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Don't ignore forward osmosis

Modern Water backs its technology

Technology, branding and R&D

Secrets to growth of BWA Additives

Forward osmosis is not to be ignored

Peter Nicoll, technical director, Modern Water plc

Editor's Note: For about 3 or 4 years now, *D&WR* has annually requested a feature from Modern Water about the company's development of forward osmosis and its desalination plants in Gibraltar and Oman. So it was with pleasure that we finally received the article below which shows the consistent strides the firm has been making with the process.

READERS OF this article may occasionally read an article or see a reference about forward osmosis (FO) in *D&WR* and, whilst the process may not currently be 'mainstream', it is increasingly becoming a topic of some interest.

At the last World Congress of the International Desalination Association in Perth, Australia, in September 2011, six papers were published on this subject. In the *Journal of Membrane Science,* the number of papers published has seen a very significant increase over the last three years (24 in 2012), showing the increasing level of academic interest. We have also seen the emergence of a number of commercial organisations with significant funding to develop and exploit the technology, such as Modern Water plc, Oasys Water Inc and Hydration Technology Innovations Inc. This brief article discusses two processes that have been commercialised by Modern Water plc.

FO, or more simply just osmosis, has been used in nature for rather a long time by plants, trees, sharks and human cells to name just a few. All biological cells have a semipermeable membrane which causes osmosis to occur in the presence of liquids of differing solute concentrations.

It also takes place as drawback when a reverse-osmosis (RO) plant shuts down and the permeate flows back across the membrane to dilute the feed solution, so this should give some clue as to its potential.

The process, just like RO, requires a selectively permeable membrane separating two fluids with different osmotic pressures. If the solvent is water then effectively almost pure water flows from the fluid of lower osmotic pressure to dilute the fluid of higher osmotic pressure.

The process in its pure form takes place at atmospheric pressure, with variations such as pressure-enhanced osmosis and pressure-retarded osmosis. These are simply illustrated in Figure 1.

It is worth just reminding ourselves just what FO can do:

- It can dilute a solution of higher osmotic pressure with a solution of lower osmotic pressure.
- It can concentrate a solution of lower osmotic pressure with a solution of higher osmotic pressure.

So why might this be useful in a water treatment application? One key element is that the dilution/concentration process takes place across a selectively permeable membrane, at low pressure and the ions are rejected in both the direction of forward flow and reverse

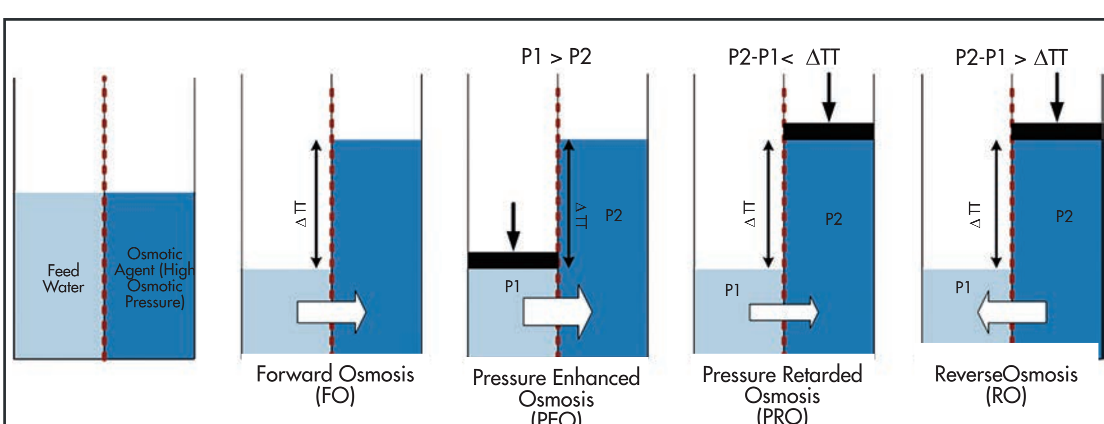

Figure 1. Osmotic Processes

flow. In a similar way to RO, we talk about *salt passage* in the direction of forward flow, but ion mass transfer also takes place in the reverse direction, which is often termed as *back diffusion*.

