Optimising mine pit dewatering treatment techniques to meet production deadlines

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Abstract Mine operators use membrane technology to treat wastewater for discharge or reuse. Membrane characteristics and their respective separation capabilities are contrasted apropos waterborne contaminants and how pH adjustment, precipitation and microfiltration can offer economic treatment solutions for the reduction of metals in mine wastewater applications. A case study describes dewatering a mine pit to allow continued production of the mine. The water was contaminated with cadmium, manganese and nickel amongst other species and was treated with chemical addition and MF alone to achieve the pit dewatering volumetric target of > 35 % and metals reduction to within discharge standards.

Keywords microfiltration, membrane, water treatment

Introduction

Mine operators are facing increasingly challenging water management targets. Stringent discharge controls are demanding improvements in water treatment methods be employed and water scarcity is driving operators to review treatment technologies for prospective water reuse for processes and shift maintenance.

Conventional water treatment techniques continue to provide solutions to these challenges but recent advances in membrane technology has greatly extended the scope and performance of water processing plant. Experiences gained in integrating established chemical methods with membrane systems have greatly enhanced the performance of the conventional techniques. Furthermore, the use of membranes introduces a degree of design flexibility that allows treatment selection and sizing to be matched to specific economic operational targets.

A detailed understanding of the waterborne contaminants and the corresponding treatment targets together with an in-depth knowledge of membrane capabilities and chemical processes is central to the effective economic solution to a given application.
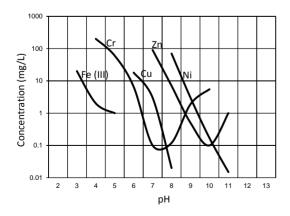
Characterisation of waterborne contaminants and membrane separation processes

Water will act as a host for a range of contaminants and the first step in devising a treatment process to remove them is to understand whether these contaminants exist in either suspended or dissolved forms. Materials that dissolve in water will do so according to their own individual chemical properties and that of the host water. Consequently, the level and form of which all dissolved species exist in water will depend on the physical and chemical characteristics of the solution. When a substance dissolves in water, it imparts new chemical properties to the solution and can create potentially damaging environmentally characteristics. Consequently, the principal discharge treatment standards are generally focused on these dissolved components. In contrast, suspended materials will mix indiscriminately with the host water and, importantly, these constituents will not significantly change the chemical characteristics of the resulting mixture and will largely retain their original structure and properties.

Suspended material can be removed from water by filtration though a porous medium or membrane; in contrast dissolved components

can be removed by the diffusional process of reverse osmosis (RO; Lorch 1981). Where treated water targets are based on dissolved materials and RO membranes are to be used, it will be necessary to remove the suspended components prior to the RO to enable the latter stage to perform its design function of chemical separation; this protection can be achieved with a microfiltration (MF) membrane. Failure to do so will result in inefficient RO performance and an unacceptable maintenance burden. However, by adjusting the chemical environment of the solution, dissolved constituents can be precipitated as a suspended form for subsequent separation by physical means. Indeed, separation of dissolved contaminants from waste streams has historically been brought about with conventional chemical treatments (Plasari and Muhr 2007). These techniques involve pH adjustment of the solution or oxidation/reduction of species to reduce solubility; separation of the resulting solid can then be achieved by settlement or filtration. Fig. 1 indicates how the solubility of some common metals changes with the pH of the host water (Freeman 1989). In this case, the pH can be increased with the addition of a base and the metals precipitate as the corresponding hydroxide.

However, Fig. 1 indicates that certain metals exhibit complex solubility characteristics as pH increases. In the Figure, chromium and zinc have a minimum solubility as pH increases above which points the metals have increasing solubility. In such cases it is necessary to use stage wise pH adjustment and filtration to avoid re-dissolving previously precipitated metals. Alternatively, where such mixtures exist it can be advantageous to use additional metal precipitants. As discussed above, the behaviour of dissolved species is dependent upon other components within the solution and the coexistence of certain metals and sulphide ions results in precipitation of the corresponding metal sulphide. Sodium sulphide is a soluble solid and can be used in such a way. Fig. 2 indicates the sparingly soluble characteristic of nickel, zinc and cadmium sulphides (Freeman 1989) – metals that were of particular importance in a pit lake water treatment application of the following case study.

