Industrial Wastewater Recycling and Energy Conservation using High Temperature RO Membranes

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Abstract

Limitations on the use of RO membranes for industrial wastewater reclamation are well known. A well-established limitation is the maximum temperature to which RO elements can be exposed. Typical RO elements cannot be exposed to temperatures above 45°C. In response to this limitation, alternative elements have been developed to allow for operation at higher temperatures. This paper will review the development and use of high-temperature RO membranes in various applications, including laundry wastewater reclamation.

Keywords: reverse osmosis, laundry wastewater, reclamation, high temperature

Introduction

The standard RO spiral wound element is used in numerous separation applications ranging from reclamation of municipal wastewaters to desalination of seawater. Because these elements are constructed of plastic materials, they come with specific limitations on feed water quality, pH, pressure, and temperature. Specifically, the standard spiral element is limited to a maximum temperature of 45°C. For the most part, this temperature limitation has restricted the direct use of RO for treating some high-temperature streams such as:

1. hot condensate
2. boiler-water blow down
3. laundry
4. annealing baths
5. high-temperature mining wastewater
6. produced water in the oil and gas industry

Exceeding the 45°C limit of the RO element may not necessarily cause immediate, catastrophic failure of the element. However, some specific components of the element undergo a physical change at a high temperature which will adversely affect performance. Specifically, the polyamide chemistry of the RO membranes undergoes a permanent annealing process as temperature exceeds 45°C. The change leads to lower flow through the membrane, which results in greater feed pressures to maintain flow from the RO system.

Another plastic component of the element that is affected by high temperatures is the permeate carrier. The permeate carrier is a plastic sheet inserted between the membrane leaves on the back side, or permeate side, of the membrane. The permeate carrier sheet is comprised of parallel channels which direct the permeated water toward the central permeate core tube and out of the element. These channels are less than a millimeter in width. When temperature exceeds 45°C, the permeate carrier loses rigidity. When pressure is applied, the permeate channels will then collapse, restricting the flow of water. It is because of the potential collapse of the permeate channel that temperature limitations are coupled with pressure limitations. At a max temperature of 45°C, the element is limited to a max pressure of 70 bar (1000 psi). At lower temperature, the max pressure can be increased such that an element can withstand 1200 psi when temperature is reduced to 10°C.

Another component of the spiral element affected by the temperature/pressure is the permeate core tube. The core tube, around which the membrane leaves are spiraled, receives the permeate coming from the membrane leaves. The external portion of the permeate tube is exposed to the high feed pressure; while the internal portion of the tube is exposed to the lower permeate pressure. Exceeding the pressure temperature limit of the permeate core tube will cause catastrophic collapse. The pressure limits of the permeate core tube are a function of temperature. As temperatures increases, the pressure limit of the core tube decreases.

Despite these limitations, specific applications, in use for many years, expose spiral elements to temperature up to 95°C. But exposer to these high temperatures is done at very low pressures.

For example, commercially available sanitary elements used in the pharmaceutical industry are regularly flushed and sanitized at temperatures up to 95°C. The high temperature sanitization is done for several hours when the system is taken offline and pressures are reduced to less than 60 psi. Though the membrane used in these elements is modified to prevent the annealing of the chemistry mentioned earlier, the challenge of permeate spacer compaction remains and prevents running above 45°C at normal operating conditions when feed pressures exceed 60 psi.

Laboratory Testing and Characterization

In an effort to better understand these behaviors of the spiral element at high temperatures and pressures, two specially designed RO units were constructed of stainless steel and insulated piping. One unit allows for the testing of the standard 8-inch diameter spiral element at temperatures up to 65°C and pressures up to 600 psi. A second unit can test the smaller, 4-inch diameter elements at higher temperatures up to 95°C and high pressures up to 1000 psi. Using both laboratory RO units, new materials and new element constructions were developed and demonstrated to mitigate the effect of operating at high temperature and high pressure.

Specifically, Figure 1 below shows the results of a long term stability test while operating at high temperature and pressure on the larger, 8 inch elements. This test was run continuously for 900 hours (37 days) on 12,000 ppm NaCl feed water at 65°C and 435 psi (3.0 Mpa). During this run, the elements showed an initial permeate flow loss of 40% within the first 10 days, followed by stable flux for the remainder of the test. Inversely, the salt rejection started lower at 99.5% rejection and then increased to 99.7%, where it stabilized. It is important to note that this increase in rejection serves to cancel the decrease in rejection associated with increasing temperatures. As temperature increases, the membrane opens and allows more salt to pass. This effect is true to a point. As the membrane is exposed to higher temperatures and higher pressure, the annealing effect serves to tighten the membrane, thus canceling the temperature tendency to open the membrane. Based on this type of data and numerous other data sets generated from running the two laboratory ROs, the design of a high temperature RO system can accurately account for this change in performance as a function of temperature and pressure.

