MANIPULATED OSMOSIS APPLIED TO EVAPORATIVE COOLING MAKE-UP WATER – REVOLUTIONARY TECHNOLOGY

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Abstract

Modern Water is in the process of developing a number of manipulated / forward osmosis based technologies, ranging from desalination to power generation. This paper outlines the progress made to date on the development and commercial deployment of a forward osmosis process applied to evaporative cooling tower make-up water.

Evaporative cooling requires significant amounts of good quality water to replace the water lost by evaporation, drift and blowdown. This water can be provided by conventional desalination processes or by the use of tertiary treated sewage effluent. The conventional processes are well documented and understood in terms of operation and power consumption. Modern Water has successful developed and demonstrated a new process that provides make-up water directly, using their platform 'manipulated osmosis' technology.

This new technology shows significant promise in allowing various raw water sources, such as seawater, to be used directly in the manipulated osmosis step, thus releasing the use of scarce and valuable desalinated water for other more important uses. The paper presents theoretical and operational results for the process, where it is shown that the process can produce make-up water at lower capex and a fraction of the opex, when compared to conventional processes. Results on the inherently low fouling propensity of the forward osmosis membranes are also reported.

I INTRODUCTION

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 [1] and Abu Dhabi, legislative changes prohibit the use of mains supplied water for new installations.

In California the use of open seawater intakes for once through cooling of power stations is being actively discouraged [2], primarily driven by the need to protect the marine environment and is the subject of some debate about suitable economically viable alternatives.

It is in this climate, with increasing demands on our resources, that Modern Water has developed a new and ground breaking technology for the preparation of make-up water from impaired water sources, ranging from seawater to treated sewage effluent. This process uses manipulated osmosis, a low pressure and low energy process, to produce permeate quality make-up water. 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 desalinated water substitution. Thus freeing up valuable potable water or treated sewage effluent for more appropriate use.

II 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 the 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 (Figure 1). A good example of this in nature is the mechanism whereby plants take up moisture in their root systems and become turgid.

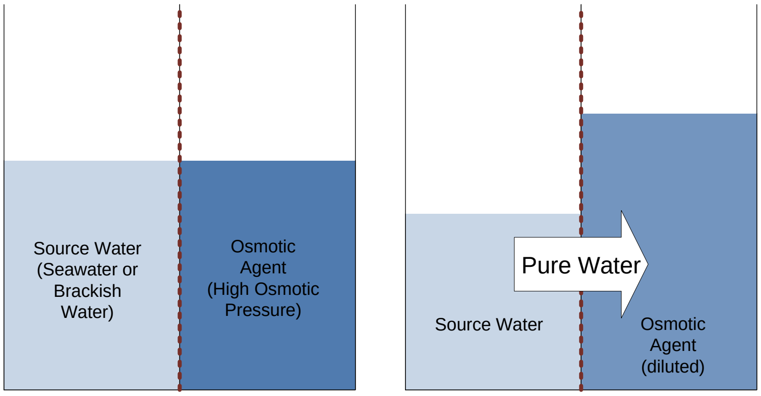

Figure 1: Manipulated / Forward Osmosis

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. 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 to 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 USA. HTI's emergency sugar drink [3] 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 [4], and Modern Water's evaporative cooling make-up water system, the subject of this paper.

2.1 Manipulated Osmosis and Evaporative Cooling

Having established the basic principles of manipulated osmosis, we can now look at how it may be simply 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 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. 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 lost in the process. Figure 2 illustrates a typical arrangement.

