MANIPULATED OSMOSIS – AN ALTERNATIVE TO REVERSE OSMOSIS?

When applied to evaporative cooling make-up water, the new technology of manipulated osmosis provides an economical and technically attractive solution, argues Peter Nicoll.

The use of evaporative cooling towers is set to increase across the world, driven by both economic and environmental concerns, with a corresponding increase in the demand for make-up water. 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 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 waste water 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 and Abu Dhabi, legislative changes prohibit the use of mains-supplied water for new installations.

It is in this climate and context, with increasing demands on our resources, that Modern Water has developed a new technology for the preparation of make-up water from impaired water sources, ranging from seawater to treated sewage effluent. The process uses manipulated osmosis, a low-pressure and low-energy process, to produce permeate quality make-up water. The technique allows the economic use of water sources, which otherwise, would not be considered for make-up and, therefore, extends the applicability of evaporative cooling.

MANIPULATED OSMOSIS

In order to explain the process, first, let us consider the principles of manipulated osmosis. In the industry, most people are familiar with reverse osmosis (RO), where high-quality permeate is separated from a feed solution, such as, seawater or brackish water, by a selectively permeable membrane. When the hydraulic pressure of the feed is greater than its osmotic pressure – a property of the solution – essentially pure water flows through the membrane. It can, then, be collected and used for various purposes, the most common application being the production of fresh water suitable for human consumption or irrigation. This is a high-pressure, high-energy process.

"Manipulated osmosis", "forward osmosis" or just "osmosis" are terms used to describe the natural phenomenon, whereby a solvent flows from a region of lower osmotic pressure across a selectively permeable membrane to an area of higher osmotic pressure (See Figure 1). A good example of this in nature is the mechanism, whereby plants take up moisture in their root systems and become turgid.

We can manipulate two fluids with differing osmotic pressures to exploit this natural phenomenon, so that, for instance, we can make essentially pure water flow out of seawater across a selectively permeable membrane to dilute a solution with a higher osmotic pressure.

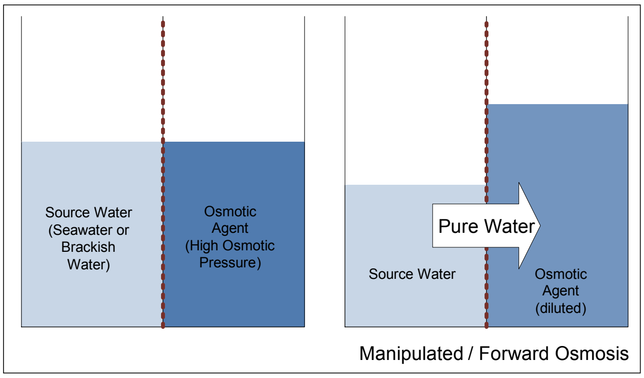

Figure 1: Manipulated osmosis

It is important to note that this process takes place without any significant applied pressure. All that is required is to overcome the frictional resistance on either side of the membrane (typically 2 – 3 barg). This is markedly different from the case for reverse osmosis, where very high pressures may be applied, generally up to 82 barg. High osmotic pressure solutions may be made safely and easily, without any impurities or foulants by dissolving in water a suitable salt or combination of salts, of which there are many.

Successful "real-world" applications of this phenomenon are emerging. One example of these applications has been developed by Hydration Technology Innovations (HTI) in the United States. HTI's emergency sugar drink can be produced from contaminated water, simply by placing a pouch fabricated from a selectively permeable membrane in the available water. The sugar solution inside the pouch has a high osmotic pressure and, over time, clean water flows from the contaminated side to the sugar side to produce an energy drink. Two examples on an industrial scale are Modern Water's multi-patented manipulated osmosis desalination process, which produces drinking water, and Modern Water's evaporative cooling make-up water system, the subject of this article.

MANIPULATED OSMOSIS AND EVAPORATIVE COOLING

Having established the basic principles of manipulated osmosis, we can now look at how it may be applied to the production of evaporative cooling make-up water. There are two ways it could be applied: as a complete desalination process producing low TDS water (using a two-step process) or as just a single forward osmosis step, which is what is considered here.

