CHAPTER 18

Forward Osmosis Hybrid Processes for Mining Wastewater Treatment

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In this chapter the integration of forward osmosis (FO) with other water treatment methods will be examined with a particular focus on the integration of FO and reverse osmosis (RO) technologies. The limitations of RO in relation to the quality of the feed water will be discussed; in particular for the treatment of mine-affected water. Different modes of integration will be presented, and the advantage and limitations of different hybrid configurations will be examined.

18.1 INTRODUCTION

Membrane processes have been used for the desalination of saline water since 1960 (Loeb and Sourirajan 1960). The most widely used process of these technologies is reverse osmosis (RO), whereby water is forced through a semi-permeable membrane by the application of a hydraulic pressure greater than the osmotic pressure of the feed solution. Forward osmosis (FO) has only been studied as a method of desalination for the last ten years (McCucheon et al. 2005). In FO pure water is 'drawn' from the feed solution across a semi-permeable membrane into a draw solution with a higher osmotic pressure than the feed, whereby the osmotic pressure difference between the feed and the draw solutions drives the process. One major drawback of the FO process is that the pure water must be recovered subsequently from the draw solution. As such, FO is not currently used as a stand-alone water treatment method on a commercial scale, although research is being carried out to find draw solutions from which pure water can be readily recovered (Kim et al. 2012; Hancock et al. 2013; Stone et al. 2013), including the use of fertilisers as draw solutions (Phuntsho et al. 2012). Research is also being carried out into the effect of membrane composition on the permeate flow and rejection of the FO process (Cath et al. 2006; Han et al. 2012; Setiawan et al. 2012).

18.1.1 Hybrid FO Systems

The bulk of FO systems used in water treatment are hybrid systems whereby FO is combined with another membrane treatment method, generally replacing either chemical pre-treatment, which this chapter will focus on, or it is used to reduce the volume of the waste stream as a post treatment step. FO membranes are stronger and more resistant to fouling than the finer membranes used in other membrane processes making them more suitable to be used for the pre-treatment of raw water (Lee et al. 2010; Hickenbottom et al. 2013; Richardson et al. 2013).

18.1.1.1 Pre-treatment Hybrid Systems

Hybrid water treatment systems have been investigated which combine Membrane Distillation (MD), Ultrafiltration (UF), Nanofiltration (NF) and RO with FO as a pre-treatment system. These systems each have advantages and limitations as to the water that can be treated and the draw solutions that can be selected.

Forward Osmosis-Membrane Distillation (FO-MD)

Traditionally, particularly in the food industry, liquids are concentrated through multi-stage vacuum evaporation which is a high energy process (Onsekizoglu 2012). MD was developed to reduce this cost. In MD, the feed is heated and run parallel to a hydrophobic membrane through which only water vapour can pass. On the other side of the membrane is a cold condensing surface or a sweep gas which collects the vapour. FO is used in combination with MD when pure solutions, such as proteins and pharmaceuticals, need to be concentrated without the use of evaporation. The feed solution concentrates and dilutes the draw solution. The draw solution, of higher osmotic pressure than the protein or pharmaceutical feed solution, is then reconcentrated using MD (Wang et al. 2011). Recently this technology has been used to treat a feed solution containing a coloured dye which models the ability of FO-MD to treat domestic wastewater (Ge et al. 2012). The major limitations of FO-MD is the limited range of draw solutions which can be used in tandem with MD, the energy required to heat the draw solution for reconcentration (generally supplied by waste heat) and the necessity of a condensing or sweep gas apparatus to collect the pure water by-product.

FO-Ultrafiltration (FO-UF)/Nanofiltration (FO-NF)

FO can also act as a pre-treatment process for UF or NF. Not only do FO membranes foul less frequently than UF or NF membranes but by diluting the draw solution, the hydraulic pressure required for UF and NF is reduced. However, combining FO with either UF or NF requires the selection of a draw solution containing large ions that cannot pass through the UF or NF membrane pores when regenerating the draw solution. Recent research has focussed on polymeric draw solutions such as polyacrylic acids, which can have high osmotic pressures and can be rejected by UF and NF due to the high molecular weight of the polymer (Ling and Chung 2011). The advantage of UF and NF over RO is that the processes run at lower hydraulic pressures (Fritzmann et al. 2007), however RO has a higher rejection rate than UF and NF and a wider range of possible draw solutions to select from for the hybrid processes (Tan and Ng 2010).

