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ENERGY EFFICIENT STRATEGIES AND RENEWABLE ENERGY TECHNOLOGIES FOR DESALINATION

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ABSTRACT

Energy is often the most significant factor in the affordability and sustainability of treating various different source waters with reverse osmosis membrane facilities. More than 33% of the cost to produce water using reverse osmosis (RO) technology is attributed to electrical demands. The largest energy-consuming component of the overall treatment are the high pressure pumps required to feed water to the process. Because of the high energy burden and production of greenhouse gas (GHG) emissions, renewable energy is being increasingly considered for desalination projects. The selection of the appropriate renewable energy resource depends on several factors, including plant size, feed water salinity, remoteness, availability of grid electricity, technical infrastructure, and the type and potential of the local renewable energy resource. The cost of desalination with renewable energy resources, as opposed to desalination with conventional energy sources, can be an important alternative to consider when reduced environmental impact and lower gas emissions are required. Considering the proposed climate protection targets that have been set and the strong environmental drivers for lowered energy usage, future water desalination and advanced water treatment systems around the world could be increasingly powered by renewable energy resources. In addition to renewables, energy optimization/minimization is deemed critical to desalting resource management. Methods employed include enhanced system design, high efficiency pumping, energy recovery devices and use of advanced membrane materials.

INTRODUCTION AND OBJECTIVE

Energy is often the most significant factor in the economics of treating different source waters with reverse osmosis membrane facilities. Despite the large energy investment in desalination facilities, the global installed capacity continues to expand rapidly. Until recently, conventional fossil fuel based power plants have been utilized as the primary source for supplying energy to seawater desalination plants. However, the use of fossil fuels for generating power has spurred environmental concerns, specifically with GHG emissions. Thus, there are a large number of energy minimization approaches and renewable energy alternatives being developed, investigated and implemented around the globe. The applicability of a particular alternative is inherently dependant on the maturity of the technology, the geography-specific abundance of natural resources, a feasible means of handling renewable energy power intermittency, technological and economic scale-up issues and permitting issues.

To enable utilities to meet the increasing need for desalination and water reuse facilities, a study was undertaken to develop a knowledgebase on the most updated developments in energy minimization and renewable energy techniques for desalting processes. This paper presents a summary of some of the important aspects of energy minimization and renewable energy.

ENERGY CONSUMPTION

More than 33% of the cost to produce water using RO technology is attributed to the electric power requirements. When the RO process is considered, energy consumption is the major cost component while treating water with a high TDS content. As shown in Figures 1 and 2, the high pressure pumps required to feed the water for the first pass of the RO process are the largest consumers of the overall process power usage [1]. More than 33% of the cost to produce water is attributed to electric power requirements. In an RO process, the energy requirement increases with salt concentration in the feed water. In thermal-based processes the energy requirement is independent of feed water salinity. Energy is therefore a determining factor in the economics of treating different source waters and demonstrates the vulnerability of desalination to energy costs which encompass 40% of the cost of the produced water for RO membrane facilities to 60% of the cost of the produced water for thermal facilities [2]. Hence, reducing energy consumption is critical in lowering the cost of desalination.

UTILIZATION OF RENEWABLE RESOURCES

Renewable energy sources can provide thermal energy (solar collectors, geothermal energy), electricity (photovoltaics, wind energy, solar thermal power systems), or mechanical energy (wind energy). All these forms of energy can be used to power desalination and water reuse plants. The selection of the appropriate renewable energy resource depends on several factors including plant size, feed water salinity, remoteness, availability of grid electricity, technical infrastructure, and the type and potential of the local renewable energy resource. The applicability of renewable energy resources for desalination strongly depends on the local availability of renewable energy and the quality of water required after treatment. In addition, some combinations of resources are better suited for large size plants, whereas others are better suited for small-scale applications. Other important factors that need to be considered are the capital cost of the equipment and the land area required for the equipment installation.

When considering resource availability, solar thermal energy and photovoltaics are considered to be a better choice over wind and geothermal energy which are location-dependant. When considering the continuity and predictability of power output, geothermal energy is the most reliable resource as the output is intermittent and less predictable for solar thermal, photovoltaic, and wind energy. With respect to plant size, a majority of the energy applications for small size plants with a capacity of 1 – 50 m^3/d of water production capacity consist of different types of solar energy. Wind energy is applied predominantly for medium size plants with a capacity of 50 – 250 m^3/d of water production capacity. Geothermal energy is applied mostly to large size plants with a water production capacity exceeding 250 m^3/d. Although the initial capital installation cost and various system components are still expensive compared with use of traditional fossil fuel energy supplies, the cost of renewable energy technologies, especially photovoltaics, is expected to decrease substantially by the year 2020 due to the maturity of the technology. Several incentives are offered worldwide for utilization of renewable energy technology that further support declining costs for renewable energy relative to conventional supplies.