The process is very simple in its concept. To draw in water, to replace that which is lost by evaporation drift and blowdown, the cooling water chemistry is changed to increase its osmotic pressure. This high osmotic pressure solution may be known as an "osmotic agent" or "draw solution". A portion of the high osmotic pressure cooling water is introduced to one side of a selectively permeable membrane and, on the other side, we have 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 which was lost in the process. Figure 2 illustrates a typical arrangement.

Like any membrane process, a certain amount of pre-treatment is required, which may include screening, multi-media filtration or other suitable systems. Given the inherently low-fouling potential of the membranes, less conservative design values for these systems could be used, compared to conventional membrane plant.

The membrane chemistry is suitable for use with oxidising biocides used in cooling water systems, unlike most conventional reverse osmosis membranes, which are not chlorine resistant.

The question that is often asked is: "What is the osmotic agent?" The composition is proprietary, but what we can say is that it is based on a safe, economical, readily available commodity chemical, which is not corrosive to all normal heat transfer surfaces. Like any evaporative cooling system, the dissolved solids are lost via drift and blowdown. So, in the case of manipulated osmosis, there could be a loss of the main chemical base of the osmotic agent, unless a recovery system is incorporated.

Modern Water has developed a patented system that recovers and reuses the osmotic agent in the blowdown stream to minimise the loss of chemical and, therefore, further improve the economics. There is clearly a loss to the atmosphere via drift. However, with drift eliminators this is insignificant.

CAPEX AND OPEX

The capital cost of a system will be no more than a conventional reverse osmosis plant designed to operate on the same feed water. Unlike the conventional plant, which may use super duplex stainless steels, the manipulated osmosis-based ▶

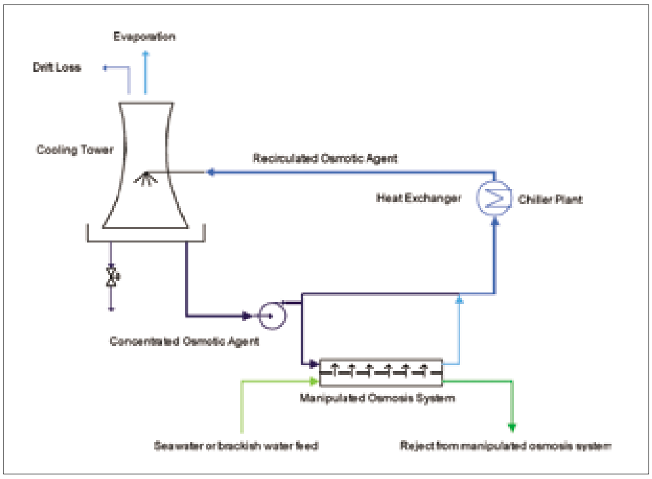

Figure 2: Manipulated osmosis make-up system

system makes extensive use of lower cost plastic components, owing to the low operating pressures.

There is much debate in the desalination industry as to the actual capital costs of plants. Various surveys have been undertaken by several authors, with wide variations in capital cost. Hence, it is difficult to be specific as to the capital costs of this new process, other than to say it would normally be considerably less than the equivalent reverse osmosis plant.

Let us make the conservative assumption that in the worst case, the capex costs are the same for the manipulated osmosis and reverse osmosis processes (they are in fact lower), and consider the differential operational costs for each process. In the case of reverse osmosis, we will consider only electricity, and in the case of manipulated osmosis, electricity and the cost of osmotic agent lost via drift and blowdown.

Power consumption comparison:

This comparison is based on the following assumptions:

- Feedwater temperature is at 25°C
- Pre-treatment requirements are the same for MO and RO
- Pump overall efficiency is at 70%
- Energy-recovery efficiency is at 70%
- Maximum conversion with MO is limited to 30% (very conservative)
- Conversion for RO is 80% to 41%, depending on feed TDS
- Cooling tower concentration ratio is five

Figure 3 shows the significantly better power consumption of manipulated osmosis when compared to reverse osmosis, across the spectrum of differing feed waters. This is particularly true with seawater, typically being 35,000 – 45,000 mg/l total dissolved solids (TDS). using the osmotic agent recovery system on the blowdown. It is interesting to note that in the case of manipulated osmosis, without stream, the power consumption does not vary with feed TDS. Indeed, the economic advantages of the process increase the more challenging the feed water source.

