A Review of Brine Treatment Technology for Mine Impacted Water (MIW) Plants

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Abstract

Treatment of Mine Impacted Water using reverse osmosis (RO) technology has proven extremely effective. Most MIW water, however, cannot be treated to a zero-brine discharge with RO alone. The final reject produced has typically been stored in brine evaporation dams with the expectation of efficient natural evaporation. In practice it has been found that over time the natural evaporation has not been sufficient over the long term. That coupled with space constraints in new plants being designed, cost of new dams and the reluctance of environmental authorities to approve the construction of new brine dams, means alternative methods for dealing with the brine are required. More prevalently, it has also become a requirement to dispose of the brine off-site using approved waste disposal companies, thus incurring excessive operational costs for plant operations. An evaluation of available technologies suitable for treatment of brine was completed.

Keywords: Mine Impacted Water, Mine Water Treatment, Brine Treatment, ZLD, Evaporative Crystallisation, Freeze Crystallisation

Introduction

The treatment technologies considered fall into two main categories, evaporation technology and freeze technology. Evaporation technologies have been around for many years and have been optimised considerably in that time. Freeze technology is an up and coming solution showing promise and is currently being aggressively pursued in the industry.

The implementation requirements, capital costs and operational costs for various scenarios within these categories were considered as key factors to the technology selection.

An internal case study (with a complex brine) was used to explore different brine treatment scenarios, as presented. The scenarios evaluated includes a combination of RO with evaporation technology, evaporation technology on its own, freeze technology on its own and a combination of freeze and evaporation technologies

Basis

A typical complex brine composition was used as a basis for the comparison between scenarios. The feed water quality is defined in table 1 below:

Table 1. *Feed Brine Composition.*

Parameter	Unit	Value	Parameter	Unit	Value
Na	mg/L	7000	Al	mg/L	0.2
Ca	mg/L	1200	F	mg/L	1.2
Mg	mg/L	596	Fe	mg/L	4
K	mg/L	1480	Mn	mg/L	0.2
Cl	mg/L	1580	SiO2	mg/L	1.5
HCO3	mg/L	134	SS	mg/L	70
SO4	mg/L	19404	Temp	˚C	22
NO3	mg/L	0.6	pH		8.1
Acidity	mg/L	8.8	TDS	mg/L	31401

The system is specified on the basis that a brine evaporation dam is in place and brine volume removal target of 12m^3/h is required for each scenario. The resultant brine/salt is required to be disposed of off-site.

Technologies

In developing the scenarios for evaluation, a screening of the technologies and their capabilities was completed. The first technology considered was *reverse osmosis technology.* This type of system would typically require an upfront softening step, followed by clarification, multi-media filtration and reverse osmosis separation. Due to the nature of the brine soda ash chemistry was selected for the softening system. Seawater desalination membranes were specified to maximise the brine reduction achievable in the system. This configuration can achieve a maximum recovery of 50%. The RO system will produce two reject streams, the clarifier sludge and the RO reject. The quantity of RO reject at this point will still be too high to feasibly consider off-site disposal and will be returned to the brine dam. As the RO system removes permeate the brine concentration in the dam will cycle up to a point where the brine concentration is above the operational limit of the RO System. An RO System would therefore not be the most suitable on its own. An additional treatment step is required to further reduce the brine volume and manage the TDS build up in the dam. At this point evaporative crystallisation and freeze crystallisation systems need to be considered for the further treatment of the RO Reject.

Evaporator technology is a well-developed, robust and mature technology. A number of suppliers can be found in industry, each with their own variations on the system and offering process guarantees on their systems. In principle evaporators are centred around either using steam to control temperatures or to use pressure (indirectly electricity) to control the temperatures. Modern optimisations on these systems include the use of solar power or waste heat available to minimise the energy requirement from external sources. It is unfortunate however that often the locations of water treatment plants in South Africa are not conveniently located to waste heat sources. Waste heat technology has been excluded in this evaluation. The solar systems available are too small to be considered for the industrial application of this brine treatment evaluation.

Steam dependant evaporator systems evaluated here include; multi-effect low temperature evaporation and thermal vapour recompression (TVR) systems. The multi-effect low temperature system offers the optimal solution in physical size, with the lowest power consumption in terms of electricity costs between the two systems. The TVR systems use more power and less steam, than the multi effect system to achieve the required separations. For the purposes of this evaluation the multi-effect low temperature system was used in the evaluation as the steam driven evaporator option. The Mechanical Vapour Recompression (MVR) system only requires steam for start-up. The energy required is supplied indirectly through electricity. The MVR system is more expensive and has a larger footprint than its steam dependant counterparts. It is included in the evaluation because of the lower operational costs associated with it not requiring steam.

