Yale constructs forward osmosis desalination pilot plant

This brief feature article provides details of a novel desalination process that is being investigated and further developed at Yale University in New Haven, Connecticut. The technology promises lower energy costs, higher recovery and less brine discharge than conventional desalination systems.

Osmosis is a physical phenomenon that has been extensively studied by scientists in various disciplines of science and engineering. Early researchers studied the mechanism of osmosis through natural materials, and from the 1960s, special attention has been given to osmosis through synthetic materials.

Following the progress in membrane science in the last few decades – especially for reverse osmosis (RO) applications – the interests in engineered applications of osmosis has been spurred. Osmosis, or as it is currently referred to as forward osmosis (FO), has new applications in separation processes for wastewater treatment, food processing, and sea water and brackish water desalination.

Other unique areas of FO research include pressure-retarded osmosis for the generation of electricity from saline and fresh water and 'implantable' osmotic pumps for controlled drug release.

Pilot-scale plant

In the US, researchers at Yale University are building a pilot-scale plant (Figure 1) to demonstrate a novel FO desalination process.

The project, led by Professor Menachem Elimelech and graduate students Robert McGinnis and Jeffery McCutcheon, features a process that differs from existing desalination technologies in that it uses osmotic pressure, rather than hydraulic pressure or thermal evaporation, to separate fresh water from a sea water or brackish water source. This approach promises a significant reduction in energy consumption and costs, as well as high feed-water recoveries and greatly reduced brine discharge streams.

Efficient

The key to the ability of the FO process to achieve efficient desalination is in the composition of the osmotic 'draw' solution used.

It is a well known fact that water will flow from a dilute to a concentrated solution, (when these solutions are separated by a semi-permeable membrane), and that a very concentrated solution will draw water from a brackish or seawater saline source.

The difficulty of making use of this phenomenon in practice has been identifying a concentrated solution that contains solutes which can be efficiently and entirely removed. A concentrated sugar solution could be used, for instance, to effect desalination of brackish water, but this would result only in a less concentrated sugar solution, not fresh water.

The FO process developed at Yale uses a unique group of removable solutes to create a draw solution for desalination.[1] When ammonia and carbon dioxide gases are dissolved in water in the correct proportion, they favour the formation of a highly concentrated solution of ammonium salts. This solution can have a very high osmotic pressure, which makes it ideal for drawing water from saline feeds, but what makes this solution most advantageous for use in FO is the ability of the salts to decompose from solution, when heated, into ammonia and carbon dioxide gases again, thus allowing for their efficient and complete removal and reuse (Figure 2).

Therefore, this process is both a membrane and a thermal process, such that the separation is achieved using a semi-permeable membrane, but the energy used for that separation is in the form of heat.

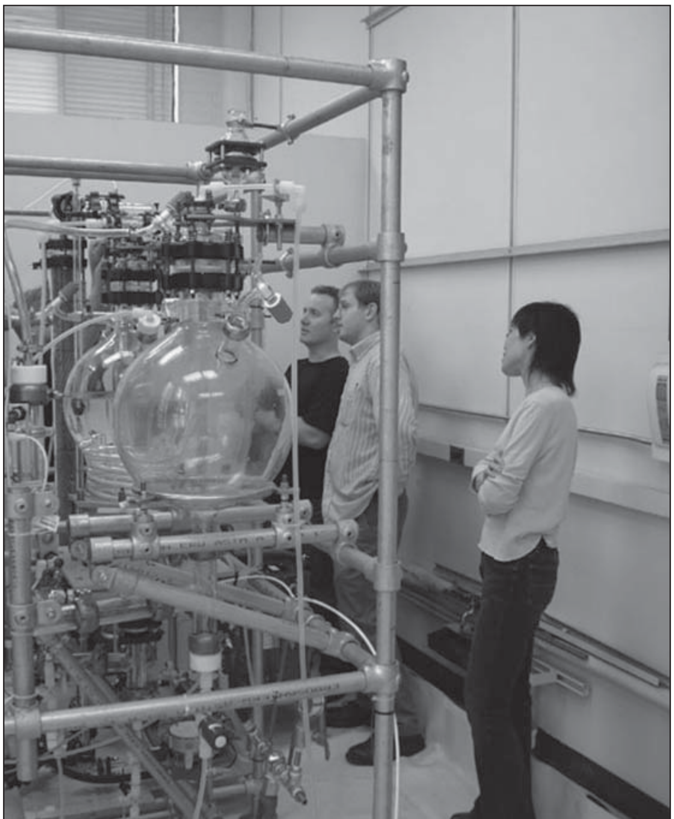

Figure 1. Yale researchers are building a pilot-scale plant to demonstrate a novel forward osmosis desalination process.

Energy costs

The heat used by the FO process can be minimized in both quantity and cost, or set to some balance between the two. In most cases, FO will use approximately 25–45% of the thermal energy needed by multi-effect distillation (MED), the most efficient existing thermal desalination technology.