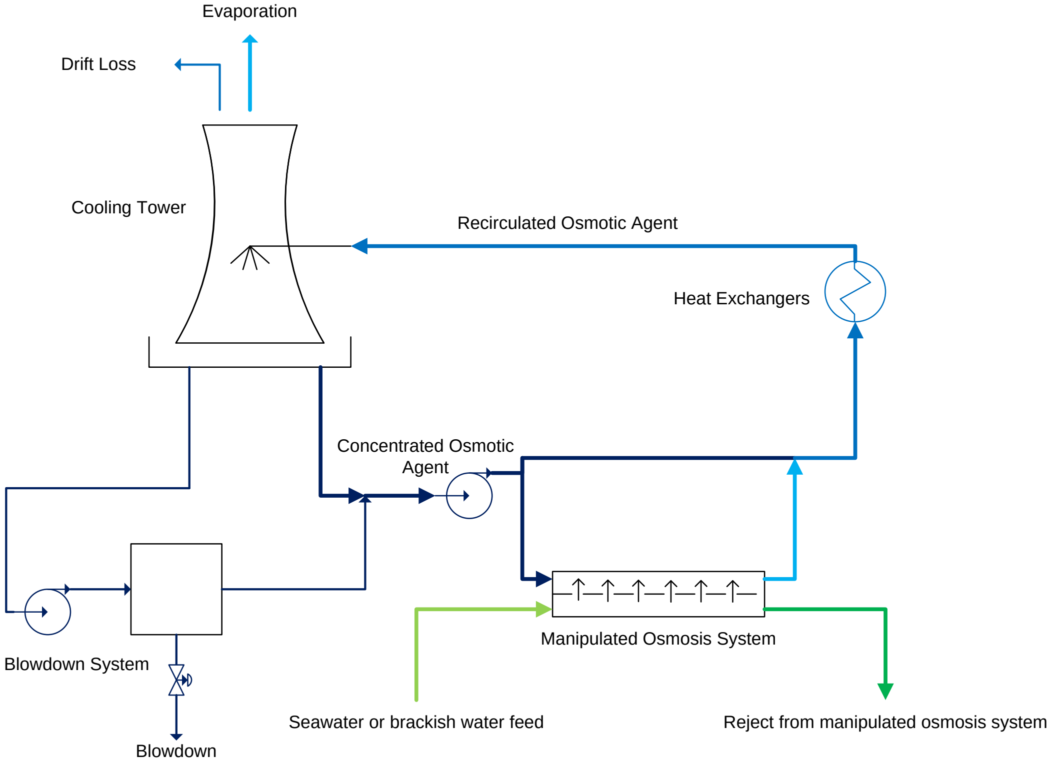

Figure 2: Evaporative Cooling Make-up Water Process

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.

2.2 Forward Osmosis Membranes

These membranes operate at low pressure, typically 2-3 barg on either side of the membrane with minimal pressure loss. Recovery on the feed water side is similar to that of a reverse osmosis plant, with similar limitations based on scaling depending on the feedwater source.

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 membranes are contract manufactured specifically for Modern Water and to our specific design requirements. It is worthy of note that there have been a number of design/specification improvements over the last three years, with significant improvements in the bulk permeability. The details are commercially sensitive and so are not presented here.

2.3 Osmotic Agent

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 cooling water system there is a need for chemical conditioning of the recirculating osmotic agent (cooling water), to minimise biological material and to ensure and to ensure the metallic materials are suitably protected from corrosion.

As part of the ongoing development of the process and in particular the chemistry and it’s compatibility both with the forward osmosis membranes and just as importantly the common materials found in cooling water circuits. A detailed investigation was undertaken to measure the corrosion rates of various metals that may be used in cooling water systems.

These tests were done on the operational demonstration unit, with seawater used as the raw water and an osmotic agent (cooling water) with an osmotic pressure of 55 barg, using both corrosion test coupons and real time on-line corrosion monitors. The materials tested were carbon steel, 304 stainless steel, 316 stainless steel and copper. The results indicated little or no corrosion of the stainless steels and copper, with some corrosion of the carbon steel. The corrosion rates of the carbon steel were significantly reduced after the addition of a corrosion inhibitor based on a blend of phosphonates and carboxylic acids. These results will be reported in a future paper.

Further work has been done to determine whether bacteria hazardous to human health were able to grow in the untreated osmotic agent, specifically *Legionella pneumophila* and *Pseudomonas aeruginosa* commonly found in cooling towers. Tests were undertaken at different concentrations of osmotic agent (without any biocide) to determine the minimum inhibitory concentration. It was found that *Legionella pneumophila* was unable to grow, but *Pseudomonas aeruginosa* was able to grow and multiply. The fact that the Legionella was unable to grow is particularly significant given its potential to harm human health. These results will also be reported in a future paper.

2.4 Blowdown

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 chemicals and therefore further improve the economics. There is clearly a loss to the atmosphere via drift, however with modern drift eliminators this is insignificant.

