Concentration and desalination of industrial effluents with membrane distillation

by S Muhammad Suhail Osman and Prof Japie Schoeman

Industry generates large quantities of saline aqueous effluent and brine that need to be disposed of in such a way as to prevent the pollution of the environment. For landlocked plants, a serious challenge is posed, as ocean disposal of brine is not readily available.

Effluent disposal options for inland industries include brine disposal into lined and unlined evaporation ponds, the treatment of effluent with membrane technologies, such as reverse osmosis (RO) and electrodialysis reversal (EDR), the treatment of brine with mechanical evaporation technologies and deep-well injection.

Brine disposal to evaporation ponds holds the danger of ground and surface water pollution. Treatment of effluent with RO and EDR generates large quantities of brine. This brine is a potential water and chemical source. Mechanical evaporation technologies for brine treatment are very expensive and scaling is a big problem. Deep-well injection is an attractive technology for brine disposal, but is not practised in South Africa.

Membrane distillation (MD) is an alternative technology that has potential for brine treatment for water and chemical recovery. This technology makes use of hydrophobic microporous membranes, which are claimed to be fairly well resistant to membrane fouling or scaling. Water and chemicals can be extracted from brine with high water recoveries without serious fouling or scaling of the membranes. The driving force for this process is a temperature difference across the membrane for the concentration and desalination of brine. This process uses lower pressures than RO, lower temperatures than distillation processes and membranes with less demanding properties as required by RO. Salt rejections of more than 99% are possible. A further advantage of this process is that it should be possible to apply waste heat from industry to drive this process. This will have economic advantages.

However, very little information is available in South Africa regarding the use of MD for brine treatment, and research concluded in the University of Pretoria's Department of Chemical Engineering was aimed at evaluating this technology for brine treatment for effluent volume reduction and water recovery.

The main objectives of this study were to evaluate MD for the concentration and desalination of salt solutions and industrial brines for effluent volume reduction and water recovery for reuse. The industrial effluents selected for the study included petrochemical effluent, EDR brine, RO brine and ion exchange (IX) spent regenerant. The specific objectives of the study were to determine the effect of temperature, concentration and flow rate on process performance for the concentration and desalination of salt and industrial brines, to develop a theoretical model that could be used to predict permeate flux, and to determine the fouling or scaling potential of the effluents for the membranes and investigate membrane cleaning methods.

It was found that sodium chloride feed solutions could be successfully concentrated by reducing their volumes. Salt rejections of greater than 99% and water recoveries up to 79% could be obtained. Little or no decline in permeate flux was experienced, showing that membrane fouling or scaling should not be a serious problem. An increase in feed water temperature increases the permeate flux, while an increase in the sodium chloride feed solution concentration results in a decrease in the permeate flux, as well as a decrease in temperature polarisation effects. An increase to the feed flow rates increases the permeate flux, but to a lesser degree than the increase in feed temperature. An increase in the permeate flow rates also increases the permeate flux, but to a lesser degree than the increase in feed temperature. The fouling or scaling potential of the salt solutions for the membranes appears to be negligible. An excellent

quality permeate could be produced, which would be suitable for boiler feed make-up.

The model that was developed agreed relatively well with the experimental data. The transition flow model was found to be the most suitable predictive model, as it best described the permeate flux of the system. The model shows that an increase in feed flow rate, permeate flow rate and feed inlet concentration leads to an improvement in the temperature polarisation coefficient (TPC). It is also evident from the model that the TPC becomes more significant as the feed inlet temperature increases. The model further confirms that as the feed inlet temperature, feed inlet flow rate and permeate inlet flow rate increase, so the heat flux also increases. However, as the concentration increases, the heat flux decreases. This decrease is fairly negligible and can be considered constant. The effect that the tortuosity factor (τ) plays on the permeate flux is very important, as it determines the mass transport mechanism. The larger the value of the tortuosity factor, the lower the permeate flux.

An increase in the feed temperature to the membrane increases the permeate flux in the case of the petrochemical effluent. The permeate quality produced from the brines should be suitable for boiler feed make-up. The fouling or scaling potential of all four industrial brines for the membranes, except the IX brine, was not found to be very serious. The permeate flux remained almost the same for three consecutive runs for the petrochemical effluent. Permeate flux, however, declined with time, but the permeate flux could be restored with a water rinse. The clean water flux (CWF) at the end of the runs was slightly less than the CWF on the clean membrane surface.

In the case of the EDR brine, the permeate flux decrease was more or less the same for three consecutive runs, but declined somewhat with time. The CWF was approximately 17% lower after the runs. However, cleaning of the membranes with acid solution almost restored the flux.

The permeate flux also remained more or less constant for three consecutive runs in the case of the tubular reverse osmosis (TRO) brine, but also decreased with time. The CWF was approximately 14% lower after the runs. Acid cleaning could not restore flux. However, cleaning of the membranes with a salt or caustic solution almost restored the flux. The permeate flux of the spent IX regenerant also remained more or less the same for three consecutive runs. Permeate flux, however, declined with time. Water rinsings between the runs apparently restored the flux. However, the CWF flux was approximately 21% lower after the runs and it was not possible to restore the CWF after cleaning the membranes with hydrochloric acid, sodium chloride or caustic, citric acid or EDTA cleaning solutions. The average CWF had decreased by about 15%. Therefore, fouling or scaling of the membranes took place.

Crystals were detected in the MD brine when the EDR and TRO brines were used as feed. Calcium sulphate hydrate crystals formed in the case of the EDR brine. A mixture of sodium sulphate, calcium carbonate and glauberite formed when the TRO brine was treated. No solids were observed in the feed tank when the petrochemical effluent and IX brine were used as feed.

The experimental studies showed that membrane distillation has the potential to concentrate and desalinate industrial brines effectively. It appears that membrane fouling or scaling should not be a problem with the limited amount of runs conducted on the TRO and EDR brines. However, more serious membrane fouling or scaling was observed in the case of the spent IX regenerant brine. Therefore, longer runs should be conducted to work out a membrane cleaning strategy for fouled or scaled membranes.

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The industrial effluents (petrochemical, EDR, TRO and IX brines) could be successfully concentrated and desalinated with MD. The salt rejections, water recoveries and permeate conductivities were as follows:

Effluent	Water recovery (%)	Salt rejection (%)	Permeate quality (µS/cm)
Petrochemical effluent	84	99.77	127.2
EDR	75	99.70	119.2
TRO	78	99.66	120.3
IX	68	N/A	131.4