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Desalination

Current challenges in energy recovery for desalination

Desalination processes, with their increasing requirements for advanced efficient pumping and energy recovery solutions, are developing as a result of meeting the requirements of accelerated fresh water demand coupled with the effects of global climate change. In this article Anthony Bennett looks at the various desalination processes, thermal, membrane and hybrid, and how they have evolved, what the current challenges are for increasing energy efficiency, and what the future might hold for the desalination industry.

Origins of distillation

Today, desalination can be achieved by using thermal or membrane processes, or a hybrid combination. Desalination using thermal processes was first mentioned by Aristotle, who wrote about seawater distillation around 300-400 BC. Different techniques have been used through the centuries, with the explorers Jean De Lery and James Cook recording that they regularly distilled seawater in the 18th Century. In the 19th Century, distillation had been commercialized by companies such as Caird & Rayner (a brand which still exists today), with firms located in various countries such as the UK, France, Germany and the US.

As steam engines were developed and high pressure steam became readily available, pure water for boiler feed became necessary to reduce the effects of corrosion and eliminate the likelihood of boiler damage. On ships such as the Titanic, single effect distillation processes were employed that utilized 'waste' heat to produce fresh water for boiler feed, but also for drinking and cooking.

Multiple effect distillation

In the late 19th Century, the first major technical advance in desalination technology was the development of the Multiple Effect Distillation (MED) process. Here, preheated feed water flowing over tubes in the first effect is heated by prime steam, resulting in evaporation of a fraction of the water content of the feed.

The water vapor generated by brine evaporation in each effect flows to the next effect, where heat is supplied for additional evaporation at a lower temperature. There the vapor condenses, giving up its latent heat to evaporate an additional fraction of water from the brine. The process of evaporation-plus-condensation is repeated from effect to effect, each at successively lower pressure and temperature.

The combined condensed vapor constitutes the product: distillate water. The first large-scale MED system for maritime use was installed on the Queen Mary in 1934.

Electrodialysis

In the 1950s scientists began looking at alternatives to thermal desalination by studying membrane processes. Electrodialysis (ED) was the first of these processes to be developed commercially. This process was significantly more efficient in brackish water applications (especially those with a higher-temperature feed supply) than distillation, and hence the use of ED became commonplace in lower salinity applications. The introduction of electrodialysis reversal (EDR) greatly reduced the early scaling problems associated with ED.

In EDR, an electric current migrates dissolved salt ions through an electrodialysis stack consisting of alternating layers of cationic and anionic ion exchange membranes. Periodically, the direction of ion flow is reversed by reversing the polarity of the applied electric current.

Multistage flash distillation

In the mid-1960s virtually all the world's seawater desalination capacity (about 1,000 m^3/day) was in the Middle East and was produced by multistage flash (MSF) distillation, a technology that was independently, and at around the same time, invented in the UK and the USA by J & G Weir Ltd and in the USA by Bethlehem Steel and Westinghouse, followed later by Agua Chem and Baldwin Lima Hamilton.

In MSF, seawater (after mixing with the recycle stream) is pressurized and heated to the

Fujairah I MSF-RO Hybrid Desalination Plant. Courtesy of William Chang, Emirates Sembcorp Water and Power Company.

maximum top brine temperature (TBT). When the heated brine flows into a stage maintained at slightly below the saturation vapor pressure of the water, a fraction of its water content flashes into steam. The flashed vapor passes through a mist eliminator and condenses on the exterior surface of heat transfer tubing.

The condensed liquid drips into trays as a product water. The unflashed brine enters a second stage, where it flashes again to vapor at a lower temperature, producing a further quantity of product water. The flashing-cooling process is repeated from stage to stage until both the cooled brine and the cooled distillate are finally discharged from the plant as blow-down brine and product water.

