High Recovery Reverse Osmosis Water Treatment for Industrial & Municipal Applications

A Review of Closed Circuit Desalination Technology

Demand for water is high and global resources are limited. Reverse osmosis (RO) is an effective and widely-applied water treatment purification method, 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 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 purification and water reuse. The theory behind this breakthrough technology is explained.

Introduction

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

The Closed Circuit Desalination (CCD) process promises to improve nearly every aspect of RO performance. Compared to traditional RO systems, the CCD semi-batch approach provides:

- High, adjustable recovery rates
- Independently adjustable cross-flow
- Resistance to and even reversal of fouling and scaling
- Lower energy consumption

High recovery operation reduces concentrate production, source water pumping and pretreatment requirements. High cross-flow reduces lead element flux, provides more even flux distribution and reduces the effects of fouling and the associated chemical and cleaning requirements. These performance improvements are particularly beneficial for industrial water purification and water reuse. Reduced energy consumption and smaller membrane arrays used in the CCD process save cost. These improved features are particularly beneficial for industrial water purification and water reuse.

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 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.

Permeate is produced at a rate equal to the flow rate of a high pressure pump. Brine is recirculated without depressurization. When a desired (high) 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 normal operation (closed-circuit), during which there is no brine reject stream.

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

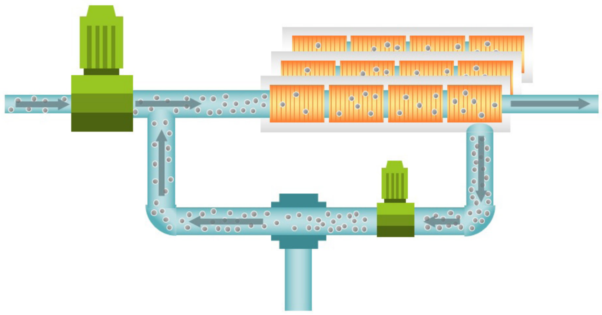

Figure 1. CCD technology Process Schematic Diagram

For lower-recovery, higher-pressure applications, such as seawater desalination, an alternative CCD process is used to maximize energy savings. This 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. With this process, Desalitech has achieved record low seawater desalination energy consumpetion of 1.45 kWh/ m3; which trumps current state-of-the-art seawater desalination plants - generally operating with energy requirements of 2.2 to 3.0 kWh/m3.

Design and Modeling

The performance of CCD 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 CCD systems in the same way they do for all other 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.

Increased Recovery

CCD systems can achieve over 98% recovery whereas traditional multi-stage RO systems typically operate at only 75% recovery. The recovery rate in a CCD process 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 of CCD RO and has 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 all other 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.

Energy Savings

The initial pressure requirement of each CCD sequence is proportional to the osmotic pressure of the feedwater. The maximum is proportional to the osmotic pressure of the final brine - the same (high) pressure as the running pressure of a traditional 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. CCD systems also dramatically reduce energy loss to the brine reject stream by reducing its pressure prior to release.

Fouling and Scaling Resistance

Good resistance to fouling and scaling and high recovery operation are important in most applications. CCD 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. The more balanced flux distribution that is inherent with shorter membrane arrays limits the maximum flux and recovery experienced by each individual membrane element.

In particular, the flux through the first or lead 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, calcium sulfate and organics, producing brine concentrations of these constituents that are four times higher than can be sustained in other RO systems.

Simplified Design and Flexible Operations

In traditional RO systems, 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 ndependent manipulation of these functions. The resulting extreme operational flexibility allows for reduced feedwater pretreatment requirements. It also allows and the process designer and operator to cope with variations in feedwater quality and other requirements, therefore optimizing process performance and minimizing costs.

Conclusions

Reverse osmosis water treatment costs can be lowered by increasing water recovery, reducing energy consumption and increasing flexibility and reliability. The CCD RO process enables permeate recovery rates of over 98% without multiple stages of membrane elements and without precipitation of sparingly soluble salts.

These systems can operate with 35% less energy than traditional 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. CCD RO represents major improvement in RO performance and economics.

For a more comprehensive understanding of CCD Reverse Osmosis, including applicable case studies supporting this summary and informational videos, please visit our website: www.desalitech.com