open	open	open	**closed**
BV-15	Membrane PV-02 to sampling point SP-01 (perm from membrane 2 to combined perm stream)	open	open	open	open	**closed**
BV-16	sampling point SP-01 to feed tank TK-01(combined perm back to feed tank)	open	**closed**	**closed**	open	**closed**
BV-17	sampling point SP-01 to perm vessel out (combined perm out)	**closed**	open	open	open	**closed**
BV-18	sampling point SP-02 to feed tank TK-01(combined conc back to feed tank)	open	**closed**	**closed**	open	**closed**
BV-19	sampling point SP-02 to conc vessel out (combined conc out)	**closed**	open	open	open	**closed**
BV-20	Chiller CH-01 to drain	**closed**	**closed**	**closed**	**closed**	**closed**

Appendix B. TEST 1 DATA

CI	**Mpho**	
Operators	**Joe/tebogo**	
Test	**Effects of Pressure & Time**	
Membrane	**NF**	
MW cut off size	[redacted]	**Da**
Operational Time	[redacted]	**hrs**
Membrane Surface area	**28**	**cm^2**
Temperature	**25**	**˚C**
Mode of operation	**recycle of Perm and Conc**	
Solution	**Cu**	**ppm**
Membrane surface area	**5.2**	**m^2**

Test 1										
Time	**PI-01**	**PI-02**	**PI-03**	**PIT-01 Feed**	**PIT-02 Conc**	**FIT-01 Feed**	**FIT-02 Perm**	**FIT-03 Conc**	**TT-01**	**VSD**
mm	**kPa**	**kPa**	**kPa**	**[bar]**	**[bar]**		**[L/min]**		**[˚C]**	**[Hz]**
00:00	0	0	0	4.15	4.04	0	0	0	21.1	16.71
10	320	325	320	8.84	8.63	12.2	0	11.9	24.7	20.07
20	275	280	275	15.33	15.09	18.9	1.2	16.3	26.3	30.37
30	290	280	270	25.47	25.23	18.7	2.3	14.7	28.2	30.73
40	285	285	270	30.76	30.54	17.9	5.4	13.1	30.1	30.73
50	285	300	275	36.27	36.04	18.5	5.4	12.8	32.1	30.73
60	300	305	295	40.23	40.01	17.1	5.2	13.2	34.3	30.73

	Feed tank volume	**Permeate sample volume**	**pH of Permeate**	**Concentrate sample volume**	**pH of Concentrate**	**Pressure**	**Permeate Flux (LMH):**	**Permeate Recovery**	**Concentrate Flux (LMH):**	**Concetrate Recovery**
	L	**[mL]**		**[mL]**		**Bar**	***$L/h.m^2$***	***%***	***$L/hr.m^2$***	***%***
Feed	90		3.7		3.7					
Sample 1	72	20	4.24	25	3.24	20	14	6%	188.1	86%
Sample 2	72	22	5.27	21	3.6	25	27	12%	169.6	79%
Sample 3	72	25	5.42	33	3.58	30	62	30%	151.2	73%
Sample 4	71	32	4.02	29	3.45	35	62	29%	147.7	69%
Sample 5	71	25	5.57	28	3.58	40	60	30%	152.3	77%

Mass Balance										
	Cu	**Ca**	**Mg**	S	**Mn**	Ni	**Si**	**Zn**	**Al**	**Co**
					mg/L					
Feed	457	350	526	1315	39	10	31	5	14	2
Permeate 1	3	7	6	9	0	0	5	0	0	0
Permeate 2	2	5	4	14	0	0	5	0	0	0
Permeate 3	2	7	4	9	0	0	7	0	0	0
Permeate 4	3	4	3	30	0	0	4	0	0	0
Permeate 5	3	6	4	9	0	0	5	0	0	0
Conc 1	336	366	1200	2220	28	8	25	4	18	0
Conc 2	614	655	643	1780	51	14	39	6	19	3
Conc 3	663	676	653	1820	54	16	43	7	20	3
Conc 4	674	634	665	1750	55	16	42	7	20	3
Conc 5	656	566	646	1650	53	15	41	7	20	3
					mg/min					
Feed1	8637	6615	9941	24854	745	193	584	101	266	40
Feed2	8546	6545	9836	24591	737	191	578	100	264	40
Feed3	8180	6265	9415	23539	705	183	553	96	252	38
Feed4	8455	6475	9731	24328	729	189	572	99	261	40
Feed5	7815	5985	8995	22487	674	174	528	92	241	37
PERM1	4.01	8.72	7.79	10.80	0.00	0.00	6.53	0.00	0.00	0.00
PERM2	5.43	11.71	10.28	31.97	0.00	0.00	10.72	0.00	0.00	0.00
PERM3	12.53	35.69	20.14	48.60	0.00	0.00	36.56	0.00	0.00	0.00
PERM4	14.47	22.14	17.28	164.16	0.00	0.00	21.76	0.00	0.00	0.00
PERM5	14.04	29.22	18.41	46.80	0.00	0.00	27.66	0.00	0.00	0.00
CONC1	5477	5966	19560	36186	456	133	403	63	285	0
CONC2	9026	9629	9452	26166	745	206	567	95	279	40
CONC3	8685	8856	8554	23842	710	206	559	93	258	37
CONC4	8627	8115	8512	22400	703	205	539	94	260	41
CONC5	8659	7471	8527	21780	694	202	546	89	264	37
Account 1	63	90	197	146	61	69	70	63	107	0
Account 2	106	147	96	107	101	108	100	95	106	100
Account 3	106	142	91	101	101	113	108	97	102	96
Account 4	102	126	88	93	96	109	98	95	100	103
Account 5	111	125	95	97	103	116	109	97	109	100
av	98	126	113	109	93	103	97	89	105	80

Rejection									
Cu	**Ca**	**Mg**	S	Mn	Ni	Si	Zn	Al	Co
99%	98%	99%	99%	100%	100%	82%	100%	100%	100%
99%	99%	99%	99%	100%	100%	85%	100%	100%	100%
99%	98%	99%	99%	100%	100%	78%	100%	100%	100%
99%	99%	99%	98%	100%	100%	87%	100%	100%	100%
99%	98%	99%	99%	100%	100%	83%	100%	100%	100%
Passage									
Cu	**Ca**	**Mg**	S	Mn	Ni	Si	Zn	Al	Co
1%	2%	1%	2%	0%	0%	1%	0%	0%	0%
1%	1%	1%	3%	0%	0%	1%	0%	0%	0%
1%	2%	1%	2%	0%	0%	1%	0%	0%	0%
1%	1%	1%	6%	0%	0%	1%	0%	0%	0%
1%	2%	1%	2%	0%	0%	1%	0%	0%	0%
Concentration factor CF									
Cu	**Ca**	**Mg**	S	Mn	Ni	Si	Zn	Al	Co
0.74	1.05	2.28	1.69	0.71	0.80	0.80	0.73	1.24	0.00
1.34	1.87	1.22	1.35	1.29	1.37	1.25	1.21	1.35	1.27
1.45	1.93	1.24	1.38	1.38	1.54	1.38	1.32	1.40	1.32
1.47	1.81	1.26	1.33	1.39	1.57	1.36	1.37	1.44	1.49
1.44	1.62	1.23	1.25	1.34	1.50	1.34	1.26	1.42	1.29

Appendix C. TEST 2 DATA

CI	**Mpho**	
Operators	**Joe/tebogo**	
Test	**optimized conditions**	
Membrane	**NF**	
MW cut off size		**Da**
Operational Time		**hrs**
Membrane Surface area	**28**	**cm^2**
Temperature		**˚C**
Mode of operation	**recycle of Conc**	
Solution	**Cu**	**ppm**
Membrane surface area	**5.2**	**m^2**

Test 2										
Time	**PI-01**	**PI-02**	**PI-03**	**PIT-01 Feed**	**PIT-02 Conc**	**FIT-01 Feed**	**FIT-02 Perm**	**FIT-03 Conc**	**TT-01**	**VSD**
mm	**kPa**	**kPa**	**kPa**	**[bar]**	**[bar]**	**[L/min]**			**[˚C]**	**[Hz]**
00:00	320	325	305	9.13	8.92	12.6	0	11.9	28.6	20.31
10	325	335	315	9.08	8.87	12.3	0	12	29.7	20.31
20	290	295	270	14.02	13.88	18.8	0.9	15.7	30.6	30.07
30	285	290	270	19.14	18.9	19.4	1.5	16	31.9	31.58
40	285	285	280	26.73	26.42	19.3	2	15.5	33	32.53
50	290	295	275	31.66	31.4	19.4	4.9	14.5	34.3	32.53
60	300	305	280	36.62	36.37	19.1	5.7	13.4	36.2	32.53
70	305	310	290	40.23	39.99	19.5	5.9	13.4	37.7	32.53

	Feed tank volume	**Permeate sample volume**	**pH of Permeate**	**Concentrate sample volume**	**pH of Concentrate**	**Permeate cummulative volume**	**Permeate Recovery**	**Permeate Flux (LMH):**	**Permeate Recovery**	**Concentrate Flux (LMH):**	**Concetrate Recovery**
	L	**[mL]**		**[mL]**		L	***%***	***$L/h.m^2$***	***%***	***$L/h.m^2$***	***%***
feed	55										
Sample 1	52.05	35	5.21	40	3.89	2.95	0.05				
Sample 2	49.10	29	5.08	27	3.8	5.90	0.11	10	5%	181.2	84%
Sample 3	46.15	36	5.12	68	3.81	8.85	0.16	17	8%	184.6	82%
Sample 4	43.20	25	5.1	40	3.8	11.80	0.21	23	10%	178.8	80%
Sample 5	40.25	31	5.09	27	3.78	14.75	0.27	57	25%	167.3	75%
Sample 6	37.30	32	4.99	38	3.75	17.70	0.32	66	30%	154.6	70%
Sample 7	34.35	39	4.94	42	3.73	20.65	0.38	68	30%	154.6	69%
Sample 8	31.40	30	4.92	34	3.7	23.60	0.43				
Sample 9	28.45	29	4.9	26	3.69	26.55	0.48				
Sample 10	**25.50**	39	4.81	49	**3.66**	29.50	0.54				
Total volume		**325**	4.7	**391**	3.64						

Mass Balance										
	Cu	**Ca**	**Mg**	**S**	**Mn**	**Ni**	**Si**	**Zn**	**Al**	**Co**
mg/L										
Feed	505	544	495	1480	42	12	35	6	16	2
Permeate 1	3	5	3	9	0	0	6	0	0	0
Permeate 2	3	6	4	9	0	0	10	0	0	0
Permeate 3	3	6	4	9	0	0	6	0	0	0
Permeate 4	4	4	4	15	0	0	4	0	0	0
Permeate 5	4	6	5	9	0	0	8	0	0	0
Permeate 6	4	4	5	16	0	0	6	0	0	0
Permeate 7	5	4	5	9	0	0	4	0	0	0
Permeate 8	5	6	6	9	0	0	7	0	0	0
Permeate 9	6	5	6	27	0	0	5	0	0	0
Permeate 10	6	6	7	21	0	0	6	0	0	0
mg/L										
Conc 1	600	406	675	1460	48	14	39	6	20	3
Conc 2	732	477	822	1780	58	18	46	8	24	3
Conc 3	703	461	790	1700	55	16	44	7	23	3
Conc 4	787	510	883	1930	62	19	49	8	25	3
Conc 5	812	522	911	2000	64	19	50	8	26	4
Conc 6	934	596	1040	2200	72	22	57	9	31	5
Conc 7	991	625	1110	2330	76	23	60	10	33	5
Conc 8	1080	671	1200	2570	83	25	65	11	35	5
Conc 9	1100	677	1230	2700	87	26	66	11	35	5
Conc 10	1230	727	1380	2960	96	28	75	13	42	5
Combined	1140	718	1270	3110	96	26	68	12	38	4

Mass balance	mg									
Feed1	27775	29920	27225	81400	2332	660	1947	326.15	902	104.5
PERM10	126.41	153.64	150.01	390.29	0.00	0.00	180.98	0.00	0.00	0.00
CONC10	29070	18309	32385	79305	2435.25	650.25	1731.45	300.9	969	112.455
Account 1	105	62	120	98	104	99	98	92	107	108

	Rejection									
Permeate recovery	**Cu**	**Ca**	**Mg**	**S**	**Mn**	**Ni**	**Si**	**Zn**	**Al**	**Co**
5%	99%	99%	99%	99%	100%	100%	84%	100%	100%	100%
11%	99%	99%	99%	99%	100%	100%	72%	100%	100%	100%
16%	99%	99%	99%	99%	100%	100%	84%	100%	100%	100%
21%	99%	99%	99%	99%	100%	100%	88%	100%	100%	100%
27%	99%	99%	99%	99%	100%	100%	77%	100%	100%	100%
32%	99%	99%	99%	99%	100%	100%	84%	100%	100%	100%
38%	99%	99%	99%	99%	100%	100%	89%	100%	100%	100%
43%	99%	99%	99%	99%	100%	100%	80%	100%	100%	100%
48%	99%	99%	99%	98%	100%	100%	86%	100%	100%	100%
54%	99%	99%	99%	99%	100%	100%	82%	100%	100%	100%
av	**99%**	**99%**	**99%**	**99%**	**100%**	**100%**	**83%**	**100%**	**100%**	**100%**

Passage									
Cu	**Ca**	**Mg**	**S**	**Mn**	**Ni**	**Si**	**Zn**	**Al**	**Co**
1%	1%	1%	2%	0%	0%	1%	0%	0%	0%
1%	1%	1%	2%	0%	0%	2%	0%	0%	0%
1%	1%	1%	2%	0%	0%	1%	0%	0%	0%
1%	1%	1%	3%	0%	0%	1%	0%	0%	0%
1%	1%	1%	2%	0%	0%	2%	0%	0%	0%
1%	1%	1%	3%	0%	0%	1%	0%	0%	0%
1%	1%	1%	2%	0%	0%	1%	0%	0%	0%
1%	1%	1%	2%	0%	0%	1%	0%	0%	0%
1%	1%	1%	5%	0%	0%	1%	0%	0%	0%
1%	1%	1%	4%	0%	0%	1%	0%	0%	0%
Concentration factor CF									
Cu	**Ca**	**Mg**	**S**	**Mn**	**Ni**	**Si**	**Zn**	**Al**	**Co**
2.26	1.32	2.57	2.10	2.25	2.13	1.92	1.99	2.32	2.32

Appendix D. SCREENING TEST AMS AND DOW MEMBRANES SYNTHETIC SOLUTION

Operator	**Mpho/Jo**	
Date	[redacted]	
Test	[redacted]	
membrane	A3011	
residence time	1	hrs
Membrane Surface area	13	cm^2
Temperature	Ambient	
Feed	100	ml
Synthetic solution solution as is		

Operational conditions	
Temp	Ambient
pressure	20,30,40
pH	as is

20 bar

	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**
	mL	***hr***	***hr***	***%***	***%***	***$L/h.m^2$***		
Feed	100							
Water run	15.5	0.7				16		
Permeate 1	20.5	1.3	1.3	21%	21%	12	2.07	386.00
Permeate 2	20.0	1.4	2.7	20%	41%	11	2.05	389.70
Permeate 3	20.0	1.5	4.2	20%	61%	11	2.01	397.00
Permeate 4	20.0	2.4	6.6	20%	81%	6	2.03	409.20
Concentrate	**20.0**						**2.37**	**505.50**
Water run	9.0	0.5				14		

	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg/L									
Feed as is	269.00	501.67	556.00	35.70	639.00	292.00	5.60	11.40	4995.95
Permeate 1	2.52	95.00	1.74	0.01	5.27	0.01	0.01	0.02	151.58
Permeate 2	5.27	150.33	3.93	0.01	19.72	0.91	0.01	0.09	187.04
Permeate 3	11.70	206.71	9.99	0.01	35.95	2.19	0.16	0.20	264.70
Permeate 4	7.20	311.80	8.66	0.01	38.22	1.87	0.08	0.12	323.38
Concentrate	509.00	1500.00	2170.00	132.00	2320.00	602.00	30.00	41.50	18270.00
Combined permeate	**6.65**	**190.36**	**6.05**	**0.01**	**24.67**	**1.24**	**0.06**	**0.11**	**231.18**

	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg									
Feed	26.90	50.17	55.60	3.57	63.90	29.20	0.56	1.14	499.60
Permeate 1	0.05	1.95	0.04	0.00	0.11	0.00	0.00	0.00	3.11
Permeate 2	0.11	3.01	0.08	0.00	0.39	0.02	0.00	0.00	3.74
Permeate 3	0.23	4.13	0.20	0.00	0.72	0.04	0.00	0.00	5.29
Permeate 4	0.14	6.24	0.17	0.00	0.76	0.04	0.00	0.00	6.47
Concentrate	10.18	30.00	43.40	2.64	46.40	12.04	0.60	0.83	365.40

	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
Passing into permeate (mg)	0.54	15.32	0.49	0.00	1.99	0.10	0.01	0.01	18.61
Rejected into concetrate (mg)	10.18	30.00	43.40	2.64	46.40	12.04	0.60	0.83	365.40
Retained	98%	69%	99%	100%	97%	100%	99%	99%	96%
loss to permate	0.02	0.31	0.01	0.00	0.03	0.00	0.01	0.01	0.04
Accoutability	**40%**	**90%**	**79%**	**74%**	**76%**	**42%**	**108%**	**74%**	**77%**
Metal rejected	98%	69%	99%	100%	97%	100%	99%	99%	96%

30 bar								
	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**
	mL	***hr***	***hr***	***%***	***%***	***L/h.m²***		
Feed	100							
Water run	16	0.5				25		
Permeate 1	22	1.2	1.2	22%	22%	14	2.11	412.50
Permeate 2	20	1.15	2.4	20%	42%	13	2.01	410.10
Permeate 3	20	1.15	3.5	20%	62%	13	2.00	410.80
Permeate 4	20	1.5	5.0	20%	82%	10	2.02	410.90
Concentrate	**18**						**2.32**	**513.00**
Water run	13.5	0.5				21		

	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg/L									
Feed as is	269.00	501.67	556.00	35.70	639.00	292.00	5.60	11.40	4991.88
Permeate 1	4.95	100.00	6.82	0.01	15.68	1.09	0.01	0.08	246.85
Permeate 2	4.95	152.48	6.82	0.01	22.75	1.09	0.01	0.08	246.85
Permeate 3	5.92	193.90	5.85	0.01	28.13	0.62	0.01	0.06	237.65
Permeate 4	6.45	315.47	8.12	0.01	42.36	6.76	0.06	0.29	348.44
Concentrate	521.00	1560.00	2640.00	162.00	2880.00	673.00	30.00	50.60	15120.00
Combined permeate	5.55	188.26	6.90	0.01	26.95	2.36	0.02	0.13	269.38
	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg									
Feed	26.90	50.17	55.60	3.57	63.90	29.20	0.56	1.14	499.19
Permeate 1	0.11	2.20	0.15	0.00	0.34	0.02	0.00	0.00	5.43
Permeate 2	0.10	3.05	0.14	0.00	0.46	0.02	0.00	0.00	4.94
Permeate 3	0.12	3.88	0.12	0.00	0.56	0.01	0.00	0.00	4.75
Permeate 4	0.13	6.31	0.16	0.00	0.85	0.14	0.00	0.01	6.97
Concentrate	9.38	28.08	47.52	2.92	51.84	12.11	0.54	0.91	272.16
	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
Passing into permeate (mg)	0.46	15.44	0.57	0.00	2.21	0.19	0.00	0.01	22.09
Rejected into concetrate (mg)	9.38	28.08	47.52	2.92	51.84	12.11	0.54	0.91	272.16
Retained	98%	69%	99%	100%	97%	99%	100%	99%	96%
loss to permate	2%	31%	1%	0%	3%	1%	0%	1%	4%
Accoutability	**37%**	**87%**	**86%**	**82%**	**85%**	**42%**	**97%**	**81%**	**59%**
Metal rejected	98%	69%	99%	100%	97%	99%	100%	99%	96%

40 bar								
	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**
	mL	***hr***	***hr***	***%***	***%***	***L/h.m²***		
Feed	100							
Water run	25	0.5				38		
Permeate 1	20	0.7	0.7	20%	20%	21	2.13	410.10
Permeate 2	20	0.8	1.5	20%	40%	20	2.04	407.80
Permeate 3	20	1.0	2.5	20%	60%	15	2.02	406.60
Permeate 4	20	1.4	3.9	20%	80%	11	2.02	401.60
Concentrate	**20**						**2.34**	**515.60**
Water run	17.5	0.5				27		

	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg/L									
Feed as is	269.00	501.67	556.00	35.70	639.00	292.00	5.60	11.40	4995.95
Permeate 1	6.25	107.60	15.02	0.37	10.63	3.13	0.44	0.24	126.94
Permeate 2	4.53	160.00	7.33	0.01	17.90	1.34	0.01	0.09	261.97
Permeate 3	2.21	205.00	2.50	0.01	32.66	0.03	0.01	0.02	308.78
Permeate 4	5.05	304.29	9.41	0.11	51.10	0.64	0.27	0.16	314.45
Concentrate	689.00	1574.00	1990.00	41.60	2876.00	2.15	28.00	39.10	12300.00
Combined permeate	4.51	194.22	8.57	0.13	28.07	1.29	0.18	0.13	253.04
	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg									
Feed	26.90	50.17	55.60	3.57	63.90	29.20	0.56	1.14	499.60
Permeate 1	0.13	2.15	0.30	0.01	0.21	0.06	0.01	0.00	2.54
Permeate 2	0.09	3.20	0.15	0.00	0.36	0.03	0.00	0.00	5.24
Permeate 3	0.04	4.10	0.05	0.00	0.65	0.00	0.00	0.00	6.18
Permeate 4	0.10	6.09	0.19	0.00	1.02	0.01	0.01	0.00	6.29
Concentrate	13.78	31.48	39.80	0.83	57.52	0.04	0.56	0.78	246.00
	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
Passing into permeate (mg)	0.36	15.54	0.69	0.01	2.25	0.10	0.01	0.01	20.24
Rejected into concetrate (mg)	13.78	31.48	39.80	0.83	57.52	0.04	0.56	0.78	246.00
Retained	99%	69%	99%	100%	96%	100%	97%	99%	96%
loss to permate	1%	31%	1%	0%	4%	0%	3%	1%	4%
Accoutability	**53%**	**94%**	**73%**	**24%**	**94%**	**0%**	**103%**	**69%**	**53%**
Metal rejected	99%	69%	99%	100%	96%	100%	97%	99%	96%

