Mini-Project Mark Sheet

Student: **Richard Smith** **Mark:** fail/satisfactory/good/very-good/excellent

Supervisor:

Feedback:

	Excellent	**Good**	**Average**	**Poor**	**Very Poor**	**Not Done**	**Not applicable**
Introduction to the problem / subject							
Statement of aims							
Experimental description							
Presentation of results / findings							
Quality and depth of discussion / interpretation							
Relevance of conclusions							
Quality of English							
Use of reference material							
Evidence of external reading							
Quality of presentation							
Use of figures							

Comments:

The University Of Sheffield.

E-Futures

Mini-project summary report

Biodesalination: Review of current desalination technology and outlook for a biologically based desalination technology

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Introduction

Freshwater is one of the most essential natural resources, vital for agriculture, human health, economic development and ecosystem stability. Although humans withdraw only fraction of the available global renewable freshwater resources, because water resources are not spread evenly through time or space, approximately 2.4 billion people live in water stressed regions where water withdrawal exceeds supply by renewable sources (Oki and Kanae, 2006, FAO 2007). Water scarcity is likely to become further exacerbated in the future due a combination of climate change, population growth and economic development, increasing the population living in water stressed regions to 2.8-6.9billion by 2080 depending on climate, economic and population projections (Bates 2008).

Demand reduction tools are inherently cheaper than deploying technology to increase supply; however, in regions which are particularly water stressed, an increase in the supply is also needed. Currently, desalination of brackish water (salinity 5000-30000 ppm) or seawater is the only viable technology which can increase supply (Shannon *et al.* 2008, Elimelech and Phillips 2011). Although there have been major advances in desalination technology over the last 40 years the process still remains prohibitively energy intensive, limiting desalinations deployment to wealthy and densely populated water stressed regions (NCR 2008).

In October last year a research group launched a totally new research project, aimed at finding a cheaper and more sustainable and way of desalting water through the use of micro-algae. The conceptual aim is to grow a volume of algae in salt water, reverse the cell surface salt pumps and draw salt from the surrounding saltwater into the cells. The microalgae can then be further processed as a commercial product, such as biofuels, pharmaceutical products and fertilizer. This mini-project was aimed to evaluate the current state of the technology from an energy point of view in order to assess whether biodesalination could ever be a competitor to current technologies, and what role it could take in integrating into them.

Desalination Technology

The desalination stage, where dissolved solutes are removed from feedwater to produce freshwater, is the most energy intensive process of desalination system. The main desalination technologies, categorised by the process of separation, are thermal and membrane desalination (Macedonio *et al.* 2012).

The basic premise of thermal desalination is to heat the saline feedwater to its boiling point in order to generate vapour. This vapour is channelled towards a cooling surface, where it condenses with significantly reduced dissolved solutes (NRC 2008). Multi-stage flash distillation (MSF) is a thermal desalination, which until recently was the most dominant method of desalination due to its large capacity potential and high reliability. Feedwater is taken through and preheated in the ‘stage’ or ‘effect’ chambers, heated in a brine heater, then released into a low pressure chamber. At this lower pressure the boiling point is depressed and part of the liquid instantly flashes into vapour, removing nearly all the dissolved solids. The vapour condenses on the intake pipes, transferring heat and preheating the intake water. Non-evaporated feedwater is channelled to the next chamber at lower pressure causing further partial evaporation. This process continues to the last chamber, where the brine is re-circulated to recover further heat (Khawafi *et al.* 2008). Multi-effect distillation (MED) is an older technology which achieves vaporisation by spraying feedwater onto a heat transfer material which carries and condenses the vapour from the previous chamber. The foremost difference between MSF and MED technologies is that MED uses heat transfer surfaces such as evaporator pipes to vaporise the water, while MSF heats bulk water which is then vaporised at a lower pressure (Khawafi *et al.* 2008). The lack of boiling in MSF averts the problem of scaling on the heat transfer material, which reduces the efficiency of heat transfer and ultimately limits the scale of the plant (as in MED). Consequently, MSF has a very large production capacity, which is the main reason for its dominance in the Gulf States (Macedonio *et al.* 2012). Despite the central design of energy recovery, both processes are very energy intensive which has limited there deployment to energy rich and arid Gulf States (Khawafi *et al.* 2008).

Reverse osmosis (RO) is a non-thermal single phase desalination process. By applying a pressure difference over a hyperfiltration semipermeable membrane, water is able to permeate through, against the osmotic pressure, leaving behind concentrated brine (Fritzmann *et al.* 2007). Improvements in membrane technology and energy recovery devices (which transfer pressure from the concentrated brine back to the feedwater) over the last few decades have led to a dramatic decline in both the cost and energy consumption of RO (Elimelech and Phillips 2011).

The main limitations of RO are the problems of membrane fouling, from chemical and biological precipitation, and the strong relationship between salinity and energy consumption. As a higher salinity increases the osmotic pressure, hydraulic pressure must increase to maintain flux, which increases energy consumption (Fritzmann *et al.* 2007).

Energy Use

The process of desalination requires a theoretical minimum amount of energy, independent of the method employed (Elimelech and Phillips 2011). This minimum energy requirement can be calculated from the understanding that desalting water is a reversible thermodynamic process, where the minimal isothermal reversible energy used to separate the molecules will always be at least equal but opposite in sign, to the free energy of mixing (NCR 2008, Semiat 2008, Elimelech and Phillip 2011). The free energy of mixing is closely related to the temperature and osmotic pressure within the solution. As more water is recovered, the feedwater becomes more saline and the energy needed to separate the molecules increases. At a 50% recovery and 25°C temperature, a minimum of 1.06 kWh would be required to desalinate a meter cube of 35,000 ppm salinity seawater.