By using these chemical properties, separation of certain contaminates, principally metals can be achieved with chemical additions and single stage membrane microfiltration. The 0.1 micron rating and durability of the correct MF membrane will result in a filtrate of exceptional quality. Moreover, the efficiency of solids removal will be maintained for many years with performance verified for operational and regulatory compliance by routine, non-destructive membrane integrity testing.
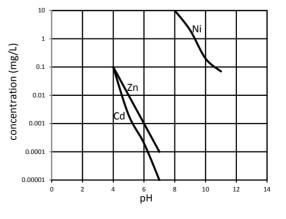

Fig. 1 Solubility of metal hydroxides vs. pH.

Fig. 2 Solubility of metal sulphides vs. pH.

The selection of the MF membrane is particularly important when the feed water exhibits the variability of those from chemical precipitation processes. This front-end treatment represents a very demanding duty and an exceptionally robust membrane construction will be central to economic long term efficacy of the whole system. An example of a high efficiency MF membrane is illustrated in Fig. 3.

This PVDF (polyvinylidene fluoride) 0.1 μm rated filtration membrane is the wall of a hollow fibre where feed water filters from the outside to the inside of the filtration medium. In doing so, the often high and variable suspended solids in the feed including the precipitated target contaminants collects on the upstream surface of the membrane resulting in an increase in transmembrane pressure (TMP) as the contaminants are retained. This process necessitates frequent back flushing cleaning cycles which typically include air-scrubbing agitation and reverse flow (backwash) with previously filtered water. Periodically, chemical cleaning in place (CIP) will further enhance membrane flux maintenance. It has been shown that physically robust and chemically inert polymer chemistry is a critical feature of the MF stage (Liu 2007). Otherwise, fibre degradation will result in deterioration in filtrate quality and compromise the treated water quality with the passage of target contaminants.
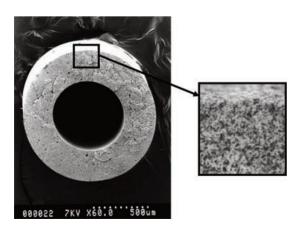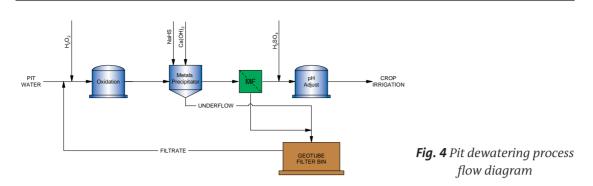

Fig. 3 *Homogeneous PVDF MF membrane*

Design considerations and technology selection

Application of these principles and that of tailoring a system to suit given performance and economic targets is exemplified in a site example from a barite mine in Nevada, USA. It was necessary to partially dewater a 150,000 m³ pit lake against a tight time schedule to allow continued operation of the mine. The water was contaminated with approximately 2000 mg/L of total dissolved solids (TDS) made up primarily of sulphate but also metals including cadmium, manganese and nickel.

The volumetric targets and timescale demanded a plant that was capable of processing >50 m³/h for a period of two months with water quality targets being dependent on treated water destination options. Water utilisation options can include surface water course or aquifer reinjection discharge, process reuse or irrigation. Discharge to surface water course or aquifer typically requires tight water quality standards be met as these are generally subsequent drinking water sources. For the barite mine pit lake water makeup TDS and dissolved metal reduction to local regulatory standards would be required. As referenced earlier, in a membrane context reduction of dissolved contaminants requires RO together with the associated MF to protect the RO construction. Also distribution pipework would be required in this particular case, all of which would be additional sources of contamination and cost. Considering the discharge options, water for irrigation would require only metals reduction from the pit lake composition as TDS and sulphate were already within applicable standard limits (NDEP Profile 1, 2012).

Figs. 1 and 2 illustrate the solubility dependence on pH of the relevant species of the barite pit lake water. As can be seen, all critical metal species can be precipitated with chemical adjustment and can therefore be subsequently filtered with single stage MF thereby offering considerable application cost reductions over the alternative of MFRO technolo-

Fig. 4 *Pit dewatering process flow diagram*

gies. However, the specific combination of metals meant that simple pH adjustment was not the most efficacious route as pH would have to be increase to around 10 for the hydroxide precipitation of nickel and, as discussed earlier, at such levels, re-solubilising zinc would be likely to take place (Fig. 1). Therefore the combination of pH adjusted hydroxide precipitation of aluminium, oxidation of manganese and sulphide precipitation of nickel, cadmium and zinc would be the optimum route. Particularly dissolved cadmium and zinc can be reduced to target levels at significantly lower pH than the hydroxide precipitation alternative route. The conceptual process chemistry as described in the following sequence was explored with bench scale testing to ensure dose rates and reaction time was optimised.