Operator	**Mpho/Jo**	
Date	[redacted]	
Test	[redacted]	
membrane	A3012	
residence time	1	hrs
Membrane Surface area	13	cm^2
Temperature	Ambient	
Feed	100	ml
Synthetic solution solution as is		

Operational conditions	
Temp	Ambient
pressure	20,30,40
pH	as is

20 bar								
	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**
	mL	***hr***	***hr***	***%***	***%***	***L/h.m²***		
Feed	100						2.24	480.1
Water run	22.5	1				17		
Permeate 1	20	1.25	1.3	20%	20%	12	2.10	320.40
Permeate 2	20	1.25	1.3	20%	40%	12	2.20	320.20
Permeate 3	20	1.3	1.3	20%	60%	12	2.08	338.80
Permeate 4	20	2	2.0	20%	80%	8	2.06	354.80
Concentrate	**20**						**2.31**	**468.90**
Water run	9	0.5				14		

	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
	mg/L								
Feed as is	269.00	501.67	556.00	35.70	639.00	292.00	5.60	11.40	4995.95
Permeate 1	7.54	50.00	8.98	0.25	23.66	4.63	0.67	0.39	176.56
Permeate 2	9.03	67.71	12.09	0.45	14.83	3.58	0.87	0.27	231.84
Permeate 3	11.14	94.94	13.93	0.49	17.24	4.74	0.96	0.26	225.49
Permeate 4	27.45	180.84	40.17	2.17	49.19	11.54	2.76	0.98	400.85
Concentrate	465.00	2500.00	2610.00	148.00	2690.00	600.00	160.00	47.80	17460.00
Combined permeate	13.79	98.37	18.79	0.84	26.23	6.12	1.32	0.48	258.69

	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
	mg								
Feed	26.90	50.17	55.60	3.57	63.90	29.20	0.56	1.14	499.60
Permeate 1	0.15	1.00	0.18	0.01	0.47	0.09	0.01	0.01	3.53
Permeate 2	0.18	1.35	0.24	0.01	0.30	0.07	0.02	0.01	4.64
Permeate 3	0.22	1.90	0.28	0.01	0.34	0.09	0.02	0.01	4.51
Permeate 4	0.55	3.62	0.80	0.04	0.98	0.23	0.06	0.02	8.02
Concentrate	9.30	50.00	52.20	2.96	53.80	12.00	3.20	0.96	349.20

	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
Passing into permeate (mg)	1.10	7.87	1.50	0.07	2.10	0.49	0.11	0.04	20.69
Rejected into concetrate (mg)	9.30	50.00	52.20	2.96	53.80	12.00	3.20	0.96	349.20
Retained	96%	84%	97%	98%	97%	98%	81%	97%	96%
loss to permate	4%	16%	3%	2%	3%	2%	19%	3%	4%
Accoutability	**39%**	**115%**	**97%**	**85%**	**87%**	**43%**	**590%**	**87%**	**74%**
Metal rejected	96%	84%	97%	98%	97%	98%	81%	97%	96%

30 bar								
	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**
	mL	***hr***	***hr***	***%***	***%***	***L/h.m²***		
Feed	100						2.24	480.1
Water run	16.5	0.5				25		
Permeate 1	20	1	1.0	20%	20%	15	2.11	412.50
Permeate 2	21.5	1.1	2.1	22%	42%	15	2.01	410.10
Permeate 3	20	1.1	3.2	20%	62%	14	2.00	410.80
Permeate 4	20	1.12	4.3	20%	82%	14	2.02	410.90
Concentrate	18						**2.32**	**513.00**
Water run	15	0.5				23		

	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
					mg/L				
Feed as is	269	501.67	556	35.7	639	292	5.6	11.4	4995.95
Permeate 1	6.02	54.37	5.69	0.29	24.57	5.69	0.53	0.3	289.14
Permeate 2	7.52	50	3.75	0.54	15.46	3.75	0.88	0.23	219.02
Permeate 3	5.39	67.2	2.48	0.23	9.44	2.48	0.53	0.09	169.01
Permeate 4	7.07	114.15	2.72	0.24	10.65	2.72	0.56	0.12	152.18
Concentrate	465	2114.8	2930	168	3050	677	25	53.2	19590
Combined permeate	6.57	71.78	3.77	0.33	15.51	3.77	0.63	0.19	212.39
	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
					mg				
Feed	26.90	50.17	55.60	3.57	63.90	29.20	0.56	1.14	499.60
Permeate 1	0.14	1.22	0.13	0.01	0.55	0.13	0.01	0.01	6.51
Permeate 2	0.15	1.00	0.08	0.01	0.31	0.08	0.02	0.00	4.38
Permeate 3	0.11	1.34	0.05	0.00	0.19	0.05	0.01	0.00	3.38
Permeate 4	0.14	2.28	0.05	0.00	0.21	0.05	0.01	0.00	3.04
Concentrate	9.30	42.30	58.60	3.36	61.00	13.54	0.50	1.06	391.80
	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
Passing into permeate (mg)	0.54	5.85	0.31	0.03	1.26	0.31	0.05	0.02	17.31
Rejected into concetrate (mg)	9.30	42.30	58.60	3.36	61.00	13.54	0.50	1.06	391.80
Retained	98%	88%	99%	99%	98%	99%	91%	99%	97%
loss to permate	2%	12%	1%	1%	2%	1%	9%	1%	3%
Accoutability	**37%**	**96%**	**106%**	**95%**	**97%**	**47%**	**98%**	**95%**	**82%**
Metal rejected	98%	88%	99%	99%	98%	99%	91%	99%	97%

40 bar								
	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**
	mL	***hr***	***hr***	***%***	***%***	***L/h.m²***		
Feed	100						2.24	480.1
Water run	19	0.5				29		
Permeate 1	20	0.7	0.7	20%	20%	23	2.13	410.10
Permeate 2	20	0.8	0.8	20%	40%	18	2.04	407.80
Permeate 3	20	1.0	1.0	20%	60%	15	2.02	406.60
Permeate 4	20	1.2	1.2	20%	80%	13	2.20	401.60
Concentrate	**19.5**						**2.34**	**515.60**
Water run	17	0.5				26		

	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
					mg/L				
Feed as is	269	501.67	556	35.7	639	292	5.6	11.4	4995.95
Permeate 1	4.85	100	17.59	0.29	19.77	2.55	0.36	0.3	246.79
Permeate 2	5.18	112.25	13.34	0.78	17.2	5.09	0.93	0.27	214.38
Permeate 3	5.24	154.37	12.01	0.33	16.74	3.65	0.82	0.19	203.24
Permeate 4	4.03	83.81	7.3	0.24	9.59	1.99	0.51	0.08	134.54
Concentrate	454	1881	2810	155	2820	613	20	49.1	18330
Combined permeate	4.98	115.73	13.11	0.42	16.44	3.40	0.67	0.22	207.45
	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
					mg				
Feed	26.90	50.17	55.60	3.57	63.90	29.20	0.56	1.14	499.60
Permeate 1	0.11	2.25	0.40	0.01	0.44	0.06	0.01	0.01	5.55
Permeate 2	0.10	2.25	0.27	0.02	0.34	0.10	0.02	0.01	4.29
Permeate 3	0.10	3.09	0.24	0.01	0.33	0.07	0.02	0.00	4.06
Permeate 4	0.08	1.68	0.15	0.00	0.19	0.04	0.01	0.00	2.69
Concentrate	9.08	37.62	56.20	3.10	56.40	12.26	0.40	0.98	366.60
	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	SO4
Passing into permeate (mg)	0.40	9.26	1.05	0.03	1.32	0.27	0.05	0.02	16.60
Rejected into concetrate (mg)	9.08	37.62	56.20	3.10	56.40	12.26	0.40	0.98	366.60
Retained	99%	82%	98%	99%	98%	99%	90%	98%	97%
loss to permate	1%	18%	2%	1%	2%	1%	10%	2%	3%
Accoutability	**35%**	**93%**	**103%**	**88%**	**90%**	**43%**	**81%**	**88%**	**77%**
Metal rejected	99%	82%	98%	99%	98%	99%	90%	98%	97%

Operator	**Mpho/Jo**	
Date		
Test		
membrane	A3014	
residence time	1	hrs
Membrane Surface area	13	cm^2
Temperature	Ambient	
Feed	100	ml
Synthetic solution solution as is		

Operational conditions	
Temp	Ambient
pressure	20,30,40
pH	as is

20 bar

	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**
	mL	***hr***	***hr***	***%***	***%***	***L/h.m²***		
Feed	100						2.24	480.1
Water run	12	0.5				18		
Permeate 1	20	1.2	1.2	20%	20%	13	2.07	376.40
Permeate 2	20	1.2	1.2	20%	40%	13	2.04	388.70
Permeate 3	20	1.3	1.3	20%	60%	12	2.01	395.50
Permeate 4	20	1.45	1.5	20%	80%	11	2.02	403.60
Concentrate	**21**						**2.28**	**476.80**
Water run	11	0.5				17		

	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
					mg/L				
Feed as is	269	501.67	556	35.7	639	292	5.6	11.4	4995.95
Permeate 1	19.95	158.95	20.13	0.64	31.37	3.46	1.13	1.13	1100
Permeate 2	18.43	208.43	21.16	0.56	35.9	4.42	1.26	1.26	1150
Permeate 3	22.51	290.34	24.74	0.64	43.78	4.76	1.57	1.57	1250
Permeate 4	29.51	333.4	31.37	0.98	57.28	6.13	2.08	2.08	1600
Concentrate	419	1233.9	2310	132	2330	557	15	39.7	13140
Combined permeate	22.60	247.78	24.35	0.71	42.08	4.69	1.51	1.51	1275.00

	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
					mg				
Feed	26.90	50.17	55.60	3.57	63.90	29.20	0.56	1.14	499.60
Permeate 1	0.40	3.18	0.40	0.01	0.63	0.07	0.02	0.02	22.00
Permeate 2	0.37	4.17	0.42	0.01	0.72	0.09	0.03	0.03	23.00
Permeate 3	0.45	5.81	0.49	0.01	0.88	0.10	0.03	0.03	25.00
Permeate 4	0.59	6.67	0.63	0.02	1.15	0.12	0.04	0.04	32.00
Concentrate	8.80	25.91	48.51	2.77	48.93	11.70	0.32	0.83	275.94

	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
Passing into permeate (mg)	1.81	19.82	1.95	0.06	3.37	0.38	0.12	0.12	102.00
Rejected into concetrate (mg)	8.80	25.91	48.51	2.77	48.93	11.70	0.32	0.83	275.94
Retained	93%	60%	96%	98%	95%	99%	78%	89%	80%
loss to permate	7%	40%	4%	2%	5%	1%	22%	11%	20%
Accoutability	**39%**	**91%**	**91%**	**79%**	**82%**	**41%**	**78%**	**84%**	**76%**
Metal rejected	93%	60%	96%	98%	95%	99%	78%	89%	80%

30 bar

	Volume	Time	Cumulative time	Permeate recovery	Cumulative permeate recovery	Flux	pH	Eh
	mL	*hr*	*hr*	*%*	*%*	*L/h.m²*		
Feed	100						2.24	480.1
Water run	21	0.50				32		
Permeate 1	20	0.83	0.8	20%	20%	18	2.1	424.4
Permeate 2	21	1.00	1.8	21%	41%	16	2.11	426.1
Permeate 3	20	1.20	3.0	20%	61%	13	2.06	408.3
Permeate 4	19	1.25	4.3	19%	80%	12	2.04	413.5
Concentrate	**18.5**						**2.3**	**487.9**
Water run	15	0.5				23		

	Ca	Na	Mg	Al	Cu	Fe	Mn	Ni	SO4
mg/L									
Feed as is	269	501.67	556	35.7	639	292	5.6	11.4	4995.95
Permeate 1	30.09	97.7	35.81	2.18	42.3	8.5	2.14	0.79	2100
Permeate 2	21.55	124.41	23.82	1.35	33.16	5.58	1.34	0.49	2500
Permeate 3	28.38	218.37	32.23	1.31	49.74	6.42	2.04	0.68	2800
Permeate 4	27.07	336	43.22	1.65	73.74	6.75	2.94	0.92	3000
Concentrate	434	1300	2500	146	2540	599	20	41.6	3600
Combined permeate	19.18	167.05	24.58	1.07	38.65	4.67	1.56	0.52	2068.75
	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg									
Feed	26.90	50.17	55.60	3.57	63.90	29.20	0.56	1.14	499.60
Permeate 1	0.60	1.95	0.72	0.04	0.85	0.17	0.04	0.02	42.00
Permeate 2	0.45	2.61	0.50	0.03	0.70	0.12	0.03	0.01	52.50
Permeate 3	0.57	4.37	0.64	0.03	0.99	0.13	0.04	0.01	56.00
Permeate 4	0.51	6.38	0.82	0.03	1.40	0.13	0.06	0.02	57.00
Concentrate	8.03	24.05	46.25	2.70	46.99	11.08	0.37	0.77	66.60

	Ca	Na	Mg	Al	Cu	Fe	Mn	Ni	SO4
Passing into permeate (mg)	2.14	15.32	2.68	0.13	3.94	0.54	0.17	0.06	207.50
Rejected into concetrate (mg)	8.03	24.05	46.25	2.70	46.99	11.08	0.37	0.77	66.60
Retained	92%	69%	95%	96%	94%	98%	70%	95%	58%
loss to permate	8%	31%	5%	4%	6%	2%	30%	5%	42%
Accoutability	**38%**	**78%**	**88%**	**79%**	**80%**	**40%**	**96%**	**73%**	**55%**
Metal rejected	92%	69%	95%	96%	94%	98%	70%	95%	58%

40 bar

	Volume	Time	Cumulative time	Permeate recovery	Cumulative permeate recovery	Flux	pH	Eh
	mL	*hr*	*hr*	*%*	*%*	*L/h.m²*		
Feed	100						2.24	480.1
Water run	22	0.50				34		
Permeate 1	20	0.62	0.6	20%	20%	25	2.13	397.3
Permeate 2	20	0.67	0.7	20%	40%	23	2.12	397.3
Permeate 3	20	0.80	0.8	20%	60%	19	2.03	382.8
Permeate 4	20	0.83	0.8	20%	80%	18	2.01	387.6
Concentrate	**20.5**						**2.28**	**488.2**
Water run	19	0.5				29		

	Ca	Na	Mg	Al	Cu	Fe	Mn	Ni	SO4
mg/L									
Feed as is	269	501.67	556	35.7	639	292	5.6	11.4	4995.95
Permeate 1	3.59	60.4	2.86	0.01	6.08	0.57	0.01	0.04	3200
Permeate 2	3.14	49.49	2.95	0.01	5.82	0.97	0.01	0.06	2560
Permeate 3	4.03	74.07	3.85	0.01	7.44	0.16	0.01	0.07	3400
Permeate 4	5.29	122.49	5.06	0.03	10.46	1.15	0.03	0.11	2800
Concentrate	413	1583.7	2500	145	2580	549	25	41.8	4820
Combined permeate	4.01	76.61	3.68	0.02	7.45	0.71	0.02	0.07	2990.00
	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg									
Feed	26.90	50.17	55.60	3.57	63.90	29.20	0.56	1.14	499.60
Permeate 1	0.07	1.21	0.06	0.00	0.12	0.01	0.00	0.00	64.00
Permeate 2	0.06	0.99	0.06	0.00	0.12	0.02	0.00	0.00	51.20
Permeate 3	0.08	1.48	0.08	0.00	0.15	0.00	0.00	0.00	68.00
Permeate 4	0.11	2.45	0.10	0.00	0.21	0.02	0.00	0.00	56.00
Concentrate	8.47	32.47	51.25	2.97	52.89	11.25	0.51	0.86	98.81

	Ca	Na	Mg	Al	Cu	Fe	Mn	Ni	SO4
Passing into permeate (mg)	0.32	6.13	0.29	0.00	0.60	0.06	0.00	0.01	239.20
Rejected into concetrate (mg)	8.47	32.47	51.25	2.97	52.89	11.25	0.51	0.86	98.81
Retained	99%	88%	99%	100%	99%	100%	100%	100%	52%
loss to permate	1%	12%	1%	0%	1%	0%	0%	0%	48%
Accoutability	**33%**	**77%**	**93%**	**83%**	**84%**	**39%**	**92%**	**76%**	**68%**
Metal rejected	99%	88%	99%	100%	99%	100%	100%	100%	52%

Operator	**Mpho/Jo**	
Date		
Test		
membrane	B4021	
residence time	1	hrs
Membrane Surface area	13	cm^2
Temperature	Ambient	
Feed	100	ml
Synthetic solution solution as is		

Operational conditions	
Temp	Ambient
pressure	20,30,40
pH	as is

TEST 1 20 bar

	Volume	Time	Cumulative time	Permeate recovery	Cumulative permeate recovery	Flux	pH	Eh
	mL	*hr*	*hr*	*%*	*%*	*$L/h.m^2$*		
Feed	100						2.24	480.1
Water run	15	0.6				19		
Permeate 1	20.5	1.3	1.3	21%	21%	12	2.15	570.10
Permeate 2	20.0	1.4	1.4	20%	41%	11	2.08	566.50
Permeate 3	20.0	1.5	1.5	20%	61%	11	2.12	573.60
Permeate 4	20.0	2.4	2.4	20%	81%	6	2.11	551.60
Concentrate	**20.0**						**2.50**	**570.90**
Water run	10	0.5				15		

	Ca	Na	Mg	Al	Cu	Fe	Mn	Ni	SO4
mg/L									
Feed as is	269	501.67	556	35.7	639	292	5.6	11.4	4995.95
Permeate 1	8.87	160	8.7	1.04	13.84	0.44	0.73	0.11	260.54
Permeate 2	4.07	180	4.74	0.47	13.93	0.38	0.42	0.01	152.89
Permeate 3	66.18	150	93.41	6.32	9.34	0.2	7.46	1.85	1100
Permeate 4	14.73	200	17.13	1.55	36.59	21.33	1.52	0.29	398.19
Concentrate	552	1500	1890	38.1	1630	1.9	15	36.8	11220
Combined permeate	23.37	172.42	30.86	2.34	18.40	5.56	2.52	0.56	476.55

	Ca	Na	Mg	Al	Cu	Fe	Mn	Ni	SO4
mg									
Feed	26.90	50.17	55.60	3.57	63.90	29.20	0.56	1.14	499.60
Permeate 1	0.18	3.28	0.18	0.02	0.28	0.01	0.01	0.00	5.34
Permeate 2	0.08	3.60	0.09	0.01	0.28	0.01	0.01	0.00	3.06
Permeate 3	1.32	3.00	1.87	0.13	0.19	0.00	0.15	0.04	22.00
Permeate 4	0.29	4.00	0.34	0.03	0.73	0.43	0.03	0.01	7.96
Concentrate	11.04	30.00	37.80	0.76	32.60	0.04	0.30	0.74	224.40

	Ca	Na	Mg	Al	Cu	Fe	Mn	Ni	SO4
Passing into permeate (mg)	1.88	13.88	2.48	0.19	1.48	0.45	0.20	0.05	38.36
Rejected into concetrate (mg)	11.04	30.00	37.80	0.76	32.60	0.04	0.30	0.74	224.40
Retained	93%	72%	96%	95%	98%	98%	64%	96%	92%
loss to permate	7%	28%	4%	5%	2%	2%	36%	4%	8%
Accoutability	**48%**	**87%**	**72%**	**27%**	**53%**	**2%**	**90%**	**69%**	**53%**
Metal rejected	93%	72%	96%	95%	98%	98%	64%	96%	92%

30 bar

	Volume	Time	Cumulative time	Permeate recovery	Cumulative permeate recovery	Flux	pH	Eh
	mL	*hr*	*hr*	*%*	*%*	*L/h.m²*		
Feed	100						2.24	480.1
Water run	18	0.5				28		
Permeate 1	21	1.1	1.1	21%	21%	15	2.15	561.90
Permeate 2	21	1.1	1.1	21%	42%	15	2.15	546.30
Permeate 3	20	1.12	1.1	20%	62%	14	2.11	541.80
Permeate 4	20	1.3	1.3	20%	82%	12	2.11	536.80
Concentrate	**19.5**						**2.52**	**551.00**
Water run	13	0.5				20		

	Ca	Na	Mg	Al	Cu	Fe	Mn	Ni	SO4
mg/L									
Feed as is	269	501.67	556	35.7	639	292	5.6	11.4	4995.95
Permeate 1	14.12	200	9.68	0.9	43.19	0.69	1.22	0.17	411.57
Permeate 2	15.94	211	15.77	1.09	78.43	2.66	2.09	0.42	575.64
Permeate 3	16.31	230	23.55	1.28	110	2.2	3.32	0.55	728.71
Permeate 4	16.49	300	30.03	1.41	110	2.93	4.51	0.79	851.15
Concentrate	485	1600	1970	40	1690	1.9	15	38.2	11520
Combined permeate	15.70	234.52	19.59	1.17	84.81	2.11	2.76	0.48	638.15

	Ca	Na	Mg	Al	Cu	Fe	Mn	Ni	SO4
mg									
Feed	26.90	50.17	55.60	3.57	63.90	29.20	0.56	1.14	499.60
Permeate 1	0.30	4.20	0.20	0.02	0.91	0.01	0.03	0.00	8.64
Permeate 2	0.33	4.43	0.33	0.02	1.65	0.06	0.04	0.01	12.09
Permeate 3	0.33	4.60	0.47	0.03	2.20	0.04	0.07	0.01	14.57
Permeate 4	0.33	6.00	0.60	0.03	2.20	0.06	0.09	0.02	17.02
Concentrate	9.46	31.20	38.42	0.78	32.96	0.04	0.29	0.74	224.64