To fully incorporate the evaporative crystalliser into an implementable solution, a boiler system, a cooling water circuit and chemical dosing systems are required. The evaporative crystalliser system will produce a salt slurry that requires dewatering. Installing decanters on the backend allows for the concentration of the slurry to a 25% moisture salt stream that can easily be disposed of off-site. All the required peripheral systems are included in the build-up of the capital costs determined in the evaluation. For the steam generation it has been identified that there is a significant cost difference in using various fuel sources for the boiler. Coal Boilers as well as Fuel/Gas Boilers have been included in the evaluation to indicate the impact of the cheaper (coal) versus the more expensive (fuel oil) boiler fuel. In terms of the evaluation, evaporation systems are considered as smaller systems following RO brine reduction as well as larger systems treating the full volume on their own.

Freeze technology is a much newer process that theoretically offers benefits in terms of operational costs in comparison to evaporator technology. There are not many suppliers able to offer freeze technology solutions and are also able to offer process guarantees without extensive test work before implementation. This technology currently has limited track record in actual treatment of complex brine streams. These factors are a serious drawback of the viability of freeze technology as a commercial option for brine treatment. The technology is, however, incorporated in this evaluation to show the merits it presents.

There are two operational stages to be considered with freeze technology. The first is the concentration of the brine by freezing of the water, retaining a concentrated brine. The second follows the first and is the combination of freezing the water and precipitation of salt crystals. The concentration step is extremely efficient, using far less power than an evaporator to achieve the same brine concentration. Investigations have, however, shown that for the complex brines produced by RO systems, the energy requirements to achieve the salt formation step is much less efficient than an evaporator system. The salt crystal formed have a higher value of waters of hydration, resulting in a greater mass of brine salt that needs to be disposed of in comparison to Evaporative Crystallisation.

The optimal solution based on the above is a combination of freeze technology to achieve the stage 1 brine concentration and an evaporator system to achieve the required salt formation and a final brine salt of 25% moisture for disposal. This combination is included as part of the evaluation. It was found that the most optimal split is for the freeze technology to remove 90% of the water from the brine and for an evaporator to treat the remaining 10%. This combination yields a 25% power saving over an MVR evaporator system treating the full capacity. All peripheral equipment for both the freeze and evaporator systems have been allowed for in the capital cost build up for these scenarios. The freeze system does not require additional chemical dosing.

Evaluation Procedure

The evaluation of the different scenarios will be done on a life cycle cost basis. The life cycle costs need to be considered in terms of Capital Costs and the Operations and Maintenance Costs.

The *Capital Cost* for each system has been compiled to include the design and implementation costs of a full turnkey scenario for each. The market has been engaged in preparing these costs to obtain an accurate budget cost for each scenario.

The *Operations and Maintenance (O&M)* have been calculated in terms of the variable costs only. It has been assumed that the labour requirements of each scenario will be similar and therefore bear no difference in comparison of the scenarios. The variable cost component includes the costs for; chemicals, electricity, other fuel sources and the brine disposal costs off-site. Each scenario is considered on the basis that the waste brine/brine salt will be removed off-site.

A summary of the assumption made in determining the life cycle is given in table 2.

Only present values have been used in the comparative calculation. No allowance has been made for funding or escalation of the costs as this would unnecessarily complicate the evaluation. The disposal costs also assume a proximity to available disposal sites. Cost for disposal will increase with distance to the disposal sites.

Table 2. *Evaluation Assumptions for O&M Costs*

Description	Assumption
Cost of Electricity	R1.03/kW.hr
Chemical Costs	Market Related Costs Q1 2018
Disposal Costs	Q1 Costs for rental of bins, periodic removal from site, disposal costs.
Labour and Maintenance Costs	Excluded
Life Cycle Costs	10 Years
Fuel Costs	Market Related Costs Q1 2018

Scenarios Compared

The following scenarios were considered as part of the case study:

Scenario 1 – Utilises an upfront RO brine reduction step that produces a portion of the treated brine. The side stream off the RO reject is then treated through an evaporator to produce a salt with a 25% moisture content and a clean water stream that is blended with the RO permeate. The balance of the brine stream is returned to the brine dam. The brine salt is disposed of offsite. The flowsheet for this scenario is given in figure 1. There are three sub-scenarios considered, each utilising different technology around the evaporation system:

1a. Multi-effect steam driven evaporator, coupled with a coal steam boiler;
1b. Multi-effect steam driven evaporator, coupled with a fuel oil steam boiler; and
1c. A MVR evaporator, that does not require steam for operation.