The process has considerable potential across a wide variety of applications;

- Emergency drinks
- Power generation
- Enhanced oil recovery
- Produced water treatment
- Fluid concentration
- Thermal desalination feedwater softening
- Desalination
- Water substitution.

However only a few of these applications have been currently commercialised; emergency drinks, produced water treatment, desalination and water substitution. It is the latter two applications that are outlined in this article and in particular the progress that Modern Water has made to develop and commercialise them.

FO DESALINATION

The basic principles of this process, in all its variations, is an initial FO step followed by a regeneration step to reconcentrate the osmotic agent / draw solution for reuse and to separate the 'desalinated' water, prior to any post-treatment. The regeneration step is generally either thermal or membrane based.

Modern Water has successfully used a RO regeneration step, with a simplified process illustrated in Figure 2.

At first sight this might seem a trivial problem to have solved, however what also must be considered is:

- The selection of the osmotic agent / draw solution, which by necessity must be non-toxic
- Maintaining a constant osmotic pressure for the concentrated osmotic agent
- Managing the contamination of the osmotic agent with salts from the feed solution
- Minimising back diffusion of the osmotic agent to the feed solution
- A robust FO membrane that can adequately deal with flow on both sides
- Operating on a continuous and economic basis.

MAIN ADVANTAGES OF FO

Given the above challenges, why then bother to solve them? The answers again are not so straightforward and, like all membrane processes, can be site-specific. Briefly, the two main advantages over conventional RO are lower fouling propensity and lower energy consumption.

The significantly *lower fouling potential* of the FO process compared with RO membranes, operating under the same feed conditions, has been shown by a number of academic researchers.

More importantly under real-world conditions on challenging feedwaters, Modern Water has demonstrated that, on one particular site in Oman, no chemical cleaning was required over several years operation, whereas the conventional process required cleaning every few weeks with several membrane changes[1]. This of course also means a reduction in the use of membrane cleaning chemicals and improved availability.

The potential for a *lower energy consumption*, which is sometimes not so readily understood and requires careful explanation, comes about in a number of ways.

Consider that a state-of-the-art RO system has a similar energy consumption to a state-of-the-art FO system in the clean state. Then, given that FO fouls at a lower rate than RO, then it is clear that to maintain the same output the RO-based process will require more energy. The degree of energy saving depends on the degree of fouling.

Now consider the regeneration step, which is where the bulk of the energy is consumed for this FO desalination process. The osmotic agent is free of all particulates and large molecular weight organics from the feedwater, as the solution is made from permeate.

As such, a parallel should be drawn with the normal design criteria for second-pass RO systems. This means that the recovery rate, the membrane selection and configuration can be fully optimised, and, of course, conventional energy-recovery systems can be applied to the high-pressure concentrated osmotic agent stream.

The regeneration step, again because it is fed with a 'perfect' solution, has improved salt rejection compared to conventional RO. This may eliminate the use of a second pass and as such, energy is saved.