	Ca	Na	Mg	Al	Cu	Fe	Mn	Ni	SO4
Passing into permeate (mg)	1.29	19.23	1.61	0.10	6.95	0.17	0.23	0.04	52.33
Rejected into concetrate (mg)	9.46	31.20	38.42	0.78	32.96	0.04	0.29	0.74	224.64
Retained	95%	62%	97%	97%	89%	99%	60%	97%	90%
loss to permate	5%	38%	3%	3%	11%	1%	40%	3%	10%
Accoutability	**40%**	**101%**	**72%**	**25%**	**62%**	**1%**	**93%**	**69%**	**55%**
Metal rejected	95%	62%	97%	97%	89%	99%	60%	97%	90%

40 bar

	Volume	Time	Cumulative time	Permeate recovery	Cumulative permeate recovery	Flux	pH	Eh
	mL	*hr*	*hr*	*%*	*%*	*L/h.m²*		
Feed	100						2.24	480.1
Water run	26	0.5				40		
Permeate 1	20.5	0.8	0.8	21%	21%	20	2.11	552.90
Permeate 2	20	0.8	0.8	20%	41%	19	2.06	550.90
Permeate 3	20	0.95	1.0	20%	61%	16	2.07	557.70
Permeate 4	20	1.2	1.2	20%	81%	13	2.08	545.20
Concentrate	**20**						**2.66**	**571.10**
Water run	16	0.5				25		

	Ca	Na	Mg	Al	Cu	Fe	Mn	Ni	SO4
mg/L									
Feed as is	269	501.67	556	35.7	639	292	5.6	11.4	4995.95
Permeate 1	5.5	270	3.15	0.71	11.11	0.01	0.32	0.01	228.19
Permeate 2	5.96	266	3.74	0.75	13.94	0.01	0.41	0.04	258.8
Permeate 3	7.22	300	4.6	0.78	19.06	2.25	0.52	0.03	253.29
Permeate 4	7.44	350	6.55	0.86	31.01	0.01	0.82	0.07	288.72
Concentrate	527	1700	1900	38.4	1640	4.14	23	37	11310
Combined permeate	6.52	296.34	4.50	0.77	18.73	0.57	0.52	0.04	257.07

	Ca	Na	Mg	Al	Cu	Fe	Mn	Ni	SO4
mg									
Feed	26.90	50.17	55.60	3.57	63.90	29.20	0.56	1.14	499.60
Permeate 1	0.11	5.54	0.06	0.01	0.23	0.00	0.01	0.00	4.68
Permeate 2	0.12	5.32	0.07	0.02	0.28	0.00	0.01	0.00	5.18
Permeate 3	0.14	6.00	0.09	0.02	0.38	0.05	0.01	0.00	5.07
Permeate 4	0.15	7.00	0.13	0.02	0.62	0.00	0.02	0.00	5.77
Concentrate	10.54	34.00	38.00	0.77	32.80	0.08	0.46	0.74	226.20

	Ca	Na	Mg	Al	Cu	Fe	Mn	Ni	SO4
Passing into permeate (mg)	0.53	23.86	0.36	0.06	1.51	0.05	0.04	0.00	20.69
Rejected into concetrate (mg)	10.54	34.00	38.00	0.77	32.80	0.08	0.46	0.74	226.20
Retained	98%	52%	99%	98%	98%	100%	93%	100%	96%
loss to permate	2%	48%	1%	2%	2%	0%	7%	0%	4%
Accoutability	**41%**	**115%**	**69%**	**23%**	**54%**	**0%**	**90%**	**65%**	**49%**
Metal rejected	98%	52%	99%	98%	98%	100%	93%	100%	96%

Operator	**Mpho/Jo**	
Date		
Test		
membrane	N90	
residence time	1	hrs
Membrane Surface area	13	cm^2
Temperature	Ambient	
Feed	100	ml
Synthetic solution solution as is		

Operational conditions	
Temp	Ambient
pressure	20,30,40
pH	as is

20 bar								
	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**
	mL	***hr***	***hr***	***%***	***%***	***L/h.m²***		
Feed	100						2.24	480.1
Water run	30	0.5				46		
Permeate 1	20	1.17	1.2	20%	20%	13	2.16	405.40
Permeate 2	20	1.3	2.5	20%	40%	12	2.08	407.40
Permeate 3	24	1.6	4.1	24%	64%	12	2.06	400.90
Permeate 4	15	2	6.1	15%	79%	6	2.05	412.30
Concentrate	**20**						**2.24**	**479.90**
Water run	20	0.5				31		

	Ca	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg/L								
Feed as is	269	556	35.7	639	292	5.6	11.40	4995.95
Permeate 1	29.94	55.54	3.33	61.86	11.09	4.28	1.02	392.85
Permeate 2	26.73	49.43	3.08	59.67	9.56	3.79	0.88	350.53
Permeate 3	11.82	25.08	1.52	30.55	4.32	1.92	0.36	173.86
Permeate 4	26.35	52.98	3.14	64.45	9.83	4.1	0.97	373.90
Concentrate	518	2580	143	2570	708	19	44.30	17220.00
Combined permeate	22.94	44.25	2.68	52.29	8.41	3.40	0.77	312.01
	Ca	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
	mg							
Feed	26.90	55.60	3.57	63.90	29.20	0.56	1.14	499.60
Permeate 1	0.60	1.11	0.07	1.24	0.22	0.09	0.02	7.86
Permeate 2	0.53	0.99	0.06	1.19	0.19	0.08	0.02	7.01
Permeate 3	0.28	0.60	0.04	0.73	0.10	0.05	0.01	4.17
Permeate 4	0.40	0.79	0.05	0.97	0.15	0.06	0.01	5.61
Concentrate	10.36	51.60	2.86	51.40	14.16	0.38	0.89	344.40
	Ca	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
Passing into permeate (mg)	1.81	3.50	0.21	4.13	0.66	0.27	0.06	24.65
Rejected into concetrate (mg)	10.36	51.60	2.86	51.40	14.16	0.38	0.89	344.40
Retained	93%	94%	94%	94%	98%	52%	95%	95%
loss to permate	7%	6%	6%	6%	2%	48%	5%	5%
Accoutability	**45%**	**99%**	**86%**	**87%**	**51%**	**116%**	**83%**	**74%**
Metal rejected	93%	94%	94%	94%	98%	52%	95%	95%

30 bar								
	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**
	mL	***hr***	***hr***	***%***	***%***	***$L/h.m^2$***		
Feed	100						2.24	480.1
Water run	45	0.8				46		
Permeate 1	29	1.0	1.0	29%	29%	22	2.17	346.7
Permeate 2	20	0.8	1.8	20%	49%	21	2.15	361.5
Permeate 3	20	1.0	2.7	20%	69%	16	2.1	353.5
Permeate 4	15	1.3	4.0	15%	84%	9	2.07	359.6
Concentrate	**16**						**2.27**	**471.9**
Water run	25	0.5				38		

	Ca	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
				mg/L				
Feed as is	269	556	35.7	639	292	5.6	11.4	4995.95
Permeate 1	5.13	7.24	0.74	9.59	1.14	0.64	0.05	63.07
Permeate 2	4.88	7.07	1.02	7.94	0.6	0.52	0.02	56.58
Permeate 3	4.57	7.52	0.81	8.91	1.74	0.56	0.05	58.61
Permeate 4	11.35	21.33	1.7	24.71	4.27	1.63	0.35	162.09
Concentrate	462	3260	178	3230	869	29	55.2	20670
Combined permeate	6.05	9.78	0.99	11.74	1.71	0.77	0.10	78.15

	Ca	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
				mg				
Feed	26.90	55.60	3.57	63.90	29.20	0.56	1.14	499.60
Permeate 1	0.15	0.21	0.02	0.28	0.03	0.02	0.00	1.83
Permeate 2	0.10	0.14	0.02	0.16	0.01	0.01	0.00	1.13
Permeate 3	0.09	0.15	0.02	0.18	0.03	0.01	0.00	1.17
Permeate 4	0.17	0.32	0.03	0.37	0.06	0.02	0.01	2.43
Concentrate	7.39	52.16	2.85	51.68	13.90	0.46	0.88	330.72

	Ca	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
Passing into permeate (mg)	0.51	0.82	0.08	0.99	0.14	0.06	0.01	6.56
Rejected into concetrate (mg)	7.39	52.16	2.85	51.68	13.90	0.46	0.88	330.72
Retained	98%	99%	98%	98%	100%	88%	99%	99%
loss to permate	2%	1%	2%	2%	0%	12%	1%	1%
Accoutability	**29%**	**95%**	**82%**	**82%**	**48%**	**94%**	**78%**	**68%**
Metal rejected	98%	99%	98%	98%	100%	88%	99%	99%

40 bar

	Volume	Time	Cumulative time	Permeate recovery	Cumulative permeate recovery	Flux	pH	Eh
	mL	*hr*	*hr*	*%*	*%*	*L/h.m²*		
Feed	100						2.24	480.1
Water run	50	0.6				66		
Permeate 1	20	0.5	0.5	20%	20%	31	2.14	377.8
Permeate 2	20	0.6	1.1	20%	40%	26	2.12	389.7
Permeate 3	20	0.8	1.9	20%	60%	19	2.12	355.9
Permeate 4	11	0.5	2.4	11%	71%	17	2.12	352.7
Concentrate	**28**						**2.21**	**471.8**
Water run	35	0.5				54		

	Ca	Mg	Al	Cu	Fe	Mn	Ni	SO4
mg/L								
Feed as is	269	556	35.7	639	292	5.6	11.4	4995.95
Permeate 1	6.52	11.59	1.14	13.61	1.84	0.9	0.13	85.39
Permeate 2	5.14	9.89	0.89	11.39	1.13	0.75	0.08	74.37
Permeate 3	4.77	8.69	0.88	10.14	1.02	0.66	0.07	67.24
Permeate 4	7.68	12.64	1.34	15.66	2.32	0.99	0.24	106.62
Concentrate	503	1890	111	2020	577	16	35.2	13680
Combined permeate	5.82	10.46	1.03	12.32	1.48	0.80	0.12	80.46

	Ca	Mg	Al	Cu	Fe	Mn	Ni	SO4
mg								
Feed	26.90	55.60	3.57	63.90	29.20	0.56	1.14	499.60
Permeate 1	0.13	0.23	0.02	0.27	0.04	0.02	0.00	1.71
Permeate 2	0.10	0.20	0.02	0.23	0.02	0.02	0.00	1.49
Permeate 3	0.10	0.17	0.02	0.20	0.02	0.01	0.00	1.34
Permeate 4	0.08	0.14	0.01	0.17	0.03	0.01	0.00	1.17
Concentrate	14.08	52.92	3.11	56.56	16.16	0.45	0.99	383.04

	Ca	Mg	Al	Cu	Fe	Mn	Ni	SO4
Passing into permeate (mg)	0.41	0.74	0.07	0.88	0.11	0.06	0.01	5.71
Rejected into concetrate (mg)	14.08	52.92	3.11	56.56	16.16	0.45	0.99	383.04
Retained	98%	99%	98%	99%	100%	90%	99%	99%
loss to permate	2%	1%	2%	1%	0%	10%	1%	1%
Accoutability	**54%**	**97%**	**89%**	**90%**	**56%**	**90%**	**87%**	**78%**
Metal rejected	98%	99%	98%	99%	100%	90%	99%	99%

Operator	**Mpho/Jo**	
Date		
Test		
membrane	N245	
residence time	1	hrs
Membrane Surface area	13	cm^2
Temperature	Ambient	
Feed	100	ml
Synthetic solution solution as is		

Operational conditions	
Temp	Ambient
pressure	20,30,40
pH	as is

20 bar

	Volume	Time	Cumulative time	Permeate recovery	Cumulative permeate recovery	Flux	pH	Eh
	mL	*hr*	*hr*	*%*	*%*	*L/h.m²*		
Feed	100						2.24	480.1
Water run	73	0.5				112		
Permeate 1	20	0.6	0.6	20%	20%	26	2.05	336.3
Permeate 2	20	0.7	1.3	20%	40%	23	20.9	282.9
Permeate 3	20	0.8	2.1	20%	60%	18	2.01	291.8
Permeate 4	20	1.0	3.1	20%	80%	15	2.06	366.3
Concentrate	**20**						**2.23**	**359.9**
Water run	45	0.6				57		

	Ca	**Mg**	**Al**	**Cu**	Fe	Mn	**Ni**	SO4
mg/L								
Feed as is	269	556	35.7	639	292	5.6	11.4	4995.95
Permeate 1	6.2	7.95	0.94	14.9	2.96	0.54	0.09	570.3
Permeate 2	8.95	18.4	1.54	28.9	6.35	1.26	0.26	844.8
Permeate 3	18	46	1.49	62.7	17.3	1.26	0.8	1307.2
Permeate 4	53.4	171	3.39	208	55.7	3.16	3.08	2744.2
Concentrate	537	2740	163	2930	788	25	49	19680
Combined permeate	21.64	60.84	1.84	78.63	20.58	1.56	1.06	1366.63

	Ca	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	SO4
mg								
Feed	26.90	55.60	3.57	63.90	29.20	0.56	1.14	499.60
Permeate 1	0.12	0.16	0.02	0.30	0.06	0.01	0.00	11.41
Permeate 2	0.18	0.37	0.03	0.58	0.13	0.03	0.01	16.90
Permeate 3	0.36	0.92	0.03	1.25	0.35	0.03	0.02	26.14
Permeate 4	1.07	3.42	0.07	4.16	1.11	0.06	0.06	54.88
Concentrate	10.74	54.80	3.26	58.60	15.76	0.50	0.98	393.60

	Ca	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	SO4
Passing into permeate (mg)	1.73	4.87	0.15	6.29	1.65	0.12	0.08	109.33
Rejected into concetrate (mg)	10.74	54.80	3.26	58.60	15.76	0.50	0.98	393.60
Retained	94%	91%	96%	90%	94%	78%	93%	78%
loss to permate	6%	9%	4%	10%	6%	22%	7%	22%
Accoutability	**46%**	**107%**	**95%**	**102%**	**60%**	**112%**	**93%**	**101%**
Metal rejected	94%	91%	96%	90%	94%	78%	93%	78%

30 bar

	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**
	mL	***hr***	***hr***	***%***	***%***	***L/h.m²***		
Feed	100						2.24	480.1
Water run	100	0.5				154		
Permeate 1	20	0.5	0.5	20%	20%	32	1.95	344.1
Permeate 2	21.5	0.6	1.1	22%	42%	28	1.94	387.9
Permeate 3	21	0.6	1.7	21%	63%	26	2.08	350.9
Permeate 4	15	0.5	2.2	15%	78%	23	2.14	378.6
Concentrate	**13**							
Water run	60	0.5				92		

	Ca	**Mg**	**Al**	**Cu**	Fe	Mn	**Ni**	SO4
mg/L								
Feed as is	269	556	35.7	639	292	5.6	11.4	4995.95
Permeate 1	8.11	13.3	19.6	27.1	4.73	2.1	5.62	456
Permeate 2	115	301	45.2	345	102	5.1	14.2	2667
Permeate 3	299	743	45.2	824	235	5.1	14.2	6060
Permeate 4	355	836	50	923	258	5.8	15.6	6750
Concentrate	559	928	55.3	1030	281	20	17.4	7890
Combined permeate	183.73	450.07	39.52	504.63	143.13	4.46	12.26	3806.07

	Ca	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	SO4
mg								
Feed	26.90	55.60	3.57	63.90	29.20	0.56	1.14	499.60
Permeate 1	0.16	0.27	0.39	0.54	0.09	0.04	0.11	9.12
Permeate 2	2.47	6.47	0.97	7.42	2.19	0.11	0.31	57.34
Permeate 3	6.28	15.60	0.95	17.30	4.94	0.11	0.30	127.26
Permeate 4	5.33	12.54	0.75	13.85	3.87	0.09	0.23	101.25
Concentrate	7.27	12.06	0.72	13.39	3.65	0.26	0.23	102.57

	Ca	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	SO4
Passing into permeate (mg)	14.24	34.88	3.06	39.11	11.09	0.35	0.95	397.54
Rejected into concetrate (mg)	7.27	12.06	0.72	13.39	3.65	0.26	0.23	102.57
Retained	47%	37%	14%	39%	62%	38%	17%	20%
loss to permate	53%	63%	86%	61%	38%	62%	83%	80%
Accoutability	**80%**	**84%**	**106%**	**82%**	**50%**	**108%**	**103%**	**80%**
Metal rejected	47%	37%	14%	39%	62%	38%	17%	20%

40 bar

	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**
	mL	***hr***	***hr***	***%***	***%***	***L/h.m²***		
Feed	100						2.24	480.1
Water run	84	0.3				191		
Permeate 1	24	0.4	0.4	24%	24%	44	1.96	356.30
Permeate 2	21.5	0.5	0.5	22%	46%	33	2.04	347.60
Permeate 3	20	0.7	0.7	20%	66%	23	2.06	349.90
Permeate 4	18.5	1.0	1.0	19%	84%	14	2.10	366.60
Concentrate	**18.5**							
Water run	45	0.3				102		

	Ca	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg/L								
Feed as is	269	556	35.7	639	292	5.6	11.4	4995.95
Permeate 1	19.2	39.5	4.89	444	128	2.7	1.31	567
Permeate 2	178	398	24.1	444	128	2.7	7.44	3360
Permeate 3	294	610	36.4	679	190	4.2	11.4	5100
Permeate 4	281	561	33.8	623	175	3.9	10.5	4680
Concentrate	607	927	56.6	1020	283	35	17.2	8010
Combined permeate	182.93	381.95	23.68	539.38	153.11	3.32	7.31	3267.00

	Ca	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg								
Feed	26.90	55.60	3.57	63.90	29.20	0.56	1.14	499.60
Permeate 1	0.46	0.95	0.12	10.66	3.07	0.06	0.03	13.61
Permeate 2	3.83	8.56	0.52	9.55	2.75	0.06	0.16	72.24
Permeate 3	5.88	12.20	0.73	13.58	3.80	0.08	0.23	102.00
Permeate 4	5.20	10.38	0.63	11.53	3.24	0.07	0.19	86.58
Concentrate	11.23	17.15	1.05	18.87	5.24	0.65	0.32	148.19

	Ca	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
Passing into permeate (mg)	15.37	32.08	1.99	45.31	12.86	0.28	0.61	274.43
Rejected into concetrate (mg)	11.23	17.15	1.05	18.87	5.24	0.65	0.32	148.19
Retained	43%	42%	44%	29%	56%	50%	46%	45%
loss to permate	57%	58%	56%	71%	44%	50%	54%	55%
Accoutability	**99%**	**89%**	**85%**	**100%**	**62%**	**165%**	**82%**	**85%**
Metal rejected	43%	42%	44%	29%	56%	50%	46%	45%

Appendix E. SCREENING TEST AMS AND DOW MEMBRANES REAL SOLUTION

Operator	**Mpho/Jo**	
Date	[redacted]	
Test	[redacted]	
membrane	A3011	
residence time	1	hrs
Membrane Surface area	13	cm^2
Temperature	Ambient	
Feed	100	ml
Real solution solution as is		

Operational conditions	
Temp	Ambient
pressure	20,30,40
pH	as is

20 bar								
	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**
	mL	***hr***	***hr***	***%***	***%***	***$L/h.m^2$***		
Feed	100						3.78	322.3
Water run	18	0.5				28		
Permeate 1	21.5	1.2	1.2	22%	22%	14	3.38	380.7
Permeate 2	22	1.3	2.5	22%	44%	14	3.26	367.2
Permeate 3	20.5	1.3	3.7	21%	64%	12	3.22	361.5
Permeate 4	20.5	1.5	5.3	21%	85%	10	3.22	354.2
Concentrate	**16.5**						**3.15**	**426.5**
Water run	15	0.5				23		

	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg/L									
Feed as is	290.00	454.00	417.00	9.26	426.72	2.30	29.60	8.38	3060.00
Permeate 1	3.24	117.93	3.73	0.01	3.27	0.56	0.35	0.27	64.60
Permeate 2	5.11	130	5.56	0.01	8.01	0.56	0.51	0.20	91.77
Permeate 3	6.45	169.12	6.23	0.01	10.24	2.31	0.49	0.16	104.59
Permeate 4	8.55	271.51	8.82	0.01	16.25	3.3	0.73	0.23	156.52
Concentrate	711	1271.4	2080	47.9	1820	5.6	142	40.30	13080.00
Combined permeate	5.79	170.75	6.05	0.01	9.34	1.65	0.52	0.22	103.68
	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg									
Feed	29.00	45.40	41.70	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.07	2.54	0.08	0.00	0.07	0.01	0.01	0.01	1.39
Permeate 2	0.11	2.86	0.12	0.00	0.18	0.01	0.01	0.00	2.02
Permeate 3	0.13	3.47	0.13	0.00	0.21	0.05	0.01	0.00	2.14
Permeate 4	0.18	5.57	0.18	0.00	0.33	0.07	0.01	0.00	3.21
Concentrate	11.73	20.98	34.32	0.79	30.03	0.09	2.34	0.66	215.82
	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
Passing into permeate (mg)	0.49	14.43	0.51	0.00	0.79	0.14	0.04	0.02	8.76
Rejected into concetrate (mg)	11.73	20.98	34.32	0.79	30.03	0.09	2.34	0.66	215.82
Retained	98%	68%	99%	100%	98%	39%	99%	98%	97%
loss to permate	2%	32%	1%	0%	2%	61%	1%	2%	3%
Accoutability	**42%**	**78%**	**84%**	**85%**	**72%**	**101%**	**81%**	**82%**	**73%**
Metal rejected	98%	68%	99%	100%	98%	39%	99%	98%	97%

