Realistically predicting separation behaviour of RO membranes

In this edited white paper, Uli Dölchow, Julien Ogier and Jens Lipnizki from chemical technology specialist, LANXESS, strive to better characterise the performance of reverse osmosis (RO) membranes.

Using appropriate design software to simulate the performance of RO elements in advance of practical implementation at a plant is common practice and generally useful. The actual operational performance of RO elements, however, depends on a whole range of different parameters, such as the temperature, pH and salt concentration of the water to be filtered. While these are taken into account by design programs, the calculations are based on pre-defined performance parameters such as permeate flow and salt rejection, which are determined under standard test conditions.

These standard conditions are defined according to product classes, which might include: standard brackish water elements, low-pressure elements or other similar groups. The outlined test conditions generally define values for the operating temperature, pH, inflow pressure, recovery and the concentration of table salt (NaCl) in the feed water.

Natural water sources and industrial and municipal wastewater, however, generally contain a variety of salts and substances, which creates greater complexity. When considering natural water sources, which by their nature have a very diverse composition, operating conditions can have a huge impact on rejection from RO elements and the substances that remain dissolved in the water. The NaCl rejection figure given on data sheets cannot, therefore, be seen as a definitive value.

In addition, practical operating conditions also frequently differ from standard test conditions, primarily in terms of temperature and pH.

In this investigation, multi-component inflow water containing a variety of common substances was used, the goal being to apply statistical methods to examine the impact of temperatures and the pH on the permeate flux and the rejection of various dissolved substances. The original intention was to identify a new way of characterising membrane performance, but these results also offer a valuable contribution to optimising future engineering simulation software.

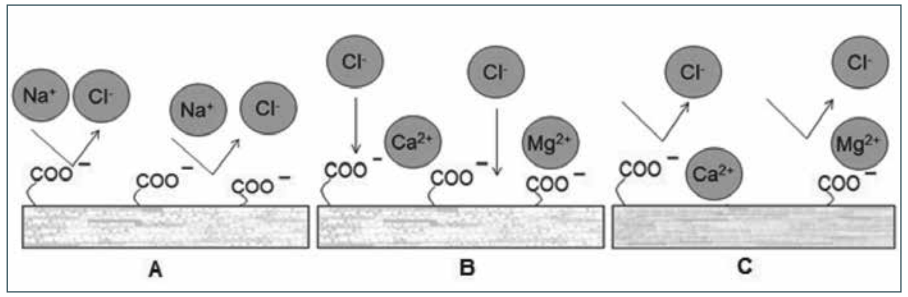

Figure 1: Surface effects and rejection. A: rejection of sodium chloride through electrostatic interactions with an open RO membrane. B: reduction in rejection caused by polarisation effects with an open RO membrane. C: consistent rejection with a sealed RO membrane with few electrostatic interactions.

Surface effects, most notably, membrane charge, also play a role in relation to the analysis of rejection results, as they have a significant impact on salt rejection. Test results were used as a basis for examining whether a relationship could be established between the different performance characteristics of various membranes and a range of membrane structures (Figure 1).

The surface charge is determined by varying degrees of crosslinking during the polymerisation of the polyamide coating. The two components TMC (trimesoyl chloride) and m-PDA (m-phenylenediamine) make up the polyamide, which contains the structural elements 1 and 2 (Figure 2). Depending on how the polymerisation process is controlled, the result is either a highly crosslinked RO membrane with less surface charge, or one with less crosslinking and a more pronounced negative surface charge.

Test procedure, material and methods

The tests were conducted using 4-inch low-pressure RO elements on an automated laboratory test bench. The test compared the performance of a highly crosslinked Lewabrane® membrane with that of a membrane that differs in only minor ways in terms of data sheet specifications. A test pressure of 10.3 bar and a recovery of 15% were used. The temperature was varied in the range of 15 to 35 °C, and the pH between 3 and 11. Compositions of the multi-component inflow water used in the tests are listed in Table 1.

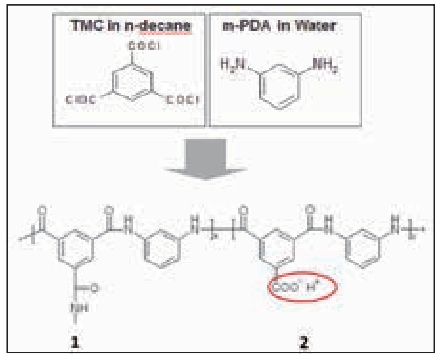

Figure 2: The polymerisation processes used for manufacturing RO membranes.