The blowdown system is primarily membrane based using ‘loose’ membranes because of the nature and molecular weight of the osmotic agent. It has the added advantage that any large molecular weight additives used in the cooling water are retained and therefore a reduction in chemical usage can be achieved. This is an area of ongoing work and may be reported in a future paper.

2.5 Input from manipulated osmosis desalination application

At the heart of this process is the same core technology that Modern Water has successfully applied on challenging feedwaters in operational plants at a number of locations across the world. This experience helps Modern Water respond confidently to questions regarding how well the system will perform in real-world conditions.

In September 2008, Modern Water successfully commissioned the world’s first manipulated osmosis desalination plant located in Gibraltar on the Mediterranean Sea. The local water utility, AquaGib, completed rigorous testing procedures of the product water and on 1 May 2009, water was exported and put into the public water supply. The export of water has continued since that time.

A year later, in September 2009, a larger seawater plant was installed in the Sultanate of Oman at the Public Authority of Electricity and Water’s (PAEW) site at Al Khaluf, shown in Figure 3. PAEW selected this site because of the extremely challenging seawater, taken from a very shallow open seawater intake which was sometimes exposed at low tide. The plant shares a common pre-treatment with an existing similarly sized seawater reverse osmosis facility, thus providing a unique opportunity to trial the two technologies on a like-for-like basis.

The results from Modern Water’s Al Khaluf plant [3] were significantly better than expectations, in particular on resistance to fouling and product water quality. The key input to the evaporative cooling process is that despite the atrocious feed water conditions at Al Khaluf, the forward osmosis membranes have not required cleaning in over a year of operation. This contrasts with the conventional reverse osmosis plant which has required cleaning every two to four weeks and has had a number of membrane changes. This clearly demonstrates the inherent low fouling of the forward osmosis based processes.

Figure 3: Al Khaluf, Oman

2.6 Demonstration plant

Further confidence in the operation of the system has been obtained following the operation of Modern Water’s demonstration / pilot plant. This facility allows the process to be trialled at different Client sites. A pre-requisite was that the design of the plant should not interrupt the operation of an existing cooling water system, so that there was little or no risk to the Client. In order to do this, the plant is completely self-contained and equipped with its own evaporative cooling system. A separate heat exchanger is installed between the heat load supplied by the host.

The demonstration unit is housed in a 20-foot container, with an external packaged evaporative cooling tower with a nominal cooling capacity of 50 kW.

Feed water can be supplied from any appropriate source ranging from treated sewage effluent to seawater. The plant incorporates a full pre-treatment system for the raw water, based on multi-media filtration. Other systems include the manipulated osmosis membranes and the osmotic agent blowdown recovery system. Hence all aspects of the process can be demonstrated on a Client site.

The plant is currently being trialled on a petrochemical plant in Sohar, Oman (Figure 4).

Figure 4: Demonstration Plant

III CAPEX AND OPEX

The capital cost of a system will be similar to that of a conventional reverse osmosis plant designed to operate on the same feed water. Unlike the conventional plant which may use exotic super duplex stainless steels, the manipulated osmosis based system makes extensive use of lower cost plastic components because of the low operating pressures.

Let us make the assumption that capex costs are the same for the manipulated osmosis and reverse osmosis processes 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.

3.1 Power consumption comparison

This comparison is based on the following assumptions:

- Feedwater temperature 25ºC
- Pre-treatment requirements the same for MO and RO
- Pump overall efficiency 70%
- Energy recovery efficiency 70%
- Pressure loss across MO membrane systems including pre-treatment 3 bar
- Maximum conversion with MO limited to 30% (very conservative)
- Conversion for RO, 80% - 41% depending on feed TDS
- Cooling tower concentration ratio 5

Figure 5 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).