Scenario 2 – Utilises evaporative crystallisation technology to treat the raw feed from the brine pond. The brine is processed through the Evaporator to produce a salt with a 25% moisture content and a clean water stream that is taken away as product. The brine salt is disposed of offsite. The flowsheet for this scenario is given in figure 1. There are three sub-scenarios considered, each utilising different technology around the evaporation system:

2a. Multi-effect steam driven evaporator, coupled with a coal steam boiler;
2b. Multi-effect steam driven evaporator, coupled with a fuel oil steam boiler; and
2c. A MVR evaporator, that does not require steam for operation.

Scenario 3 - Utilises freeze crystallisation technology to treat the raw feed from the brine pond. The brine is processed through the freeze crystalliser to produce a concentrated brine having extracted 90% of the volume as clean water. The concentrated brine will need to be disposed of off-site. The flowsheet for this scenario is given in figure 1. There are no subcategories for this scenario.

Scenario 4 - Utilises a combination of freeze technology and evaporative crystallisation technology. The brine is processed through the freeze crystalliser to produce a concentrated brine scenario having extracted 90% of the volume as clean water. The concentrated brine scenario is then processed through the evaporator to produce a brine salt with a 25% moisture content and a clean water stream that is blended with the freeze crystallisation product water. The brine salt will be disposed of off-site. The flowsheet for this scenario is given in figure 1. There are two sub-scenarios considered, each utilising different technology around the evaporation system:

4a. Three stage multi-effect steam driven evaporator, coupled with a coal steam boiler;
4b. A mechanical vapour recompression evaporator, that does not require steam for operation.

Evaluation

Based on the evaluation criteria discussed above the comparison of each O&M cost is reported in table 3 on the next page for each of the scenarios and their sub-scenarios.

The results of the complete lifecycle costs of each scenario are summarised in table 4. The rand per cube rate calculated below is based on the 12m^3/h product flow for uniformity in evaluation.

The best capital costs can be achieved with the RO brine reduction coupled with the smaller evaporators. However, the lifecycle costs, specifically due to the costs of chemicals and the clarifier sludge removal, put it amongst the most expensive over a full ten-year lifecycle. In South Africa steam production using coal is much more cost effective than gas/fuel oil.

The combination of freeze reduction and evaporative crystallisation yields the best overall lifecycle costs, but the investment cost is the highest. The freeze reduction solution also shows merit, offering efficient operating costs that are mainly dependant on the cost of disposal, which may vary depending on the site location.

