ASSESSMENT OF DESALINATION TECHNOLOGIES: CORRECTION TO THE TUNNEL VISION BASIS OF ENERGY EFFICIENCY TO A HOLISTIC VIEW OF SUSTAINABILITY

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Summary

Desalination of seawater is an expensive affair since it involves investments in equipment, energy, process operation and maintenance. As there are no freshwater sources in many places in the vicinity of the sea, especially in many countries of the Arabian Gulf, seawater desalination is the main method of obtaining freshwater from the sea to meet the needs of the region. For over 40 years, desalination has been used in these countries and elsewhere also in the world based on different technologies. Desalination technologies are mainly of two kinds. Thermal methods use heat energy and cause phase change of water to separate fresh water from the saline seawater. This class includes methods such as multistage flash (MSF), Multiple Effect Desalination (MED), etc. The other is based on osmotic principle of reverse osmosis or RO in short. Forward osmosis is also being considered but its applications are insignificant relative to the reverse process. Both thermal and RO plants have now assumed large capacities around the world and people are concerned about the costs, efficiencies, reliability, availability, maintainability, sustainability etc. issues as these play a vital role in the process of decision making to choose the type of technology for water security in their regions. The players in the field of desalination- the suppliers and of the technologies and buyers are sensitive to such issues related to their chosen technology which is mainly between thermal and RO. Each party has its own interests- the supplier has business interest and the buyer has interests of economy and sustainability. This paper presents a critical study of the many issues based on the scenario of developments and applications of various technologies and attempts to make a reasonable assessment which is intended to help decision making especially in the case of new projects. It takes the reader from the tunnel vision electricity economics to the broad and holistic view of sustainability considerations.

1. Introduction

The global population is increasing and world's fresh water resources are depleting due to consumption and pollution. More people are heading towards severe water crisis in many regions of the world. The prescribed amount of fresh water per capita an annum ($1000m^3$) for healthy living is becoming far from the reach many populations. The arid regions of the world, especially the countries around the Arabian Gulf are naturally most concerned about life and development of their nations. Owing to the availability of other forms of natural wealth which is oil in many of these countries, these countries have been managing to meet their fresh water demands by obtaining fresh water by desalination of seawater that is available in the seas in their close neighborhood. For over forty years in the past desalination plants grew in number and the need for more plants compels these nations to build new plants. The interest for the most appropriate desalination technology is no less important than obtaining freshwater. Consideration of costs in terms of equipment, energy use, operation and maintenance, reliability and sustainability is essential to achieve water security in any region. Use of nonrenewable resources such as fossil fuels for energy is now to be critically examined for sustainability and global climate change. Alternative energy especially from the sun has to be considered to replace the traditional fossil fuels. Apart from other costs, energy efficiency seems to be the criterion on the basis of which decisions are made to choose certain technologies. This is increasing clear from certain reports which assert that the choice of RO is better in view of its energy efficiency. The energy criterion is shallow and superficial as will be clear from this work. This term 'energy' a seemingly simple entity needs an in depth analysis and the criterion has to be critically analyzed. This paper attempts to unveil the real picture of the term 'energy', and considers performance evaluation of the system on the basis of the primary energy that drives the entire system. The ability of the desalination system to use energy of lower grade is properly taken into account in the assessment process. The discussion is extended to provide a useful basis for the assessment of the system for sustainability, a condition that is key to assure water and energy security. The work is based on recent publications by distinguished scientists from repute establishments and not on any personal opinion. We consider three major desalination processes: Reverse Osmosis (RO), Multistage Flash (MSF), and Multiple Effect Distillation (MED).

2. Considerations for Efficiency and Sustainability of Desalination Systems

Any seawater desalination system requires the following for its operation as shown in Figure 1:

- Energy to drive the process of separation of fresh water from the saline seawater.
- A feed system for seawater of admissible quality in terms of the contaminants other than salts.
- A system of pumps
- Materials required for the construction of the plants
- Other materials such as chemicals to treat the feed water to achieve the permissible level of quality
- Monitoring system of measurements and instruments to track the health of the entire plant
- A system to dispose the wastes from the plants.