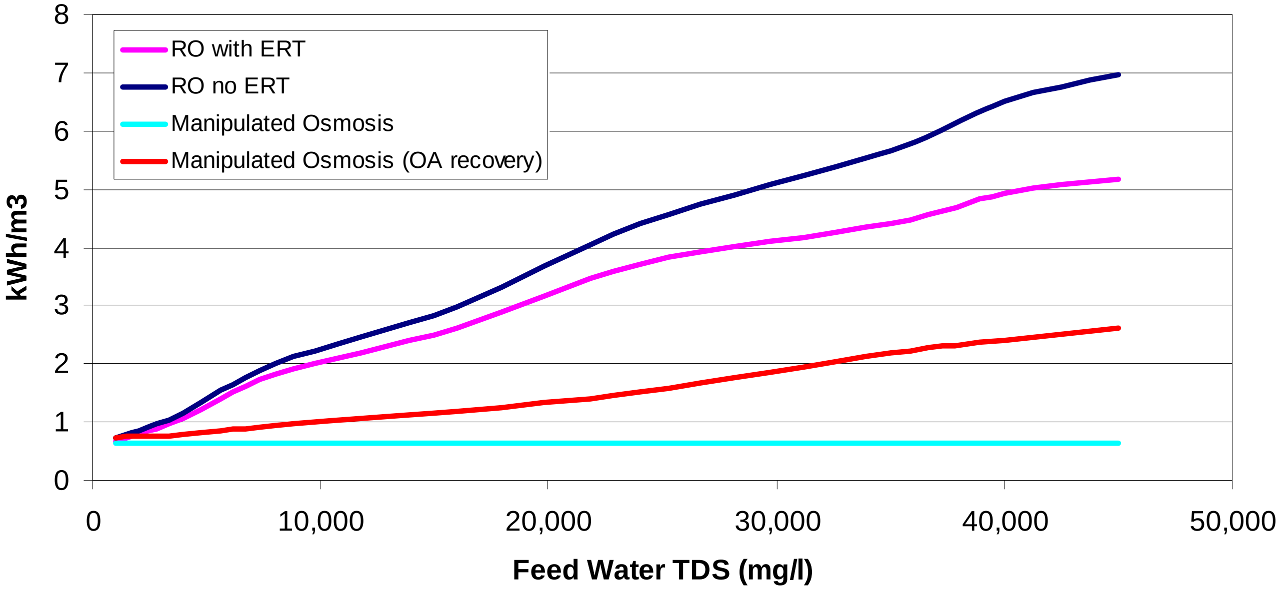

Figure 5: Power Consumption Comparison

3.2 Power and Chemical Operational Costs

It is interesting to note that in the case of manipulated osmosis, without using the osmotic agent recovery system on the blowdown 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.

If we now consider the same technical assumptions and the following economic assumptions:

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

Figure 6, 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 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 account of the other advantages when compared to a reverse osmosis based process including: an increased availability, fewer membrane replacement and lower chemical cleaning costs.