In each area of testing, test conditions were varied in line with the design of experiments. The substances used were selected for their relevance to various applications.

Design of experiments

The experiments were planned and conducted in line with the design of experiments (DoE) methodology, which offers advantages when examining the effect of two or more parameters (factors) on one particular target value.

DoE is based around the principle that the settings of the various different factors can be changed simultaneously, whereas conventional investigations change the value of only one factor at a time between test runs. In order to assess which factors impact the target value, regression analysis is used to fit a model function to the test results. In general terms, this means trying to describe the target value (y) as accurately as possible as a function of the factors (e.g. x_1, x_2) using a quadratic function.

In this investigation, the responses are the permeate flux, the TDS rejection and the rejection levels for nitrate, boron and silicon dioxide, while the factors are temperature and pH.

One of the major advantages of DoE is the opportunity to identify interactions. Where there is an interaction, the impact of one factor depends on the value at which the other is set. As soon as the model functions have been determined, they can be used to calculate membrane performance across the entire test range. The various correlations can then be illustrated via contour plots, for example.

Salt	Concentration	Application/source
Nitrate	200 mg/ℓ	Wastewater, drinking water
Ammonium	35 mg/ℓ	Wastewater, industrial applications
Boron	6 mg/ℓ	Groundwater, seawater
Silicon dioxide	75 mg/ℓ	Process water, groundwater
Sodium chloride	2 000 mg/ℓ	Standard components

Table 1: Information about multi-component inflow water.

Results

Figure 3 shows the permeate flux in the form of the flow rate per membrane area of the Lewabrane® membrane and the comparative membrane. The permeate flux of the membranes tested hardly differs at all. It is clear that the flux is heavily dependent on the temperature, and increases as the temperature rises. This increase in flux under exposure to higher temperatures can be explained by the reduction in water viscosity. It is also clear that the pH has no significant impact on the flux.

Figure 4 compares the rejection of the total dissolved solids in the water (TDS rejection) for the various membranes. It is clear from the contour plots that rejection in both membranes drops significantly at the extremes of the pH scale. This drop in rejection can be attributed to the dissociation of the various dissolved substances. The charge of the membranes is also important, and varies with the pH. It is evident that the Lewabrane® membrane exhibits excellent rejection across a larger range, and that the drop in rejection is less pronounced at higher and lower pH values.

Figure 5 shows the results for boron rejection. Typically, boron rejection does not pose a problem at high pH values. When the pH is high, boric acid is primarily present in ionised form, so the negatively charged membrane rejects it very efficiently. This is no longer the case when the pH falls below 9, however.

It is clear that the Lewabrane® membrane is able to maintain greater rejection at lower pH values. This behaviour can be attributed to the highly crosslinked and less charged membrane. The level of boron rejection is also influenced by temperature. Higher temperatures improve boron permeability, which leads to a slight reduction in boron rejection.

Just as with boron, nitrate rejection is also

Lewabrane RO elements consist of highly crosslinked, spiral-wound, thin-film composite membranes designed specifically for water treatment applications.

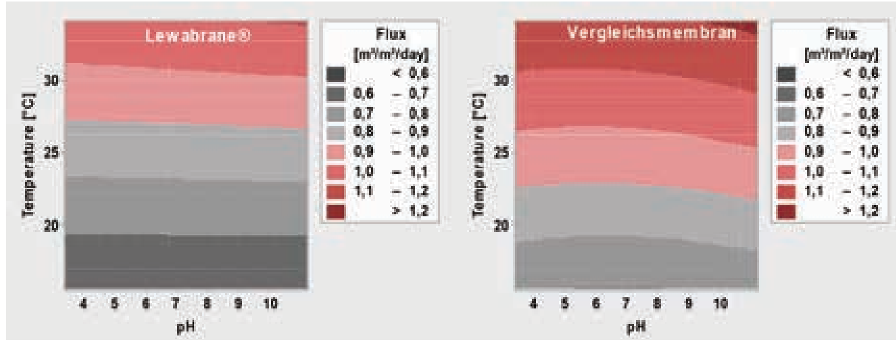

Figure 3: Flux in relation to pH value and temperature. Left: Lewabrane®. Right: comparative membrane.