COSTS OF RENEWABLE ENERGY RESOURCES

A detailed cost analysis is necessary for important investment decisions. In the literature, the calculation of desalination costs is based on different assumptions by various authors. For example, there could be significant variations in the interest rates and life expectancy of the equipment. In some cases, the estimation of fresh water cost does not include the investment cost, labor or other operational costs [3]. Cost estimates for brackish and seawater desalination using conventional and renewable energy resources are listed in Table 1. The cost of water produced from desalination systems using a conventional source of energy, such as gas, oil or electricity can be lower when compared to the cost of water produced from desalination systems using a renewable energy resource,

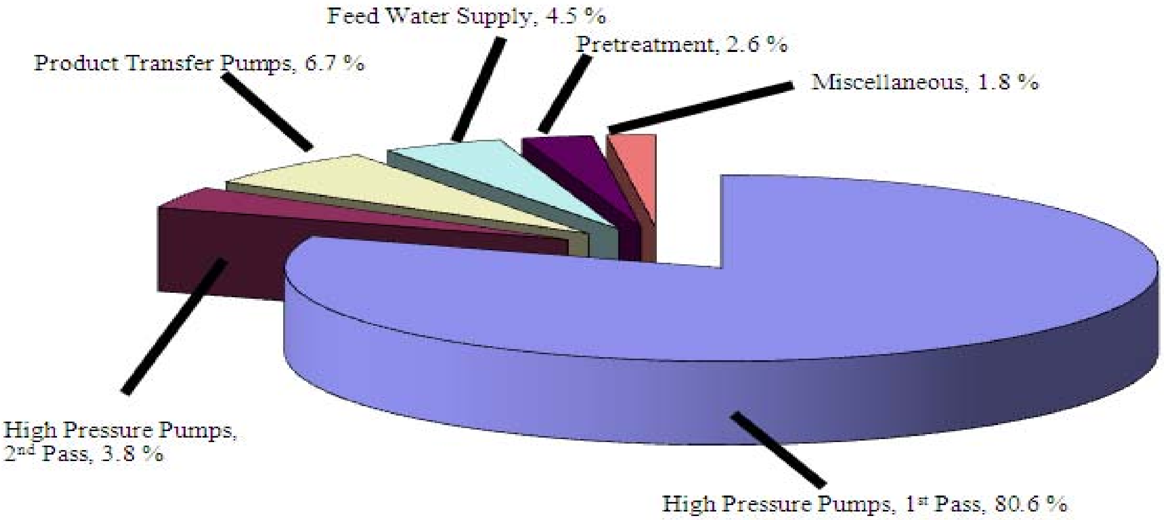

FIGURE 1 POWER USAGE IN A RO SEAWATER PLANT WITH PARTIAL SECOND STAGE [1].

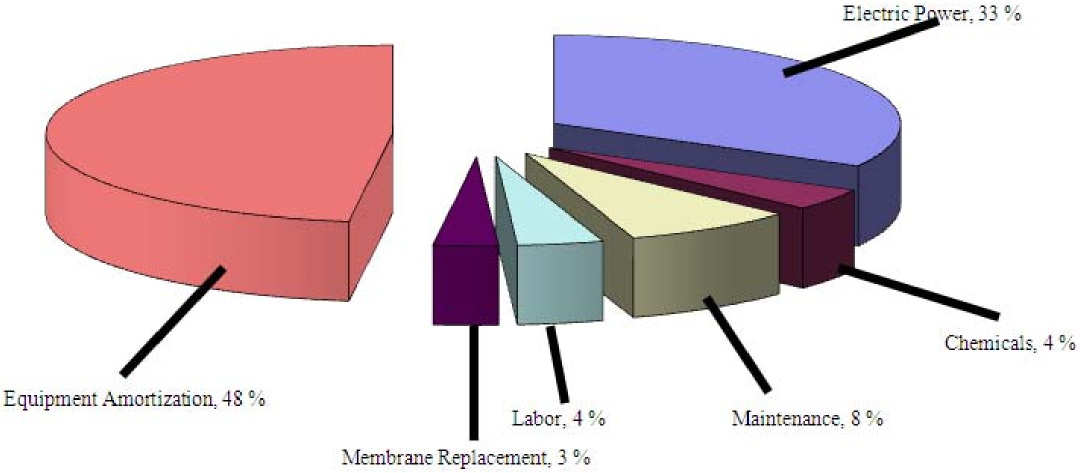

FIGURE 2 WATER COST COMPONENTS IN A RO SEAWATER PLANT [1].

