EVAPORATION RATES ON BRINE PRODUCED DURING MEMBRANE TREATMENT OF MINE WATER

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ABSTRACT

Recent developments in treating excess mine water to potable water has lead to an increase in the number of brine ponds in South Africa. The high salinity in the water results in a decrease in the evaporation rate. Information on the evaporation rate is crucial when designing brine ponds.

Various salinity factors have been suggested in literature but very few studies have been conducted on the evaporation of brines produced from the membrane treatment of mine water. The Water Research Commission have sponsored a research project to carry out field investigations on the rate of evaporation on brine.

This paper presents the results obtained from the literature review carried out on the evaporation of saline solutions and the methodology that will be followed in the field investigations.

1. INTRODUCTION

Historically, mine water was considered a lost resource. The scarcity of fresh water resources has resulted in mine water being used as a viable potable water resource. This paper focuses coal mines in the Mpumalanga and Northern KwaZulu Natal provinces with excess mine water being treated to potable water. Reverse osmosis technology is often applied for the treatment of such water to potable standards. A salt concentrate waste stream, referred to as brine, is produced during this process.

The brine produced often has a Total Dissolved Solids (TDS) concentration of between 20 000 mg/ℓ and 35 000 mg/ℓ. Evaporation ponds become a viable disposal option for the brines produced at these water treatment plants. The high salinity makes options such as discharge to sewer and surface irrigation unfeasible and long pipelines and high pumping costs will be associated with disposal to sea.

The design of an evaporation pond is highly dependent on the evaporation rate. Dissolved salt in the water results in a lower saturation vapour pressure due to the decreased chemical potential of the water and thus a lower evaporation rate. (Leaney & Christen, 2000) indicated that the evaporation rate decreases exponentially with increasing salinity. The evaporation rate of saline solutions is calculated by multiplying the rate of evaporation of water by a salinity factor (Mickley, 2001). Figure 1 provides an indication of the effect of the salinity factor on the size of a pond. Large ponds lead to higher capital costs, due to additional land requirements and expensive liner systems. Designs are generally very conservative due to the limited information available on the evaporation of these brines.

The evaporation rate depends on the concentration of salt and type of salt present in the water. The Water Research Commission is funding a study to carry out field investigations to determine the salinity factor for brines typically produced from the treatment of coal mine water using the reverse osmosis method.

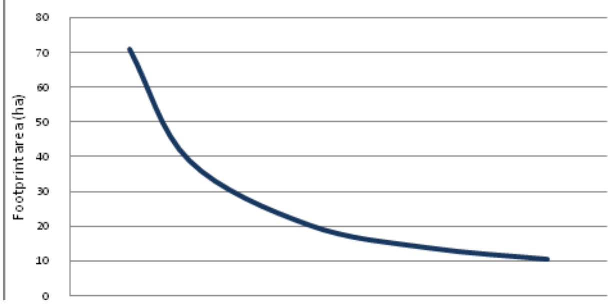

Figure 1. Effect of salinity factor on size of pond

2. FACTORS AFFECTING EVAPORATION

Apart from salinity, there are several other factors which have an influence on the rate of evaporation.

Climatic Effects

Evaporation occurs when water is supplied with sufficient energy to change it from liquid to vapour and removing this moist air to allow the process to continue. The climatic factors effecting the rate of evaporation include:

- Temperature – heating the water molecules to the required temperature,
- Humidity – if the humidity levels are high, less evaporation would occur,
- Solar radiation – providing heat to enable evaporation,
- Wind – to blow away the saturated air in order to allow for further evaporation to occur.

Properties of Liquid Being Disposed

In this study, we will be considering a concentrated brine solution. The factors related to the brine which will have an impact on the evaporation rate include:

- Concentration of brine – The greater the TDS, the lower the evaporation rate,
- Composition of brine – The type of salt dissolved will have an effect on the humidity at which evaporation will stop, for example for a water body saturated with sodium chloride, there will be no evaporation during periods where the humidity is above 70 %, with other salts, evaporation may cease at lower evaporation rates. (Leaney & Christen, 2000)
- Salt precipitates – This will have a greater effect on shallow dams.
- Rate of disposal – The brine concentrates with time due to evaporation. The rate of disposal results in a dilution effect.

The Oasis Effect

The main effect on the evaporation for areas of similar climates is the size of the water body. The evaporation rate from a water body is reduced from a maximum value for small water bodies, as determined for a standard evaporation pan, to a fraction of that value for larger bodies. (Leaney & Christen, 2000). This fraction is often referred to as the pan factor.