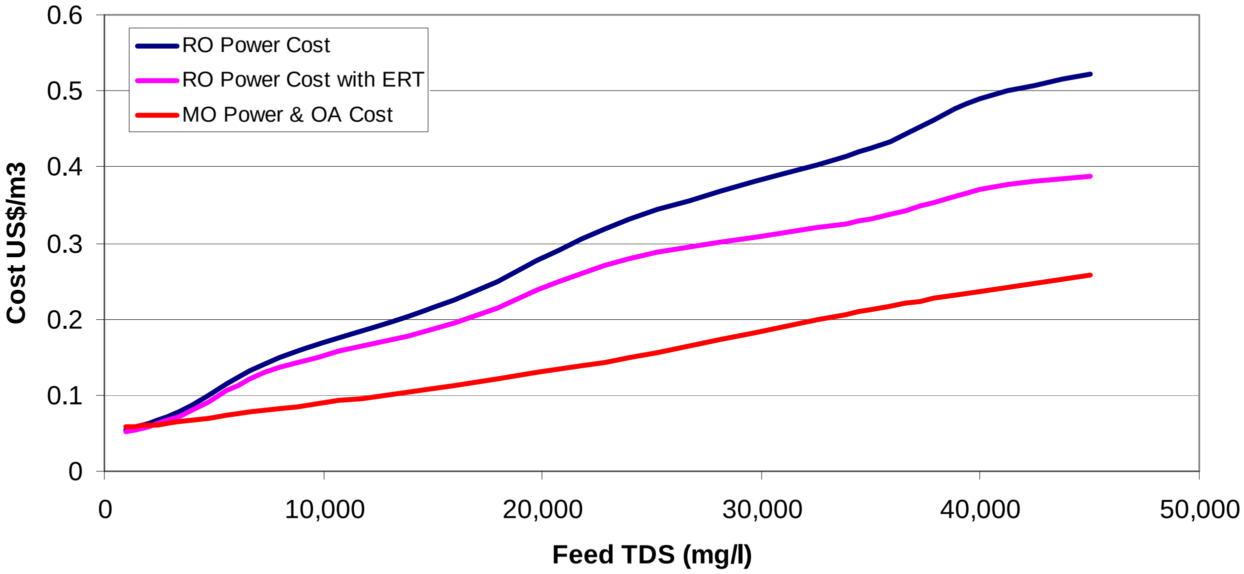

Figure 6: Operational cost comparison

IV DEPLOYMENT OPPORTUNITIES

This innovative technology provides an additional consideration when sitting evaporative cooling towers and the supply of make-up water. Clearly 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, it is clear that manipulated osmosis provides an economical and technically attractive solution.

The process is unlikely to be suitable for hyperbolic natural draft cooling towers because of 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 back 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 7, 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.

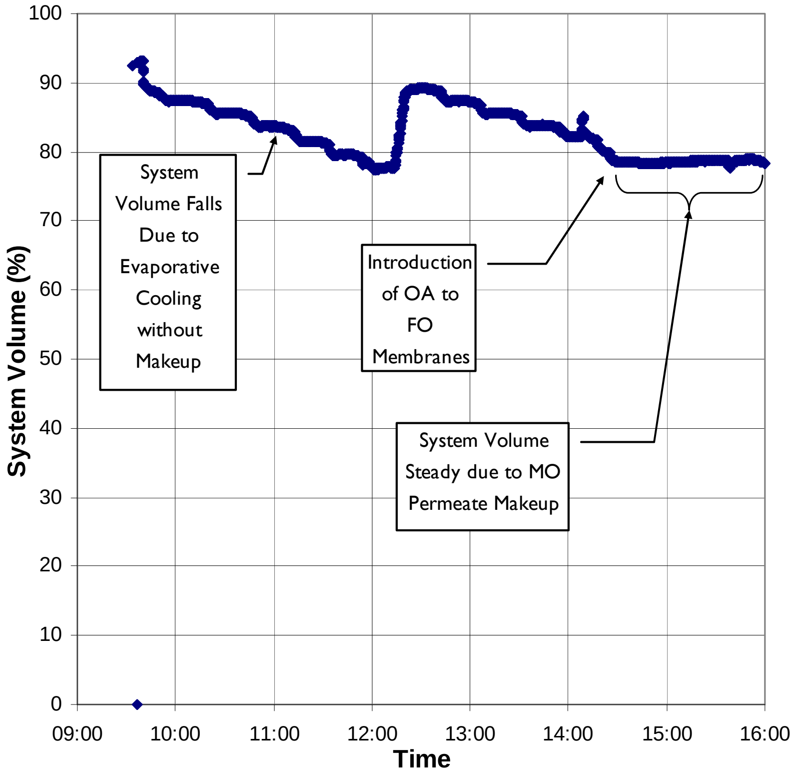

Figure 7: Manipulated osmosis operational

4.1 Other Make-up Water Sources

The manipulated process is a new process that provides an alternative solution to traditional water sources and clearly 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 of which have a role to play depending on local conditions.

Table 1 - Alternative make-up Water Sources

	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

V CONCLUSIONS

‘Desalination’ is not always about producing low TDS water using what is normally an energy intensive process. The manipulated / forward osmosis process has an important role to play in delivering water in a form that is ‘fit for purpose’. In this case providing a source of low TDS make-up water to a recirculating cooling water acting as an osmotic agent (draw solution). The economics and robustness of the process are quite compelling, however as this application of the process is completely new and has not been factored into developers’ planning, it will take some time to become accepted.

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.

This 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 uneconomic.

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.

Clearly 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.

So is the process revolutionary? It can certainly be described as ‘disruptive’ in that a low energy process can be used to desalinate water to a form that is suitable for its intended purpose at considerably lower operational cost than any conventional desalination process. So ‘yes’ it is revolutionary!

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