- Pit lake neutralised and pH adjusted with $Ca(OH)_2$
- Manganese oxidised $Mn(II) > MnO_2$ with H_2O_2
- Aluminium precipitated and $Al(OH)_3$ at pH ≈ 7
- Nickel, cadmium & zinc precipitated as sulphides with NaHS addition at pH ≈ 10
- pH reduced to ≈ 7 with H_2SO_4

The schematic process flow diagram is illustrated in Fig. 4.

In the context of generic membrane water treatment methodology there are aspects to the design presented here that suited the economic goals of the specific project which may not be ideal for a permanent installation. This exemplifies the earlier point of the degrees of flexibility that the use of membranes systems enables. This temporary, partial dewatering target allowed aggressive use of chemicals in the use of hydrogen peroxide for the oxidation of manganese, simultaneous precipitation of metals and final pH adjustment to discharge limits with sulphuric acid. This latter stage being acceptable as the sulphate and TDS discharge limit did not apply in this case.

The temporary plant illustrated in Figs. 4 and 5, ran from mid-August until early October 2012 at a flowrate of 60 m³/h and achieved a pit dewatering volumetric target of >35 % which exceeded the required target to allow production at the minesite to continue. The process acheived continuous metals reduction to 1 μg/L cadmium, < 0.1 mg/L manganese and < 0.05 mg/L nickel. A more detailed summary of water quality is presented in Table 1.

Fig. 5 *Pit dewatering site installation*

Parameter (mg/L or –)	Pit water	Discharge Standard (NDEP Profile 1)	Treated Water
Aluminum	1.7	0.2	0.045
Cadmium	0.66	0.005	0.001
Manganese	11.0	0.1	0.09
Nickel	1.8	0.1	0.04
Zinc	10.0	5.0	0.02
Sulfate	1,300	—	—
TDS	2,000	—	—
pH	5.4	6.0 – 8.5	6.5 – 7.0

Table 1 Summary water analysis of barite mine, Nevada 2012.

CapEx/OpEx balance and application objectives

Permanent membrane installation, particularly those of higher flows would usually be optimised to operate at higher MF flux rates (flow per unit filtration area). This is to minimise the capital cost of the installation by minimising the number of MF modules installed. This inevitably results in higher pumping costs by virtue of the elevated TMP. Furthermore, membrane cleaning burden will also be increase at higher flux operation both of which naturally creates a trade off with increased operating cost. For optimisation of operational MF flux, single module pilot tests can be run, the results of which can be accurately scaled up to reflect the performance of the final plant (Lilley 2005).

The plant described in the case study above was run at lower flux and would benefit from significantly reduced pumping costs and despite the high feed solids from the precipitated metals the elevated membrane cleaning burden did not compare to the higher energy costs and operating costs were about 75 % of the equivalent fixed plant. Table 2 summarises the operating costs of two typical alternative configurations.

In this way, we are able to tailor membrane treatment designs to match individual application targets. The temporary installation above was run at reduced flux, partly to minimise chemical usage at that particular site but other temporary projects could attract much higher flux if the economic drivers dictate. It is important to note that filtrate quality is independent of flux for the PVDF MF membranes described above so overall plant performance will be assured irrespective of *modus operandi*.

Conclusions

Conventional water treatment chemistry can be used synergistiaclly with robust polymeric microfiltration membranes to treat mine waste streams to exceptional quality.

A detailed study of influent water characterises, matched to the relevant treated water standards and the economic targets is the key to a successful site installation and operation.

Selection of the optimum treatment chemistry can eliminate the need for multistage membrane processes

Membrane systems lend themselves to containerised as well as temporary mine site applications that require rapid deployment

Operating costs can be tailored to suit individual application needs and targets

Installation	Flowrate m³/h	Electrical consumption kWh/a	(at $0.07/kW)	CIP $/Year	OpEx $/m³
Temporary	10.9	190000	13300	2840	0.17
Fixed	10.0	255500	17885	2253	0.23

* Excluding membrane replacement costs

Table 2 Typical operating costs* for temporary and fixed MF installations

Acknowledgments

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