Institution: University of Surrey

Unit of Assessment: UOA 15 General Engineering

Title of case study:

Low energy production of fresh water from the sea by Forward Osmosis

1. Summary of the impact (indicative maximum 100 words)

University of Surrey has a strong legacy of research into membrane separation and osmosis, culminating the commercialisation of Surrey's spin-out company Modern Water plc. Modern Water plc. was floated on AIM (London Stock Exchange) in June 2007 raising £30m cash with a market value of £70m.

The research itself is having direct impact via the operating desalination plants in Gibraltar and Oman producing high quality drinking water typically using 30% less energy than conventional desalination plants. In Oman, because of the poor quality of the feed water the forward osmosis process uses 42% less energy per litre of water produced when compared to convential equipment. The two plants currently operating in Oman serve 600 people in Al-Khuluf and 800 people in Naghdah.

2. Underpinning research (indicative maximum 500 words)

The Food and Agriculture Organisation of the United Nations (FAO) predicts that by 2025 1.8 billion people will be living in areas of absolute water scarcity, and two-thirds of the world's population will live in water stressed areas. 97.5% of the earth's water is salt water.

Natural osmosis occurs when water passes from an area of low solute concentration to an area of high concentration, through a semi-permeable membrane, equalising the level of concentration between the two areas. By applying high levels of pressure to the process, it is possible to force this water movement to run in the opposite direction (Reverse Osmosis), creating an area of high solute concentration and an area of low solute concentration; when applied to seawater, Reverse Osmosis results in concentrated brine and drinking water. However, due to the large number of different chemical components in seawater, the instruments used during the desalination process suffer from significant corrosion, fouling and scaling problems, all of which increase the cost of operation by increasing energy and chemical consumption. Previously, research into reducing the problem has focused on mechanical solutions, for example the addition of chemicals and frequent filters replacement.

The Centre for Osmosis Research & Applications (CORA) at Surrey University, which was founded in 2003, adopted a different approach by researching the chemistry of seawater, benefiting from a £249,000 award by the Royal Society (Brain Mercer Award for Innovation) and £115,000 from the University SEED fund for the period 2005-2009. Funding has also come from Modern Water plc, £714,000, 2007-2012, and the Medicor Foundation, £120,000, 2012-2014. By building on previous research in membrane separation they found that by adding osmotic agents to a formulated solution, they could manipulate the osmotic barrier and allow only pure water to move from seawater creating a single ionic solution, which did not possess any of the undesirable corrosive, fouling and scaling properties of seawater. By avoiding the problem, rather than just providing a remedy, Surrey has developed a much more sustainable solution.

The Manipulated (Forward) Osmosis Technology process developed at Surrey has a further benefit of being highly efficient. The process begins with the manipulation of the osmotic pressure by adding an osmotic agent to a draw solution, thus allowing water to move from the source, seawater, leaving the salt behind. The resulting diluted solution then undergoes a separation stage using lower cost membrane to produce potable water, while the osmotic agent is recycled for reuse. Manipulated Osmosis provides a fouling resistance *process* rather than a fouling resistance *membrane*, achieved through the selection of osmotic agents that have high solubility and do not foul the membrane.

Research and field trials also confirmed that Manipulated (Forward) Osmosis membranes experience only reversible fouling which can be removed by backwashing, as a result of operating under low pressure with none of the compacting effect which normally occurs at high pressure. The Manipulated Osmosis process has been operating since 2009 in harsh conditions in Oman serving high quality water to the public, without the membranes requiring cleaning. The research undertaken at Surrey has focused on selecting suitable osmotic agents and their regeneration processes, which involves both fundamental and applied studies in physical chemistry and process engineering. Research into the modelling and optimisation of the osmosis processes as well as integrating them with renewable energy sources such as solar thermal has also been undertaken.

The Manipulated Osmosis concept provides a platform technology for applications in renewable energy using the salinity gradient method for clean power production. The Manipulated Osmosis process has also been used in preparing the makeup water for cooling towers and for secondary oil recovery operations among other applications.

The research has also led to new IP to consolidate the background IP in the area of osmotic power and desalination, as well as having the potential to make the step-change in these industries to make them more sustainable and cost effective. The research activities have also been extended to cover other low carbon water treatment methods using electrical and mechanical principles.

3. References to the research (indicative maximum of six references)

1. Bowen, W.R., Sharif, A.O., “Prediction of optimum membrane design: pore entrance shape and surface potential”, Colloids and Surfaces A – Physicochemical And Engineering Aspects, Vol. 20, Issue: 1-3, pp 207-217, (2002). DOI: 10.1016/S0927-7757(01)01023-8

2. Bowen, W.R.; Filippov A.N.; Sharif, A.O., et al., “A model of the interaction between a charged particle and a pore in a charged membrane surface”, Advances in Colloid and Interface Science, Vol. 81, Issue 1, pp 35-72, (1999). PII: S0001 - 868699.00004 – 4.