TABLE 1 COST OF WATER PRODUCED BASED ON THE TYPE OF ENERGY SUPPLY SYSTEM.

Feed water type	Type of energy	Cost ($\$/m^3$)	Source of information
Brackish	Conventional	0.26 - 1.33	[5-7]
			[8,9]
			[10,11]
	Photovoltaics	5.57 - 12.77	[12]
	Geothermal	2.47	[12]
Seawater	Conventional	0.43 - 3.34	[5,6]
			[13,14]
	Wind	1.24 - 6.19	[12,15]
			[16,17]
	Photovoltaics	3.88 - 11.14	[16]
	Solar Collectors	4.33 - 9.90	[12,18]

depending on the cost of electricity, inter-grid connection, and the availability and variability of the renewable energy resource. For systems treating brackish water using a conventional source of energy, the total cost of water produced ranges between \$0.26/m^3 (\$1 per 1000 gallons (gal)) and \$1.33/m^3 (\$5 per 1000 gal) with the higher cost representing plants which are small in size. Seawater desalination plants have a total cost that varies between \$0.43/m^3 (\$1.6 per 1000 gal) and \$3.34/m^3 (\$12.6 per 1000 gal) with the higher cost representing small plants with 2 – 3 m^3 daily production. The capital cost of desalination using renewable energy resources is high now due to lack of infrastructure and the need for capital intensive installations. The cost of desalination with renewable energy resources, as opposed to desalination with conventional energy sources, can be an attractive solution when reduced environmental impact and lower gas emissions are required.

ENERGY MINIMIZATION

Minimization of energy consumption while using RO for desalination can be achieved using several methods. These methods are enhanced system design, high efficiency pumping, energy recovery devices, use of advanced membrane materials, application of new technologies, and renewable energy utilization.

Design and configuration of the membrane unit can have a significant effect on the performance and economics of the RO plant. The reduction in pressure drop by using a single stage instead of a two stage system can result in a 2.5% lower power requirement. Optimization of energy consumption for an RO process treating high salinity feed water can also be performed by using a hybrid system with concentrate staging. More than 5% and 12% reduction in energy consumption is obtained by using brackish water and nano-filtration elements, respectively, instead of using seawater elements alone. The use of high speed and high flow pumps at lower total dynamic head can result in optimal speed for highest efficiency. The use of energy recovery devices can result in reducing energy consumption by about 2.0 kWh/m^3 (7.5 kWh/1000 gal) of water produced. Several energy recovery devices are available and proper choice of the equipment should be based on efficiency, availability, potential energy savings, and cost.

Significant improvements in the salt rejection capacity and permeability of the RO membranes for treating high salinity feed water have also been achieved in recent years through the development of nano-composite, nanotube, and biomimetic RO membranes. Initial results have indicated that the new type of membranes utilizing can reduce energy consumption by almost 20%. However, the technology involving advanced membrane material is still under development and pilot-scale or full-scale data are not available. New technologies such as forward osmosis, membrane distillation, ion concentration polarization, and Voltea process show promise in reducing the energy consumption for desalination but the technologies are still under developmental stage and operational data are not available.

GHG EMISSIONS

When considering GHG emissions from various desalination technologies, the emissions from an RO system are an order of magnitude lower than those from corresponding thermal processes. This section provides a comparative evaluation of GHG emissions from the three most commonly used desalination technologies, namely, multi-stage flash evaporation, multi-effect distillation, and RO. Table 2 shows CO_2 and NO_X emissions reported by Raluy et al. [4] for these three desalination technologies. The assessment was conducted by applying life cycle analysis to examine cradle-to grave consequences of making and using products and services, energy and material usage and waste discharges. The results suggest that the emissions from the RO system are an order of magnitude lower than those from thermal processes. The primary sources of electricity used for this analysis were in terms of origin: 43% thermal, 40% nuclear and 17% hydropower. The energy consumption of RO desalination technology has progressively declined in recent years due to the installation of energy recovery systems, utilization of more energy efficient membranes, and better system designs. An analysis was conducted by Raluy et al. [4] to show how utilization of less energy reduces the life cycle emissions of the primary GHGs. The results shown in Figure 3 indicate that both CO_2 and NO_X emissions drop as less energy is consumed, but the rate of emission reduction is faster for NO_X which has about 300 times more global warming potential than CO2 emission. Recent results indicate that as energy

TABLE 2 GHG EMISSIONS PRODUCED BY DESALINATION SYSTEM (ADAPTED FROM [4]).