FO-Reverse Osmosis (FO-RO)

FO, also referred to as osmotic dilution, has been investigated as a replacement for the chemical pre-treatment of RO since 2009 (Choi et al. 2009). The system has two main advantages, firstly the FO unit dilutes the feed to the RO unit and lowers the required hydraulic pressure, which is the main operating cost of RO and secondly, FO replaces chemical pre-treatment which can be costly, particularly for remote systems. Experiments on FO-RO have focussed on lowering the energy cost (Quintanilla et al. 2011), theoretically modelling the process (Choi et al. 2010; Bamaga et al. 2011) and treating low osmotic pressure solutions like secondary or tertiary treated domestic wastewater (Cath et al. 2010). As the osmotic gradient is the driving force behind FO, this technology is well suited for low osmotic pressure feedwaters. However a combined FO-RO process would also be ideally suited to treating mine affected water, as the FO process would act as a low cost pre-treatment and screen for the raw mine water, protecting the RO membrane and lowering the operating cost of the RO unit. Furthermore, RO is the cheapest desalination method currently in use making it the most economic technology for the regeneration of the draw solution.

18.1.1.2 Post-treatment Hybrid Systems

FO has been used for several years as a post treatment method for the concentration of liquids such as fruit juice (Petrotos and Lazarides 2001), which reduces the cost of transportation, and also to concentrate sugar solutions (Garcia-Castello et al. 2009). Recently FO has been used as a post-treatment method to concentrate sludge slurries to reduce waste volumes (Holloway et al. 2007). One such system, which has been tested at pilot scale, uses a standard hybrid FO-RO configuration with the feed solution low osmotic pressure secondary or tertiary treated effluent and the draw solution sea water (Cath et al. 2009). The effluent dilutes the draw solution which is then treated with conventional RO to create drinking water. The reject from the RO unit is then used as a draw solution in a second pass FO unit to concentrate the feed waste water from the first FO unit further, making it a FO-RO-FO process. The RO reject is diluted and returned to the sea.

Another domestic wastewater treatment method that utilises FO technology is the Osmotic Membrane BioReactor (OMBR) system. In sewage treatment, the feed water is treated in three steps – removal of heavy solids by gravity separation (primary treatment), removal of dissolved or suspended biological matter by oxidation (secondary treatment) and then chemical treatment (tertiary treatment)

(Forster 2003). A membrane bioreactor system involves a membrane (UF or MF) being submerged into the secondary treatment aeration tank. The aeration stops the membrane from fouling and clean water passes through the pores of the membrane. The osmotic membrane bioreactor system replaces the UF or MF membrane with a FO membrane. The FO membrane has a higher rejection rate and is more resistant to fouling then the other membranes (Achilli et al. 2009). The osmotic membrane bioreactor system is similar to other hybrid FO-RO systems. The FO membrane is submerged in the bioreactor and a draw solution of higher osmotic pressure is passed on the outer side of the membrane. The FO process dilutes the draw solution and concentrates the activated sludge. The draw solution is then conventionally treated using RO to recover the water and regenerate the draw solution (Cornelissen et al. 2008). A summary of hybrid FO systems is presented in Table 18.1

Although FO hybrid systems, particularly FO-RO systems, are ideal for treating raw brackish mine affected water, Table 18.1 shows that the FO hybrid systems currently in use are mainly used to treat NaCl solutions or secondary/ tertiary treated effluent. Furthermore, the hybrid system that does treat brackish water employs NF which is a lower energy water treatment method but does not have the same rejection rate as RO or the wide range of available draw solutions.