30 bar								
	Volume	Time	Cumulative time	Permeate recovery	Cumulative permeate recovery	Flux	pH	Eh
	mL	*hr*	*hr*	*%*	*%*	*L/h.m²*		
Feed	100						3.78	322.3
Water run	17.5	0.5				27		
Permeate 1	21	0.8	0.8	21%	21%	20	3.15	344.1
Permeate 2	20	0.8	1.6	20%	41%	18	3.36	332.1
Permeate 3	20	0.8	2.4	20%	61%	19	3.31	330.4
Permeate 4	20	0.92	3.4	20%	81%	17	3.31	328.1
Concentrate	**19**						**3.71**	**395.5**
Water run	15	0.5				23		

	Ca	Na	Mg	Al	Cu	Fe	Mn	Ni	SO4
				mg/L					
Feed as is	290.00	454.00	417.00	9.26	426.72	2.30	29.60	8.38	3060.00
Permeate 1	4.28	50.34	1.98	0.01	1.68	0.01	0.14	0.15	49.81
Permeate 2	3.35	55	3.23	0.01	3.07	0.01	0.28	0.12	34.14
Permeate 3	2.41	68.58	3.08	0.01	3.56	0.01	0.32	0.09	37.5
Permeate 4	3.08	117.28	3.73	0.01	5.29	0.01	0.31	0.11	47.65
Concentrate	692	1569	1960	40.3	1710	1.9	134	38.6	12480
Combined permeate	3.29	72.52	2.99	0.01	3.38	0.01	0.26	0.12	42.37

	Ca	Na	Mg	Al	Cu	Fe	Mn	Ni	SO4
				mg					
Feed	29.00	45.40	41.70	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.09	1.06	0.04	0.00	0.04	0.00	0.00	0.00	1.05
Permeate 2	0.07	1.10	0.06	0.00	0.06	0.00	0.01	0.00	0.68
Permeate 3	0.05	1.37	0.06	0.00	0.07	0.00	0.01	0.00	0.75
Permeate 4	0.06	2.35	0.07	0.00	0.11	0.00	0.01	0.00	0.95
Concentrate	13.15	29.81	37.24	0.77	32.49	0.04	2.55	0.73	237.12

	Ca	Na	Mg	Al	Cu	Fe	Mn	Ni	SO4
Passing into permeate (mg)	0.27	5.87	0.24	0.00	0.27	0.00	0.02	0.01	3.43
Rejected into concetrate (mg)	13.15	29.81	37.24	0.77	32.49	0.04	2.55	0.73	237.12
Retained	99%	87%	99%	100%	99%	100%	99%	99%	99%
loss to permate	1%	13%	1%	0%	1%	0%	1%	1%	1%
Accoutability	**46%**	**79%**	**90%**	**83%**	**77%**	**16%**	**87%**	**89%**	**79%**
Metal rejected	99%	87%	99%	100%	99%	100%	99%	99%	99%

40 bar								
	Volume	Time	Cumulative time	Permeate recovery	Cumulative permeate recovery	Flux	pH	Eh
	mL	*hr*	*hr*	*%*	*%*	*L/h.m²*		
Feed	100						3.78	322.3
Water run	28	0.6				38		
Permeate 1	27.4	0.8	0.8	27%	27%	28	3.42	340.1
Permeate 2	20	0.7	1.4	20%	47%	23	3.24	333.4
Permeate 3	20	0.9	2.3	20%	67%	18	3.38	318.8
Permeate 4	15	0.9	3.1	15%	82%	13	3.34	328
Concentrate	**19**						**3.76**	**404.6**
Water run	24	0.5				37		

	Ca	Na	Mg	Al	Cu	Fe	Mn	Ni	SO4
				mg/L					
Feed as is	290.00	454.00	417.00	9.26	426.72	2.30	29.60	8.38	3060.00
Permeate 1	9.5	50.34	4.31	0.01	9.56	0.01	0.45	0.12	86.91
Permeate 2	9.56	55	6.75	0.01	18.51	0.01	0.73	0.24	123.9
Permeate 3	18.51	68.58	7.85	0.01	24.57	0.01	0.86	0.23	141.09
Permeate 4	24.57	117.28	12.64	0.01	37.47	0.01	1.32	0.36	204.62
Concentrate	552	1569	2030	40.8	1660	1.9	126	35.2	10170
Combined permeate	14.44	68.08	7.28	0.01	20.46	0.01	0.78	0.22	130.47

	Ca	Na	Mg	Al	Cu	Fe	Mn	Ni	SO4
				mg					
Feed	29.00	45.40	41.70	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.26	1.38	0.12	0.00	0.26	0.00	0.01	0.00	2.38
Permeate 2	0.19	1.10	0.14	0.00	0.37	0.00	0.01	0.00	2.48
Permeate 3	0.37	1.37	0.16	0.00	0.49	0.00	0.02	0.00	2.82
Permeate 4	0.37	1.76	0.19	0.00	0.56	0.00	0.02	0.01	3.07
Concentrate	10.49	29.81	38.57	0.78	31.54	0.04	2.39	0.67	193.23

	Ca	Na	Mg	Al	Cu	Fe	Mn	Ni	SO4
Passing into permeate (mg)	1.19	5.61	0.60	0.00	1.69	0.00	0.06	0.02	10.75
Rejected into concetrate (mg)	10.49	29.81	38.57	0.78	31.54	0.04	2.39	0.67	193.23
Retained	96%	88%	99%	100%	96%	100%	98%	98%	96%
loss to permate	4%	12%	1%	0%	4%	0%	2%	2%	4%
Accoutability	**40%**	**78%**	**94%**	**84%**	**78%**	**16%**	**83%**	**82%**	**67%**
Metal rejected	96%	88%	99%	100%	96%	100%	98%	98%	96%

Operator	**Mpho/Jo**	
Date		
Test		
membrane	A3012	
residence time	1	hrs
Membrane Surface area	13	cm^2
Temperature	Ambient	
Feed	100	ml
Real solution solution as is		

Operational conditions	
Temp	Ambient
pressure	20,30,40
pH	as is

20 bar

	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**
	mL	***hr***	***hr***	***%***	***%***	***L/h.m²***		
Feed	100						3.66	341.2
Water run	10	0.5				15		
Permeate 1	20	0.95	1.0	20%	20%	16	3	295.2
Permeate 2	20	1	1.0	20%	40%	15	3.28	297.4
Permeate 3	23	1.22	1.2	23%	63%	15	3.34	290.5
Permeate 4	20	1.36	1.4	20%	83%	11	3.43	290.2
Concentrate	**17**						**2.54**	**377.9**
Water run	9	0.5				14		

	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg/L									
Feed as is	290.00	454.00	417.00	9.26	426.72	2.30	29.60	8.38	3060.00
Permeate 1	23.47	0.00	19.30	0.01	14.75	0.01	0.01	0.50	1100.00
Permeate 2	11.98	79.33	16.11	0.01	14.47	0.01	0.01	0.38	1200.00
Permeate 3	8.60	71.29	9.32	0.01	9.27	0.01	0.01	0.20	582.95
Permeate 4	10.81	123.85	12.76	0.01	12.06	0.01	0.01	0.26	732.70
Concentrate	412.00	1776.00	2060.00	43.30	1780.00	1.90	132.00	36.50	10860.00
Combined permeate	13.53	66.14	13.85	0.01	12.18	0.01	0.01	0.32	871.24

	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg									
Feed	29.00	45.40	41.70	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.47	0.00	0.39	0.00	0.30	0.00	0.00	0.01	22.00
Permeate 2	0.24	1.59	0.32	0.00	0.29	0.00	0.00	0.01	24.00
Permeate 3	0.20	1.43	0.19	0.00	0.19	0.00	0.00	0.00	11.66
Permeate 4	0.22	2.48	0.26	0.00	0.24	0.00	0.00	0.01	14.65
Concentrate	7.00	35.52	41.20	0.87	35.60	0.04	2.64	0.73	217.20

	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
Passing into permeate (mg)	1.12	5.49	1.15	0.00	1.01	0.00	0.00	0.03	72.31
Rejected into concetrate (mg)	7.00	35.52	41.20	0.87	35.60	0.04	2.64	0.73	217.20
Retained	96%	88%	97%	100%	98%	100%	100%	97%	76%
loss to permate	4%	12%	3%	0%	2%	0%	0%	3%	24%
Accoutability	**28%**	**90%**	**102%**	**94%**	**86%**	**17%**	**89%**	**90%**	**95%**
Metal rejected	96%	88%	97%	100%	98%	100%	100%	97%	76%

30 bar								
	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**
	mL	***hr***	***hr***	***%***	***%***	***L/h.m*** ^{2}		
Feed	100							
Water run	19.5	0.5				30		
Permeate 1	20	0.70	0.7	20%	20%	22	3.9	275.6
Permeate 2	20	0.7	0.7	20%	40%	22	3.84	276.3
Permeate 3	25	0.97	1.0	25%	65%	20	3.74	280.8
Permeate 4	20	0.83	0.8	20%	85%	18	3.56	320.7
Concentrate	**14**						**3.87**	**349.2**
Water run	15	0.5				23		

	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
	mg/L								
Feed as is	290.00	454.00	417.00	9.26	426.72	2.30	29.60	8.38	3060.00
Permeate 1	16.3	0	24.92	0.01	20.12	0.01	1.28	0.51	80.51
Permeate 2	10.04	90.15	16.41	0.01	17.39	0.01	0.67	0.33	1100
Permeate 3	6.78	66.34	8.66	0.01	8.94	0.11	0.18	0.19	967.56
Permeate 4	26.3	440.7	75.85	0.62	78.49	0.01	5.13	1.67	505.92
Concentrate	418	1252.7	1890	39.5	1610	1.9	120	33.1	9891.875
Combined permeate	12.99	156.07	29.35	0.17	29.80	0.03	1.74	0.63	632.85

	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
	mg								
Feed	29.00	45.40	41.70	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.16	0.00	0.25	0.00	0.20	0.00	0.01	0.01	0.81
Permeate 2	0.20	1.80	0.33	0.00	0.35	0.00	0.01	0.01	22.00
Permeate 3	0.14	1.33	0.17	0.00	0.18	0.00	0.00	0.00	19.35
Permeate 4	0.60	10.14	1.74	0.01	1.81	0.00	0.12	0.04	11.64
Concentrate	8.36	25.05	37.80	0.79	32.20	0.04	2.40	0.66	197.84

	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
Passing into permeate (mg)	1.10	13.27	2.50	0.01	2.53	0.00	0.15	0.05	53.79
Rejected into concetrate (mg)	8.36	25.05	37.80	0.79	32.20	0.04	2.40	0.66	197.84
Retained	96%	71%	94%	98%	94%	99%	95%	94%	82%
loss to permate	4%	29%	6%	2%	6%	1%	5%	6%	18%
Accoutability	**33%**	**84%**	**97%**	**87%**	**81%**	**18%**	**86%**	**85%**	**82%**
Metal rejected	96%	71%	94%	98%	94%	99%	95%	94%	82%

40 bar								
	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**
	mL	***hr***	***hr***	***%***	***%***	***L/h.m*** ^{2}		
Feed	100							
Water run	23	0.5				35		
Permeate 1	24	0.7	0.7	24%	24%	26	3.76	280.6
Permeate 2	23	0.7	0.7	23%	47%	25	3.73	280
Permeate 3	20	0.6	0.6	20%	67%	24	3.58	283.7
Permeate 4	20	0.7	0.7	20%	87%	21	3.5	285
Concentrate	**12**						**1.56**	**388.2**
Water run	21	0.5				32		

	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
	mg/L								
Feed as is	290.00	454.00	417.00	9.26	426.72	2.30	29.60	8.38	3060.00
Permeate 1	5.36	60.6	8.88	0.01	6.88	0.01	0.22	0.21	610.92
Permeate 2	4.06	69.29	7.82	0.01	7.28	0.01	0.06	0.17	512.74
Permeate 3	2.74	55.08	4.84	0.01	5.2	0.01	0.01	0.1	330.92
Permeate 4	3.11	80.91	4.78	0.01	4.8	0.01	0.01	0.09	325.2
Concentrate	358	3393.8	2360	53.2	2050	4.64	150	41.5	15120
Combined permeate	3.00	56.95	5.19	0.01	4.93	0.01	0.04	0.11	350.14

	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
	mg								
Feed	29.00	45.40	41.70	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.05	0.61	0.09	0.00	0.07	0.00	0.00	0.00	6.11
Permeate 2	0.08	1.39	0.16	0.00	0.15	0.00	0.00	0.00	10.25
Permeate 3	0.05	1.10	0.10	0.00	0.10	0.00	0.00	0.00	6.62
Permeate 4	0.07	1.86	0.11	0.00	0.11	0.00	0.00	0.00	7.48
Concentrate	7.16	67.88	47.20	1.06	41.00	0.09	3.00	0.83	302.40

	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	SO4
Passing into permeate (mg)	0.26	4.95	0.45	0.00	0.43	0.00	0.00	0.01	30.46
Rejected into concetrate (mg)	7.16	67.88	47.20	1.06	41.00	0.09	3.00	0.83	302.40
Retained	99%	89%	99%	100%	99%	100%	100%	99%	90%
loss to permate	1%	11%	1%	0%	1%	0%	0%	1%	10%
Accoutability	**26%**	**160%**	**114%**	**115%**	**97%**	**41%**	**101%**	**100%**	**109%**
Metal rejected	99%	89%	99%	100%	99%	100%	100%	99%	90%

Operator	**Mpho/Jo**	
Date	[redacted]	
Test	[redacted]	
membrane	A3014	
residence time	1	hrs
Membrane Surface area	13	cm^2
Temperature	Ambient	
Feed	100	ml
Real solution solution as is		

Operational conditions	
Temp	Ambient
pressure	20,30,40
pH	as is

20 BAR								
	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**
	mL	***hr***	***hr***	***%***	***%***	***L/h.m²***		
Feed	100							
Water run	15	0.72				16		
Permeate 1	20	1.25	1.3	20%	20%	12	3.27	360.8
Permeate 2	20	1.2	1.2	20%	40%	13	3.27	357.3
Permeate 3	20	1.21	1.2	20%	60%	13	3.3	355
Permeate 4	20	1.3	1.3	20%	80%	12	3.4	346
Concentrate	**21.5**						**3.24**	**376.5**
Water run	10	0.3				23		

	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
					mg/L				
Feed as is	290	454	417	9.26	426.72	2.3	29.6	8.38	3060
Permeate 1	14.58	0	13.22	0.01	11	1	1.16	0.37	94.52
Permeate 2	11.74	74.68	13.66	0.01	14.13	0.01	1.95	0.24	80.09
Permeate 3	12.9	87.69	13.6	0.01	13.05	0.01	1.01	0.27	76.25
Permeate 4	17.01	144.15	19.11	0.01	19.67	0.01	1.44	0.34	107.49
Concentrate	492	1241	1790	36.2	1510	1.9	112	31.2	9180
Combined permeate	14.06	76.63	14.90	0.01	14.46	0.26	1.39	0.31	89.59
	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
					mg				
Feed	29.00	45.40	41.70	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.29	0.00	0.26	0.00	0.22	0.02	0.02	0.01	1.89
Permeate 2	0.23	1.49	0.27	0.00	0.28	0.00	0.04	0.00	1.60
Permeate 3	0.26	1.75	0.27	0.00	0.26	0.00	0.02	0.01	1.53
Permeate 4	0.34	2.88	0.38	0.00	0.39	0.00	0.03	0.01	2.15
Concentrate	10.58	26.68	38.49	0.78	32.47	0.04	2.41	0.67	197.37
	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
Passing into permeate (mg)	1.12	6.13	1.19	0.00	1.16	0.02	0.11	0.02	7.17
Rejected into concetrate (mg)	10.58	26.68	38.49	0.78	32.47	0.04	2.41	0.67	197.37
Retained	96%	86%	97%	100%	97%	91%	96%	97%	98%
loss to permate	4%	14%	3%	0%	3%	9%	4%	3%	2%
Accoutability	**40%**	**72%**	**95%**	**84%**	**79%**	**27%**	**85%**	**83%**	**67%**
Metal rejected	96%	86%	97%	100%	97%	91%	96%	97%	98%

	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg/L									
Feed as is	290	454	417	9.26	426.72	2.3	29.6	8.38	3060
Permeate 1	5.84	0	11.55	0.01	2.03	0.01	0.26	0.18	80.51
Permeate 2	7.51	72.67	9.56	0.01	8.55	0.01	0.72	0.19	63.55
Permeate 3	7.47	108.09	10.05	0.01	11.11	0.11	0.79	0.16	65.29
Permeate 4	10.35	154.23	14.69	0.01	16.86	0.01	1.33	0.29	90.18
Concentrate	508	1168	1860	37.3	1560	1.9	115	31.1	9450
Combined permeate	7.79	83.75	11.46	0.01	9.64	0.04	0.78	0.21	74.88
	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
					mg				
Feed	29.00	45.40	41.70	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.12	0.00	0.23	0.00	0.04	0.00	0.01	0.00	1.61
Permeate 2	0.15	1.45	0.19	0.00	0.17	0.00	0.01	0.00	1.27
Permeate 3	0.15	2.16	0.20	0.00	0.22	0.00	0.02	0.00	1.31
Permeate 4	0.21	3.08	0.29	0.00	0.34	0.00	0.03	0.01	1.80
Concentrate	10.16	23.36	37.20	0.75	31.20	0.04	2.30	0.62	189.00
	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
Passing into permeate (mg)	0.62	6.70	0.92	0.00	0.77	0.00	0.06	0.02	5.99
Rejected into concetrate (mg)	10.16	23.36	37.20	0.75	31.20	0.04	2.30	0.62	189.00
Retained	98%	85%	98%	100%	98%	99%	98%	98%	98%
loss to permate	2%	15%	2%	0%	2%	1%	2%	2%	2%
Accoutability	**37%**	**66%**	**91%**	**81%**	**75%**	**18%**	**80%**	**76%**	**64%**
Metal rejected	98%	85%	98%	100%	98%	99%	98%	98%	98%

40 bar								
	Volume	Time	Cumulative time	Permeate recovery	Cumulative permeate recovery	Flux	pH	Eh
	mL	*hr*	*hr*	*%*	*%*	*L/h.m²*		
Feed	100							
Water run	19.5	0.50				30		
Permeate 1	20	0.60	0.6	20%	20%	26	3.64	324.4
Permeate 2	22.5	0.67	0.7	23%	43%	26	3.63	315.1
Permeate 3	20	0.67	0.7	20%	63%	23	3.47	317.2
Permeate 4	20	0.67	0.7	20%	83%	23	3.48	323.8
Concentrate	**18**						**2.25**	**388.2**
Water run	29.5	0.67				34		

	Ca	Na	Mg	Al	Cu	Fe	Mn	Ni	SO4
					mg/L				
Feed as is	290	454	417	9.26	426.72	2.3	29.6	8.38	3060
Permeate 1	1.93	0	2.13	0.01	1.04	0.01	0.09	0.03	81.49
Permeate 2	4.09	37.84	5.22	0.01	4.54	0.01	0.37	0.03	37.05
Permeate 3	3.21	51.8	3.56	0.01	3.54	0.01	0.28	0.03	28.06
Permeate 4	5.19	86.26	4.78	0.01	4.86	0.01	0.33	0.08	36.45
Concentrate	484	1679.3	2050	42	1740	1.9	128	35.5	10740
Combined permeate	3.62	43.79	3.96	0.01	3.53	0.01	0.27	0.04	45.50
	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
					mg				
Feed	29.00	45.40	41.70	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.04	0.00	0.04	0.00	0.02	0.00	0.00	0.00	1.63
Permeate 2	0.09	0.85	0.12	0.00	0.10	0.00	0.01	0.00	0.83
Permeate 3	0.06	1.04	0.07	0.00	0.07	0.00	0.01	0.00	0.56
Permeate 4	0.10	1.73	0.10	0.00	0.10	0.00	0.01	0.00	0.73
Concentrate	8.71	30.23	36.90	0.76	31.32	0.03	2.30	0.64	193.32
	Ca	**Na**	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
Passing into permeate (mg)	0.30	3.61	0.33	0.00	0.29	0.00	0.02	0.00	3.75
Rejected into concetrate (mg)	8.71	30.23	36.90	0.76	31.32	0.03	2.30	0.64	193.32
Retained	99%	92%	99%	100%	99%	100%	99%	100%	99%
loss to permate	1%	8%	1%	0%	1%	0%	1%	0%	1%
Accoutability	**31%**	**75%**	**89%**	**82%**	**74%**	**15%**	**79%**	**77%**	**64%**
Metal rejected	99%	92%	99%	100%	99%	100%	99%	100%	99%

Operator	**Mpho/Jo**	
Date	[redacted]	[redacted]
Test	[redacted]	[redacted]
membrane	B4021	
residence time	1	hrs
Membrane Surface area	13	cm²
Temperature	Ambient	
Feed	100	ml
Real solution solution as is		

Operational conditions	
Temp	Ambient
pressure	20,30,40
pH	as is

20 bar								
	Volume	Time	Cumulative time	Permeate recovery	Cumulative permeate recovery	Flux	pH	Eh
	mL	*hr*	*hr*	*%*	*%*	*L/h.m²*		
Feed	100							
Water run	15.5	0.5				24		
Permeate 1	20	0.9	0.9	20%	20%	18	3.25	462.5
Permeate 2	20	0.9	0.9	20%	40%	17	3.26	466.9
Permeate 3	20	0.9	0.9	20%	60%	17	3.21	454.7
Permeate 4	20	1.1	1.1	20%	80%	15	3.45	448.9
Concentrate	**20**						**4.08**	**413.5**
Water run	14	0.5				22		