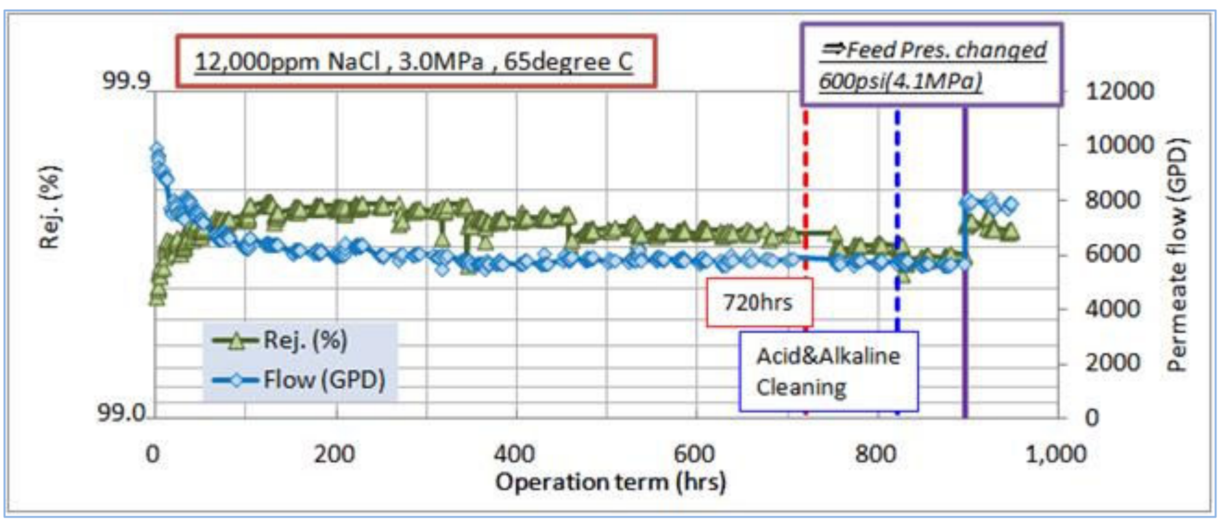

Figure 1: Effect on salt rejection and flow of single, high temperature, element running at 65°C and 400-600 psi for 37 days

System Experience

One industry that benefits from the use of high temperature membranes is found in mining. A pilot study was conducted for the reclamation of 50°C mine waste while rejecting a 500 MW organic contaminant. The pilot used ceramic MF membrane pretreatment to remove the 18,000 ppm of suspended solids followed by high temperature nanofiltration and RO membranes treating 10,000 ppm of total dissolved solids. The membranes operated successfully for 37 days at a recovery of 85% and a flux of 10 gfd. The use of nanofiltration membranes kept the feed pressure low, as only 200 psi, which meant that the resulting flux loss was only 7% (de la Cruz, 2015).

Another area that could potentially benefit from high temperature RO is found in the Oil and Gas Industry. Specifically, enhanced oil recovery (EOR) can require the use of large volumes of water that are injected into the oil formation to increase the productivity of the oil wells. Using steam assisted gravity drainage (SAGD), the water is first converted to steam before injection. The produced water that returns to the surface along with the oil is highly contaminated and, in the case of SAGD, is elevated to temperatures as high as 85°C. Often, this produced water is disposed through deep well injection. Due to limited water supplies and increasing regulations, it is becoming more economical to treat and reuse this produced water. In the case of SAGD, the produced water would first need to be cooled before treatment with RO and then reheated for injection. However, the use of high temperature RO would element the cooling and reheating steps. A three month pilot study, conducted in late 2013 using high temperature elements for treating 85°C produced water, has demonstrated the stable performance of these elements for this application. The elements were run in a two pass configuration to produce water for boiler feed make up. Thanks to extensive pretreatment, which included electrocoagulation, ceramic UF, and hardness removal, the RO elements were able to operate stably, without cleanings, while reducing conductivity from 2600 us/com in the feed, down to 210 us/cm in the permeate. (Daza, 2016).