18.2 TREATMENT OF MINE AFFECTED WATER

In 2010–11 the mining industry accounted for 4% (540 GL) of water consumption (10% more compared to 2009–10), increasing its gross value by $243 million per GL of water consumed (ABS 2012). The coal industry is by far the largest water user in the mining sector because of the huge mass of product mined (fourth largest producer in the world with total production of raw black coal of 471Mt in 2009–10, according to the Australian Coal Association (http://www.australian-coal.com.au/coal-production.html). Water is an integral part of coal mining operations and uses approximately 200–300 L per tonne of saleable coal produced. This "water use" compensates for water entrained in sold product and rejects. However, many coal mines are located in areas experiencing significant climate variability where water can be scarce, or where water systems are fully utilised (e.g. Hunter Valley region and the Murray-Darling Basin). It can be difficult to obtain new water entitlements. Water used by the coal industry (inputs) is obtained from a variety of sources including allocation from bulk water infrastructure (third party water), groundwater and surface water (rainfall and runoff). Water is used onsite for various purposes including longwall dust suppression (in underground mines), coal washing, road dust suppression, washing of mine equipment and vehicles, human consumption,. Water is returned to the environment (output) after contact with mining or processing activities, mainly through evaporation. Releases to the creeks or rivers are rare, but permitted in some river

Table 18.1. Summary of hybrid FO water treatment systems

Configuration	*Water treated*	*Flux rate* *(Lm^{-2}-h^{-1})*	*Scale*	*Reference*
FO-MD	Acid orange 8 dye solution	15–40	Lab-Scale	Ge et al. 2012
FO-UF	NaCl solution	2–15	Lab-Scale	Ling and Chung 2011
FO-NF	NaCl solution	5–25	Lab-Scale	Tan and Ng 2010
FO-NF	Brackish lake water	8–14	Lab-Scale	Zhao et al. 2012
FO-RO	NaCl solution	2–3	Lab-Scale	Choi et al. 2009
FO-RO	Tap water	4–14	Lab-Scale	Bamaga et al. 2011
FO-RO	Secondary waste water effluent	1–5	Lab-Scale	Quintanilla et al. 2011
FO-RO	Secondary/Tertiary effluent	1–8	Lab-Scale	Cath et al. 2010
FO-RO	Anaerobic digester centrate	7–16	Lab-Scale	Holloway et al. 2007
FO-RO-FO	Secondary/Tertiary effluent	21.4	Pilot-Scale	Cath et al. 2009

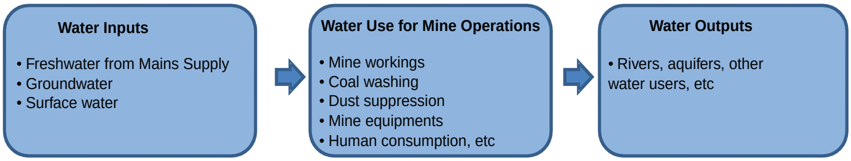

Figure 18.1. Water interactions with coal mining operation

systems, under highly controlled conditions. Figure 18.1 shows a diagrammatic representation of the water interactions in mining.

In the past, many coal mine operations managed water as an environmental issue, but today there is a paradigm shift towards viewing water as key business resource. Some coal mining companies have developed and adopted holistic water management principles and policies to ensure water is used efficiently and to maintain an appropriate water balance as well as minimising any potential environmental impacts from mine-affected water, in accordance to the water quality compliance regulations. Such measures are more likely to have a competitive, economic and reputational advantage. Guidance in identifying, mitigating and monitoring key water-related risks is also available (DRET 2008). Many of these risks are underpinned by the rapidly changing regulatory and economic environment, in the context of highly variable climatic conditions. The extreme variability in rainfall patterns makes water management for mines in Australia even more difficult. The most severe drought on record was witnessed during 1993–2008 and mines sites began to store sufficient water to provide adequate water supply. But this period was followed by above average rainfall resulting in flooding of mines in 2008 and more recently in 2010/11. Due to stringent water discharge regulations, most mines could not release any water and this led to many mines in Fitzroy Basin accumulating large volumes of water. The threat to the licence to operate mine sites due to non-compliant release of low quality mine-affected water and extreme variation in weather conditions (changes to rainfall, temperature and evaporation) are two main economic drivers to improve the approach to water management and to better control the risks.

