Membrane based water and wastewater treatment solutions

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Abstract

Water purification processes are described with reference to the categories of waterborne contaminants and respective membrane properties and capabilities. Robust microfiltration membranes are shown to remove heavy metals following precipitation to meet international regulatory drinking water standards. Integrating microfiltration membranes with reverse osmosis removes other dissolved contaminants to meet the increasingly stringent discharge standards and offers the opportunity for process reuse and potable supply.

Three case studies address the key physical and chemical treatment challenges with site data from installations in all geographic regions. Firstly, a potable supply demanding removal of arsenic through oxidation and coagulation and single stage microfiltration achieving treated water to within EPA targets. The second case study describes the treatment of formation water to EU standards (98/83/EU) for reinjection discharge. Finally, an effluent from a coal seam facility in Australia exhibited highly variable feed quality and required pilot trials to design a treatment plant to reduce suspended and dissolved contaminants to within discharge limits with long term operational sustainability.

Introduction

Water management has become a major topic for mining operations in all geographies. Many highly publicised environmental upsets have been associated with mining industries and the public awareness has increased the pressure on regulatory bodies to enforce change. These increasingly stringent discharge controls are demanding improvements in treatment of waste streams, often against tight timelines. Furthermore, water scarcity is driving operators to review treatment technologies for prospective water reuse for processes and shift maintenance.

Significant advances in membrane technology have enabled elegant, membrane based treatment techniques to be employed to meet the needs of this changing landscape. Target treatment levels can be achieved by combining conventional treatment methods with membranes. The overriding focus has to be the economic balance, identifying contaminants in the feed or source water and establishing appropriate treatment technologies to achieve the targets with sustainable operation.

Constituents of water

When devising a membrane based water treatment process, we must firstly consider the distinction between dissolved and suspended contaminants. Materials that dissolve in water will do so according to their own individual chemical properties. When a substance dissolves in water, it imparts new chemical properties to the solution and can create environmentally damaging characteristics. Consequently, discharge treatment targets are generally focussed on these dissolved components. Water can also be contaminated by suspended material but unlike the dissolved components these will mix indiscriminately with the host water. These constituents will not significantly change the chemical characteristics of the water and will retain their original structure and properties. Figure 1 represents this spectrum of contaminants.

These contaminants can be removed from the solution or mixture using a range of techniques as indicated at the bottom of Figure 1. Waste streams will be made up of contaminants across the whole spectrum and where treatment targets are based on dissolved contaminants, the chart indicates that RO (reverse osmosis) will be used to achieve the required separation. However, it will also be necessary to remove the corresponding suspended material to allow the RO to perform its function economically.

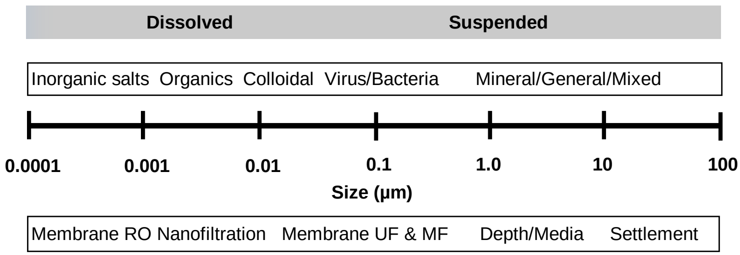


Figure 1 *Spectrum of contaminants*

Conventional chemical treatments have historically been employed to remove dissolved components from waste streams. Indeed, these simple and cost effective techniques continue to play an important role. Moreover, combining these traditional techniques with membrane microfiltration (MF) can produce a filtrate of exceptional cleanliness and purity levels where effective chemical treatments and MF can be used synergistically to enhance the performance of both stages.

Membrane Technology

RO membranes have been used for several decades for the removal of dissolved salts for potable and industrial water applications. However, a limitation of the use of RO is the suspended physical and biological contamination that is also present in the water. To prevent these materials from blocking the fine meshes in the RO construction they have to be removed to a level that is defined by the Silt Density Index test (SDI) (ASTM, D4189-07). The minimum water quality is set at SDI <5.