Reverse osmosis

In 1963 Loeb and Sourirajan at the University of California, in Los Angeles, developed the first synthetic reverse osmosis (RO) membrane. In RO, permeate passes from the feed to the product side of the membrane when a pressure exceeding the osmotic pressure is applied. This 'reverses' the natural osmotic effect and concentrates salt ions into a waste concentrate stream. However, high pressure energy-intensive pumps (up to 60-70 bar) were required to drive the process.

By the late 1960s, commercial desalination systems producing up to 8,000 m^3/d were beginning to be installed in various parts of the world. Most of these installations used thermal processes but by the 1970s larger scale commercial RO and ED/EDR systems began to be used more extensively.

Initially, in brackish applications, RO had to compete against the now established ED and EDR technologies and early RO was complicated and not always reliable.

The growth of RO was due to market standardization on the spiral wound membrane module, and the introduction of thin film composite (TFC) membranes to replace earlier cellulose acetate materials.

In the late 1970s and 1980s the development by Dow of the FilmTec TFC polyamide membrane brand resulted in process improvements including lower operating pressures, higher fluxes and higher salt rejection, which helped to reduce energy consumption and pumping pressures.

In the 1970s, the introduction of isobaric energy recovery technology significantly reduced the operating costs of seawater RO.

By the 1980s, desalination technology had become a fully commercial enterprise and by the 1990s, the use of RO desalination technologies for municipal water supplies had become commonplace.

Emerging technology

Newer emerging desalination technologies take advantage of various processes including forward osmosis, osmotic power, membrane distillation, membrane nanotechnology and more futuristic ideas of desalination like bio-engineered bacteria able to consume specific ions and eat salt. Thoughts on future developments in desalination are included later.

Current desalination status

We asked Leon Awerbuch, Dean of the International Desalination Association's Desalination Academy, about the current global status of the desalination industry. As of September 2013, the amount of new desalination capacity expected to come on line during 2013 was 50% more than previous year's total, according to new data from the International Desalination Association and GWI DesalData. Desalination plants with a total capacity of 6 million m^3/d were expected to come on line during 2013, compared with 4 million m^3/d in 2012. Data has yet to be confirmed for the last 12 months with the next global plant inventory due later this year.

Current data takes the total capacity of all 17,277 commissioned desalination plants in the world to at least 80.9 million m^3/d. Awerbuch explained, "This is equivalent to nearly 32 years of rain for London or just over 21 years of rain in New York."

While the 2013 growth rate is somewhat lower than 2010, when 6.5 million m^3/d of new capacity was completed, Awerbuch told us that the data shows demand for desalination continues to grow. "An increasing proportion of that growth is coming from the industrial sector," he explained.

Since 2010, 45% of new desalination plants have been ordered by industrial users such as power stations and refineries, while in the previous four years, only 27% of new capacity was ordered by industrial water users.

Industrial applications for desalination grew to 7.6 million m^3/d for 2010-2013 compared with 5.9 million m^3/d for 2006-2009. Of the 7.6 million m^3/d, the power industry accounted for 16%; oil and gas, 12% (up from 7% from 2006-2009); mining and metals, 11%; refining and chemicals, 11%; electronics, 5%; and food and beverage, 3%. Other numerous industrial applications accounted for the remaining 40%.

Seawater desalination continues to represent the largest percentage of online global capacity at 59%, followed by brackish water applications at 22%, river water projects at 9%, and wastewater recovery and pure water systems at 5% each.

The largest operational desalination plant in the world had been the 880,000 m^3/d Shoaiba 3 thermal desalination plant in Saudi Arabia. This was displaced in April 2014 by the Ras Al-Khair plant.

As the world's largest hybrid seawater desalination plant, for which Doosan won the construction order in September 2010 from the Saline Water Conversion Corporation, the Ras Al-Khair plant produces 1,036,000 m^3/d desalinated water (RO at 309,360 m^3/d and MSF at 727,130 m^3/d). The plant is dual purpose with an electricity production capacity of 2,400 MW. The combined cycle power plant is one of the more efficient power plants in the world. The total length of the double transmission lines from the plant to Riyadh and Hafr Al-Batin will be 1,290 km.