During dry conditions, water management must focus on minimising dependence on high quality water. Adapting coal handling and preparation plants (CHPP) and dust suppression to use highly saline water reduces the volume of raw water that needs to be treated on mine sites. However, high quality water is still required for underground mining, and mine sites where the mine-affected water is hypersaline (typically with an electrical conductivity over 10000 μS/cm) require treatment to bring the water under the regulated discharge limits. Water sharing between sites and other industries also reduce the reliance on freshwater supply (Luba et al. 2006). Minimising the import of freshwater also has an advantage of minimising the introduction of additional water into the water balance, which will assist in controlling mine water inventory during wet season. During wet conditions, the build up of water on a mine site can occur at a faster rate than the discharge and so water management must focus on managing the water inventory by providing sufficient storage capacity and ensure monitoring and discharge conditions are met. However, augmenting storage capacity at an existing mine site can be hugely challenging (Cote et al. 2010). Adopting efficient treatment technologies on-site would minimise the risk of wet season run-offs and freshwater contamination and allow segregation into different qualities of water to enable greater water recycling.

18.2.1 Mine Water Characteristics

Characteristics of mine affected water vary from mine to mine and the possible impacts on local water sources vary according to local conditions. Water access and environmental performances including mine water discharge, is regulated through number of government agencies both Federal (DSEWPaC) and State-based (DEHP in Queensland, DLWC and DEP in NSW). A study conducted by the Qeensland-based (then) Department of Environment and Resource Management (DERM 2008) found that discharge quality limits and operating requirements for coal mine water discharges were inconsistent, and in the case of some coal mines, did not adequately protect downstream environments. The report's key recommendations included the need to improve the management of wastewater in mining activities, reduce the potential for cumulative impacts and improve water quality data. Most coal mines in the region now have highly regulated discharge conditions.

A recent study on the water quality from two representative mines from New South Wales and one from Queensland (Thiruvenkatachari 2011) has shown significant variation in the characteristics of mine water. Table 18.2 shows the concentration of some of the different parameters analysed from the various streams from the mine sites. These values are approximate concentration ranges obtained from various streams within the mine sites. The pH of the water sources

Table 18.2. Coal mine water quality characteristics

Parameters	*Units*	*Values*
pH	pH unit	3.5–8.9
Total Dissolved Solids	mg/L	700–20000
Suspended Solids	mg/L	5–50
Calcium	mg/L	20–500
Magnesium	mg/L	25–700
Sodium	mg/L	100–6000
Potassium	mg/L	10–120
Iron	mg/L	0–120
Chloride	mg/L	200–1300
Sulphate	mg/L	50–14000
Silica	mg/L	0–15
Bicarbonate Alkalinity	mg/L	5–250

ranged from acidic to basic in nature. Some streams showed high dissolved solids concentration and had the characteristics of scale formation.

Ongoing water management initiatives on site are helping to maximise the amount of water being reused and to minimise the volume discharged off site. Any discharges from site are undertaken in accordance with regulatory requirement. Part of the water management plan involves developing suitable water treatment facility to obtain more water for reuse and to enable water to be discharged off site without harming the environment.

18.2.2 Water Treatment Technologies

Mine affected waters are typically strongly acidic or alkaline and carry high concentrations of salts and trace metals and generally requires treatment before discharge into natural waterways. Mine water treatment technologies can be placed under different categories such as neutralisation of acid, removal of metals, desalination and removal of specific target compounds, as shown in Figure 18.2 (Niekerk et al. 2006).

An appropriate treatment process for a given site is selected based on the quality and quantity of mine-affected water, type of parameters that require removal/reduction, treated water quality objectives and capital and operating costs. Broadly, technologies have focussed on three main areas, namely lime neutralisation and chemical precipitation, desalination and passive treatment systems. Lime is the simple, low cost neutralising agent of choice in most applications. Lime sludges are heavy, low volume, easy to handle, and easy to clarify. Most metals contained in the sludge are as metal hydroxides which are insoluble and will not