	Ca	Mg	Al	Cu	Fe	Mn	Ni	SO4
	mg/L							
Feed as is	290	417	9.26	426.72	2.3	29.6	8.38	3060
Permeate 1	2.54	3.31	0.42	2.39	0.01	0.3	0.01	45.79
Permeate 2	4.23	5.63	0.55	6.59	0.01	0.51	0.08	80
Permeate 3	2.96	3.63	0.38	5.83	0.01	0.34	0.01	63.82
Permeate 4	4.71	4.87	0.4	10.67	0.01	0.5	0.02	105.06
Concentrate	418	1770	110	1830	10	116	33	14160
Combined permeate	3.61	4.36	0.44	6.37	0.01	0.41	0.03	73.67
	Ca	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
	mg							
Feed	29.00	41.70	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.05	0.07	0.01	0.05	0.00	0.01	0.00	0.92
Permeate 2	0.08	0.11	0.01	0.13	0.00	0.01	0.00	1.60
Permeate 3	0.06	0.07	0.01	0.12	0.00	0.01	0.00	1.28
Permeate 4	0.09	0.10	0.01	0.21	0.00	0.01	0.00	2.10
Concentrate	8.36	35.40	2.20	36.60	0.20	2.32	0.66	283.20
	Ca	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
Passing into permeate (mg)	0.29	0.35	0.04	0.51	0.00	0.03	0.00	5.89
Rejected into concetrate (mg)	8.36	35.40	2.20	36.60	0.20	2.32	0.66	283.20
Retained	99%	99%	96%	99%	100%	99%	100%	98%
loss to permate	1%	1%	4%	1%	0%	1%	0%	2%
Accoutability	**30%**	**86%**	**241%**	**87%**	**87%**	**79%**	**79%**	**94%**
Metal rejected	99%	99%	96%	99%	100%	99%	100%	98%

30 bar

	Volume	Time	Cumulative time	Permeate recovery	Cumulative permeate recovery	Flux	pH	Eh
	mL	*hr*	*hr*	*%*	*%*	*L/h.m^2*		
Feed	100							
Water run	17	0.5				26		
Permeate 1	23	0.9	0.9	23%	23%	20	3.34	465
Permeate 2	21.5	0.9	1.8	22%	45%	19	3.38	455.9
Permeate 3	20	0.9	2.7	20%	65%	17	3.49	448.9
Permeate 4	19.5	1	3.7	20%	84%	15	3.47	458.8
Concentrate	**19**						**3.91**	**408.4**
Water run	15	0.5				23		

	Ca	Mg	Al	Cu	Fe	Mn	Ni	SO4
	mg/L							
Feed as is	290	417	9.26	426.72	2.3	29.6	8.38	3060
Permeate 1	2.45	2.58	0.46	3.68	0	0.25	0.01	42.5
Permeate 2	2.94	3.45	0.65	6.52	0	0.31	0.01	51.36
Permeate 3	3.03	3.22	0.46	8.15	0.02	0.33	0.01	57.29
Permeate 4	3.71	4.03	0.41	12.86	0.02	0.45	0.06	76.01
Concentrate	558	2630	151	2450	10.9	161	46.3	16470
Combined permeate	3.01	3.29	0.50	7.60	0.01	0.33	0.02	56.07
	Ca	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
	mg							
Feed	29.00	41.70	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.06	0.06	0.01	0.08	0.00	0.01	0.00	0.98
Permeate 2	0.06	0.07	0.01	0.14	0.00	0.01	0.00	1.10
Permeate 3	0.06	0.06	0.01	0.16	0.00	0.01	0.00	1.15
Permeate 4	0.07	0.08	0.01	0.25	0.00	0.01	0.00	1.48
Concentrate	10.60	49.97	2.87	46.55	0.21	3.06	0.88	312.93
	Ca	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
Passing into permeate (mg)	0.25	0.28	0.04	0.64	0.00	0.03	0.00	4.71
Rejected into concetrate (mg)	10.60	49.97	2.87	46.55	0.21	3.06	0.88	312.93
Retained	99%	99%	95%	99%	100%	99%	100%	98%
loss to permate	1%	1%	5%	1%	0%	1%	0%	2%
Accoutability	**37%**	**120%**	**314%**	**111%**	**90%**	**104%**	**105%**	**104%**
Metal rejected	99%	99%	95%	99%	100%	99%	100%	98%

40 bar

	Volume	Time	Cumulative time	Permeate recovery	Cumulative permeate recovery	Flux	pH	Eh
	mL	*hr*	*hr*	*%*	*%*	$L/h.m^{2}$		
Feed	100							
Water run	17	0.5				26		
Permeate 1	20	0.7	0.7	20%	20%	23	3.27	476.3
Permeate 2	20	0.7	1.4	20%	40%	22	3.24	470.9
Permeate 3	20	0.7	2.1	20%	60%	21	3.39	463.9
Permeate 4	20	0.9	3.0	20%	80%	18	3.4	465.3
Concentrate	**20**							
Water run	21	0.5				32		

	Ca	Mg	Al	Cu	Fe	Mn	Ni	SO4
mg/L								
Feed as is	290	417	9.26	426.72	2.3	29.6	8.38	3060
Permeate 1	2.28	2.73	0.39	2.65	0.01	0.21	0.01	30.94
Permeate 2	1.95	3.32	0.43	4.63	0.01	0.28	0.01	33.24
Permeate 3	4.23	5.67	0.81	8.75	0.01	0.69	0.1	57.17
Permeate 4	4.52	4.84	0.54	9.05	0.94	0.39	0.03	49.06
Concentrate	453	2420	132	2380	12	148	42.4	15270
Combined permeate	3.25	4.14	0.54	6.27	0.24	0.39	0.04	42.60

	Ca	Mg	Al	Cu	Fe	Mn	Ni	SO4
mg								
Feed	29.00	41.70	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.05	0.05	0.01	0.05	0.00	0.00	0.00	0.62
Permeate 2	0.04	0.07	0.01	0.09	0.00	0.01	0.00	0.66
Permeate 3	0.08	0.11	0.02	0.18	0.00	0.01	0.00	1.14
Permeate 4	0.09	0.10	0.01	0.18	0.02	0.01	0.00	0.98
Concentrate	9.06	48.40	2.64	47.60	0.24	2.96	0.85	305.40

	Ca	Mg	Al	Cu	Fe	Mn	Ni	SO4
Passing into permeate (mg)	0.26	0.33	0.04	0.50	0.02	0.03	0.00	3.41
Rejected into concetrate (mg)	9.06	48.40	2.64	47.60	0.24	2.96	0.85	305.40
Retained	99%	99%	95%	99%	92%	99%	100%	99%
loss to permate	1%	1%	5%	1%	8%	1%	0%	1%
Accoutability	**32%**	**117%**	**290%**	**113%**	**113%**	**101%**	**102%**	**101%**
Metal rejected	99%	99%	95%	99%	92%	99%	100%	99%

Operator	**Mpho/Jo**	
Date	[redacted]	
Test	[redacted]	
membrane	N90	
residence time	1	hrs
Membrane Surface area	13	cm^2
Temperature	Ambient	
Feed	100	ml
Real solution solution as is		

Operational conditions	
Temp	Ambient
pressure	20,30,40
pH	as is

20 bar

	Volume	Time	Cumulative time	Permeate recovery	Cumulative permeate recovery	Flux	pH	Eh
	mL	*hr*	*hr*	*%*	*%*	$L/h.m^{2}$		
Feed	100							
Water run	32	0.5				49		
Permeate 1	21.5	0.6	0.6	22%	22%	27	3.73	234.1
Permeate 2	26.5	0.9	1.5	27%	48%	23	3.63	191.6
Permeate 3	21	0.9	2.4	21%	69%	18	3.63	180.5
Permeate 4	11	0.6	3.0	11%	80%	14	3.63	202.5
Concentrate	**24**						**3.58**	**201.9**
Water run	25	0.6				34		

	Ca	Mg	Al	Cu	Fe	Mn	Ni	SO4
				mg/L				
Feed as is	290.00	417.00	9.26	426.72	2.30	29.60	8.38	3060.00
Permeate 1	17.08	24.42	0.01	17.8	0.01	1.34	0.40	119.08
Permeate 2	12.26	19.48	0.021	17.94	0.01	1.34	0.39	116.86
Permeate 3	12.78	19.64	0.01	21.31	0.01	1.65	0.49	140.35
Permeate 4	15.07	23.45	0.01	21.78	0.03	1.72	0.51	159.42
Concentrate	823	1440	28.1	1600	1.9	103	28.60	9900.00
Combined permeate	14.08	21.40	0.01	19.32	0.01	1.47	0.44	129.47

	Ca	Mg	Al	Cu	Fe	Mn	Ni	SO4
				mg				
Feed	29.00	41.70	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.37	0.53	0.00	0.38	0.00	0.03	0.01	2.56
Permeate 2	0.32	0.52	0.00	0.48	0.00	0.04	0.01	3.10
Permeate 3	0.27	0.41	0.00	0.45	0.00	0.03	0.01	2.95
Permeate 4	0.17	0.26	0.00	0.24	0.00	0.02	0.01	1.75
Concentrate	19.75	34.56	0.67	38.40	0.05	2.47	0.69	237.60

	Ca	Mg	Al	Cu	Fe	Mn	Ni	SO4
Passing into permeate (mg)	1.13	1.71	0.00	1.55	0.00	0.12	0.03	10.36
Rejected into concetrate (mg)	19.75	34.56	0.67	38.40	0.05	2.47	0.69	237.60
Retained	96%	96%	100%	96%	100%	96%	96%	97%
loss to permate	4%	4%	0%	4%	0%	4%	4%	3%
Accoutability	**72%**	**87%**	**73%**	**94%**	**20%**	**87%**	**86%**	**81%**
Metal rejected	96%	96%	100%	96%	100%	96%	96%	97%

30 bar

	Volume	Time	Cumulative time	Permeate recovery	Cumulative permeate recovery	Flux	pH	Eh
	mL	*hr*	*hr*	*%*	*%*	*L/h.m²*		
Feed	100							
Water run	55.0	0.5				85		
Permeate 1	20.0	0.3	0.3	20%	20%	46	4.18	244.8
Permeate 2	20.0	0.4	0.8	20%	40%	37	3.95	216.5
Permeate 3	20.0	0.5	1.3	20%	60%	29	4.01	199.2
Permeate 4	22.0	0.7	2.0	22%	82%	25	3.49	196.1
Concentrate	**18.0**						**3.27**	**281.6**
Water run	40.0	0.5				62		

	Ca	Mg	Al	Cu	Fe	Mn	Ni	SO4
				mg/L				
Feed as is	290.00	417.00	9.26	426.72	2.30	29.60	8.38	3060.00
Permeate 1	2.63	3.58	0.01	3.49	0.07	0.14	0.05	23.84
Permeate 2	2.51	3.77	0.01	3.38	0.01	0.14	0.03	16.11
Permeate 3	3.06	3.95	0.01	3.7	0.95	0.16	0.2	16.44
Permeate 4	4.14	5.42	0.01	5.07	0.01	0.26	0.09	25.34
Concentrate	600	2050	39.7	2100	1.9	146	40.7	12780
Combined permeate	3.11	4.21	0.01	3.94	0.25	0.18	0.09	20.55

	Ca	Mg	Al	Cu	Fe	Mn	Ni	SO4
				mg				
Feed	29.00	41.70	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.05	0.07	0.00	0.07	0.00	0.00	0.00	0.48
Permeate 2	0.05	0.08	0.00	0.07	0.00	0.00	0.00	0.32
Permeate 3	0.06	0.08	0.00	0.07	0.02	0.00	0.00	0.33
Permeate 4	0.09	0.12	0.00	0.11	0.00	0.01	0.00	0.56
Concentrate	10.80	36.90	0.71	37.80	0.03	2.63	0.73	230.04

	Ca	Mg	Al	Cu	Fe	Mn	Ni	SO4
Passing into permeate (mg)	0.26	0.35	0.00	0.32	0.02	0.01	0.01	1.69
Rejected into concetrate (mg)	10.80	36.90	0.71	37.80	0.03	2.63	0.73	230.04
Retained	99%	99%	100%	99%	91%	100%	99%	99%
loss to permate	1%	1%	0%	1%	9%	0%	1%	1%
Accoutability	**38%**	**89%**	**77%**	**89%**	**24%**	**89%**	**88%**	**76%**
Metal rejected	99%	99%	100%	99%	91%	100%	99%	99%

40 bar								
	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**
	mL	***hr***	***hr***	***%***	***%***	***L/h.m ^{2}***		
Feed	100							
Water run	87.0	0.6				109		
Permeate 1	20.0	0.3	0.3	20%	20%	62	4.19	216.4
Permeate 2	20.0	0.3	0.6	20%	40%	46	3.77	198.1
Permeate 3	20.0	0.5	1.1	20%	60%	31	3.48	167.3
Permeate 4	18.0	1.1	2.2	18%	78%	13	3.79	157.8
Concentrate	**19.0**						**3.42**	**281.2**
Water run	65.0	0.7				75		

	Ca	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
				mg/L				
Feed as is	290.00	417.00	9.26	426.72	2.30	29.60	8.38	3060.00
Permeate 1	8.33	13.57	0.01	2.65	0.01	0.91	0.32	84.1
Permeate 2	6.53	11.03	0.01	2.06	0.01	0.7	0.2	62.87
Permeate 3	5.46	8.86	0.01	2.35	0.01	0.52	0.14	47.47
Permeate 4	5.48	9.31	0.01	2.63	0.08	0.56	0.16	48.4
Concentrate	589	1940	37.8	2035	1.9	139	38.5	12210
Combined permeate	6.47	10.73	0.01	2.42	0.03	0.68	0.21	61.03

	Ca	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
				mg				
Feed	29.00	41.70	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.17	0.27	0.00	0.05	0.00	0.02	0.01	1.68
Permeate 2	0.13	0.22	0.00	0.04	0.00	0.01	0.00	1.26
Permeate 3	0.11	0.18	0.00	0.05	0.00	0.01	0.00	0.95
Permeate 4	0.10	0.17	0.00	0.05	0.00	0.01	0.00	0.87
Concentrate	11.19	36.86	0.72	38.67	0.04	2.64	0.73	231.99

	Ca	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
Passing into permeate (mg)	0.51	0.84	0.00	0.19	0.00	0.05	0.02	4.76
Rejected into concetrate (mg)	11.19	36.86	0.72	38.67	0.04	2.64	0.73	231.99
Retained	98%	98%	100%	100%	99%	98%	98%	98%
loss to permate	2%	2%	0%	0%	1%	2%	2%	2%
Accoutability	**40%**	**90%**	**78%**	**91%**	**17%**	**91%**	**89%**	**77%**
Metal rejected	98%	98%	100%	100%	99%	98%	98%	98%

Operator	**Mpho/Jo**	
Date	[redacted]	
Test	[redacted]	
membrane	N245	
residence time	1	hrs
Membrane Surface area	13	cm^2
Temperature	Ambient	
Feed	100	ml
Real solution solution as is		

Operational conditions	
Temp	Ambient
pressure	20,30,40
pH	as is

20 bar								
	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**
	mL	***hr***	***hr***	***%***	***%***	***L/h.m ^{2}***		
Feed	100							
Water run	74.0	0.5				114		
Permeate 1	20.0	0.4	0.4	20%	20%	42	3.39	328.9
Permeate 2	28.0	0.6	0.9	28%	48%	39	3.42	296.9
Permeate 3	20.5	0.5	1.4	21%	69%	32	3.53	238.8
Permeate 4	15.0	0.5	1.9	15%	84%	24	3.57	241
Concentrate	**17.0**						**3.69**	**243.6**
Water run	58.0	0.5				89		

	Ca	**Mg**	**Al**	**Cu**	Fe	Mn	**Ni**	SO4
mg/L								
Feed as is	290.00	417.00	9.26	426.72	2.30	29.60	8.38	3060.00
Permeate 1	6.92	7.63	2.56	13.7	2	3.05	0.78	151.2
Permeate 2	7.32	14.2	0.75	23.3	1.56	1.14	0.19	192
Permeate 3	16.7	46.9	0.55	55.5	0.01	3.44	0.83	405
Permeate 4	37.9	126	1.18	131	0.01	8.98	2.36	909
Concentrate	714	2000	45	1840	0.9	148	40.4	13680
Combined permeate	8.21	18.10	1.00	24.72	1.00	1.96	0.45	200.03

	Ca	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	SO4
mg								
Feed	29.00	41.70	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.14	0.15	0.05	0.27	0.04	0.06	0.02	3.02
Permeate 2	0.20	0.40	0.02	0.65	0.04	0.03	0.01	5.38
Permeate 3	0.34	0.96	0.01	1.14	0.00	0.07	0.02	8.30
Permeate 4	0.57	1.89	0.02	1.97	0.00	0.13	0.04	13.64
Concentrate	12.14	34.00	0.77	31.28	0.02	2.52	0.69	232.56

	Ca	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	SO4
Passing into permeate (mg)	1.25	3.40	0.10	4.03	0.08	0.30	0.07	30.34
Rejected into concetrate (mg)	12.14	34.00	0.77	31.28	0.02	2.52	0.69	232.56
Retained	96%	92%	89%	91%	63%	90%	91%	90%
loss to permate	4%	8%	11%	9%	37%	10%	9%	10%
Accoutability	**46%**	**90%**	**94%**	**83%**	**43%**	**95%**	**91%**	**86%**
Metal rejected	96%	92%	89%	91%	63%	90%	91%	90%

30 bar								
	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**
	mL	***hr***	***hr***	***%***	***%***	***L/h.m²***		
Feed	100							
Water run	100.0	0.5				158		
Permeate 1	21.0	0.3	0.3	21%	21%	54	3.49	236.9
Permeate 2	22.0	0.4	0.7	22%	43%	46	3.51	201.4
Permeate 3	20.0	0.4	1.1	20%	63%	38	3.44	204.2
Permeate 4	20.0	0.6	1.6	20%	83%	28	3.45	207.6
Concentrate	**15.0**						**3.53**	**211.4**
Water run	75.0	0.7				81		

	Ca	**Mg**	**Al**	**Cu**	Fe	Mn	**Ni**	SO4
mg/L								
Feed as is	290.00	417.00	9.26	426.72	2.30	29.60	8.38	3060.00
Permeate 1	6.12	7.95	1.27	15.2	1.95	10.13	2.75	123.3
Permeate 2	11.9	29.8	3.43	37.1	0.11	9.98	2.73	263.7
Permeate 3	51.5	136	3.37	132	0.07	10.1	2.75	980
Permeate 4	171	422	9.16	391	0.6	31.2	8.69	2940
Concentrate	741	1630	35.1	1510	1.9	121	33	11640
Combined permeate	58.32	144.37	4.25	139.70	0.68	15.16	4.18	1045.67

	Ca	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	SO4
mg								
Feed	29.00	41.70	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.13	0.17	0.03	0.32	0.04	0.21	0.06	2.59
Permeate 2	0.26	0.66	0.08	0.82	0.00	0.22	0.06	5.80
Permeate 3	1.03	2.72	0.07	2.64	0.00	0.20	0.06	19.60
Permeate 4	3.42	8.44	0.18	7.82	0.01	0.62	0.17	58.80
Concentrate	11.12	24.45	0.53	22.65	0.03	1.82	0.50	174.60

	Ca	**Mg**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	SO4
Passing into permeate (mg)	4.84	11.98	0.35	11.60	0.06	1.26	0.35	261.39
Rejected into concetrate (mg)	11.12	24.45	0.53	22.65	0.03	1.82	0.50	174.60
Retained	83%	71%	62%	73%	75%	57%	59%	15%
loss to permate	17%	29%	38%	27%	25%	43%	41%	85%
Accoutability	**55%**	**87%**	**95%**	**80%**	**37%**	**104%**	**100%**	**85%**
Metal rejected	83%	71%	62%	73%	75%	57%	59%	15%

40 bar

	Volume	Time	Cumulative time	Permeate recovery	Cumulative permeate recovery	Flux	pH	Eh
	mL	*hr*	*hr*	*%*	*%*	*L/h.m^2*		
Feed	100							
Water run	98.0	0.3				223		
Permeate 1	21.0	0.3	0.3	21%	21%	65	3.54	206.3
Permeate 2	20.0	0.3	0.3	20%	41%	54	3.58	228.9
Permeate 3	21.0	0.4	0.4	21%	62%	46	3.65	226.7
Permeate 4	20.0	0.5	0.5	20%	82%	34	**3.78**	**240.8**
Concentrate	**16.0**							
Water run	27.0	0.3				61		

	Ca	Mg	Al	Cu	Fe	Mn	Ni	SO4
	mg/L							
Feed as is	290.00	417.00	9.26	426.72	2.30	29.60	8.38	3060.00
Permeate 1	8.58	17	1.93	27.9	0.31	13.1	3.84	185.4
Permeate 2	60.4	175	10.19	171	0.01	33.3	3.69	1212
Permeate 3	172	452	10.6	416	1	43.2	9.17	3060
Permeate 4	244	586	11.2	536	0.02	43.2	11.8	4020
Concentrate	488	771	15.2	703	0.09	56.8	15.4	5730
Combined permeate	120.49	305.72	8.43	286.12	0.34	33.08	7.11	2107.24

	Ca	Mg	Al	Cu	Fe	Mn	Ni	SO4
	mg							
Feed	29.00	41.70	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.18	0.36	0.04	0.59	0.01	0.28	0.08	3.89
Permeate 2	1.21	3.50	0.20	3.42	0.00	0.67	0.07	24.24
Permeate 3	3.61	9.49	0.22	8.74	0.02	0.91	0.19	64.26
Permeate 4	4.88	11.72	0.22	10.72	0.00	0.86	0.24	80.40
Concentrate	7.81	12.34	0.24	11.25	0.00	0.91	0.25	91.68

	Ca	Mg	Al	Cu	Fe	Mn	Ni	SO4
Passing into permeate (mg)	9.88	25.07	0.69	23.46	0.03	2.71	0.58	172.79
Rejected into concetrate (mg)	7.81	12.34	0.24	11.25	0.00	0.91	0.25	91.68
Retained	66%	40%	25%	45%	88%	8%	30%	44%
loss to permate	34%	60%	75%	55%	12%	92%	70%	56%
Accoutability	**61%**	**90%**	**101%**	**81%**	**13%**	**122%**	**99%**	**86%**
Metal rejected	66%	40%	25%	45%	88%	8%	30%	44%