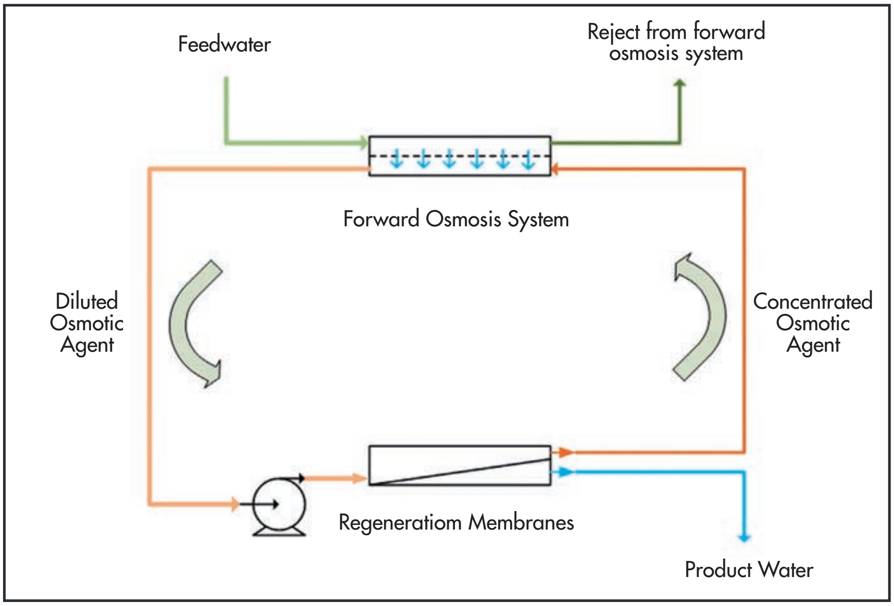

Figure 2. The Forward Osmosis Desalination Process

BORON REJECTION

Boron in desalinated water produced by RO has long presented a challenge to the membrane industry with very poor rejection and the necessity for special high pH second passes or the use of ion-exchange columns, to meet the relevant in-country standards. These add not just complexity, capital cost and operational cost but increased energy consumption.

The advantage of having a recirculating osmotic agent is that its properties can be controlled and, in combination with the FO membranes, it has improved boron rejection characteristics.

The desalination process, as it has currently been implemented by Modern Water, may be considered as an advanced pretreatment to RO and, as such, the process could be retrofitted to existing conventional RO plants, in circumstances where the economics of the process make sense and in particular when microfiltration or ultrafiltration is being considered.

FULL-SCALE SEAWATER PLANT

Modern Water's first full-scale seawater plant (18 m^3/d) was commissioned in Gibraltar in September 2008 at an AquaGib site (Figure 3), with water going into the public supply after extensive independent testing on 1 May 2009.

This was followed by a much larger plant (100 m^3/d) located at the Public Authority for Electricity & Water's site at Al Khaluf (Figure 4) in Oman in November 2009 [2]. In an open public tender for conventional RO, Modern Water was awarded a turnkey contract to build a 200 m^3/d FO-based desalination plant at Al Najdah (Figure 5) again in Oman. Each of these plants has built upon the experience and development of the previous one, together with FO membrane development and work undertaken within the laboratory.

COOLING TOWER MAKE-UP

Evaporative cooling uses very significant amounts of water and, with changes in environmental legislation, this method of cooling is likely to become even more widespread. Usually, this make-up water needs to be of high quality and, where there is an appropriate supply, this water has traditionally been supplied from rivers and mains water supplies, depending on the geographical location.

Where these sources are not available, or not available in sufficient quantity, the cost of providing suitable make-up can be costly

Figure 3. Gibraltar Plant

Figure 4. Inside the process container at Al Khaluf

both in energy and financial terms. This can prevent the installation of an evaporative cooling system in a particular location.

Make-up water has also been provided directly as seawater and more recently treated sewage effluent.

In the Middle East region, water for evaporative cooling has mainly been supplied using desalinated water, with the occasional use of seawater when the infrastructure and physical location of the site were suitable. As the wastewater infrastructure has developed and with the ever increasing demands on desalinated water, treated sewage effluent has become one of the favoured sources for make-up water. This is particularly prevalent in the district-cooling sector, where for instance in Dubai (Executive Council of Dubai, 2008) and Abu Dhabi, legislative changes prohibit the use of mains-supplied water for new installations.

It is in this climate, with increasing demands on our resources, that an FO-based process has been developed for the preparation of make-up water from impaired water sources, ranging from seawater to treated sewage effluent.

This new technique allows the economic use of water sources that otherwise would not be considered for make-up and therefore extends the applicability of evaporative cooling and, just as important, allows water substitution. This frees up valuable potable water or treated sewage effluent for more appropriate use.

The process is beautifully elegant in concept. To draw in water, to replace that lost by evaporation drift and blowdown, the cooling-water chemistry is changed to increase its osmotic pressure. A portion of the high-osmotic-pressure cooling water is introduced to one side of a FO membrane with on the other side a feedwater such as seawater, brackish water or treated sewage effluent.