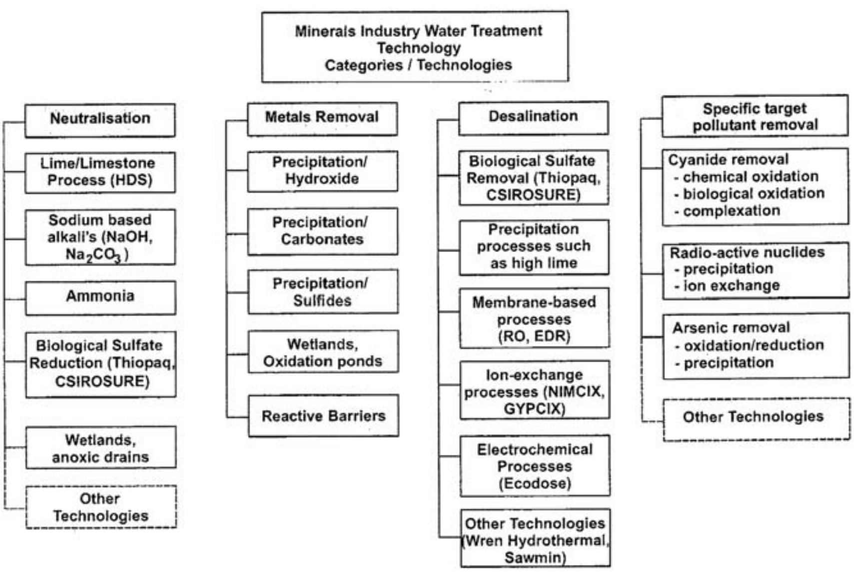

Figure 18.2. Conventional mine water treatment technologies

readily leach into the environment. Other commonly used chemical reagents are limestone, magnesium hydroxide, soda ash (sodium carbonate), caustic soda (sodium hydroxide) and in some cases ammonia. The main disadvantage in this process is they produce large amounts of sludge and the pH of the treated water needs to be readjusted to neutral values which requires large amount of chemical addition (Costello 2003; Nedved and Jansz 2006). In order to remove suspended solids in water, coagulants (such as inorganic iron and aluminium salts) and flocculants (anionic or cationic synthetic polymers) are often used. The most common passive treatment systems are sulphate reducing bacteria-based processes, anoxic limestone drains, constructed anaerobic and aerobic wetlands and biosorption (Watzlaf et al. 2004; Kuyucak 2006).

Currently, RO is a mature and one of the most commonly used desalination technologies in Australia (Hoang et al. 2009). Although membrane desalination processes are very expensive, due to a drop in the cost of membranes the cost of desalination has actually halved in the last five years, but is still not below the target value of $A500/ML (Moore 2009; Firth et al. 2002). Some mines reuse the RO treated water for their mine site operations and reduce the reliance on additional freshwater. However RO membranes can be very sensitive to fouling by various dissolved and undissolved constituents, particulate matter, salt precipitates, and microorganisms, particularly for mine affected water containing silica. It would require extensive and expensive pre-treatment to reduce membrane fouling and to ensure acceptable performance. The short life span of the membrane, membrane scaling, inability to achieve yield to design specifications, inconsistent output quality water are some of the problems generally encountered in the RO system for the treatment of mine impacted water (Davis 2009).

Mine affected water is pre-treated prior to the RO process and goes through elaborate procedures such as aeration, lime neutralisation where the pH is adjusted, coagulation and precipitation where suspended solids, excess lime, some precipitated metal elements and gypsum are allowed to settle, multimedia filters to further reduce the concentration of suspended solids, granular activated carbon filters to reduce the concentration of total organic carbon and microbiological activity, MF units to reduce colloidal material and water softener to reduce hardness and addition of antiscalents prior to RO treatment. Figure 18.3 shows the representation of pre-treatment train prior to RO process (Shao et al. 2009).

To our knowledge, FO has not been applied to the reuse of mine impacted water. As water is not forced through the membrane (osmotic pressure is the driving force, instead of hydraulic pressure), the FO system has fewer clogging or fouling problems. Application of an integrated FO-RO system for treating mine affected water would eliminate extensive pre-treatment requirements for conventional RO systems and has the potential to reduce the overall desalination cost. Through this process, the mine affected water is fed to the FO unit with minimal or no other pre-treatment and the water naturally permeates through the FO membrane to the draw solution, which is a higher salt concentration (osmotic pressure) than the feed mine water. As the treatment process proceeds, the draw solution becomes diluted. The diluted draw solution from this unit serves as the