FO has the further ability to use heat at much lower or higher temperatures than MED or multi-stage flash (MSF) systems. FO can use heat as low in temperature as 40°C, which is just above that typical of steam entering condensers

Main advantages of using forward osmosis

The main advantages of using forward osmosis (FO) are that it operates at low or no hydraulic pressures, it has high rejection of a wide range of contaminants, and it may have a lower membrane fouling propensity than pressure-driven membrane processes.[2]

Because the only pressure involved in the FO process is caused by the flow resistance in the membrane module (a few bars), the equipment used is very simple and membrane support is less of a problem. Furthermore, for food and pharmaceutical processing, FO has the benefit of concentrating the feed stream without requiring high pressures or temperatures that may be detrimental to the feed solution. For medical applications, FO can assist in the slow and accurate release of drugs that have low oral bio-availability because of their limited solubility or permeability.[3]

Versatile technology

The increased attention to FO from various disciplines arises from the fact that FO can be employed in many fields of science and engineering, including water and wastewater treatment, sea water or brackish water desalination, food processing, drug delivery and the production of electrical power.

Despite the lack of robust membranes and membrane modules for FO, basic research on FO and the development of new applications of FO are steadily growing. Currently, the most important measure to be taken in order to advance the field of FO is the development of new membranes in both flat-sheet and hollow-fibre configurations.

The membranes need to provide high water permeability, high rejection of solutes, substantially reduced internal concentration polarization (CP), high chemical stability and high mechanical strength.

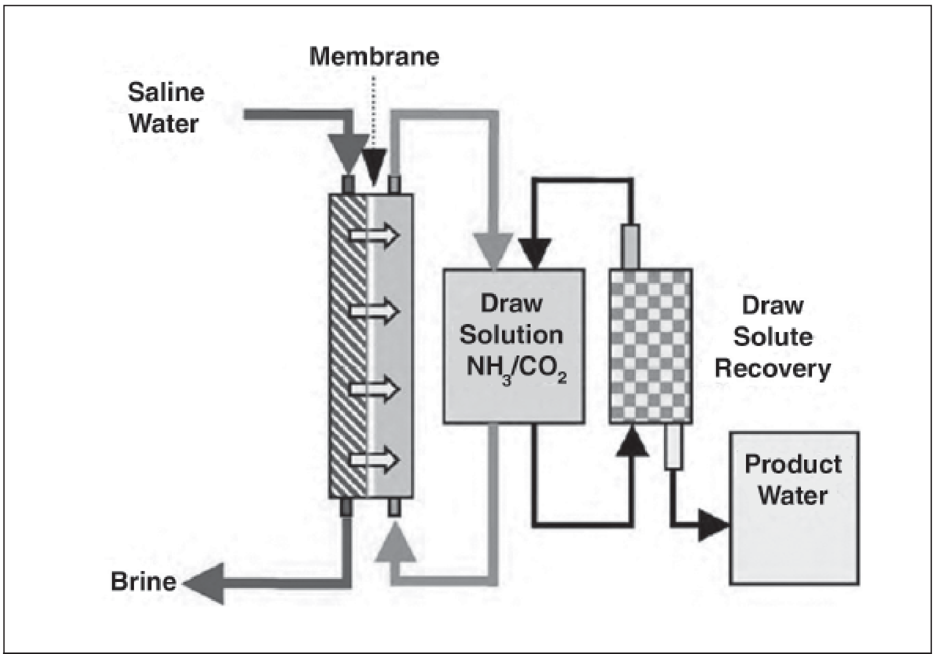

Figure 2. Schematic of Yale's novel forward osmosis desalination process.

in an electrical power plant. At this temperature, the cost of thermal energy is very low.

FO can also use higher temperature heat sources, which gives the benefit of greatly reducing the total amount of heat required. At 200–250°C, for instance, FO may achieve a gained output ratio (GOR) – commonly used to compare thermal desalination efficiencies, with higher numbers indicating less heat used – of up to 26.5. MED desalination typically has a GOR of approximately 8–15, depending on its configuration.

The electrical consumption of FO is also much lower than that of existing desalination technologies. In most cases, FO requires less than 0.25 kWh/m^3 of water produced. This is approximately 21% of what is required by MED, and 9% of what is required by RO. The combination of low-cost heat and minimal electrical consumption promises to make FO the best desalination process with respect to energy cost.

High recovery

The high osmotic pressures characteristic of the ammonium salt draw solution allow for fresh water recovery from highly concentrated saline feeds.

Laboratory tests show effective desalination of 3.4 M NaCl solutions, a salinity corresponding to around 85% recovery from a typical sea-water source. Realization of this potential will require investigation of appropriate pretreatment strategies, but the capability of FO to produce very high recoveries is unmatched by existing desalination methods.

One significant impact of this increased capability will be the reduction in the volume of brine discharge streams from desalination plants. In the case of brackish water desalination, the very high recoveries made possible by FO may allow for zero liquid discharge (ZLD) operation, a capability critical to the adoption of desalination in inland environments. ZLD may one day also be possible in sea-water desalination, provided that a use can be found for the large quantities of salt that would be produced.

Useful desalination process

The combination of low energy costs, high feed-water recoveries and minimized brine discharge promise to make FO a highly useful desalination process.

It is expected that the total water cost of FO will also be much lower than that of RO or MED, but only pilot testing will provide the necessary information for detailed estimates of total cost. Yale researchers have begun the construction of the FO desalination pilot, with funding provided by the Office of Naval Research, with completion expected by spring of 2007.

References

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Further reading

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