The natural process of osmosis takes place and essentially pure water flows into the re-circulating cooling water replacing that lost in the process. Figure 6 illustrates a typical arrangement.

This system, because it is essentially pure FO without a regeneration step, operates with very low energy-consumption, requiring only to overcome the pumping losses on either side of the membrane system, unlike RO, which is dependent on the salinity of the feed water. The higher the salinity, the more energy is saved compared with using a conventional desalination process for make-up water, typically 50% of RO. This is discussed in more detail in Reference 2.

There have been a number of spin-off benefits identified for the process, including the inhibition of *Legionella pneumophila* in the osmotic agent without the use of oxidising or non-oxidising biocides and significantly reducing the chemical consumption of large molecular weight cooling-water additives through the use of a blowdown recovery system.

Modern Water has built a complete pilot unit including the cooling tower, which was initially trialled in Sohar, Oman, in a petrochemical plant. This unit can be moved and tested to trial sites to optimise the process for that particular location.

Figure 5. Al Najdah 200 m³/day FO Desalination Plant

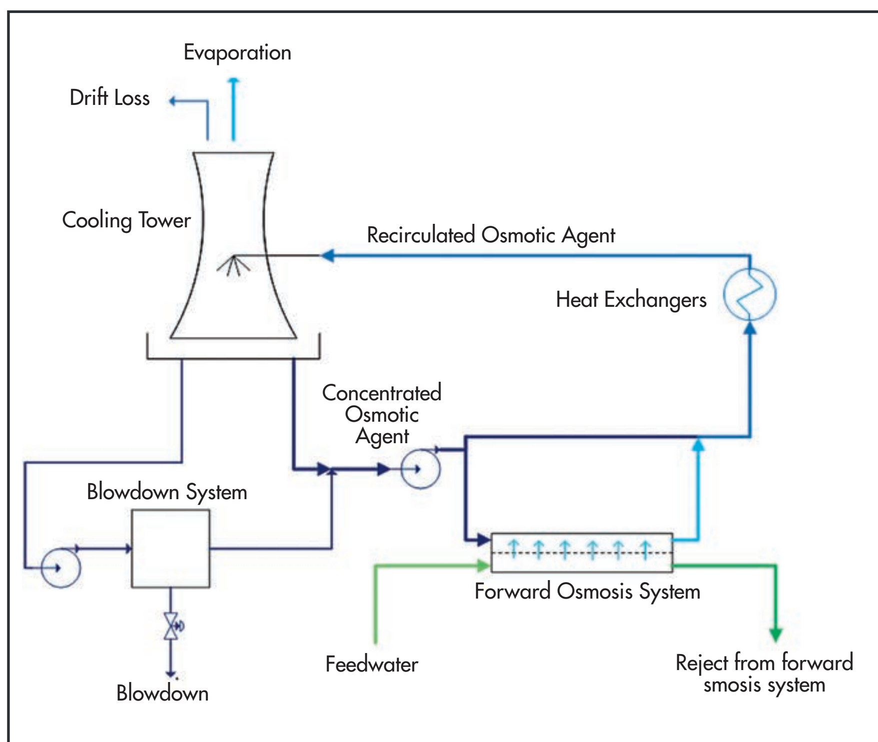

Figure 6. FO Based Evaporative Cooling Make-up Water System

CONCLUDING REMARKS

In conclusion FO-based processes are here to stay; they have vast potential across a wide range of applications and in some cases these processes are truly disruptive. The progress that has been made primarily over the last four years is enormous, yet this is only the beginning with much more yet to come in both process and FO membrane development.

Progress can be accelerated by further vision, recognition and support by public utilities and industry as a whole. Three main applications are already a commercial reality, which are the common platform on which many more will be developed across a range of industries.

REFERENCES

- N Thompson & P Nicoll, Forward Osmosis Desalination: A Commercial Reality, *Proceedings IDA World Congress*, Perth, Western Australia, September 2011.

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