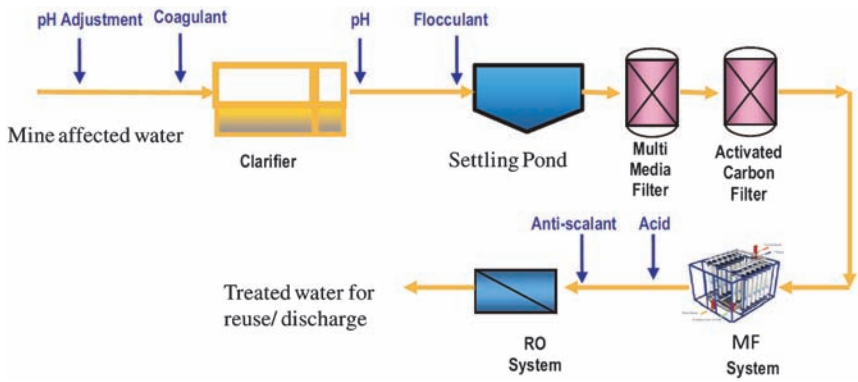

Figure 18.3. Mine affected water treatment using RO process with pre-treatment system

feed to the RO unit. The product water is the permeate from the RO unit, and the concentrate will be the draw solution which will be recirculated back into the FO unit, regenerating the draw solution.

To treat the mine affected water, once an appropriate FO draw solution (Kim et al. 2012; Ge et al. 2013; Stone et al. 2013) is selected then an suitable UF (Ling and Chung 2011), NF (Zhao et al. 2012) or RO membrane (Shaffer et al. 2013) technique can be selected to regenerate the draw solution and produce pure water from the draw solution. The ion size of the draw solution will determine whether ultra filtration, NF or RO can be selected. Although UF and NF require lower pressure than RO there are advantages to using RO as it has higher rejection and allows wider range of available draw solutions to choose.

18.3 INTEGRATED FO-RO SYSTEMS

Two modes of FO-RO integration are examined in detail in this chapter, both of which have advantages and disadvantages. The first, referred to as steady state operation, is shown in Figure 18.4. In this mode, the draw solution of a FO system is directly used as the feed water for a RO system. The permeate rate of the forward osmosis system is matched with the permeate rate of the RO system. This allows the FO system to act as a pre-treatment step and for steady state production of permeate to be produced. The draw solution/RO feed is kept at a constant volume through the re-addition of the reject stream. As the permeate rate from the RO unit is set to match the permeate rate from the FO unit, the concentration of the draw solution will remain constant. While maintaining the permeate rates, the hydraulic pressure in the RO system is decided by the concentration of the draw solution used to obtain the required osmotic gradient in FO and flux through FO for the given membrane characteristics and surface area.

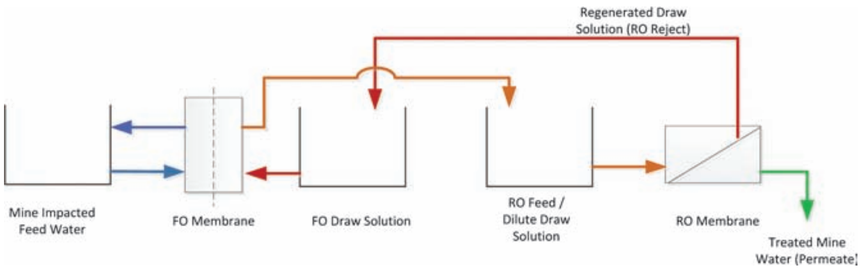

Figure 18.4. Steady state FO-RO system diagram

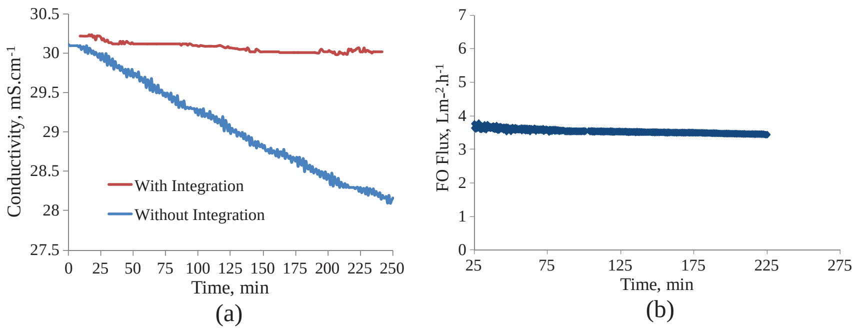

Figure 18.5. Steady state mode for hybrid FO-RO system. (a) FO draw conductivity with or without integration with RO. (b) Flux in FO when integrated with RO

