High Recovery Reverse Osmosis Water Treatment for Industrial, Agricultural and Municipal Applications

A Consolidation and Review of ReFlex Reverse Osmosis featuring CCD Technology

Demand for water is high and global resources are limited. Reverse osmosis (RO) is an effective and widely-applied technology for water treatment and desalination, yet current RO systems waste both water and energy. This paper discusses how RO water treatment can be improved with closed circuit or semi-batch RO techniques. These new but proven processes increase water-use efficiency, reduce energy consumption, increase flexibility and reliability, and greatly reduce the emission of brine waste. Permeate recovery rates of over 97% can be achieved without multiple stages of membrane elements and without precipitation of sparingly soluble salts. High recovery, low energy, flexible performance is ideal for industrial water and effluent treatment, agricultural water supply, water reuse and inland brackish desalination. The author explains the theory behind this emerging technology and supports this analysis with case-study information from commercial closed-circuit RO systems that have been running for as long as 5 1/2 years.

Introduction

Industry accounts for nearly 60 percent of fresh water withdrawals in the developed world and agriculture consumes 70 percent of fresh water supplies globally, according to UNESCO. This puts tremendous stress on water resources and drives fundamental and increasing need for more efficient and cost-effective water supply and wastewater treatment solutions. Reverse osmosis (RO) is an effective and widely-applied technology for water treatment and desalination, yet current RO systems waste both water and energy. High recovery water treatment and effluent reuse are the only sustainable and cost effective solutions.

A new process is emerging that promises to improve nearly every aspect of RO performance. Compared to conventional RO systems, ReFlex RO which utilizes semi-batch or closed-circuit (CCD) RO provides:

- High adjustable recovery rates
- Independently adjustable cross-flow
- Resistance to and even reversal of fouling and scaling
- Less energy consumption
- Fewer membrane elements and pressure vessels

High recovery operation of ReFlex RO reduces concentrate production, source water pumping and pretreatment requirements. High cross-flow, reduced lead element flux, more even flux distribution and salinity cycling reduces the effects of fouling and scaling and the associated consumption of chemicals and membrane cleaning requirements.

Reduced energy consumption and smaller membrane arrays save cost. These improved features are particularly beneficial for industrial water and effluent treatment, agricultural water supply, water reuse and inland brackish desalination applications.

Process Description

CCD technology is based on principles employed by most non-RO filtration processes. All the water fed to the filters comes out in a product stream while contaminants are held back. Extra pressure is required to maintain steady product flow as contaminants accumulate, and periodically the system is flushed.

CCD RO systems remove salts from water in exactly the same way. Product flow is equal to the feed flow and the feed pressure requirement increases as salt is retained by the RO membranes. Periodically the system is flushed, reducing the pressure requirement and restoring the system to its initial state.

The CCD process for high-permeate-recovery operation is illustrated in the diagram below, with a single membrane pressure vessel representing multiple modules operating in parallel. A high pressure pump (HP) feeds a closed loop comprised of a single-stage of membrane elements and a circulation pump (CP).

Permeate is produced at a rate equal to the flow rate of the HP. Brine is recirculated without depressurization. When a desired recovery percentage is reached, brine is throttled out of the system, displaced by feedwater from the high-pressure pump in a single plug flow sweep. The exchange of brine and feed water is executed without stopping the high-pressure pump or the production of permeate. The process then returns to closed-circuit operation, during which there is no brine reject stream.

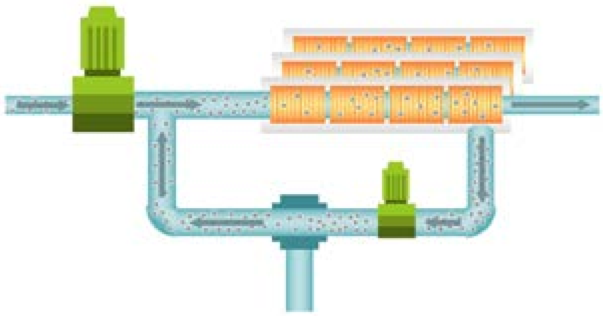

Figure 1. ReFlex RO/CCD technology Process Schematic Diagram

For lower-recovery, higher-pressure applications, such as seawater desalination, an alternative CCD process (ReFlex Max) is used to maximize energy savings. The ReFlex Max RO process displaces spent brine with pressurized feedwater from a side conduit. The exchange, emptying and refilling of the side chamber is done under hydrostatic conditions with almost no loss of pressure energy.

Design and Modeling

The performance of ReFlex RO systems can be predicted using standard membrane projection programs and basic engineering design tools. These models estimate the pressure requirements and permeate quality output of ReFlex RO systems in the same way they do for conventional RO systems. These models can also be used to study the performance of individual membrane elements in multi-element arrays. Multiple flows, recoveries and membrane configurations can be examined in the model to test the flexibility of alternative systems. The warnings generated by the projection programs identify operating limits. Specifically, this experimental modeling approach can give an indication of when lead membrane element flux is high, thereby predicting when these elements are at greatest risk of fouling. It can indicate when cross-flow is low, thereby identifying excess concentration polarization and the associated risk of fouling and scaling. It can also allow consideration of how feed composition and temperature changes affect system performance.