The following equation can be used for determining the pan factor:

$$F_{pan} = 1 - 0.029 \ln A$$

3. INFORMATION AVAILABLE

Salinity Factors

A literature survey was carried out to determine whether salinity factors are available for these types of brines. Due to complex interactions amoung site specific parameters such as air temperature, wind speed, humidity, pressure, solar absorption, reflect, thermal currents and depth of pond, a direct correlation between salinity and evaporation has not been found. (Mickley, Membrane concentrate disposal: Practices and regulation, 2001).

(Leaney & Christen, 2000) found that evaporation decreases exponentially with increasing salinity. The following equation can be used for determining the evaporation factor:

$$F = 1.025 - 0.0246 * \mathrm{Exp}(0.00879 * S)$$

Where: S = salinity level (g/ℓ)

(Ahmed, Shayya, Hoey, Mahendran, Morris, & Al-Handaly, 2000) cited a paper by (USDI, 1970) stating that brine evaporation to that of distilled water decreased by 1 % for each increase of 0.01 specific gravity.

(Kokya & Kokya, 2006) carried observed evaporation rates on various saline solutions and compared this against evaporation rates calculated using theoretical equations. The results obtained for observed evaporation rates from pans as part of the study is presented in Table 1. A reduction in evaporation rate of approximately 0.94 times that of fresh water for was observed for sea water at a TDS of approximately 40 g/ℓ.

Table 1. Results obtained by (Kokya & Kokya, 2006) on evaporation rates from pans

Day	Observed Evaporation (mm)				
	Fresh Water (TDS = 0.2 g/ℓ)	Ocean Water (TDS = 40 g/ℓ)	Semi Saline Water (TDS = 80 g/ℓ)	Salt Water (TDS = 160 g/ℓ)	Urmia Lake Water (TDS = 350 g/ℓ)
1	6.5	6.0	5.2	4.7	3.1
2	7.6	7.1	6.0	5.0	4.0
3	7.2	6.8	5.4	4.1	3.4
4	7.2	6.9	6.0	4.8	3.9
5	6.5	6.1	5.8	5.5	4.4
6	7.5	7.0	6.3	5.2	4.5
7	6.3	5.9	5.1	4.0	3.1
8	8.0	7.4	6.3	5.8	5.2

(Sartori, 2000) observed that for average sea water (salinity up to 3.5 %), the reduction in evaporation rate as the result of the salt concentration is equivalent to the salt concentration, i.e. reduction in evaporation of 3.5 % for a 35 g/l salt solution.

Typical Brine Solutions

Data has been obtained from the eMalahleni Water Reclamation Plant, a pilot-scale water treatment facility for coal mine water in the Hendrina area and brine produced on bench scale testing of water from an old mine in the Newcastle area. Refer to Figure 2 for an indication on the composition of the different brine sources being investigated.

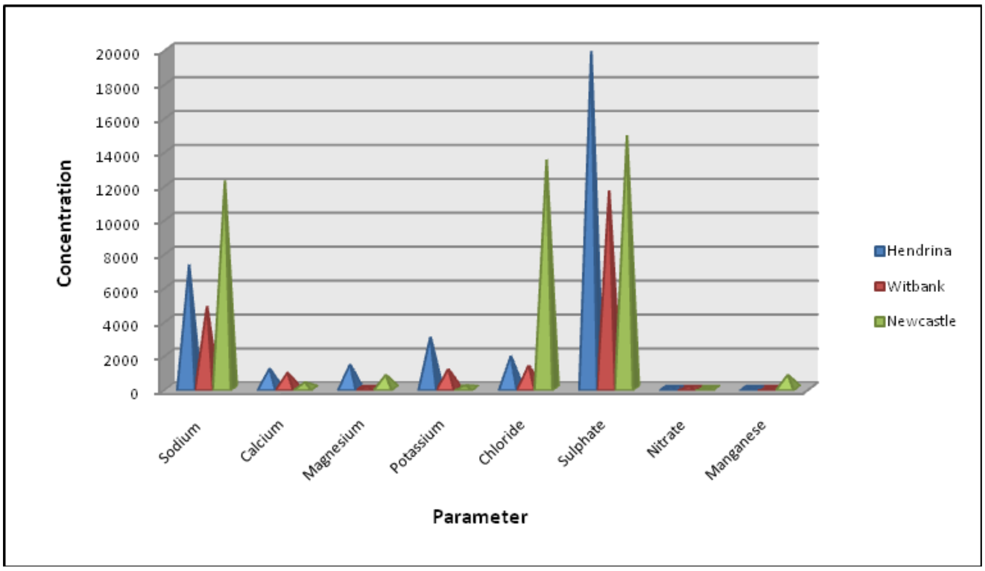

Figure 2. Composition of brine from the treatment of various coal mines.

