DOW FILMTEC™ Membranes
How to Calculate Your Bromide Rejection Levels

Despite the high bromide rejection attained by DOW FILMTEC™ Reverse Osmosis membranes, bromate formation might still take place in the final product water as a result of the post-treatment (chlorination). A proper estimation of the bromide passage through Reverse Osmosis membranes is then key for the design of any desalination plant to ensure that the concentration in the final permeate does not exceed the World Health Organization (WHO) recommended values. Based on the results of 40 water sample campaigns done on several desalination plants operated with DOW FILMTEC™ elements, the bromide passage is 15% higher than the chloride passage. This Tech Fact bulletin will discuss:

- Why bromide rejection matters
- How to calculate permeate bromide levels

Why Bromide Rejection Matters

Small quantities of bromide are present in natural sea waters. Its concentration is usually in the range between 60 and 90 mg/L in most seawaters and it is often less than 0.1 mg/L in reverse osmosis permeate water. This water is then chlorinated to reduce the risk of pathogenic infection and to provide microbiologically safe water for human consumption. While chlorination has provided substantial public health benefits by controlling infectious diseases, it is responsible for the conversion of bromide into bromate (BrO_3^-), which is a suspect carcinogen. Bromate formation is common if water with bromide is ozonated. This problem is less significant with chlorination, but still a concern.

Drinking water standards or guidelines for bromate are very low due to its potential carcinogenic properties. A maximum contaminant level of 10 µg/l has been promulgated by the US EPA (1998) and the "guidelines for drinking-water quality of the World Health Organization (3rd Edition, 2008) were recently modified from 25 µg/L to 10 µg/L.

As a rough orientation, bromide concentrations of 0.1 to 1.0 mg/L should be expected in most permeates of sea water desalination plants operated with FILMTEC™ membranes. Based on a molecular weight ratio of bromate (BrO_3^-) to bromide (Br^-) of 128/80 or 1.6 and a full conversion of bromate to bromide, the maximum expected concentration of bromate in RO product water would be in the range of about 1.6 mg/L. This value is much higher than the limits of the EPA and the WHO and hence, care needs to be taken to avoid the formation of bromate in the post-treatment and bromide to bromate conversion rates of below 1% should be targeted.

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Calculating Permeate Bromide Levels

Use the following approach to calculate bromide concentration in the permeate:

1. Perform ROSA projections with feed water under planned operation conditions
2. Calculate permeate bromide with by using the following formula:

$$Bromide_{permeate} = f_{BrCl} * Bromide_{feed} * \frac{Cl_{permeate}}{Cl_{feed}}$$

Where the bromide concentration in the permeate can be calculated as the product between a bromide/chloride factor (f_{BrCl}), the bromide concentration in the feed and the ration between the chloride concentration in the permeate and the chloride concentration in the feed. According to Equation 1, once f_{BrCl} is known, the bromide content in the permeate can be easily calculated from the feed water analysis and the chloride content in the permeate (predicted value). In order to obtain a reliable f_{BrCl} value, more than 40 water samples campaigns (including feed, permeate and brine) from different Seawater Reverse Osmosis desalination plants of several geographies (Australia, Middle East and Europe) have been undertaken since 2007.

All the samples evaluated corresponded to single pass installations operated with DOW™ FILMTEC™ SW30HRLE-400i membranes (50% of the samples) and SW30XLE-400 (10% of the samples). The remaining installations corresponded to Internally Staged Designs (iSD), where different type of FILMTEC™ membranes are combined to optimize the hydraulics inside the vessel and thus decreasing the operating expenses. Samples from second pass permeate were also initially evaluated, but not considered in the evaluation because the Bromide levels were too close to the Limit of Quantification (LOQ) of the analytical technique. Chloride and Bromide concentrations were analyzed in laboratories owned by Dow as well as in external laboratories to attain higher reproducibility of the results. The methods followed for the determination of chloride and bromide concentrations were:

- DOW: Ion Chromatograph IC850 Metrohm AG (Herisau, Switzerland) for both parameters. Limits of detection are 1.7 mg L^{-1} for chlorides and 0.1 mg L^{-1} for bromides.
- External Laboratory A: Ion Chromatography DIONEX ICS2000 (Sunnyvale, CA, United States) for both parameters with limits of detection of 1.7 mg L^{-1} for chlorides and 0.3 mg L^{-1} for bromides.
- External Laboratory B: Titration (SM 4500) Thermo Aquakem 600 (Schönenbuch Switzerland) for chlorides. and ion chromatography DIONEX ICS2000 (Sunnyvale, CA, United States) for bromides. Limits of detection are 0.2 mg L^{-1} for chlorides and 0.05 mg L^{-1} for bromides.

The result of this evaluation indicates that the bromide salt passage through DOW FIMTEC™ Reverse Osmosis membranes is on average 15% higher than the chloride passage and thus f_{BrCl} equals 1.15.

Conclusion

The bromide and chloride passage through DOW FILMTEC™ Reverse Osmosis membranes has been monitored in various desalination plants from different geographies. The results suggest that the ratio between bromide and chloride passage is 1.15 and thus the bromide content in the permeate can be predicted using the following equation, taking into account that the chloride concentration in the permeate should be previously assessed using ROSA software:

$$Bromide_{permeate} = 1.15 * Bromide_{feed} * \frac{Cl_{permeate}}{Cl_{feed}}$$

Assuming a full conversion of bromide into bromate and taking into account the limits established by the US EPA and the WHO, the design of the Reverse Osmosis Seawater installation should be done so that the bromide in the permeate is approximately 5 µg/L. Advances in membrane technology will not be able to achieve the drastic improvement needed to reach such low bromide concentrations. Hence, care needs to be taken to avoid the formation of bromate in the post-treatment and bromide to bromate conversion rates of below 1% should be targeted.

DOW FILMTEC™ Membranes
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