The system will operate in a steady state operation and is only limited by the reduction in the osmotic gradient observed as the FO feed solution concentrates. This hybrid system also allows draw solutions to be selected which are easier to treat by RO, which have higher rejection due to larger molecular sizes and that have lower levels of back diffusion into the FO feed to reduce contamination. It also removes the need for chemical pre-treatment.

This system can overcome the problems of draw solution dilution, eliminate the need for chemical pre-treatment for the RO system and allows greater control on the quality and rate of permeate production through the selection of appropriate draw solutions. In standalone FO operation, the conductivity of the draw solution is gradually reduced due to dilution, thereby lowering the osmotic gradient. However, in the hybrid FO-RO process with steady state operation, the draw solution conductivity is able to be maintained constant as shown in Figure 18.5(a). With constant draw concentration, a more stable FO flux is able to be achieved (Figure 18.5(b)).

The second integration method is the reject management mode, shown in Figure 18.6. In this mode the FO and RO units are run independently with the reject stream from the RO unit being used to keep the concentration of the draw solution constant. In this mode the RO system pressure is independent of FO flux.

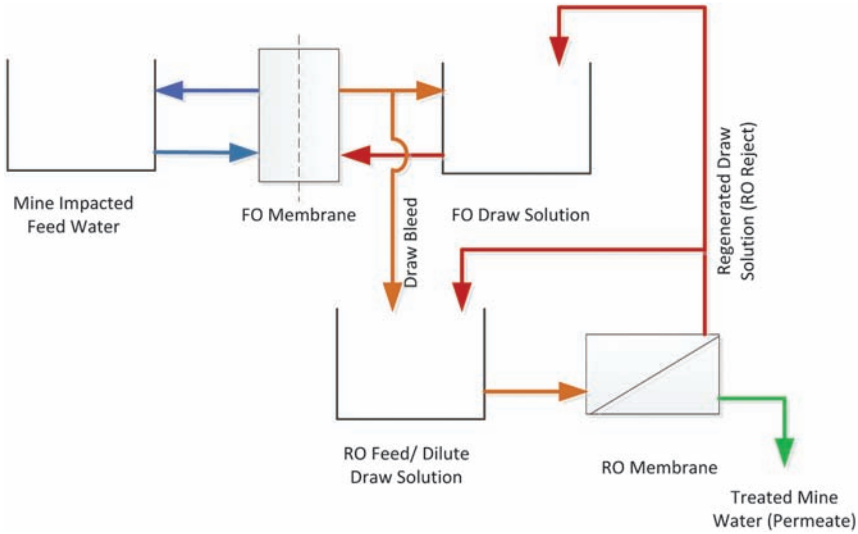

Figure 18.6. Reject management mode for hybrid FO-RO system diagram

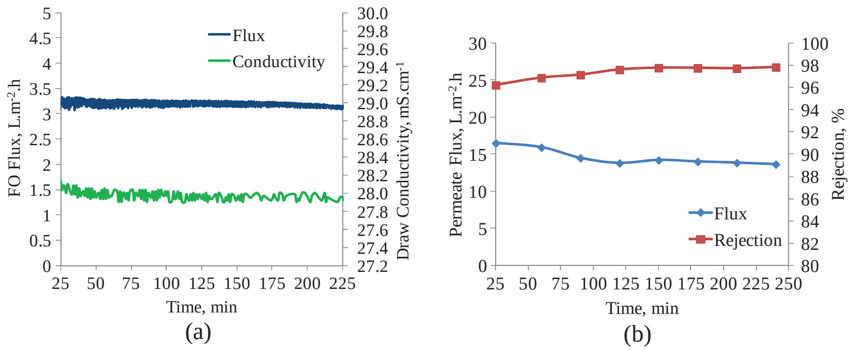

Figure 18.7. Reject management mode for hybrid FO-RO system. (a) Flux through FO and draw solution conductivity when integrated with RO. (b) Permeate water flux and salt rejection in RO

As the concentration of the RO feed increases, the quantity of RO reject added to FO draw, decreases. During this operation, the draw bleed is set to match the FO permeate flux and the reject return to FO draw, keeping the volume of the FO draw solution constant.