Power and chemical operational costs:

Now, let's consider the same technical assumptions and the following economic assumptions:

- Power is at US$0.075/kWh (low)
- Osmotic agent is at US$75/tonne

Figure 4, shows very clearly the significant economic advantages of the manipulated osmosis process for supplying make-up water. These figures are conservative for manipulated osmosis because we have fixed the conversion (make-up water to feedwater

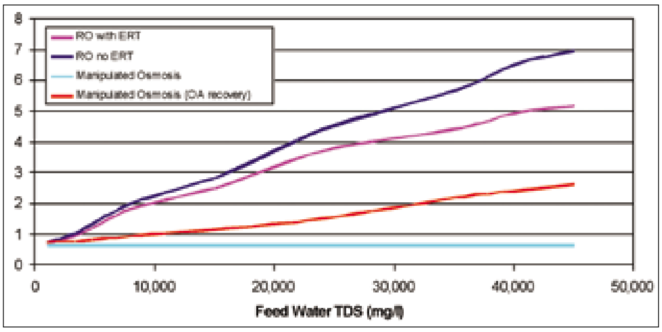

Figure 3: Power consumption comparison

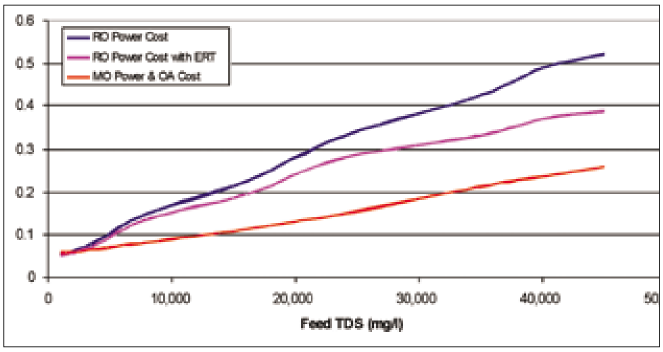

Figure 4: Simple opex comparison

ratio) of the process to 30% across the range of feed water TDS, where, in fact, the process would have a similar conversion to reverse osmosis. Therefore, for any particular case, the process economics are better than illustrated.

It will be clear that the manipulated osmosis process becomes increasingly economically attractive, the higher the cost of power and the more challenging the feedwater. This does not take into account the other advantages when compared to a reverse osmosis-based process, including an increased availability, fewer membrane replacement and lower chemical cleaning costs.

DEPLOYMENT OPPORTUNITIES

The technology provides an additional consideration when siting evaporative cooling towers and the supply of make-up water. It is evident that where there is an abundant supply of low-cost water of a suitable quality, the process would not be cost effective. However, as soon as alternatives are considered, whether seawater cooling with its inherent challenges, or the treatment of seawater, brackish water or treated sewage effluent, manipulated osmosis provides an economical and technically attractive solution.

The process is unlikely to be suitable for hyperbolic natural draft cooling towers, owing to the high drift losses associated with such installations. However, it is ideally suited to forced draft towers with appropriate drift eliminators.

The system can be easily retrofitted to existing installations, where a suitable source of raw water is available to feed the process. An important consideration is that it is quite easy to revert to a conventional make-up source, in the very unlikely event of plant failure, which of course, can be minimised with appropriate design measures. The simplicity of such a switch is illustrated in Figure 5, where initially, the cooling tower uses potable water for make-up to increase the sump level, followed by a simple switch to manipulated osmosis, which then maintains the level, replacing the evaporation, drift and blowdown losses.