Appendix F. DOW N90 OPTIMISATION TEST AGITATION INSIDE OF THE CELL

Operator	**Mpho**	
Date	03/09/2022	
membrane	N90	
Membrane Surface area	13	cm^2

Operational conditions	
Temp	Ambient
Speed	250, 500 and 750

250 rpm

	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**
	mL	***hr***	***hr***	***%***	***%***	***L/h.m²***		
Feed	100							
Water run	81	0.5				125		
Permeate 1	20	0.3	0.3	20%	20%	62	3.80	417.40
Permeate 2	20	0.3	0.6	20%	40%	46	3.69	432.00
Permeate 3	20.5	0.4	1.0	21%	61%	37	3.63	439.10
Permeate 4	20.5	0.5	1.5	21%	81%	31	3.66	443.30
Concentrate	**16.5**						**4.06**	**451.40**
Water run	55	0.5				85		

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
					mg/L					
Feed as is	290	454	417	31	9	427	2	30	8	3060
Permeate 1	3.36	38	3.24	2.37	0.78	3.12	0.01	0.66	0.21	63.55
Permeate 2	8.66	40	9.92	2.5	0.77	4.42	0.01	0.68	0.22	64.39
Permeate 3	3.07	40.5	4.7	2.93	0.69	4.58	0.01	0.32	0.14	25.13
Permeate 4	4.28	51.6	4.59	4.62	0.92	4.36	1.01	0.28	0.18	19.92
Concentrate	520	2690	2470	116	54.6	2316.7	2.93	171	46.9	31107.6
Combined permeate	4.83	42.57	5.60	3.11	0.79	4.12	0.26	0.48	0.19	42.99

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
					mg					
Feed	29.00	45.40	41.70	3.14	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.07	0.76	0.06	0.05	0.02	0.06	0.00	0.01	0.00	1.27
Permeate 2	0.17	0.80	0.20	0.05	0.02	0.09	0.00	0.01	0.00	1.29
Permeate 3	0.06	0.83	0.10	0.06	0.01	0.09	0.00	0.01	0.00	0.52
Permeate 4	0.09	1.06	0.09	0.09	0.02	0.09	0.02	0.01	0.00	0.41
Concentrate	8.58	44.39	40.76	1.91	0.90	38.23	0.05	2.82	0.77	513.28

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
Passing into permeate (mg)	0.39	3.45	0.45	0.25	0.06	0.33	0.02	0.04	0.02	3.48
Rejected into concetrate (mg)	8.58	44.39	40.76	1.91	0.90	38.23	0.05	2.82	0.77	513.28
Retained	99%	92%	99%	92%	93%	99%	91%	99%	98%	99%
loss to permate	1%	8%	1%	8%	7%	1%	9%	1%	2%	1%
Accoutability	**31%**	**105%**	**99%**	**69%**	**104%**	**90%**	**30%**	**97%**	**94%**	**169%**
Metal rejected	99%	92%	99%	92%	93%	99%	91%	99%	98%	99%

500 rpm

	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**
	mL	***hr***	***hr***	***%***	***%***	***L/h.m²***		
Feed	100							
Water run	92.5	0.42				169		
Permeate 1	20.9	0.21	0.2	21%	21%	77	3.74	411.00
Permeate 2	20.5	0.24	0.5	21%	41%	65	3.71	418.20
Permeate 3	20	0.32	0.8	20%	61%	49	3.66	428.20
Permeate 4	20.5	0.43	1.2	21%	82%	36	3.67	434.60
Concentrate	**18**						**4.11**	**441.10**
Water run	40	0.42				73		

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
					mg/L					
Feed as is	290	454	417	31	9	427	2	30	8	3060
Permeate 1	2.26	18.8	2.38	2.44	0.65	2.37	0.01	0.15	0.06	10.66
Permeate 2	2.47	31.2	2.2	2.45	0.75	1.96	0.01	0.13	0.05	9.7
Permeate 3	2.03	52.7	1.84	3.97	0.58	1.67	0.01	0.11	0.02	7.25
Permeate 4	2	53.3	1.7	3.93	0.52	1.86	0.01	0.1	0.04	6.47
Concentrate	461	1890	1890	98.4	46.5	2105	1.9	146	40.2	17796.8
Combined permeate	2.19	38.82	2.03	3.19	0.63	1.97	0.01	0.12	0.04	8.54

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
					mg					
Feed	29.00	45.40	41.70	3.14	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.05	0.39	0.05	0.05	0.01	0.05	0.00	0.00	0.00	0.22
Permeate 2	0.05	0.64	0.05	0.05	0.02	0.04	0.00	0.00	0.00	0.20
Permeate 3	0.04	1.05	0.04	0.08	0.01	0.03	0.00	0.00	0.00	0.15
Permeate 4	0.04	1.09	0.03	0.08	0.01	0.04	0.00	0.00	0.00	0.13
Concentrate	8.30	34.02	34.02	1.77	0.84	37.89	0.03	2.63	0.72	320.34

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
Passing into permeate (mg)	0.18	3.18	0.17	0.26	0.05	0.16	0.00	0.01	0.00	0.70
Rejected into concetrate (mg)	8.30	34.02	34.02	1.77	0.84	37.89	0.03	2.63	0.72	320.34
Retained	99%	93%	100%	92%	94%	100%	100%	100%	100%	100%
loss to permate	1%	7%	0%	8%	6%	0%	0%	0%	0%	0%
Accoutability	**29%**	**82%**	**82%**	**65%**	**96%**	**89%**	**15%**	**89%**	**87%**	**105%**
Metal rejected	99%	93%	100%	92%	94%	100%	100%	100%	100%	100%

750 rpm								
	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**
	mL	***hr***	***hr***	***%***	***%***	***L/h.m²***		
Feed	100							
Water run	92.5	0.42				169		
Permeate 1	20.9	0.20	0.2	21%	21%	80	3.71	436.10
Permeate 2	20.5	0.23	0.4	21%	41%	70	3.67	440.90
Permeate 3	20	0.28	0.7	20%	61%	54	3.65	449.60
Permeate 4	20.5	0.38	1.1	21%	82%	41	3.64	458.60
Concentrate	**18**						**4.14**	**449.30**
Water run	34.5	0.51				52		

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg/L										
Feed as is	290	454	417	31	9	427	2	30	8	3060
Permeate 1	2.55	23.4	2.61	2.73	0.66	2.65	0.01	0.16	0.05	11.83
Permeate 2	2.57	26.9	2.67		0.87	2.06	0.01	0.15	0.05	10.45
Permeate 3	3.09	26.9	2.45	2.89	0.63	2.35	0.01	0.15	0.05	9.43
Permeate 4	2.36	66.1	2.78	5.58	0.67	2.63	0.21	0.14	0.06	12.25
Concentrate	517	971	2000	98.5	47.5	2053.45	1.9	152	41.6	16793
Combined permeate	1.88	29.25	2.03	2.09	0.55	1.85	0.06	0.11	0.04	8.70
	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg										
Feed	29.00	45.40	41.70	3.14	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.05	0.49	0.05	0.06	0.01	0.06	0.00	0.00	0.00	0.25
Permeate 2	0.05	0.55	0.05	0.00	0.02	0.04	0.00	0.00	0.00	0.21
Permeate 3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Permeate 4	0.05	1.36	0.06	0.11	0.01	0.05	0.00	0.00	0.00	0.25
Concentrate	9.31	17.48	36.00	1.77	0.86	36.96	0.03	2.74	0.75	302.27
	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
Passing into permeate (mg)	0.15	2.40	0.17	0.17	0.05	0.15	0.00	0.01	0.00	0.71
Rejected into concetrate (mg)	9.31	17.48	36.00	1.77	0.86	36.96	0.03	2.74	0.75	302.27
Retained	99%	95%	100%	95%	95%	100%	98%	100%	100%	100%
loss to permate	1%	5%	0%	5%	5%	0%	2%	0%	0%	0%
Accoutability	**33%**	**44%**	**87%**	**62%**	**97%**	**87%**	**17%**	**93%**	**90%**	**99%**

Appendix G. DOW N90 OPTIMISATION TEST EFFECT OF PRESSURE

Operator	**Mpho**	
Date	06/09/2022	
membrane	N90	
Membrane Surface area	13	cm^2

Operational conditions	
Temp	Ambient
pressure	10,15,20,30,35,40
Speed	500 rpm

10 bar

	Volume	Time	Cumulative time	Permeate recovery	Cumulative permeate recovery	Flux	pH	Eh
	mL	*hr*	*hr*	*%*	*%*	*L/h.m²*		
Feed	100							
Water run	35	0.5				54		
Permeate 1	27	0.8	0.8	27%	27%	27	3.53	463.80
Permeate 2	20	0.7	0.7	20%	47%	24	3.45	450.60
Permeate 3	22	1.0	1.0	22%	69%	18	3.49	461.90
Permeate 4	14	1.0	1.0	14%	83%	11	3.61	465.50
Concentrate	**20**						**4.01**	**385.30**
Water run	28	0.5				43		

	Ca	Na	Mg	K	Al	Cu	Fe	Mn	Ni	SO4
					mg/L					
Feed as is	290.00	454.00	417.00	31.40	9.26	426.72	2.30	29.60	8.38	3060.00
Permeate 1	5.04	36.2	5.34	8.08	0.78	5.32	0.01	0.38	0.11	33.24
Permeate 2	3.11	35.3	4.06	5.54	0.63	3.7	0.01	0.28	0.07	17.94
Permeate 3	3.46	53.6	3.8	6.79	0.55	3.43	0.01	0.25	0.07	13.87
Permeate 4	5.92	111	5.9	28.7	0.61	5.47	0.01	0.4	0.11	22.1
Concentrate	517	1820	1930	104	47.2	1890	1.9	148	40.6	17121.8
Combined permeate	4.30	76.80	6.21	15.98	0.84	5.12	0.01	0.43	0.12	28.35

	Ca	Na	Mg	K	Al	Cu	Fe	Mn	Ni	SO4
					mg					
Feed	29.00	45.40	41.70	3.14	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.14	0.98	0.14	0.22	0.02	0.14	0.00	0.01	0.00	0.90
Permeate 2	0.06	0.95	0.11	0.15	0.02	0.13	0.00	0.01	0.00	0.48
Permeate 3	0.08	1.45	0.10	0.18	0.01	0.08	0.00	0.01	0.00	0.37
Permeate 4	0.08	3.00	0.16	0.77	0.02	0.08	0.00	0.01	0.00	0.60
Concentrate	10.34	49.14	52.11	2.81	1.27	37.80	0.05	4.00	1.10	462.29

	Ca	Na	Mg	K	Al	Cu	Fe	Mn	Ni	SO4
Passing into permeate (mg)	0.36	6.37	0.52	1.33	0.07	0.43	0.00	0.04	0.01	2.35
Rejected into concetrate (mg)	10.34	49.14	52.11	2.81	1.27	37.80	0.05	4.00	1.10	462.29
Retained	99%	86%	99%	58%	93%	99%	100%	99%	99%	99%
loss to permate	1%	14%	1%	42%	7%	1%	0%	1%	1%	1%
Accoutability	**37%**	**122%**	**126%**	**132%**	**145%**	**90%**	**23%**	**136%**	**132%**	**152%**
Metal rejected	99%	86%	99%	58%	93%	99%	100%	99%	99%	99%

15 bar

	Volume	Time	Cumulative time	Permeate recovery	Cumulative permeate recovery	Flux	pH	Eh
	mL	*hr*	*hr*	*%*	*%*	*L/h.m²*		
Feed	100							
Water run	52	0.5				80		
Permeate 1	20	0.4	0.4	20%	20%	42	3.46	471.80
Permeate 2	23	0.5	0.5	23%	43%	35	3.42	481.60
Permeate 3	23	0.6	0.6	23%	66%	29	3.52	491.60
Permeate 4	20	0.8	0.8	20%	86%	19	3.49	479.70
Concentrate	13						**3.95**	**384.50**
Water run	40	0.5				62		

	Ca	Na	Mg	K	Al	Cu	Fe	Mn	Ni	SO4
					mg/L					
Feed as is	290.00	454.00	417.00	31.40	9.26	426.72	2.30	29.60	8.38	3060.00
Permeate 1	2.61	27.4	2.62	3.21	0.53	2.48	0.01	0.18	0.07	9.43
	2.57	27.4	2.68	3.24	0.62	2.68	0.01	0.17	0.04	8.96
Permeate 3	2.4	41.1	2.82	6.35	0.48	2.82	0.01	0.19	0.1	9.43
Permeate 4	3.78	108	4.12	11.6	0.6	4.12	0.01	0.28	0.09	13.99
Concentrate		2540		108		2800	1.9			28614.8
Combined permeate	2.82	49.81	3.04	6.01	0.56	3.01	0.01	0.20	0.07	10.36

	Ca	Na	Mg	K	Al	Cu	Fe	Mn	Ni	SO4
					mg					
Feed	29.00	45.40	41.70	3.14	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.05	0.55	0.05	0.06	0.01	0.05	0.00	0.00	0.00	0.19
Permeate 2	0.06	0.63	0.06	0.07	0.01	0.06	0.00	0.00	0.00	0.21
Permeate 3	0.06	0.95	0.06	0.15	0.01	0.06	0.00	0.00	0.00	0.22
Permeate 4	0.08	2.16	0.08	0.23	0.01	0.08	0.00	0.01	0.00	0.28
Concentrate	0.00	33.02	0.00	1.40	0.00	36.40	0.02	0.00	0.00	371.99

	Ca	Na	Mg	K	Al	Cu	Fe	Mn	Ni	SO4
Passing into permeate (mg)	0.24	4.28	0.26	0.52	0.05	0.26	0.00	0.02	0.01	0.89
Rejected into concetrate (mg)	0.00	33.02	0.00	1.40	0.00	36.40	0.02	0.00	0.00	371.99
Retained	99%	91%	99%	84%	95%	99%	100%	99%	99%	100%
loss to permate	1%	9%	1%	16%	5%	1%	0%	1%	1%	0%
Accoutability	**1%**	**82%**	**1%**	**61%**	**5%**	**86%**	**11%**	**1%**	**1%**	**122%**
Metal rejected	99%	91%	99%	84%	95%	99%	100%	99%	99%	100%

20 bar								
	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**
	mL	***hr***	***hr***	***%***	***%***	***L/h.m²***		
Feed	100							
Water run	65	0.5				100		
Permeate 1	20	0.3	0.3	20%	20%	58	3.48	456.90
Permeate 2	21	0.3	0.3	21%	41%	55	3.47	458.20
Permeate 3	20	0.4	0.4	20%	61%	42	3.77	392.60
Permeate 4	20	0.6	0.6	20%	81%	28	3.65	414.50
Concentrate	**17**						**3.80**	**332.40**
Water run	24	0.5				37		

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg/L										
Feed as is	290.00	454.00	417.00	31.40	9.26	426.72	2.30	29.60	8.38	3060.00
Permeate 1	35.71	54.8	40.95	4.11	1.62	6.4	0.01	2.92	0.8	96.36
Permeate 2	19.74	54.7	21.98	4.08	1.06	1.69	0.01	1.57	0.44	48.56
Permeate 3	16.61	61.6	18.2	5.61	1.04	1.71	0.01	1.3	0.36	37.97
Permeate 4	24.31	121	26.72	9.11	1.36	0.15	0.01	1.91	0.53	56.11
Concentrate	524	4400	2230	190	50.6	2247	1.9	165	45.1	18368.6
Combined permeate	24.04	72.80	26.90	5.71	1.27	2.48	0.01	1.92	0.53	59.61

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg										
Feed	29.00	45.40	41.70	3.14	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.71	1.10	0.82	0.08	0.03	0.13	0.00	0.06	0.02	1.93
Permeate 2	0.41	1.15	0.46	0.09	0.02	0.04	0.00	0.03	0.01	1.02
Permeate 3	0.33	1.23	0.36	0.11	0.02	0.03	0.00	0.03	0.01	0.76
Permeate 4	0.49	2.42	0.53	0.18	0.03	0.00	0.00	0.04	0.01	1.12
Concentrate	8.91	74.80	37.91	3.23	0.86	38.20	0.03	2.81	0.77	312.27

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	SO4
Passing into permeate (mg)	1.95	5.90	2.18	0.46	0.10	0.20	0.00	0.16	0.04	4.83
Rejected into concetrate (mg)	8.91	74.80	37.91	3.23	0.86	38.20	0.03	2.81	0.77	312.27
Retained	93%	87%	95%	85%	89%	100%	100%	95%	95%	98%
loss to permate	7%	13%	5%	15%	11%	0%	0%	5%	5%	2%
Accoutability	**37%**	**178%**	**96%**	**118%**	**104%**	**90%**	**14%**	100%	**97%**	**104%**
Metal rejected	93%	87%	95%	85%	89%	100%	100%	95%	95%	98%

25 bar								
	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**
	mL	***hr***	***hr***	***%***	***%***	***L/h.m²***		
Feed	100							
Water run	68	0.5				103		
Permeate 1	31	0.3	0.3	31%	31%	71	3.68	400.70
Permeate 2	20	0.3	0.3	20%	51%	50	3.74	404.80
Permeate 3	20	0.3	0.3	20%	71%	48	3.70	407.10
Permeate 4	6.5	0.3	0.3	7%	78%	16	3.64	408.40
Concentrate	**22.5**						**4.25**	**374.40**
Water run	28	0.5				43		

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg/L										
Feed as is	290.00	454.00	417.00	31.40	9.26	426.72	2.30	29.60	8.38	3060.00
Permeate 1	5.7	22.9	6.73	2.07	3.01	6.15	0.01	0.42	0.13	13.67
Permeate 2	2.08	48.7	1.55	5.96	0.51	6.4	0.01	0.42	0.03	13.59
Permeate 3	3.15	11.3	1.67	0.708	0.63	1.69	0.01	0.09	0.02	147.2
Permeate 4	0.43	11.3	0.21	0.697	0.08	1.71	0.01	0.09	0.01	157
Concentrate	537		1730			1885	1.9			13708.6
Combined permeate	3.67	25.59	3.54	2.61	1.50	4.69	0.01	0.31	0.07	60.13

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg										
Feed	29.00	45.40	41.70	3.14	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.18	0.71	0.21	0.06	0.09	0.19	0.00	0.01	0.00	0.42
Permeate 2	0.04	0.97	0.03	0.12	0.01	0.13	0.00	0.01	0.00	0.27
Permeate 3	0.06	0.23	0.03	0.01	0.01	0.03	0.00	0.00	0.00	2.94
Permeate 4	0.00	0.07	0.00	0.00	0.00	0.01	0.00	0.00	0.00	1.02
Concentrate	12.08	0.00	38.93	0.00	0.00	42.41	0.04	0.00	0.00	308.44

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	SO4
Passing into permeate (mg)	0.28	1.98	0.27	0.20	0.12	0.36	0.00	0.02	0.01	4.66
Rejected into concetrate (mg)	12.08	0.00	38.93	0.00	0.00	42.41	0.04	0.00	0.00	308.44
Retained	99%	96%	99%	94%	87%	99%	100%	99%	99%	98%
loss to permate	1%	4%	1%	6%	13%	1%	0%	1%	1%	2%
Accoutability	**43%**	**4%**	**94%**	**6%**	**13%**	**100%**	**19%**	1%	**1%**	**102%**
Metal rejected	99%	96%	99%	94%	87%	99%	100%	99%	99%	98%

30 bar

	Volume	Time	Cumulative time	Permeate recovery	Cumulative permeate recovery	Flux	pH	Eh
	mL	*hr*	*hr*	*%*	*%*	*L/h.m²*		
Feed	100							
Water run	73	0.5				109		
Permeate 1	20	0.2	0.2	20%	20%	66	3.65	417.70
Permeate 2	20	0.3	0.3	20%	40%	61	3.52	461.30
Permeate 3	20	0.3	0.3	20%	60%	51	3.64	509.30
Permeate 4	20	0.4	0.4	20%	80%	42	3.64	504.30
Concentrate	**20**						**4.24**	**385.10**
Water run	50	0.5				77		

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg/L										
Feed as is	290.00	454.00	417.00	31.40	9.26	426.72	2.30	29.60	8.38	3060.00
Permeate 1	2.23	30.6	2.79	2.09	0.55	2.71	0.01	0.19	0.06	3.38
Permeate 2	2.78	30.6	2.68	2.09	0.79	2.84	0.01	0.17	0.08	2.68
Permeate 3	2.08	37.6	2.51	7.99	0.42	2.51	0.01	0.17	0.14	2.62
Permeate 4	3.44	69.2	3.09	5.09	1	3.09	0.01	0.22	0.08	3.49
Concentrate	522	3160	1900	102	45.7	2158	1.9	144	39.6	15157.4
Combined permeate	2.63	42.00	2.77	4.32	0.69	2.79	0.01	0.19	0.09	3.04

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg										
Feed	29.00	45.40	41.70	3.14	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.04	0.61	0.06	0.04	0.01	0.05	0.00	0.00	0.00	0.07
Permeate 2	0.06	0.61	0.05	0.04	0.02	0.06	0.00	0.00	0.00	0.05
Permeate 3	0.04	0.75	0.05	0.16	0.01	0.05	0.00	0.00	0.00	0.05
Permeate 4	0.07	1.38	0.06	0.10	0.02	0.06	0.00	0.00	0.00	0.07
Concentrate	7.31	44.24	26.60	1.43	0.64	30.21	0.03	2.02	0.55	212.20

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	SO4
Passing into permeate (mg)	0.21	3.36	0.22	0.35	0.06	0.22	0.00	0.02	0.01	0.24
Rejected into concetrate (mg)	7.31	44.24	26.60	1.43	0.64	30.21	0.03	2.02	0.55	212.20
Retained	99%	93%	99%	89%	94%	99%	100%	99%	99%	100%
loss to permate	1%	7%	1%	11%	6%	1%	0%	1%	1%	0%
Accoutability	**26%**	**105%**	**64%**	**56%**	**75%**	**71%**	**12%**	69%	**67%**	**69%**
Metal rejected	99%	93%	99%	89%	94%	99%	100%	99%	99%	100%