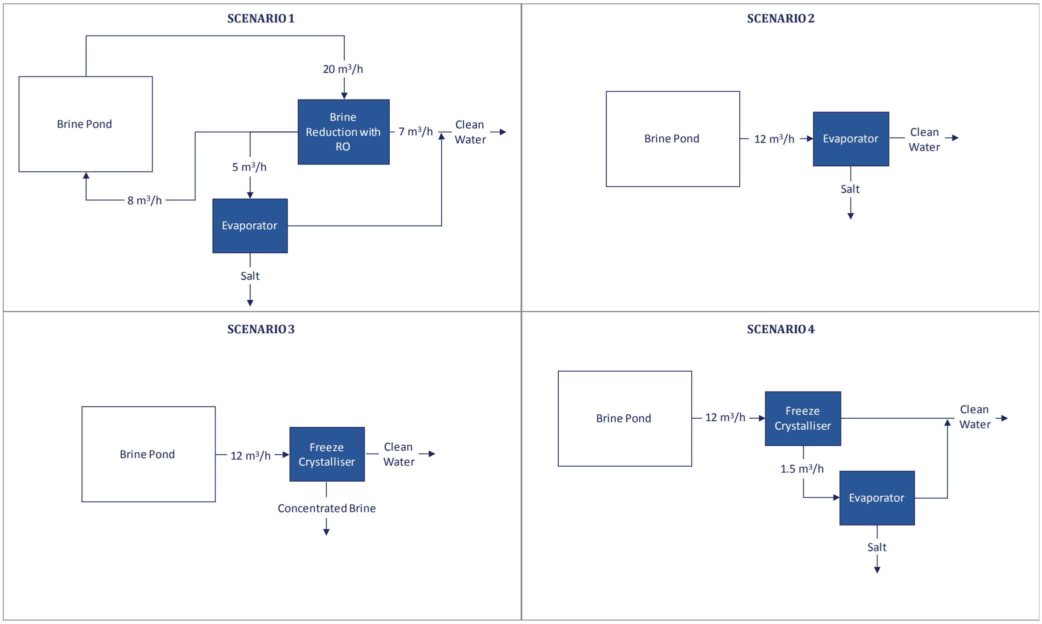

Figure 1 *Scenario Flowsheets*

Table 3. *O&M Cost Breakdown Results*

Cost Description	1a.	1b.	1c.	2a.	2b.	2c.	3.	4a.	4b.
Power (R/m³)	25.0	25.0	50.7	45.1	45.1	97.7	65.4	32.9	71.3
Chemicals (R/m³)	99.4	99.4	99.4	5.0	5.0	5.0	0	1.9	1.9
Steam (R/m³)	46.3	77.9	0	97.5	97.5	0	0	23.1	0
Disposal (R/m³)	44.2	44.2	44.2	35.0	35.0	35.0	62.5	35.0	35.0
O&M Total (R/m³)	215	246	194	183	249	138	122	93	108

Table 4. *Overall Lifecycle Cost Summary*

Cost Description	1a.	1b.	1c.	2a.	2b.	2c.	3.	4a.	4b.
Capital Costs (R mil.)	75.2	74.3	82.7	83.3	80.0	95.8	115.0	138.5	143.0
O&M Costs (R mil.)	225.8	259.0	204.2	191.9	261.9	144.7	128.5	97.7	113.8
Life Cycle Total (R/mil.)	300.9	333.3	286.9	274.5	341.2	239.7	309.9	226.5	247.0
Total Averaged per m3	286	317	273	262	325	229	232	225	244

The MVR System without upfront brine reduction shows comparative lifecycle costs to the freeze and freeze/evaporator combination, specifically due to the lower capital costs associated with the system. Considering the access and availability of process guarantees from suppliers of Evaporator systems, the MVR System is the best choice for this application presented in the case study.

To better depict the results of the lifecycle costs evaluation, figure 2 is included below. The graph indicates the cost per cube of clean water produced for each scenario and their sub-scenarios.

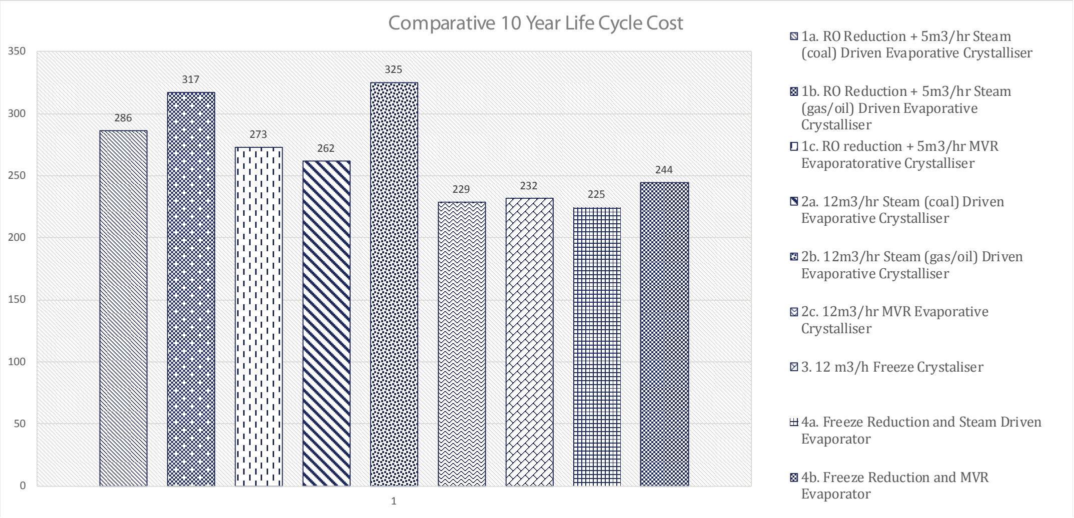

Figure 2 *Comparative 10-year lifecycle costs*

Conclusions

The comparative review from the case study showcases that the older more mature evaporation technology is still the best scenario for brine treatment. Comparable lifecycle costs coupled with performance security from suppliers outweighs the lower operational costs benefits of the freeze technologies. Evaporation technology often gets rejected due to the high upfront capital costs in favour of freeze technology or no solution at all. This should not be the standard outcome.

Water treatment systems are all singular in their requirements and need to be considered on a case by case basis. However, there are viable solutions to treatment of complex RO brine. Where applicable optimised evaporation systems using waste energy or solar energy are being developed and can have far cheaper life cycle costs than those presented in this case study.