In practice, desalination processes are irreversible and operated at high rates, incurring inherent energy loses. Consequently, the actual energy consumptions of the various desalination methods will always be larger than the theoretical minimum (Table 1). In thermal distillation the main energy losses are friction, heat loss to the environment, heat loss due to minimal driving force, and heat loss due to boiling point elevation (Semiet 2008, Elimelech and Phillip 2011). Dual purpose thermal plants, which combine the generation of electricity with thermal desalination, can reduce this energy use at a cost to electrical production (NCR 2008). It is important to note that unlike RO, thermal desalination costs are nearly independent from feedwater salinity because the ebullioscopic increase in the boiling temperature of water caused by the addition of solutes is small relative to the range of seawater concentrations (Fritzmann *et al* 2007). With RO desalination, in order to operate at a high flux (needed due to the high capital cost of the installation), the hydraulic pressure needs to be significantly higher than the osmotic pressure, which incurs higher energy consumption (Fritzmann *et al.* 2007, Elimelech and Phillip 2011). In addition to the energy costs of the desalination process the vital stages of pre-treatment, post-treatment and pumping systems consume around 1.2-4.5 kWh m^{-3} (Semiet 2008)

Table 1. Comparison of seawater desalination processes. Adapted from Semiat 2008[a], Verripaneni *et al.* 2007[b], Macedonio *et al.* 2012[c]. Energy consumption includes pre-treatment, post-treatment and pumping systems. Energy reported in kWh m^{-3} of freshwater produced.

Desalination Method	Energy Consumption (work eq.) (kWh m^{-3})	Method of operation	Recovery %	Capital cost
MSF (dual purpose)	17-58 (~17) [a]	Heat and vacuum [b]	40%[c]	High [b]
MED (dual purpose)	15-58 (5.2) [a]	Heat and vacuum [b]	40%[c]	Medium-High [b]
RO	3-6.7 [a, c]	Pressure [b]	40-60%[c]	Medium [b]

Biodesalination

Currently desalination research is focused on material improvements for the RO process, such as creating membranes with ultra-high permeabilities (Majumder *et al.* 2005, Scholl and Johnson 2006, Falk *et al.* 2010). These advances will not reduce the absolute energy consumption significantly as we are already close to theoretical minimum (Shannon *et al.* 2008, Elimelech and Phillps 2011). Because of the small potential gains made by improving the desalination stage of the process it may be more effective to focus research in improving the efficiency of pre-treatment processes and renewable energy integration (Elimelech and Phillps 2011).

Solar based biodesalination is unlikely to be more energy efficient than current methods, however as most of the operating cost of desalination is from energy consumption, using a free renewable energy source, biodesalination could be a more economical and low-tech method, suitable for deployment in developing countries. Additionally if biodesalination achieves only partial desalination, it could be integrated with RO desalination to dramatically reduce the RO energy consumption.

Algae based systems for wastewater treatment have been in development for 3 decades, and despite being found to be potentially cheaper, more effective, and environmentally friendly than conventional treatment it has failed to become a standard process (Rawat *et al.* 2011, Olguín 2003). As with algal biofuels the main problem is separating the cells from the liquid, which is an energy intensive process (Molina Grima *et al.* 2003, Williams and Lauren 2010, Christensen and Sims 2011, Table 2).

Flocculants are used to aggregate cells to increase their effective size, reducing the cost and difficulty of harvesting dramatically (Molina Grima *et al.* 2003). Current chemical flocculants are expensive and can contaminate the biomass (Brennan and Owende 2010). Bioflocculation is a potentially cheaper and non-toxic alternative; however the flocculating mechanisms of the active flocculant component, extracellular polymeric substances, are poorly understood (Salehizadeh and

Shojaosadati 2001, Christensen and Sims 2011). Further research is needed to understand these mechanisms in order to engineer a method of inducing bioflocculation for commercial use.

Table 2. Summary of different harvesting methods (Uduman *et al.* 2010).

Harvesting method	Energy Consumption (m^{-3} of dry algal biomass)	Limitation
Centrifugation	8kWh m^{-3}	High energy input
Gravity Sedimentation	0.1kWh	Process slow
Pressure Filtration	0.88kWh m^{-3}	Filters need replacement
Flotation (DAP)	10-20 kWh m^{-3}	High energy input

Conclusion

Desalination technology has improved dramatically over the last 40 years, with the emergence of RO as the dominate process. Despite huge advances, the process remains energy intensive. Future improvements may reduce this energy consumption; however the minimal energy requirement dictates that desalination will always be an energy intensive process. By integrating renewable energy into the desalination process, the environmental impact and cost can be reduced to a more sustainable level. The concept of biodesalination offers an alternative to the current methods of desalination. Amongst the many technical challenges this technology faces is liquid cell separation. Bioflocculation is a promising method for energy efficient harvesting for biodesalination as well as algal biofuel, wastewater applications. Further research is needed to fully understand the mechanisms of flocculation and influences of potential induction agents.

This summary is a very brief overview of the work in this project; please refer to the full report for further details.

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