3. Sharif, A.O., Merdaw, A.A., Al-Bahadili, H., et al., “A New Theoretical Approach to Estimate the Specific Energy Consumption of Reverse Osmosis and other Pressure-Driven Liquid-Phase Membrane Processes”, Desalination and Water Treatment, Vol. 3, Issue 1-3**,** 111-119 (2009). DOI:10.5004/dwt.2009.295

4. Solvent Removal Process, Abdulsalam Al-Mayahi and Adel Sharif, US Patent No: **US 7,879,243**; Date of Patent: Feb. 1, 2011; European Patent No. EP 1651570 Date of Issue: June 8, 2011.

5. Separation Process, Adel Sharif, European Patent number: **EP 2,089142**, Date of Issue: Sept. 9, 2010.

6. Merdaw, A.A, Sharif, A.O., and Derwish, G.A.W., “Mass transfer in pressure-driven membrane separation processes”, Chemical Engineering Journal, Vol. 168, Issue 1, pp 215-228, (2011). DOI: 10.1016/j.cej.2010.12.071

4. Details of the impact (indicative maximum 750 words)

Guildford-based Modern Water plc is a spin-out from the University of Surrey specialising in desalination and water treatment. Prof Adel Sharif developed the desalination technology in the University of Surrey and 5 patent families were filed between 2003 and 2006. The University, its Seed Fund and a Brian Mercer award from the Royal Society, with others (altogether £455,000) funded early proof of concept and commercialisation, and external investors including the IP Group followed with £685,000. IP Group led the flotation on AIM (London Stock Exchange) in 2007 raising £30m in cash and with a market value of £70m with Surrey's desalination technology being the cornerstone of the flotation. Modern Water plc. has offices in the UK, Middle East and China and employs 52 staff, with a turnover of £3.7 million (2012). The company has plans for further expansion. The company provides successful desalination plants in Gibraltar and Oman based on Surrey's Manipulated/Forward Osmosis (FO) technology.

Gibraltar

The plant in Gibraltar produced its first drinking water in September 2008. Having operated over 3 years it has proved that FO has solved the well documented problems of membrane fouling that have existed for over 50 years. FO also scored the highest Coefficient of Desalination Reality (CDR) index of 8.9 of all new technologies in the sector in an independent study by Global Water Intelligence; (**c**).

Oman

A further plant opened in Oman in 2009 with a capacity of 100 m^3/day, operating in the harshest conditions, with both very poor quality water intake and very high salinity. Nonetheless it is producing the highest quality desalinated water (<120 mg/l TDS) very low in boron, with 42% energy saving; (note; in less harsh conditions the FO process achieves over 30% energy saving) as well as other lower operating costs because of reduced chemical usage and no membrane cleaning or replacement (**k**).

In July 2011 Modern Water (**l**) won a competitive tender in Oman for a third commercial FO plant with a capacity of 200 m^3/day. The plant was successfully commissioned in September 2012 and has since been providing the public with high quality water at a reasonable cost. A recent BBC Business News report on this latest Modern Water plant showed how happy the local people are with the quality of water; one of the villagers commented that they only started to drink desalinated water when the new FO plant opened whereas before they used to buy bottled water. The plant has a much lower environmental impact compared to conventional reverse osmosis and thermal desalination plants thereby improving on measures of sustainability.

In December 2012, a framework agreement was signed between Modern Water and Hangzhou Water, a leader in the desalination industry in China. Hangzhou Water has a 60% share in the Chinese desalination market. The framework agreement will allow both organisations to jointly identify and develop projects in China, including seawater desalination plants and other water-related opportunities.

In February 2013 Modern Water raised a further £10m from a share placement, the company maintains a research collaboration with the University of Surrey that has produced a further six desalination-related patents.

Professor Sharif and Modern Water were the winners of the Energy/Environmental award of the pan-European Enterprise ACES Award at the Royal Academy of Engineering in Stockholm on 2 December 2008 for their innovative development of water purification using desalination technologies. The University of Surrey won the Queen's Anniversary Prize for the water research in which Prof. Sharif's work has played a major role.

5. Sources to corroborate the impact (indicative maximum of 10 references)

a) Case study in “The economic benefits of chemistry research to the UK” September 2010, **Oxford Economics**

b) Christopher M. Snowden, Case study in ‘Technological innovation in industry and the role of the Royal Society’, **Notes & Records of the Royal Society**, 2010.

c) Bankratz, T., “FO plant completes 1-year of operation”, **World Desalination Report**, 44, 15 November 2010.

d) Tim Blanchard, “Irrigation with seawater”, ***New Agriculturist***, January 2012.

e) “Low-energy production of fresh water from sea water: manipulated osmosis”, ***Changing Worlds –The Impact of University Research, House of Commons,*** UK, October, 2010.

f) Kate Ravilious, “Add salt as required: the recipe for fresh water”, ***The New Scientists***, August 2010.

g) Peter Wrobel, “Fresh Thinking about Fresh Water”***, Science Business***, 12 March 2009

h) Prof Adel Sharif won European ACES Award, ***Water Desalination Report***, Vol. 44, Issue, 44, December 2008.

i) Phil Chamberlain, “The Stuff of Life”, ***Institute of Engineering and Technology Knowledge Network***, September 2008.

j) Williams, R., “Modern Water Aims to Clean Water by Osmosis”, ***The Independent* Newspaper**, UK, 21 July 2008**.**

k) Public Authority for Electricity and Water, Sultanate of Oman. Contact details provided.

l) CEO, Modern Water plc. Contact details provided.