Membrane pre-filtration

Membrane prefiltration provides this protection. The membranes can be constructed as fibres with the fibre wall acting as a filter medium with raw feed water passing from outside to inside each fibre thereby avoiding superficial fibre occlusion. The often high and variable total suspended solids (TSS) content in the feed results in an increase in transmembrane pressure (TMP) and necessitates back flushing cycles. These cycles typically include air-scrubbing agitation and reverse flow (backwash) with previously filtered water. Periodically, chemical cleaning will further enhance membrane flux maintenance. Consequently, physically robust and chemically inert polymer chemistry is a critical feature of the MF stage. Otherwise, fibre degradation will result in deterioration in filtrate quality and a compromise in the performance of the downstream RO system. An example of a robust MF membrane is the highly cyrstaline polyvinylidene fluoride, 0.1μm membrane is illustrated in Figure 2. The importance of polymer architecture being a critcal membrane durability feature (Liu 2007)

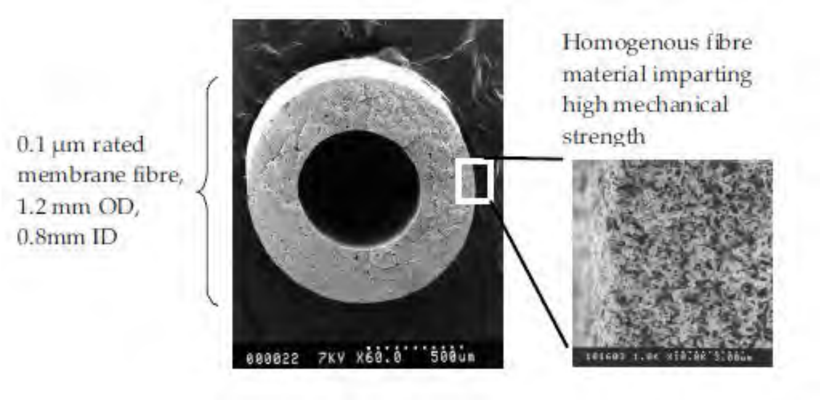


Figure 2 *PVDF Hollow fibre filtration membrane*

The membrane will produce a filtrate with a TSS value of <0.1mg/L (background) and a SDI of <3. and can be certified to provide log 6 titre reduction of certain organisms, making it particularly suitable for use in drinking water applications.

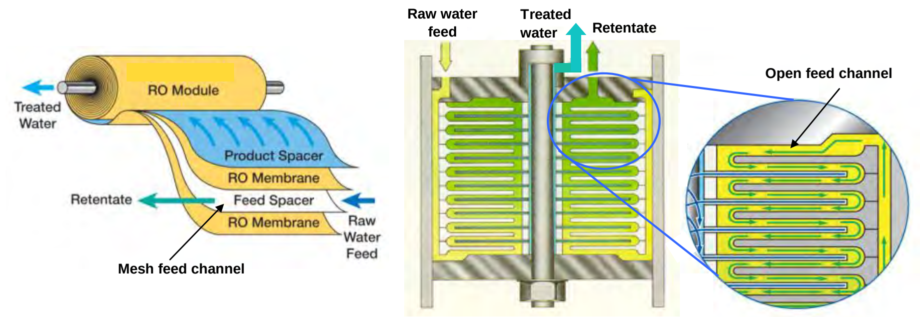
Reverse Osmosis

Reverse osmosis is a diffusional process (rather than one of filtration) where water molecules diffuse though a semi-permeable membrane while dissolved contaminants are rejected to a high degree, (Lorch 1981). Thus this type of membrane is entirely suitable for treatment of wastewater where the target quality is based on specific anions, cations or total dissolved solids (TDS).

The predominant construction of RO is based on a spiral wrap. The tightly packed module incorporates fine meshes on the upstream surface of the RO membrane to maximise the available membrane area per module. Disc Tube™ (DT) RO formats are also available which possess an open channel flow distribution on the feed side of the membrane as shown in the inset of Figure 3. Thus, DTRO is very tolerant of inlet solids and can operate successfully with feed water with a SDI up to 20.

RO membrane selection can be made according to target treatment specification. Nanofiltration (NF) range indicated on Figure 1 for reduction of larger, divalent ions such as sulfate operate at lower pressures and lower operating costs. Both NF and RO require the same level of pre-treatment that is afforded by the MF stage.

The DTRO module is also capable of operating at higher pressures than its spiral counterpart at lower construction cost. Thus DTRO can be used as a spiral RO concentrate reduction stage which can significantly alter the operating cost balance of the overall treatment with reduced waste volumes.



Spiral wound RO

Disc Tube RO

Figure 3 *RO module configurations*

Case studies and discussion

The following section describes MF alone, MFRO + DTRO and a sustainable high throughput MFRO.

Potable water from a gold mine formation water source, USA

11.6m^3/hr of formation water from the open cut gold mine was to be used as a potable source. Dissolved arsenic and iron contaminants were precipitated and removed by membrane filtration to EPA targets according to the following sequence (Chwirka *et al* 2004).