35 bar

	Volume	Time	Cumulative time	Permeate recovery	Cumulative permeate recovery	Flux	pH	Eh
	mL	*hr*	*hr*	*%*	*%*	*L/h.m²*		
Feed	100							
Water run	53	0.5				82		
Permeate 1	20	0.2	0.2	20%	20%	84	3.56	494.10
Permeate 2	20	0.2	0.2	20%	40%	68	3.53	483.10
Permeate 3	20	0.3	0.3	20%	60%	54	3.55	475.10
Permeate 4	22.5	0.4	0.4	23%	83%	43	3.50	472.80
Concentrate	**17**						**4.23**	**407.30**
Water run	52	0.5				80		

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg/L										
Feed as is	290	454	417	31	9	427	2	30	8	3060
Permeate 1	1.34	89.4	1.66	2.09	0.35	1.54	0.01	0.1	0.06	2.3
Permeate 2	1.23	88.8	1.59	2.09	0.58	1.34	0.01	0.11	0.04	2
Permeate 3	1.27	33	1.49	7.99	0.35	1.31	0.01	0.11	0.05	1.78
Permeate 4	1.59	42.6	2.2	5.09	0.58	1.97	0.01	0.15	0.07	2.78
Concentrate	523	323	1810	102	43.9	2107	1.9	140	38.3	15357.8
Combined permeate	1.36	62.82	1.75	4.34	0.47	1.55	0.01	0.12	0.06	2.23

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg										
Feed	29.00	45.40	41.70	3.14	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.03	1.79	0.03	0.04	0.01	0.03	0.00	0.00	0.00	0.05
Permeate 2	0.02	1.78	0.03	0.04	0.01	0.03	0.00	0.00	0.00	0.04
Permeate 3	0.03	0.66	0.03	0.16	0.01	0.03	0.00	0.00	0.00	0.04
Permeate 4	0.04	0.96	0.05	0.11	0.01	0.04	0.00	0.00	0.00	0.06
Concentrate	8.89	5.49	30.77	1.73	0.75	35.82	0.03	2.38	0.65	261.08

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	SO4
Passing into permeate (mg)	0.11	5.18	0.14	0.36	0.04	0.13	0.00	0.01	0.00	0.18
Rejected into concetrate (mg)	8.89	5.49	30.77	1.73	0.75	35.82	0.03	2.38	0.65	261.08
Retained	100%	89%	100%	89%	96%	100%	100%	100%	99%	100%
loss to permate	0%	11%	0%	11%	4%	0%	0%	0%	1%	0%
Accoutability	**31%**	**24%**	**74%**	**67%**	**85%**	**84%**	**14%**	81%	**78%**	**85%**
Metal rejected	100%	89%	100%	89%	96%	100%	100%	100%	99%	100%

40 bar								
	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**
	mL	***hr***	***hr***	***%***	***%***	***L/h.m*** ^{2}		
Feed	100							
Water run	80	0.5				123		
Permeate 1	20	0.2	0.2	20%	20%	91	3.33	505.40
Permeate 2	20.5	0.2	0.2	21%	41%	76	3.37	505.40
Permeate 3	20	0.2	0.2	20%	61%	64	3.50	476.00
Permeate 4	21	0.3	0.3	21%	82%	51	3.56	478.10
Concentrate	**18.5**						**4.10**	**466.50**
Water run	65	0.5				100		

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
					mg/L					
Feed as is	290	454	417	31	9	427	2	30	8	3060
Permeate 1	6.52	30.9	12.31	1.35	1.09	2.37	0.01	0.83	0.28	26.18
Permeate 2	0.91	30.9	1.64	1.35	0.53	1.34	0.01	0.11	0.04	2.66
Permeate 3	3.73	27.6	2.87	1.84	0.52	2.38	0.01	0.2	0.07	6.48
Permeate 4	1.44	41	2.03	3.02	0.61	1.61	0.01	0.13	0.07	2.76
Concentrate	517	324	2070	127	51.1	2194	1.9	159	43.7	18109.6
Combined permeate	3.12	32.69	4.66	1.90	0.69	1.92	0.01	0.31	0.11	9.39
	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
					mg					
Feed	29.00	45.40	41.70	3.14	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.13	0.62	0.25	0.03	0.02	0.05	0.00	0.02	0.01	0.52
Permeate 2	0.02	0.63	0.03	0.03	0.01	0.03	0.00	0.00	0.00	0.05
Permeate 3	0.07	0.55	0.06	0.04	0.01	0.05	0.00	0.00	0.00	0.13
Permeate 4	0.03	0.86	0.04	0.06	0.01	0.03	0.00	0.00	0.00	0.06
Concentrate	9.56	5.99	38.30	2.35	0.95	40.59	0.04	2.94	0.81	335.03
	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	SO4
Passing into permeate (mg)	0.25	2.66	0.38	0.15	0.06	0.16	0.00	0.03	0.01	0.77
Rejected into concetrate (mg)	9.56	5.99	38.30	2.35	0.95	40.59	0.04	2.94	0.81	335.03
Retained	99%	94%	99%	95%	94%	100%	100%	99%	99%	100%
loss to permate	1%	6%	1%	5%	6%	0%	0%	1%	1%	0%
Accoutability	**34%**	**19%**	**93%**	**80%**	**108%**	**95%**	**16%**	100%	**98%**	**110%**
Metal rejected	99%	94%	99%	95%	94%	100%	100%	99%	99%	100%

Appendix H. DOW N90 EFFECT OF TEMPERATURE

Operator	**Mpho**	
Date	14/09/2022	
membrane	A3014	
Membrane Surface area	13	cm^2
speed	750 rp,	

Operational conditions	
Temp	25, 30, 35,45
pressure	40

25°C								
	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**
	mL	***hr***	***hr***	***%***	***%***	***L/h.m²***		
Feed	100							
Water run	95	0.50				146		
Permeate 1	20	0.42	0.4	20%	20%	37	4.83	397.90
Permeate 2	20	0.90	0.9	20%	40%	17	4.60	402.60
Permeate 3	21	1.21	1.2	21%	61%	13	4.58	401.40
Permeate 4	14	2.11	2.1	14%	75%	5	4.62	393.90
Concentrate	**23**						**4.39**	**409.60**
Water run	88.5	0.5				136		

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg/L										
Feed as is	290	454	417	31	9	427	2	30	8	3060
Permeate 1	7.57	113	12.38	0	1.05	6.37	0.01	0.88	0.28	12.38
Permeate 2	5	114	8.12	5.49	0.77	7.95	0.01	0.58	0.14	13.56
Permeate 3	5.2	45.1	8.11	5.48	0.49	7.96	0.01	0.59	0.02	14.8
Permeate 4	6.76		6.43	3.84	0.64	12.13	0.01	0.45	0.02	11.88
Concentrate	515	290	1580	95.3	38.1	1614	1.9	121	33.3	13588
Combined permeate	6.07	73.16	8.94	3.72	0.74	8.31	0.01	0.64	0.12	13.28

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg										
Feed	29.00	45.40	41.70	3.14	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.15	2.26	0.25	0.00	0.02	0.13	0.00	0.02	0.01	0.25
Permeate 2	0.10	2.28	0.16	0.11	0.02	0.16	0.00	0.01	0.00	0.27
Permeate 3	0.11	0.95	0.17	0.12	0.01	0.17	0.00	0.01	0.00	0.31
Permeate 4	0.09	0.00	0.09	0.05	0.01	0.17	0.00	0.01	0.00	0.17
Concentrate	11.85	6.67	36.34	2.19	0.88	37.12	0.04	2.78	0.77	312.52

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
Passing into permeate (mg)	0.46	5.49	0.67	0.28	0.06	0.62	0.00	0.05	0.01	1.00
Rejected into concetrate (mg)	11.85	6.67	36.34	2.19	0.88	37.12	0.04	2.78	0.77	312.52
Retained	98%	88%	98%	91%	94%	99%	100%	98%	99%	100%
loss to permate	2%	12%	2%	9%	6%	1%	0%	2%	1%	0%
Accoutability	**42%**	**27%**	**89%**	**79%**	**101%**	**88%**	**19%**	**96%**	**92%**	**102%**
Metal rejected	98%	88%	98%	91%	94%	99%	100%	98%	99%	100%

30°C								
	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**
	mL	***hr***	***hr***	***%***	***%***	***L/h.m²***		
Feed	100							
Water run	64	0.25				197		
Permeate 1	20	0.41	0.4	20%	20%	38	3.82	432.4
Permeate 2	20	1.06	1.1	20%	40%	15	3.66	430.3
Permeate 3	23	2.00	2.0	23%	63%	9	3.86	425.3
Permeate 4	14.5	3.00	3.0	15%	78%	4	4.04	409.2
Concentrate	**20**						**4.26**	**408.6**
Water run	5.5	0.5				8		

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg/L										
Feed as is	290	454	417	31	9	427	2	30	8	3060
Permeate 1	4.47	134	5.28	5.81	0.72	5.46	0.54	0.4	0.03	9.74
Permeate 2	2.46	133	6.88	5.84	0.81	7.15	2.62	0.5	0.05	10.37
Permeate 3	82	217	110	10.8	4.78	11.66	0.01	12.38	3.67	369.55
Permeate 4	33.9	174	66.99	7.68	2.45	36.2	0.07	4.92	1.48	136.48
Concentrate	527	277	1590	4.6	38.6	1530	2.36	121	33.6	14114.6
Combined permeate	32.47	165.86	48.32	7.65	2.27	13.49	0.83	4.83	1.39	140.40

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg										
Feed	29.00	45.40	41.70	3.14	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.09	2.68	0.11	0.12	0.01	0.11	0.01	0.01	0.00	0.19
Permeate 2	0.05	2.66	0.14	0.12	0.02	0.14	0.05	0.01	0.00	0.21
Permeate 3	1.89	4.99	2.53	0.25	0.11	0.27	0.00	0.28	0.08	8.50
Permeate 4	0.49	2.52	0.97	0.11	0.04	0.52	0.00	0.07	0.02	1.98
Concentrate	10.54	5.54	31.80	0.09	0.77	30.60	0.05	2.42	0.67	282.29

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
Passing into permeate (mg)	2.52	12.85	3.74	0.59	0.18	1.05	0.06	0.37	0.11	10.88
Rejected into concetrate (mg)	10.54	5.54	31.80	0.09	0.77	30.60	0.05	2.42	0.67	282.29
Retained	91%	72%	91%	81%	81%	98%	72%	87%	87%	96%
loss to permate	9%	28%	9%	19%	19%	2%	28%	13%	13%	4%
Accoutability	**45%**	**41%**	**85%**	**22%**	**102%**	**74%**	**49%**	**94%**	**93%**	**96%**
Metal rejected	91%	72%	91%	81%	81%	98%	72%	87%	87%	96%

35°C								
	Volume	Time	Cumulative time	Permeate recovery	Cumulative permeate recovery	Flux	pH	Eh
	mL	*hr*	*hr*	*%*	*%*	*L/h.m²*		
Feed	100							
Water run	78	0.25				240		
Permeate 1	20	0.31	0.3	20%	20%	50	3.77	411.5
Permeate 2	29.9	1.10	1.1	30%	50%	21	3.6	424.2
Permeate 3	20	2.00	2.0	20%	70%	8	3.78	402
Permeate 4	17	3.00	3.0	17%	87%	4	3.66	438.8
Concentrate	**12**						**4.07**	**470.6**
Water run	22	0.60				28		

	Ca	Na	Mg	K	Al	Cu	Fe	Mn	Ni	SO4
mg/L										
Feed as is	290	454	417	31	9	427	2	30	8	3060
Permeate 1	3.76	117	4.12	5.26	0.95	18.71	0.01	0.27	0.01	6.5
Permeate 2	4.03	117	5.59	5.24	1.11	22.86	0.01	0.4	0.05	8.77
Permeate 3	3.17	78.9		6.38	1.48	26.33	0.01	0.87	0.27	21.06
Permeate 4	7.59	144		6.57	1.42	58.09	0.01	2.73	0.77	76.98
Concentrate	442		2380		47.8	2650.3	1.9	170	46.1	36500.6
Combined permeate	4.47	113.51	2.87	5.77	1.22	29.60	0.01	0.93	0.23	24.42
	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg										
Feed	29.00	45.40	41.70	3.14	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.08	2.34	0.08	0.11	0.02	0.37	0.00	0.01	0.00	0.13
Permeate 2	0.12	3.50	0.17	0.16	0.03	0.68	0.00	0.01	0.00	0.26
Permeate 3	0.06	1.58	0.00	0.13	0.03	0.53	0.00	0.02	0.01	0.42
Permeate 4	0.13	2.45	0.00	0.11	0.02	0.99	0.00	0.05	0.01	1.31
Concentrate	5.30	0.00	28.56	0.00	0.57	31.80	0.02	2.04	0.55	438.01
	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
Passing into permeate (mg)	0.39	9.86	0.25	0.50	0.11	2.57	0.00	0.08	0.02	2.12
Rejected into concetrate (mg)	5.30	0.00	28.56	0.00	0.57	31.80	0.02	2.04	0.55	438.01
Retained	99%	78%	99%	84%	89%	94%	100%	97%	98%	99%
loss to permate	1%	22%	1%	16%	11%	6%	0%	3%	2%	1%
Accoutability	**20%**	**22%**	**69%**	**16%**	**73%**	**81%**	**10%**	**72%**	**68%**	**144%**
Metal rejected	99%	78%	99%	84%	89%	94%	100%	97%	98%	99%

45°C								
	Volume	Time	Cumulative time	Permeate recovery	Cumulative permeate recovery	Flux	pH	Eh
	mL	*hr*	*hr*	*%*	*%*	*L/h.m²*		
Feed	100							
Water run	75	0.25				231		
Permeate 1	20.5	0.32	0.3	21%	21%	49	3.82	411
Permeate 2	20	0.63	0.6	20%	41%	24	3.61	412.7
Permeate 3	28.5	0.90	0.9	29%	69%	24	3.65	411.2
Permeate 4	11	0.90	0.9	11%	80%	9	3.62	411.7
Concentrate	**20**						**3.91**	**397.1**
Water run	27.5	0.25				85		

	Ca	Na	Mg	K	Al	Cu	Fe	Mn	Ni	SO4
mg/L										
Feed as is	290	454	417	31	9	427	2	30	8	3060
Permeate 1	3.47	71.1	5.39		0.89	18.86	0.01	0.39	0.04	9.55
Permeate 2	2.66		5.27	5.24	0.65	19.18	0.01	0.38	0.11	8.38
Permeate 3	81.41		120		5.89	17.08	0.01	17.89	6.01	520.56
Permeate 4	3.17	72.7	5.77	5.44	0.7	255.45	0.01	0.44	0.09	9.17
Concentrate	447	1990	1540	93.3	28.4	1646	1.9	109	30	16388.6
Combined permeate	30.99	28.22	46.24	2.06	2.59	50.84	0.01	6.63	2.19	191.25
	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
mg										
Feed	29.00	45.40	41.70	3.14	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.07	1.46	0.11	0.00	0.02	0.39	0.00	0.01	0.00	0.20
Permeate 2	0.05	0.00	0.11	0.10	0.01	0.38	0.00	0.01	0.00	0.17
Permeate 3	2.32	0.00	3.42	0.00	0.17	0.49	0.00	0.51	0.17	14.84
Permeate 4	0.03	0.80	0.06	0.06	0.01	2.81	0.00	0.00	0.00	0.10
Concentrate	8.94	39.80	30.80	1.87	0.57	32.92	0.04	2.18	0.60	327.77
	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
Passing into permeate (mg)	2.48	2.26	3.70	0.16	0.21	4.07	0.00	0.53	0.18	15.30
Rejected into concetrate (mg)	8.94	39.80	30.80	1.87	0.57	32.92	0.04	2.18	0.60	327.77
Retained	91%	95%	91%	95%	78%	90%	100%	82%	79%	95%
loss to permate	9%	5%	9%	5%	22%	10%	0%	18%	21%	5%
Accoutability	**39%**	**93%**	**83%**	**65%**	**84%**	**87%**	**17%**	**92%**	**93%**	**112%**
Metal rejected	91%	95%	91%	95%	78%	90%	100%	82%	79%	95%

Appendix I. DOW N90 EFFECTS OF PH

Operator	**Mpho**	
Date	24/09/2022	
membrane	N90	
Membrane Surface area	13	cm^2
speed	750 rpm	

Operational conditions	
Temp	Ambient
pressure	40
pH after adjustment	3.72, 4.31, 4.68, 5.16, and 5.79

pH3.87

	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**	**Cu**			
	mL	***hr***	***hr***	***%***	***%***	***L/h.m^2***			mg/L	mg		
Feed	100						3.87	428.3	416.35	41.64		
Water run	90	0.50				138						
Permeate 1	20	0.27	0.3	20%	20%	57	3.63	414.40	4.48	0.09		**Cu**
Permeate 2	20	0.38	0.4	20%	40%	41	3.58	420.40	3.23	0.06	Passing into permeate (mg)	0.28
Permeate 3	20	0.54	0.5	20%	60%	28	3.70	416.40	3.29	0.07	Rejected into concetrate (mg)	38.28
Permeate 4	20.5	0.65	0.7	21%	81%	24	3.73	411.30	2.78	0.06	Retained	99%
Concentrate	**20**						**4.24**	**425.60**	1914		loss to permate	1%
Water run	34.5	0.51				52					**Accoutability**	**93%**
Combined permeate									3.44		Metal rejected	99%

pH4.53

	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**	**Cu**			
	mL	***hr***	***hr***	***%***	***%***	***L/h.m^2***			mg/L	mg		
Feed	100						4.53	385.4	431.96	43.20		
Water run	85	0.50				131						
Permeate 1	20	0.65	0.7	20%	20%	24	3.79	429.60	3.42	0.07		**Cu**
Permeate 2	20	1.10	1.1	20%	40%	14	3.81	429.30	2.71	0.05	Passing into permeate (mg)	0.30
Permeate 3	20	2.55	2.6	20%	60%	6	3.91	420.30	3.79	0.08	Rejected into concetrate (mg)	38.37
Permeate 4	12.5	4.26	4.3	13%	73%	2	3.90	415.70	7.79	0.10	Retained	99%
Concentrate	**30**						**4.40**	**408.40**	1279	38.37	loss to permate	1%
Water run	11	0.54				16					**Accoutability**	**90%**
Combined permeate									4.08		Metal rejected	99%

pH4.83

		Time	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**	**Cu**			
	Volume	***hr***	***hr***	***%***	***%***	***L/h.m^2***			mg/L	mg		
	mL						4.83	360.5	538.9	53.89		
Feed	100	0.51				146						
Water run	96	0.90	0.9	20%	20%	17	4.13	400.40	8.86	0.18		**Cu**
Permeate 1	20	3.00	3.0	22%	42%	6	4.33	383.90	9.24	0.20	Passing into permeate (mg)	0.79
Permeate 2	22	2.52	2.5	20%	62%	6	4.45	371.40	15.6	0.31	Rejected into concetrate (mg)	34.31
Permeate 3	20	6.18	6.2	7%	69%	1	4.62	358.40	15.6	0.10	Retained	99%
Permeate 4	6.5						**4.56**	**374.50**	1183	34.31	loss to permate	1%
Concentrate	**29**	0.80				42					**Accoutability**	**65%**
Water run	44										Metal rejected	99%
Combined permeate									11.59			

pH5.36

	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**	**Cu**			
	mL	***hr***	***hr***	***%***	***%***	***L/h.m^2***			mg/L	mg		
Feed	100						5.36	343	986.94	98.69		
Water run	85.5	0.50				132						
Permeate 1	20	0.53	0.5	20%	20%	29	5.74	333.80	11.75	0.24		**Cu**
Permeate 2	20	1.10	1.1	20%	40%	14	5.74	328.00	22.65	0.45	Passing into permeate (mg)	1.76
Permeate 3	21	6.08	6.1	21%	61%	3	5.74	326.10	31.4	0.66	Rejected into concetrate (mg)	13.95
Permeate 4	10	15.28	15.3	10%	71%	1	5.64	329.20	41.3	0.41	Retained	98%
Concentrate	**29**						**5.05**	**355.80**	481	13.95	loss to permate	2%
Water run	12	0.64				15					**Accoutability**	**16%**
Combined permeate									24.79		Metal rejected	98%

pH5.68

	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**	**Cu**			
	mL	***hr***	***hr***	***%***	***%***	***L/h.m^2***			mg/L	mg		
Feed	100						5.68	318	392	39.20		
Water run	100	0.53				144						
Permeate 1	20	0.43	0.4	20%	20%	36	6.16	293.70	1.34	0.03		**Cu**
Permeate 2	20	1.14	1.1	20%	40%	13	6.33	308.70	1	0.02	Passing into permeate (mg)	0.08
Permeate 3	19.4	2.39	2.4	19%	59%	6	6.69	301.60	0.89	0.02	Rejected into concetrate (mg)	8.53
Permeate 4	7.5	4.41	4.4	8%	67%	1	6.04	315.90	1.78	0.01	Retained	100%
Concentrate	**30**						**5.54**	**338.50**	284.3	8.53	loss to permate	0%
Water run	85.8	0.87				76					**Accoutability**	**22%**
Combined permeate									1.16		Metal rejected	100%

Appendix J. DOW N90 SCALING TEST

Operator	**Mpho**	
Date	25/09/2022	
membrane	N90	
Membrane Surface area	13	cm^2

Operational conditions	
Temp	Ambient
pressure	40
speed	500 rpm

TEST 1

	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**
	mL	***hr***	***hr***	***%***	***%***	$L/h.m^2$		
Feed	100							
Water run	92.5	0.42				169		
Permeate 1	20.9	0.23	0.2	21%	21%	71	4.13	439.20
Permeate 2	20.5	0.23	0.5	21%	41%	70	4.18	435.90
Permeate 3	20	0.28	0.7	20%	61%	54	4.19	433.10
Permeate 4	20.5	0.38	1.1	21%	82%	41	3.90	459.20
Concentrate	**18**						**4.15**	**433.80**
Water run	40	0.42				73		