Another application that benefits from the use of high temperature RO is found in industrial laundries. Industrial laundries include hospitality laundries which handle linens and clothing from hotels and restaurants. Industrial laundries may also specialize in medical laundry from hospitals or uniform laundries, which deal with garments used for janitorial, automotive, petroleum and other industries associated with highly soiled garments. Subtle differences in the processing of different types of laundry lead to differences in the wastewater that must be treated. Regardless, reclamation systems treating industrial laundry wastewater will include some or all of the following components in the reclamation process:

1. Shaker screen if fine fibrous material is present.
2. Screen filter (150 microns).
3. MF for particulate removal.
4. Heat exchanger to reduce water temperature below 45°C.
5. Chemical injection (Anti-scalant, pH adjustment).
6. RO for reduction of dissolved solids.

The proper selection of each component is critical to ensure stable operation of the reclamation system. For example, the specific type of surfactant used may cause severe, irreversible fouling of a standard RO membrane.

Typical industrial laundries use 3 gallons per pound of laundry processed, depending on the type of washing equipment used and the type of soils being washed. Currently, plants that are treating wastewater for reuse are typically using MF or multi-media filtration, including sand or activated carbon filters. These methods remove particulates and suspended solids but do nothing to remove salts and other dissolved contaminants, which, in turn, limit the amount of laundry wastewater that can be reused. By failing to remove dissolved contaminants, the reuse water can have adverse effects on the laundry process, causing discoloration and also odors. Until recently, RO has not been considered a viable option to reduce dissolved solids in the reclaimed laundry wastewater due to the high fouling nature of the reclaimed wastewater. Furthermore, RO temperature limits require the use of heat exchangers to reduce the temperature of the reclaimed wastewater from 55°C to below 45°C. However, thanks to the use of advanced pretreatment as well as the development of the new high-temperature RO membranes, RO is successfully increasing the efficiency of laundry wastewater reclamation.

In laundries where standard RO elements are used, up to 80% of the wastewater can be reclaimed. This reduces the typical 3 gallons of water used per pound of laundry to only 0.6 gallons per pound of laundry. The use of standard RO elements means that heat exchangers must be used to reduce the laundry wastewater from a typical 55°C down to below 45°C. The reclaimed water must then be reheated, along with the incoming makeup water to be used in the laundry process.

When high temperature RO is used to reclaim the laundry wastewater, the heat exchangers can be eliminated, and less energy is required to reheat the water for the laundry process. Whereas normal energy consumption may be up to 6 therms (0.64 GJ) per 100 pounds of laundry, the use of high temperature RO reduces energy consumption in half to 3 therms (0.32 GJ) per 100 lbs of laundry. Depending on the specific laundry, the reclamation RO typically treats 50 gpm to 100 gpm of reclaimed water. As shown in Figure 2 below, the spiral elements are configured in a two-stage array with 4 elements per vessel.

Figure 2: Typical, high temperature RO for laundry waste reclamation

Several features of the system design ensure stable RO performance while treating the high fouling laundry waste under aggressive conditions.

- The RO operates with recirculation to achieve a high crossflow at a high recovery of 80%. This ensures contaminants do not build up in the feed channels of the spiral element.
- The RO also operates at a low flux of 10 gfd to minimize the transport of foulants to the membrane surface.
- Both high and low pH maintenance cleans are conducted on the RO every one to two weeks.
- The pretreatment to the RO includes ceramic microfilters with a pore size of 0.05 microns.

Figure 3 on the following page shows two months of operating data from a typical high temperature laundry reclamation system. The figure tracks the three key normalized parameters required for monitoring the health of an RO system: permeate flow, differential pressure (DP) and salt rejection. These parameters demonstrate how the design features of the reclamation system result in overall stable RO performance. Specifically, the normalized permeate flow, which monitors fouling on the membrane surface, remains stable at an average of 70 gpm over the two month period. During these two months, cleanings were conducted every two weeks. Between cleanings, the flow exhibits a gradual 5% to 19% decline, but the cleanings are effective at removing foulant from the membrane surface and recovering a majority of the flow. Similarly, normalized differential pressure (DP) is an indicator of the plugging of the feed/brine channel in the element. With MF preceding the RO, the feed/brine channels remain free of any particulates, and the differential pressure remains unchanged at 10 psi during the two-week cycles between cleanings. The stable DP indicates the effectiveness of the MF pretreatment at removing suspended solids. The RO in this system also successfully achieves the desired stable salt rejections, despite operation at high temperature. The annealing and compaction of the membrane offset the opening of the membrane at high temperatures, thus providing a high-quality permeate. In this specific system, the feed salinity of 3000 to 4000 mg/L TDS was successfully reduced to less than 50 mg/L. Based on a feed/brine average salinity, this is a reduction of 99.5% at 55°C.