Discussion - Increased Recovery

The overall recovery rate in a CCD process is a function of the intrinsic volume of the system and the volume fed over the course of a sequence, the latter being flexible. Therefore recovery is flexible and can be set at the system control panel. Being able to achieve high recovery in a single stage is a novel capability with beneficial implications for system cost and design and operational simplicity. It is not necessary to use multiple stages or six to eight-element-long membrane arrays to achieve high recovery as is necessary in conventional RO processes. A high-recovery CCD process can be constructed with just one membrane element, for example. More typically, CCD membrane arrays consist of three or four elements, numbers which have been found to optimally balance performance and costs. CCD systems have achieved over 97% recovery whereas traditional RO systems typically operate at only 75% recovery. Modeling analysis shows that individual ReFlex RO systems can be designed to operate well, producing high quality permeate with low energy consumption, over a recovery range of 75 to 98% recovery. ReFlex Max RO systems offer even greater energy conservation and a larger recovery range, from 40 to 98%.

Energy Savings

The initial pressure requirement of each CCD sequence is proportional to the osmotic pressure of the feedwater and the maximum is proportional to the osmotic pressure of the final brine, the same pressure as the running pressure of a conventional RO stage. The resulting average membrane feed pressure in the CCD process is much lower than the feed pressure of typical RO systems. Lower feed pressure means lower pump energy requirements and tremendous energy savings. ReFlex RO systems also dramatically reduce energy loss to the brine reject stream by reducing its pressure prior to release.

As described above, ReFlex Max RO systems can desalinate seawater with 1.6 kWh/m3 energy, compared to 2 to 3 kWh/m3 with state-of-the-art conventional RO. Similarly significant savings are achieved with ReFlex RO systems in industrial water and effluent treatment applications, for which 35% reductions in energy consumption are typical.

Fouling and Scaling Resistance

Good resistance to fouling and scaling and high recovery operation are important in most brackish water desalination, industrial water treatment and water reuse applications. ReFlex RO systems provide new or enhanced means for addressing these challenges. Cross flow supplied by a circulation pump washes the membranes and reduces the effects of scaling and fouling. Although a CCD process can be operated at higher average flux rates than conventional RO processes, the more balanced flux distribution that is inherent with shorter membrane arrays limits the maximum flux and recovery experienced by each indiv idual membrane element. In particular, the flux through the first or head element in each membrane housing in a short membrane array is less than that in a long membrane array with the same average flux. This helps reduce head element fouling.

As the salinity throughout the CCD process cycles from that of the feedwater to that of the most concentrated brine, biofilm formation and scale precipitation are disrupted. Recovery rates of over 90% have been achieved and maintained from water sources with high concentrations of silica and calcium sulfate, producing brine concentrations of these constituents that are four times higher than can be sustained in conventional RO processes.

Simplified Design and Flexible Operations

In conventional RO plants, recovery, cross flow and flux are all supplied by the high-pressure pump and are interdependent. The CCD process decouples the basic variables of the RO equation, enabling independent manipulation of these functions. The resulting extreme operational flexibility allows the RO process designer and operator to cope with variations in feedwater quality and customer requirements, optimize process performance and minimize costs.

Cost and Footprint Reduction

High recovery operation means reduced feedwater pretreatment requirements, and this can reduce the cost and footprint of the installation. In the CCD process, two 4-membrane element arrays can be housed in a single center-port pressure vessel fed from both ends, with brine take-off from a center port.

This center-port configuration can result in fewer pressure vessels than are required for a comparable conventional RO process, reducing footprint. Also, because ReFlex RO systems can often be designed to operate at higher flux than conventional RO systems, fewer membrane elements can be required, further reducing footprint.

Conclusions

Reverse osmosis water treatment costs can be lowered by increasing water-use efficiency, reducing energy consumption and increasing flexibility and reliability. A new CCD configuration of standard RO equipment and membranes (ReFlex RO) can enable permeate recovery rates of over 97% without multiple stages of membrane elements and without precipitation of sparingly soluble salts. These systems can operate with 35% less energy than conventional RO systems by significantly reducing average feed pressure requirements and by eliminating or reducing brine pressure within the process prior to discharge without the use of energy recovery devices. Good resistance to fouling and scaling and automatic adaptation to small or large changes in feedwater quality lower operations and maintenance costs. This performance is ideal for industrial water and effluent treatment, agricultural water supply and inland brackish desalination and represents major improvements in RO performance and economics.

For a more comprehensive understanding of CCD Reverse Osmosis, including applicable case studies supporting this summary, please refer to the full whitepaper, found here.

For more information on Desalitech or CCD Reverse Osmosis please visit our website at: www.desalitech.com.