4. FIELD INVESTIGATIONS

Field investigations will be set-up at the Golder Offices and at the eMalahleni Water Reclamation Facility. A weather station with data logger will be set-up at each site. The evaporation pans at the Golder Offices will contain the following:

- Pan 1 – blank sample – municipal water,
- Pan 2 – standard eMalahleni Brine – based on brine produced at the plant,
- Pan 3 – standard Hendrina Brine – based on brine sample from pilot testing,
- Pan 4 – standard Newcastle Brine – based on brine sample from bench-scale testing.

The evaporation pans at the reclamation plant will contain the following:

- Pan 1 – blank sample – treated water,
- Pan 2 – standard eMalahleni brine,
- Pan 3 – actual eMalahleni brine.

The standard solutions will be made-up as presented in Table 2. These are based on the results obtained from the brine analyses presented in Figure 2. A decision was made to use standard solutions due to the difficulties associated with assuring a constant supply of brine for the duration of the investigation. By using standard solutions, we are able to keep the concentration of the brine constant.

Table 2. Mass of salts added for standard solutions

Salt	**Salt Added (g)**		
	eMalahleni	**Hendrina**	**Newcastle**
Sodium Sulphate	14.204	18.457	14.204
Calcium sulphate	3.145	3.989	1.225
Potassium Chloride	2.177	5.218	0.373
Magnesium Sulphate	0.325	7.041	3.972
Sodium Nitrate	0.136	0.425	0
Sodium Chloride	0.584	2.922	21.917

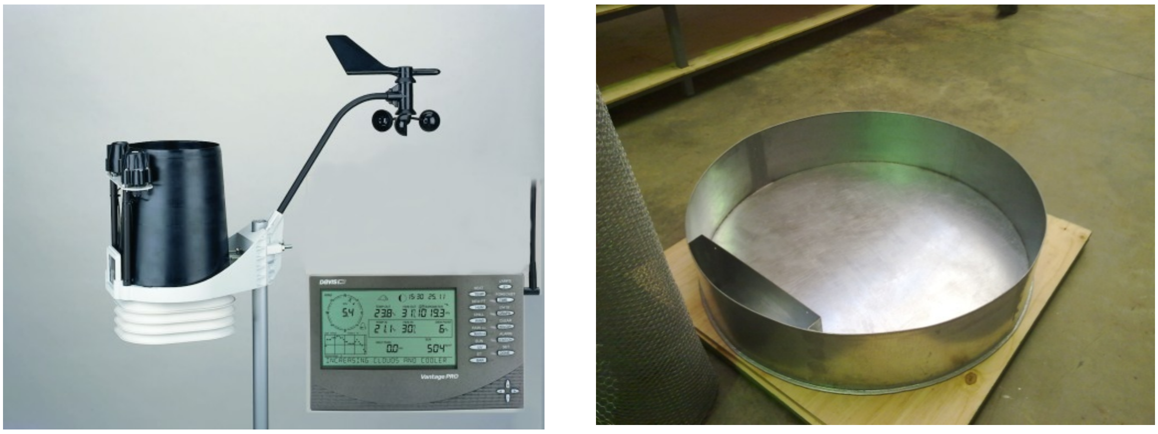

Figure 3. Weather station and evaporation pan which will be used for the investigations

The following information with be recorded:

- Hourly climate data
- Daily levels (Monday to Friday) in the evaporation pans.
- Daily conductivity and temperature readings
- TDS:
    - Standard solution
    - Before top-up – the evaporation pan will need to be topped up on a regular basis.
    - After top-up
- Actual levels in brine pond at the reclamation plant.

5. CONCLUSIONS

Microsoft excel will be used for the data analyse. Correlations will be drawn between the observed evaporation rate of the blank samples and the evaporation rate of the brines. The effects of wind speed, temperature and humidity on the evaporation in the different pans will be analysed.

Information obtained from the field studies at the eMalahleni water treatment plant will be used to draw correlations between the evaporation rate in standard solutions and the actual brine. Note that the actual brine would have traces of other salts as well as traces of anti-scalents used prior to the RO process. The observed rate of evaporation in the pan will also be compared to the observed rate of evaporation in the evaporation pond.

6. ACKNOWLEDGEMENTS

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