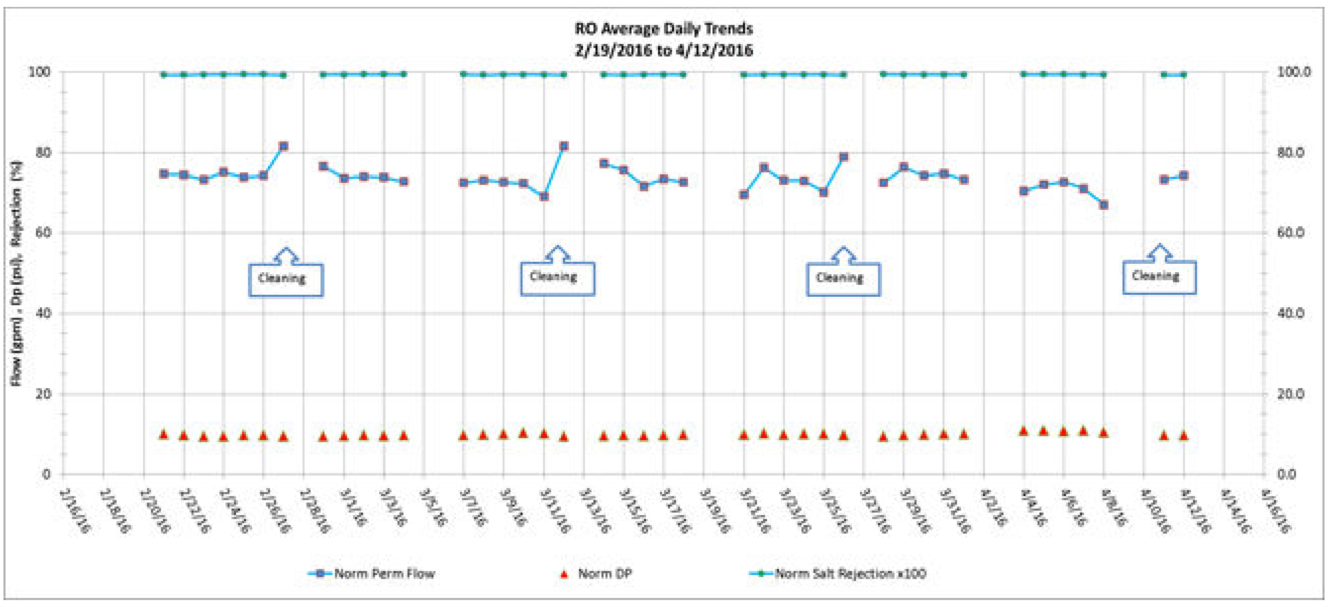

Figure 3: Normalized operating data from a typical, high-temperature laundry RO

Conclusion

A well-established limitation for conventional RO elements is the maximum temperature limitation of 45°C. This limitation stems from the RO membrane chemistry as well as the materials of construction used in the RO element. In response to this limitation, alternative elements have been developed to allow for operation at higher temperatures. These elements have been tested on such applications as the treatment of mining wastewater and the reclamation of produced water. Recently, these new elements have been used in the reclamation and reuse of high temperature, laundry wastewater. Specifically, about 80% of the wastewater from industrial laundry water can be reclaimed through a treatment processes that includes RO. The laundry waste is typically reclaimed at temperatures of 55°C and then cooled by heat exchangers to 35°C before treatment by conventional RO membranes. The use of high-temperature RO membranes allows for the heat exchangers to be removed from the treatment process and the 55°C wastewater to go directly to the RO membranes. These high-temperature membranes have been deployed in full-scale systems and have been treating laundry wastewater at temperatures of 45°C to 55°C for over three years. Reclaiming the wastewater at these sites eliminates the need to reheat the water before reuse in the laundry process. This reduces the plants' energy consumption by as much as 70%. Data from these plants shows that the RO tend to foul rapidly, and frequent cleanings are required. However, the cleanings are able to recover membrane performance. These RO systems continue to operate stably and produced a consistent, low TDS permeate for reuse in the laundry process.

References

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