OTHER MAKE-UP WATER SOURCES

The manipulated osmosis process is a new process that provides an alternative solution to traditional water sources and has distinct economic and technical advantages in particular situations. For ease of comparison, the process is compared with seawater and treated sewage effluent water sources, both

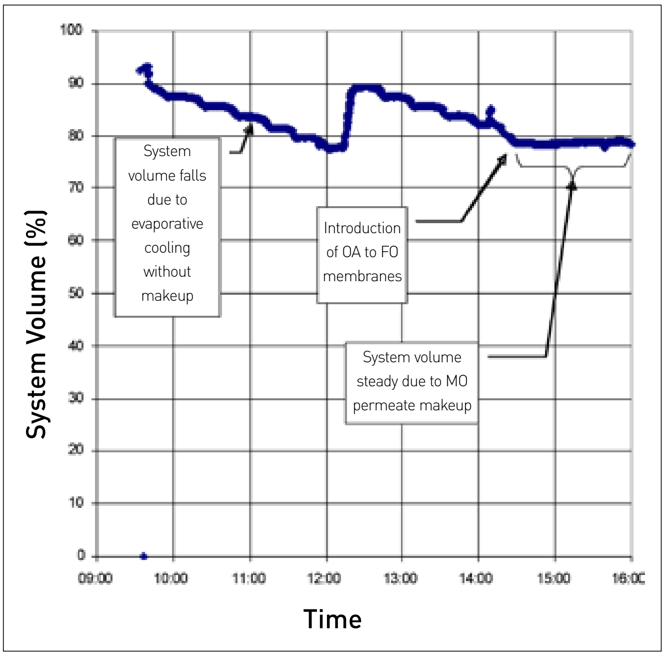

Figure 5: Manipulated osmosis operational

of which have a role to play, depending on local conditions.

CONCLUSION

The low-energy, low-fouling membrane-based process has the potential to open up evaporative cooling to sites, where up until now, it has been considered uneconomical.

While this application for the technology is new, Modern Water already has several years operating forward osmosis based processes in very challenging environments, using the same key components. All three of Modern Water's operational manipulated osmosis-based plants have demonstrated that the process is far less prone to fouling than reverse osmosis and, therefore, there can be a high degree of confidence in the robustness and reliability of the core aspect of the process.

The process lends itself to being retrofitted to existing installations, especially if there is an existing reverse osmosis plant supplying the make-up water, as all the intake and pre-treatment systems will already be in place.

Obviously, the opportunities for the economic deployment of the process are site-specific, and will depend on the availability of a suitable feedwater and the cost of power at the site. Where the cost of power is high, the advantages of using this system become greater, relative to desalinated or tertiary treated effluent, if these are being considered. ■

Peter Nicoll is a desalination specialist with over 25 years' experience in engineering and project management, especially in the design and operation of large desalination plants, business development, sales of capital equipment and professional services throughout the world. He is also the inventor of a number of patented processes relating to Modern Water's technologies. Nicoll is a Chartered Engineer and a Fellow of the Institution of Mechanical Engineers. He can be contacted at Peter.nicoll@modernwater.co.uk.

	SEAWATER	TREATED SEWAGE EFFLUENT	MANIPULATED OSMOSIS
Feed water availability	Unlimited, but requires proximity to the sea	Limited availability, transport of effluent to the point of use, subject to seasonal and population effects.	Unlimited, but requires a source of feed water (seawater, brackish water, treated effluent)
Cycles of concentration	1.2 – 1.5	2.0 – 2.5	4 - 5
Materials	Special materials required for pipework, heat transfer surfaces (titanium, cupro-nickel etc)	No special materials required for heat transfer surfaces	No special materials required for heat transfer surfaces
Chemicals	Requires significant quantities of chemicals including continuous use of oxidising biocides	Careful monitoring required to ensure biological and corrosion controls remain in place, due to wide variability of incoming sewage effluent	Requires replacement of lost osmotic agent to maintain concentration in cooling water. Blowdown recovery system minimises this loss and other chemical additives to the cooling water
Drift	Salt-laden drift requires careful selection of the site, can cause corrosion damage to surrounding structures and may affect local flora and fauna	Public perception issues associated with airborne treated sewage water	No detrimental affects to surrounding structures and flora and fauna
Other issues	Introduction of solids and biological materials from the marine environment, with potential detrimental effects on heat transfer and tower fill materials	Public perception. Disposal of blowdown due to high phosphates and nitrates. Membranes prone to fouling	Membranes not prone to fouling

Table 1 - Alternative make-up Water Sources