This system allows a higher rate of RO permeate to be produced than the steady state mode of operation as it is not limited by the FO flux (Figure 18.7(a)). The final treated mine water quality was about 600 μS/cm with RO rejection of the draw solution over 96% (Figure 18.7(b)). This method is also easier to tailor to specific mine water treatment requirements as the addition of RO reject is readily controllable. This configuration offers a greater flexibility in managing the reject volume.

The two modes adopted have their own advantages and disadvantages. The steady state mode can treat more mine affected water over a longer period of time but the RO permeate rate is limited by FO permeate rate. However this can be overcome by having FO system with higher effective membrane surface area, membrane with more permeability, or by having draw solutions with higher osmotic pressure. The reject management mode can deliver higher volume of RO permeate but is limited by the concentration of required draw solution based on the concentration of the mine affected water. The osmotic pressure of the mine affected water determines which of these two modes to be adopted. Both of these modes of integrated FO-RO systems would eliminate the need for extensive RO pre-treatment, potentially reducing the overall cost of desalination.

In some cases, two or more coal mine sites are in close proximity to each other and potentially have water streams with significantly different total dissolved solid concentrations. In such cases, water from one mine site can be used as the draw solution to treat the water from another site, without the need for any 'new' draw solution, as long as there is sufficient osmotic gradient between the waters from the mine sites. During the integrated FO-RO operation using two different mine waters, the RO is exposed to diluted mine affected water thereby reducing the cost of RO operation and the cost of any pre-treatment required to protect the membrane from fouling.

The current work at CSIRO investigating hybrid FO systems revolves around the study of a lab scale 3–5 LMH FO-RO system. The FO and RO systems were run individually, in steady state and reject management integration modes with the FO unit acting as a pre-treatment to the RO unit. Mine-affected water has been successfully treated using this system with reusable quality water produced as a final product. This unit has been used to evaluate a wide range of draw solutions including several natural products which have both high osmotic pressures and good rejection rates in post treatment. Furthermore, the unit has successfully utilised water from one mine site as the draw solution for mine-affected water from another site. Given the cost of chemicals and the water sharing agreements already in place between mine sites, this is a natural evolution of the technology.

Further to the success of the lab scale unit and the wide concentration range of mine-affected water that the system can treat, it is planned to take the hybrid FO-RO system to a pilot scale. The pilot unit will contain spiral wound FO and RO membranes and will produce about 1 m^3/day of reusable quality water per day using mine-affected water with a minimal pre-treatment system. The optimisation parameters obtained through this study using mine affected water, will provide valuable insight into the viability of this technology for mine site application. It is envisioned that the full scale FO unit with nominal capacity of 100 m^3/day would be integrated with the existing mine site RO system.

18.4 CONCLUDING REMARKS

Although FO is a promising and versatile water treatment technology, it is still not mature enough to be used in its own right. When FO is coupled with a mature treatment system like the RO, the hybrid process utilises the strengths of both technologies.

Application of the hybrid FO-RO system to mine affected water can potentially offer the industry a low cost desalination alternative. Two different integration modes of FO-RO systems were investigated to treat mine affected water. The results show that the FO and RO process can be successfully integrated to produce a reusable quality of treated mine water as permeate, while also able to continuously regenerate the FO draw solution. The hybrid system could potentially eliminate the extensive pre-treatment required for conventional RO process and thereby overall cost of desalination. The mine site application of hybrid FO-RO technology has yet to be investigated.

18.5 ABBREVIATIONS/NOMENCLATURE

FO	Forward Osmosis
MD	Membrane Distillation
MF	Microfiltration
NF	Nanofiltration
OMBR	Osmotic Membrane Bioreactor
RO	Reverse Osmosis
UF	Ultrafiltration

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