Technologies	Emissions/m^3 desalted water		Design assumptions
	CO_2 (Kg)	NO_x (g)	
MSF	23.41	28.3	• Brine recycle flow with high temperature anti-scale treatment and cross tube configuration • Average 45,000 m^3/day of desalted water • Thermal energy consumption is 333 MJ/m^3 of desalted water • Mechanical energy consumption is 4 kWh/ m^3 of desalted water
MED	18.05	21.41	• Horizontal falling film and high temperature anti-scale treatment • Average 45,000 m^3/day of desalted water • Thermal energy consumption is 263 MJ/m^3 desalted water • Mechanical energy consumption 2 kWh/m^3 of desalted water
RO	1.78	3.87	• Consists of eight trains • Average 46,000 m^3/day of desalted water with 8000 h of operation per year • Mechanical energy consumption is 4 kWh/m^3 of desalted water

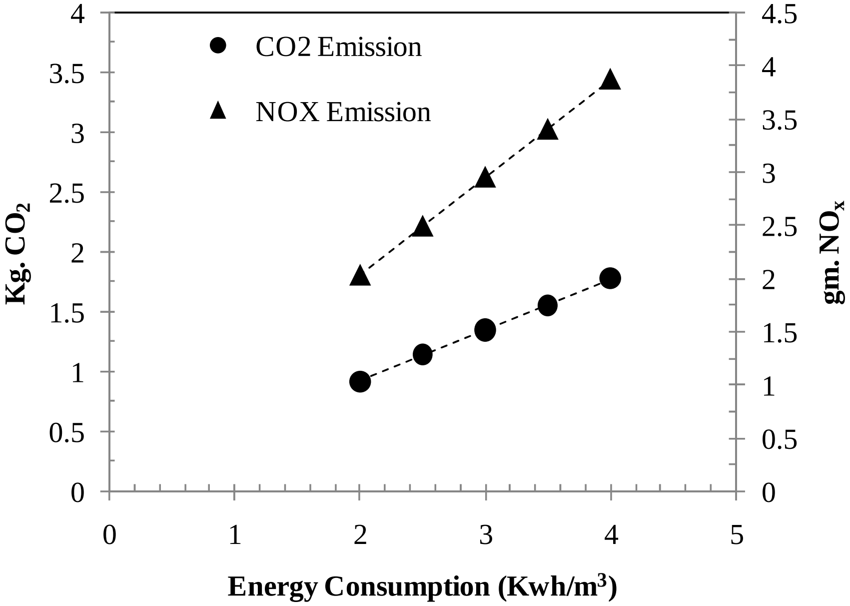

FIGURE 3 GHG EMISSIONS BY RO FOR DIFFERENT ENERGY CONSUMPTIONS [4].

consumption is reduced, both CO2 and NO_X emissions drop; however, the rate of emissions reduction is faster for NO_X, which has about 300 times more global warming potential than CO2 emissions.

While considering renewable energy resources, consideration of the up and downstream processes of the power plant (i.e. electricity generation stage) and associated GHG emissions is important to avoid any type of underestimation during a life cycle GHG emissions assessment. The estimated life-cycle GHG emissions from selected energy technologies such as fossil fuel suggest that the emissions from lignite power plants ranged from 800-1700 g CO2eq/kWh. In coal-fired and natural gas power plants, emissions values ranged from 800 -1000 g CO2eq/kWh, 360-575 g CO2eq/kWh, respectively. For wind energy sources, the emissions range for onshore and off-shore turbines are 8-30 and 9-19 g CO2eq/kWh. Comparing the performances of four different types of photovoltaic systems such as monocrystalline, polycrystalline, amorphous and CIGS (copper indium gallium diselenide), the emissions ranged between 43 and 73 g CO2eq/kWh.

SUMMARY

There are various strategies employed by utilities to optimize energy consumption during desalination. These strategies include those associated with both design and operation. The first focuses on efficient system design to reduce energy consumption. In this regard, application of efficient pumps and variable frequency drive motors are provided in the design of plants. Further, almost all new desalination plants utilize energy recovery devices. Membrane materials and configuration have evolved over the past decade. They are now more resistant to fouling, operate at lower pressures and produce a more selective water quality. Thus, selection of membranes is an important aspect of an energy optimization strategy. Finally, implementation of energy efficient measures for heating, ventilation, air conditioning and lighting are now being employed. In recent years, renewable energy has been an important aspect of many desalination projects. Wind and solar energy are the most often incorporated into desalting plants. The key drivers for incorporating renewable energy into an energy strategy are sustainability and social responsibility. However, it is evident that most plants employing renewable energy received or required a subsidy in order provide this method of energy production. As the field evolves, the costs of renewable energy will decrease and its more widespread use will be realized.

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