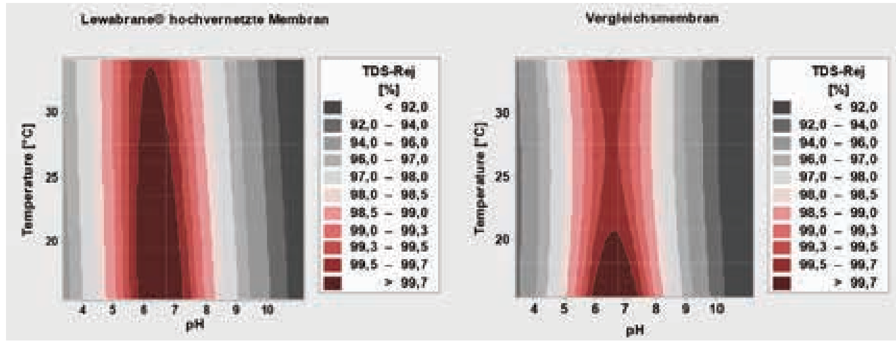

Figure 4: TDS rejection in relation to pH and temperature. Left: the highly crosslinked Lewabrane membrane. Right: A comparative membrane.

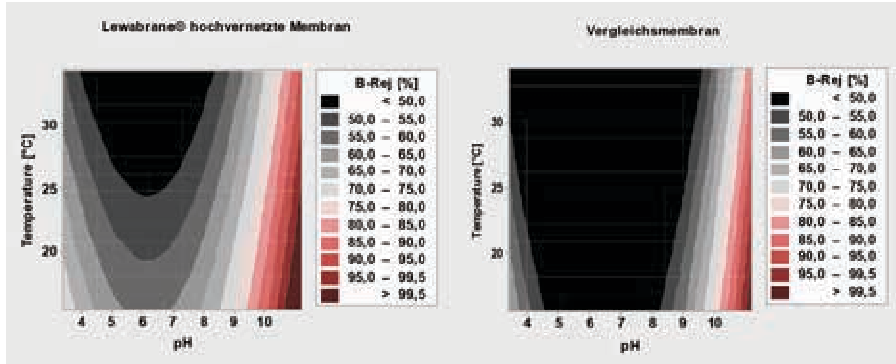

Figure 5: Boron rejection in relation to pH and temperature. Left: the highly crosslinked Lewabrane crosslinked membrane. Right: A comparative membrane.

important for the production of drinking water. Analysis shows that both RO membranes achieve outstanding nitrate rejection at pH values greater than 7, even though there is a very high nitrate concentration in the feed (NO^{3-} = 200 mg/ℓ, Figure 6).

At lower pH values, the membranes have a lower negative charge, and can even become positively charged when their isoelectric point is reached. This change in membrane charge affects nitrate rejection, as nitrates can pass through the membrane more easily at lower pH levels, leading to diminishing rejection. The reduction in nitrate rejection, however, is less pronounced in the Lewabrane® membrane. Furthermore, it is again clear that rejection falls as the temperature rises.

Silicon dioxide and silica rejection is important for treating boiler feed water. Removing silica can extend the service life of the ion exchanger, as less regeneration is required. Analysis of the silicon dioxide rejection (Figure 7) shows that rejection using the Lewabrane® membrane is higher, especially at mid-range pH values. Rejection is at least 99.2% across the entire test range.

These results can be seen as a further indication of the outstanding effectiveness of the highly crosslinked Lewabrane® membrane.

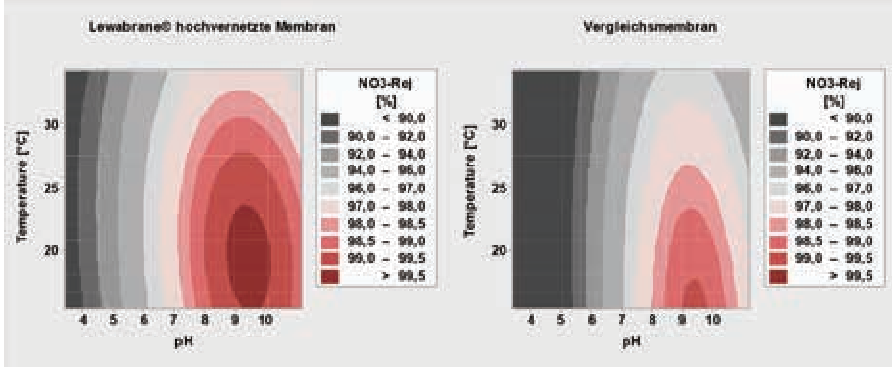

Figure 6: Nitrate rejection in relation to pH value and temperature. Left: the highly crosslinked Lewabrane membrane. Right: A comparative membrane.