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
					mg/L					
Feed as is	290	454	417	31	9	427	2	30	8	3060
Permeate 1	1.68	22.4	0.87	2.12	0.44	1.4	0.15	0.04	0.01	2.20
Permeate 2	0.98	26.5	0.79	2.62	0.48	0.91	0.18	0.03	0.01	1.16
Permeate 3	1.81	54.5	1.8	3.46	1.33	0.8	0.93	0.05	0.01	1.61
Permeate 4	1.44	90.9	0.99	6.21	0.52	0.79	1.87	0.04	0.01	0.97
Concentrate	500	2160	1900	106	42.9	1840	1.9	145	40.00	18756.80
Combined permeate	1.48	48.41	1.11	3.60	0.69	0.98	0.78	0.04	0.01	1.49

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
					mg					
Feed	29.00	45.40	41.70	3.14	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.04	0.47	0.02	0.04	0.01	0.03	0.00	0.00	0.00	0.05
Permeate 2	0.02	0.54	0.02	0.05	0.01	0.02	0.00	0.00	0.00	0.02
Permeate 3	0.04	1.09	0.04	0.07	0.03	0.02	0.02	0.00	0.00	0.03
Permeate 4	0.03	1.86	0.02	0.13	0.01	0.02	0.04	0.00	0.00	0.02
Concentrate	9.00	38.88	34.20	1.91	0.77	33.12	0.03	2.61	0.72	337.62

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
Passing into permeate (mg)	0.12	3.96	0.09	0.29	0.06	0.08	0.06	0.00	0.00	0.12
Rejected into concetrate (mg)	9.00	38.88	34.20	1.91	0.77	33.12	0.03	2.61	0.72	337.62
Retained	100%	91%	100%	91%	94%	100%	72%	100%	100%	100%
loss to permate	0%	9%	0%	9%	6%	0%	28%	0%	0%	0%
Accoutability	**31%**	**94%**	**82%**	**70%**	**89%**	**78%**	**43%**	**88%**	**86%**	**110%**
Metal rejected	100%	91%	100%	91%	94%	100%	72%	100%	100%	100%

TEST 2

	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**
	mL	***hr***	***hr***	***%***	***%***	$L/h.m^2$		
Feed	100							
Water run	44	0.5				68		
Permeate 1	20.5	0.3	0.3	21%	21%	49	4.13	413.5
Permeate 2	24	0.3	0.7	24%	45%	54	3.87	435.3
Permeate 3	20	0.3	1.0	20%	65%	45	3.9	436.5
Permeate 4	17	0.4	1.4	17%	82%	36	3.9	427.2
Concentrate	**18.5**						**4.08**	**412.3**
Water run	50	0.7				59		

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
					mg/L					
Feed as is	290	454	417	31	9	427	2	30	8	3060
Permeate 1	1.61	20.7	1.53	2.1	1.09	0.86	1.14	0.06	0.01	1.17
Permeate 2	1.45	24.5	1.08	2.52	0.77	0.87	0.9	0.05	0.01	1.01
Permeate 3	1.11	58.7	0.87	3.59	0.49	0.66	0.18	0.04	0.01	0.74
Permeate 4	1.65		1.24	3.59	0.57	0.84	0.24	0.06	0.01	1.25
Concentrate	497	1930	1900	99.2	42.9	1850	1.9	145	39.8	19115.8
Combined permeate	1.45	26.83	1.18	2.90	0.74	0.81	0.65	0.05	0.01	1.03

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
					mg					
Feed	29.00	45.40	41.70	3.14	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.03	0.42	0.03	0.04	0.02	0.02	0.02	0.00	0.00	0.02
Permeate 2	0.03	0.59	0.03	0.06	0.02	0.02	0.02	0.00	0.00	0.02
Permeate 3	0.02	1.17	0.02	0.07	0.01	0.01	0.00	0.00	0.00	0.01
Permeate 4	0.03	0.00	0.02	0.06	0.01	0.01	0.00	0.00	0.00	0.02
Concentrate	9.19	35.71	35.15	1.84	0.79	34.23	0.04	2.68	0.74	353.64

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
Passing into permeate (mg)	0.12	2.19	0.10	0.24	0.06	0.07	0.05	0.00	0.00	0.08
Rejected into concetrate (mg)	9.19	35.71	35.15	1.84	0.79	34.23	0.04	2.68	0.74	353.64
Retained	100%	95%	100%	92%	93%	100%	77%	100%	100%	100%
loss to permate	0%	5%	0%	8%	7%	0%	23%	0%	0%	0%
Accoutability	**32%**	**83%**	**85%**	**66%**	**92%**	**80%**	**38%**	**91%**	**88%**	**116%**
Metal rejected	100%	95%	100%	92%	93%	100%	77%	100%	100%	100%

TEST 3

	Volume	Time	Cumulative time	Permeate recovery	Cumulative permeate recovery	Flux	pH	Eh
	mL	*hr*	*hr*	*%*	*%*	*$L/h.m^2$*		
Feed	100							
Water run	46	0.5				68		
Permeate 1	22	0.4	0.4	22%	22%	47	3.92	407.4
Permeate 2	22.02	0.4	0.8	22%	44%	43	3.93	411.1
Permeate 3	20.5	0.4	1.1	21%	65%	42	3.96	414
Permeate 4	23	0.7	1.8	23%	88%	27	3.84	432.5
Concentrate	**8.3**						**3.82**	**412.1**
Water run	38	0.5				58		

	Ca	Na	Mg	K	Al	Cu	Fe	Mn	Ni	SO4
mg/L										
Feed as is	290	454	417	31	9	427	2	30	8	3060
Permeate 1	0.64	23.3	0.75	1.98	0.09	1.05	0.25	0.05	0.02	2.67
Permeate 2	15.12	25.4	29.72	2.61	21.75	1.04	0.15	0.62	0.13	21.95
Permeate 3	0.74	33.2	0.76	3.15	0.3	0.64	0.98	0.06	0.07	2.58
Permeate 4	5.18	52.7	8.32	6.36	5.38	1.31	7.71	0.22	0.13	9.37
Concentrate	520		4660		92	4070	1.9	314	89.2	46903
Combined permeate	5.50	33.87	10.03	3.56	6.98	1.02	2.36	0.24	0.09	9.26

	Ca	Na	Mg	K	Al	Cu	Fe	Mn	Ni	SO4
mg										
Feed	29.00	45.40	41.70	3.14	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.01	0.51	0.02	0.04	0.00	0.02	0.01	0.00	0.00	0.06
Permeate 2	0.33	0.56	0.65	0.06	0.48	0.02	0.00	0.01	0.00	0.48
Permeate 3	0.02	0.68	0.02	0.06	0.01	0.01	0.02	0.00	0.00	0.05
Permeate 4	0.12	1.21	0.19	0.15	0.12	0.03	0.18	0.01	0.00	0.22
Concentrate	4.32	0.00	38.68	0.00	0.76	33.78	0.02	2.61	0.74	389.29

	Ca	Na	Mg	K	Al	Cu	Fe	Mn	Ni	SO4
Passing into permeate (mg)	0.48	2.96	0.88	0.31	0.61	0.09	0.21	0.02	0.01	0.81
Rejected into concetrate (mg)	4.32	0.00	38.68	0.00	0.76	33.78	0.02	2.61	0.74	389.29
Retained	98%	93%	98%	90%	34%	100%	10%	99%	99%	100%
loss to permate	2%	7%	2%	10%	66%	0%	90%	1%	1%	0%
Accoutability	**17%**	**7%**	**95%**	**10%**	**148%**	**79%**	**97%**	**89%**	**89%**	**127%**
Metal rejected	98%	93%	98%	90%	34%	100%	10%	99%	99%	100%

TEST 4

	Volume	Time	Cumulative time	Permeate recovery	Cumulative permeate recovery	Flux	pH	Eh
	mL	*hr*	*hr*	*%*	*%*	*$L/h.m^2$*		
Feed	100						3.84	442.7
Water run	35	0.5				54		
Permeate 1	26	0.4	0.4	26%	26%	50	3.73	394.6
Permeate 2	20	0.4	0.8	20%	46%	44	3.74	415.2
Permeate 3	20.5	0.4	1.1	21%	67%	43	3.75	418.1
Permeate 4	14	0.3	1.4	14%	81%	37	3.77	415.7
Concentrate	**17**						**4.02**	**395.2**
Water run	38	0.5				58		

	Ca	Na	Mg	K	Al	Cu	Fe	Mn	Ni	SO4
mg/L										
Feed as is	290	454	417	31	9	427	2	30	8	3060
Permeate 1	2.21	18.9	2.79	1.54	1.81	0.91	2.68	0.08	0.05	3.41
Permeate 2	11.18	24.8	14.01	2.47	10.01	0.77	1.7	0.3	0.06	18.54
Permeate 3	1.51	31.3	1.3	3.24	0.55	0.78	0.8	0.06	0.02	3.23
Permeate 4	2.19	41.5	1.92	4.68	0.74	1.04	1.29	0.06	0.02	4.31
Concentrate	541	1400	2550	71.2	51.1	2220	1.9	173	49.9	17267.4
Combined permeate	4.26	27.45	5.05	2.75	3.34	0.86	1.72	0.13	0.04	7.28

	Ca	Na	Mg	K	Al	Cu	Fe	Mn	Ni	SO4
mg										
Feed	29.00	45.40	41.70	3.14	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.06	0.49	0.07	0.04	0.05	0.02	0.07	0.00	0.00	0.09
Permeate 2	0.22	0.50	0.28	0.05	0.20	0.02	0.03	0.01	0.00	0.37
Permeate 3	0.03	0.64	0.03	0.07	0.01	0.02	0.02	0.00	0.00	0.07
Permeate 4	0.03	0.58	0.03	0.07	0.01	0.01	0.02	0.00	0.00	0.06
Concentrate	9.20	23.80	43.35	1.21	0.87	37.74	0.03	2.94	0.85	293.55

	Ca	Na	Mg	K	Al	Cu	Fe	Mn	Ni	SO4
Passing into permeate (mg)	0.34	2.21	0.41	0.22	0.27	0.07	0.14	0.01	0.00	0.59
Rejected into concetrate (mg)	9.20	23.80	43.35	1.21	0.87	37.74	0.03	2.94	0.85	293.55
Retained	99%	95%	99%	93%	71%	100%	40%	100%	100%	100%
loss to permate	1%	5%	1%	7%	29%	0%	60%	0%	0%	0%
Accoutability	**33%**	**57%**	**105%**	**46%**	**123%**	**89%**	**74%**	**100%**	**102%**	**96%**
Metal rejected	99%	95%	99%	93%	71%	100%	40%	100%	100%	100%

TEST 5								
	Volume	**Time**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**	**pH**	**Eh**
	mL	*hr*	*hr*	*%*	*%*	*L/h.m²*		
Feed	100						3.84	442.7
Water run	36	31.5				1		
Permeate 1	20.5	0.4	0.4	21%	21%	43	3.79	403.5
Permeate 2	22	0.4	0.7	22%	43%	45	3.69	430.1
Permeate 3	23	0.4	1.1	23%	66%	43	3.64	440.9
Permeate 4	15.5	0.3	1.5	16%	81%	36	3.64	444.1
Concentrate	**19.9**						**4.15**	**390.2**
Water run	35.9	0.5				55		

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
					mg/L					
Feed as is	290	454	417	31	9	427	2	30	8	3060
Permeate 1	0.69	106	0.66	1.4	0.03	1.04	0.46	0.05	0.05	1.47
Permeate 2	0.49	26.1	0.56	2.33	0.26	1.01	0.25	0.05	0.03	1.62
Permeate 3	0.9	29.6	1.01	2.7	0.13	0.95	0.02	0.04	0.01	1.5
Permeate 4	0.16	42.7	0.09	4.46	0.53	1.04	1.92	0.05	0.09	2.07
Concentrate	560	1740	2160	72.3	45.1	1027	1.9	152	42.6	14260.2
Combined permeate	0.59	50.49	0.62	2.61	0.22	1.01	0.56	0.05	0.04	1.63

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
					mg					
Feed	29.00	45.40	41.70	3.14	0.93	42.67	0.23	2.96	0.84	306.00
Permeate 1	0.01	2.17	0.01	0.03	0.00	0.02	0.01	0.00	0.00	0.03
Permeate 2	0.01	0.57	0.01	0.05	0.01	0.02	0.01	0.00	0.00	0.04
Permeate 3	0.02	0.68	0.02	0.06	0.00	0.02	0.00	0.00	0.00	0.03
Permeate 4	0.00	0.66	0.00	0.07	0.01	0.02	0.03	0.00	0.00	0.03
Concentrate	11.14	34.63	42.98	1.44	0.90	20.44	0.04	3.02	0.85	283.78

	Ca	**Na**	**Mg**	**K**	**Al**	**Cu**	**Fe**	**Mn**	**Ni**	**SO4**
Passing into permeate (mg)	0.05	4.09	0.05	0.21	0.02	0.08	0.05	0.00	0.00	0.13
Rejected into concetrate (mg)	11.14	34.63	42.98	1.44	0.90	20.44	0.04	3.02	0.85	283.78
Retained	100%	91%	100%	93%	98%	100%	80%	100%	100%	100%
loss to permate	0%	9%	0%	7%	2%	0%	20%	0%	0%	0%
Accoutability	**39%**	**85%**	**103%**	**53%**	**99%**	**48%**	**36%**	**102%**	**102%**	**93%**
Metal rejected	100%	91%	100%	93%	98%	100%	80%	100%	100%	100%

Appendix K. AMS A-U301 PRE-TREATMENT SYNTHETIC AND REAL SOLUTION TEST WORK

CI/Operator	**Mpho/Jo**	
Membrane	UF	A-U301
Membrane Surface area	13	cm^2
Feed	150	ml
Operational conditions		
Temp	ambient	
pressure	40	

Synthetic solution UF DATA								
40 bar								
	Volume	**Time**	**pH**	**Eh**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**
	ml	***hr***			***hr***	***%***	***%***	***L/h.m²***
Feed	150							
Water run	50	0.50						
Permeate 1	20	0.27	2.32	522.6	0.27	13%	13%	58
Permeate 2	20	0.25	2.35	515.9	0.52	13%	27%	62
Permeate 3	20	0.27	2.37	507.9	0.78	13%	40%	58
Permeate 4	20	0.30	2.4	499.5	1.08	13%	53%	51
Permeate 5	20	0.32	2.43	490.4	1.40	13%	67%	49
Permeate 6	20	0.33	2.45	481.5	1.73	13%	80%	46
Concentrate	**30**							
Water run	48							

	Ca	**Cu**	**Fe**	**Mg**	**SO4**
mg/L					
Feed	398	639	172	571	4890
Permeate	86.6	197	17.8	120	1461
Concentrate	505	1430	500	1410	12420
	Ca	**Cu**	**Fe**	**Mg**	**SO4**
mg					
Feed	59.70	95.85	25.80	85.65	733.50
Permeate	10.39	23.64	2.14	14.40	175.32
Concentrate	24.24	68.64	24.00	67.68	596.16
	Ca	**Cu**	**Fe**	**Mg**	**SO4**
Passing into permeate (mg)	10.39	23.64	2.14	14.40	175.32
Rejected into concetrate (mg)	0.00	0.00	0.00	0.00	0.00
Retained	83%	75%	92%	83%	76%
loss to permate	17%	25%	8%	17%	24%
Accoutability	**58%**	**96%**	**101%**	**96%**	**105%**
Metal rejected	83%	75%	92%	83%	76%

Real solution								
40 bar								
	Volume	**Time**	**pH**	**Eh**	**Cumulative time**	**Permeate recovery**	**Cumulative permeate recovery**	**Flux**
	ml	***hr***			***hr***	***%***	***%***	***L/h.m²***
Feed	150							
Water run	75	0.5						
Permeate 1	21.5	0.18	3.83	380.9	0.18	14%	14%	90
Permeate 2	20	0.17	4.07	381.7	0.35	13%	28%	92
Permeate 3	20	0.17	4.07	391.9	0.52	13%	41%	92
Permeate 4	20	0.17	4.1	399.9	0.68	13%	54%	92
Permeate 5	20	0.17	3.96	419.9	0.85	13%	68%	92
Permeate 6	20	0.18	3.73	419.9	1.03	13%	81%	84
Concentrate	**28**							
Water run	58	0.5						89

	Ca	**Cu**	**Fe**	**Mg**	**SO4**
			mg/L		
Feed	289	427.7	1.9	416	3060
Permeate	114	215	1	198	1518
Concentrate	522	966	5	1240	8160
	Ca	**Cu**	**Fe**	**Mg**	**SO4**
			mg		
Feed	43.35	64.16	0.29	62.40	459.00
Permeate	13.68	25.80	0.12	23.76	182.16
Concentrate	14.62	27.05	0.14	34.72	228.48
	Ca	**Cu**	**Fe**	**Mg**	**SO4**
Passing into permeate (mg)	13.68	25.80	0.12	23.76	182.16
Rejected into concetrate (mg)	0.00	0.00	0.00	0.00	0.00
Retained	68%	60%	58%	62%	60%
loss to permate	32%	40%	42%	38%	40%
Accoutability	**65%**	**82%**	**91%**	**94%**	**89%**
Metal rejected	68%	60%	58%	62%	60%

Appendix L. DOW N90, UF PERMEATE TEST WORK

Synthetic as is

40 bar

	Volume	Time	pH	Eh	Cumulative time	Permeate recovery	Cumulative permeate recovery	Flux
	ml	*hr*			*hr*	*%*	*%*	*L/h.m^2*
Feed	100							
Water run	64	0.5						
Permeate 1	20	0.2	3.62	443	3.62	20%	20%	77
Permeate 2	20	0.23	3.33	417	6.95	20%	40%	66
Permeate 3	21	0.3	3.38	405	10.33	21%	61%	54
Permeate 4	21	0.3	3.79	387	14.12	21%	82%	51
Concentrate	**20**							
Water run	26	0.5						

	Ca	Cu	Fe	Mg	SO4
	mg/L				
Feed	554	427	1.9	510	4410
Permeate 1	6.93	6.95	0.35	3	947.87
Permeate 2	6.74	8.25	0.09	5	943.81
Permeate 3	7.35	8.35	0.08	6	956.64
Permeate 4	8.02	8.66	0.58	9	956
Concentrate	490	1530	4.89	1620	10470
	Ca	**Cu**	**Fe**	**Mg**	**SO4**
	mg				
Feed	55.40	42.70	0.19	51.00	441.00
Permeate 1	0.44	0.44	0.02	0.19	60.66
Permeate 2	0.13	0.17	0.00	0.10	18.88
Permeate 3	0.15	0.17	0.00	0.12	19.13
Permeate 4	0.17	0.18	0.01	0.19	20.08
Concentrate	10.29	32.13	0.10	34.02	219.87
	Ca	**Cu**	**Fe**	**Mg**	**SO4**
Passing into permeate (mg)	0.89	0.96	0.04	0.60	118.75
Rejected into concetrate (mg)	10.29	32.13	0.10	34.02	219.87
Retained	98%	98%	80%	99%	73%
loss to permate	2%	2%	20%	1%	27%
Accoutability	**20%**	**77%**	**74%**	**68%**	**77%**
Metal rejected	98%	98%	80%	99%	73%

UF feed treated

40 bar

	Volume	Time	pH	Eh	Cumulative time	Permeate recovery	Cumulative permeate recovery	Flux
	ml	*hr*			*hr*	*%*	*%*	*L/hr.m^2*
Feed	100							
Water run	62	0.5						
Permeate 1	20	0.2	5.37	252	5.37	20%	20%	92
Permeate 2	20	0.2	6.09	266	11.46	20%	40%	77
Permeate 3	20	0.2	6	272	17.46	20%	60%	71
Permeate 4	20	0.3	5.56	293	23.02	20%	80%	62
Concentrate	**20**							
Water run	35	0.5						

	Ca	Cu	Fe	Mg	SO4
	mg/L				
Feed ENC treated T2 N90	111	219	5.23	203	1527
Permeate 1	16.58	0.97	2.2	0.07	7.64
Permeate 2	14.35	1.55	5.23	0.26	3.81
Permeate 3	24.14	1.95	0.02	0.17	8.75
Permeate 4	29.36	2.33	0.06	0.09	9.49
Concentrate	423	1030	4.39	943	7260
	Ca	**Cu**	**Fe**	**Mg**	**SO4**
	mg				
Feed	11.10	21.90	0.52	20.30	152.70
Permeate 1	1.06	0.06	0.14	0.00	0.49
Permeate 2	0.29	0.03	0.10	0.01	0.08
Permeate 3	0.48	0.04	0.00	0.00	0.18
Permeate 4	0.62	0.05	0.00	0.00	0.20
Concentrate	8.88	21.63	0.09	19.80	152.46
	Ca	**Cu**	**Fe**	**Mg**	**SO4**
Passing into permeate (mg)	2.45	0.18	0.25	0.01	0.94
Rejected into concetrate (mg)	8.88	21.63	0.09	19.80	152.46
Retained	78%	99%	53%	100%	99%
loss to permate	22%	1%	47%	0%	1%
Accoutability	**102%**	**100%**	**65%**	**98%**	**100%**
Metal rejected	78%	99%	53%	100%	99%

Appendix M. WATER RUN DATA

Time	PI-01	PI-02	PI-03	PIT-01	PIT-02	FIT-01	FIT-02	FIT-03	TT-01	VSD
Minutes	kPa	kPa	kPa	bar	bar	L/min	L/min	L/min	°C	Hz
	Water run									
0	320	320	325	4.22	4.11	11.6	0	10.5	21.3	20.07
10	300	300	300	8.78	8.54	15.2	1	13.2	24.6	20.07
20	295	295	295	12.5	12.27	18.2	5.3	12.8	25.9	23.12
30	280	280	280	17.76	17.56	17.9	7.1	10.7	27.8	24.73
40	290	300	300	40.08	39.73	17.5	9.6	7.9	29.6	30..22