- $FeCl_3$ is added (20mg/l), the original Fe(II) is oxidised to Fe(III) and precipitated as $Fe(OH)_3$
- Oxidation of As(III) to As(V) with sodium hypochlorite (2mg/l)
- Adsorption of the negatively charge As(V) onto coagulated Fe(III) at pH>7
- Filtration of the resulting As/Fe suspension can achieve a filtrate within target As levels.

The MF membrane stage was then able to remove virtually all the resulting suspended As/Fe agglomerate as presented in Table 1.

Table 1 Arsenic and Iron removal to EPA drinking water standards.

Contaminant	Raw water	Filtrate	EPA Limits
Arsenic (μg/L)	142	<5	10
Iron (mg/L)	4.3	Not detected	0.3

Reinjection of formation water at a copper mine, Spain

175m3/hr of formation water was to be reinjected into the strata following removal of dissolved contaminants to EU standards. The basic layout of the respective membrane stages is illustrated in Figure 4.

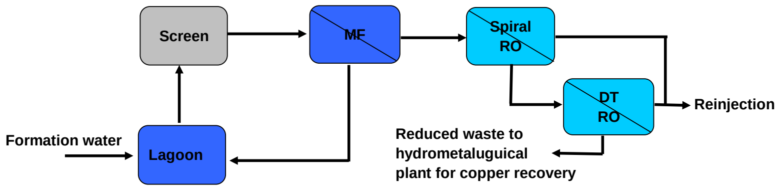


Figure 4 *Process flow block diagram of copper mine water processing system*

The site water analysis in Table 2 demonstrates compliance with the EU treatment target levels. Further concentration of the spiral RO retentate with DTRO enabled reduced waste and additional copper recovery.

Table 2 *Copper mine formation water treatment levels*

Contaminant (Units mg/L)	Formation water	Treated water	98/83/EU Target
TDS	2200	175	~
Sodium	423	51	200
Arsenic	27.5	0.003	0.01
Chloride	640	72	250
Sulfate	503	23	250

Coal seam produced water, Australia

375m^3/hr of formation water with TDS of 8000mg/L and a wide range suspended contaminants was treated to Australian Government surface water discharge standards of 175 mg/L with MFRO. Pilot MF trials established sustainable operational regimes as shown in Figure 5 where complete recovery of the transmembrane pressure was achieved (Charmers *et al* 2009).

This salinity reduction target was achieved with a RO permeate TDS of 120 mg/L. The MF stage controlled the upstream solids with a filtrate continuously exhibiting a SDI < 3 while operating sustainably with a recovered clean membrane TMP of 45 kPa by implementing the operating regimes that were detirmined during the pilot trials and cleaning regimes discussed earlier.

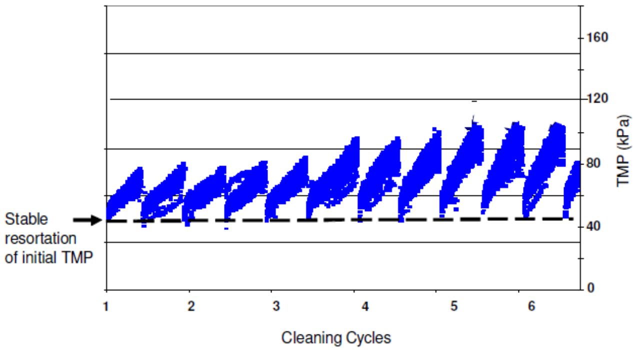


Figure 5 *MF flux sustainability*

Conclusions

Membrane technology has a long history in water treatment but recent developments in construction and polymer chemistry has enabled significant broadening of this scope.

Robust polymeric membranes can augment conventional chemical methods in wastewater treatment. Membrane systems can be used to treat mine waste streams to produce water for drinking or process reuse and for discharge at environmentally compliant standards.

The MF membranes can continuously maintain throughput when challenged with a wide range of inlet solids conditions. Integrating these membranes with RO enables the latter to function under optimum conditions and produce a treated water quality that is reliably within demanding target limits

References

Charmers, S., Kane, R., Karlapudi, R., (2009), 2nn World Coal Bed Methane Conference, March 10th & 11th, Jakarta.

Chwirka, D., Colvin, C., Gomez, J., Mueller, P., Arsenic Removal from Drinking Water using the Coagulation/Microfiltration Process, Journal American Water Works Association (2004) Volume: 96, Issue: 3, Pages: 106-114

Liu, C., Mechanical and Chemical Stabilities of Polymeric Membranes, (2007), AWWA Water Quality Technology Conference, November 4 - 8, (2007), Charlotte, NC, USA

Lorch, W., (1981), Handbook of Water Purification, McGraw-Hill, London.