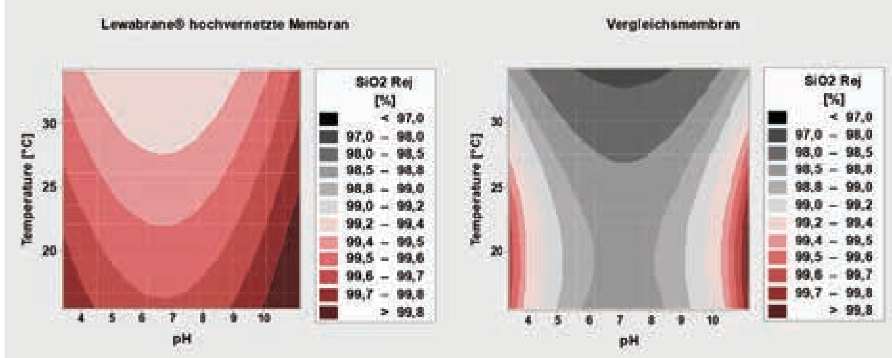

Figure 7: Silicon dioxide rejection in relation to pH and temperature. Left: the highly crosslinked Lewabrane membrane. Right: A comparative membrane.

Summary and outlook

Contour plots have been used to compare the performance of various membranes for a large range of potential application conditions and the rejection rates of different substances.

Different low-pressure RO membranes with similar specifications were shown to exhibit significant variations in rejection performance. An explanation for these differences could be differing levels of crosslinking in the membranes.

Ammonium rejection, however, could not be clearly described using the quadratic model. Experiments are currently being conducted to examine whether non-linear regression can describe this behaviour better.

Overall, using this statistical method to characterise membrane properties is an effective procedure for achieving a more complete picture under a variety of inflow parameters. The technique enables data sheets and test conditions to be adjusted to more realistically predict separation behaviour. ❑

Flat floor grating surface enhances plant safety

Not all floor gratings that claim to have a flat top surface actually do, but unfortunately this is something that is commonly misunderstood in the industry and often leads to specifiers and buyers using a product that will not meet the requisite parameters on a project. Grating made from flat bar (not slit strip) has a rounded or mill-edge, which explains the differentiation between 'true' and 'pretend' flat top surfaces.

Lance Quinlan, national technical sales consultant at Andrew Mentis, says the company is the only producer of floor grating that is able to supply a product that has a true flat top surface.

"This is a significant differentiator in the floor grating market and is something that should be factored in when making the decision to specify or purchase flat top floor grating. If it isn't, then specifiers and buyers are comparing apples with pears," Quinlan says.

He explains that Andrew Mentis, with its over 60 years of experience in the manufacture of floor grating products, has continued to invest in the correct equipment and infrastructure to be able to produce the most appropriate finish on its range of floor gratings. Having the best-in-class manufacturing facility coupled with an in-depth knowledge of floor grating applications has enabled the company to stay abreast of international trends and offer the African market world-class floor grating products.

"We are the only facility that purchases coiled steel and makes use of our own slitting process, which is engineered to produce a truly flat top surface," Quinlan says. "What is important is that our Mentis Flat Top floor grating has a non-slip surface as a result of this manufacturing process and this significantly enhances the safety of our product."

This highly engineered floor grating product is produced at Andrew Mentis' ISO-accredited facility at Elandsfontein, Johannesburg, and is manufactured using a pressure locking system pioneered by the company. This guarantees the structural integrity of the product and further enhances its integrity. The transversals on the floor grating are positively and permanently locked to the bearer bars and the locking method at the intersections is designed to use the full depth of the bearer bar when calculating loads. ❑

Andrew Mentis' floor grating has a true flat top surface, making it ideal for providing access to the mixers and aerators above water treatment ponds.