The energy required for a desalination process is usually taken from a source that provides energy either as electricity or heat or both. The primary energy source is usually a fossil fuel or solar collector. The fossil fuel is a nonrenewable source but from a solar collector is renewable, and free of charge. In the case of fossil fuel which has to be paid for it is very essential to leave minimal waste energy. Electricity is a high quality energy resulting from either a thermal power system providing at high temperature gas or steam to drive turbines. Only photovoltaic systems produce electricity directly from sunlight but only during the hours of sunlight and the only storage can be batteries which are very expensive and operation on power grid is complex. Therefore concentrated solar power systems (CSP) are recommended for large scale electricity generation since solar energy captured during the periods of sunlight can be converted to heat and stored for use when sunlight is not available. Figure 2 shows the schematic of a CSP system.

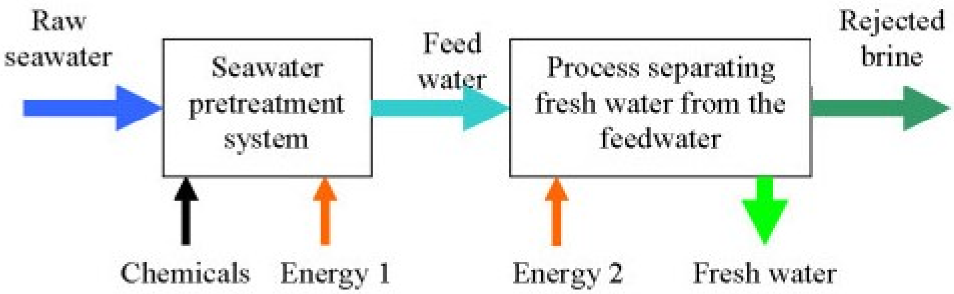

Figure 1. Schematic of a seawater desalination process

Desalination process	Energy 1 (feed water section) mainly for pumps	Energy 2 (freshwater separation process)
RO	Electricity	Electricity
MSF	Electricity	Heat
MED	Electricity	Heat

Table 1. Energy required for desalination processes

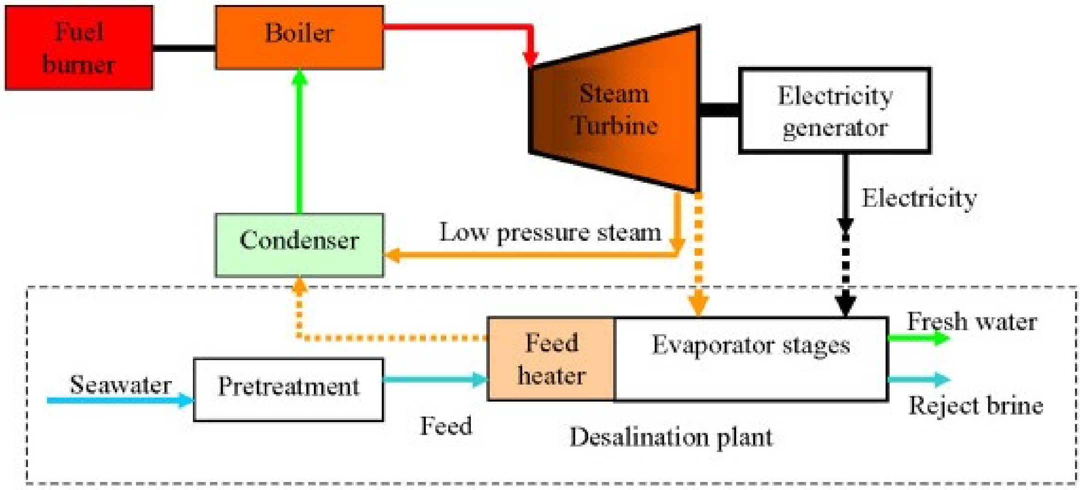

Figure 2. Simple thermal power system in isolation (but can be coupled to a desalination plant as shown in dotted lines)

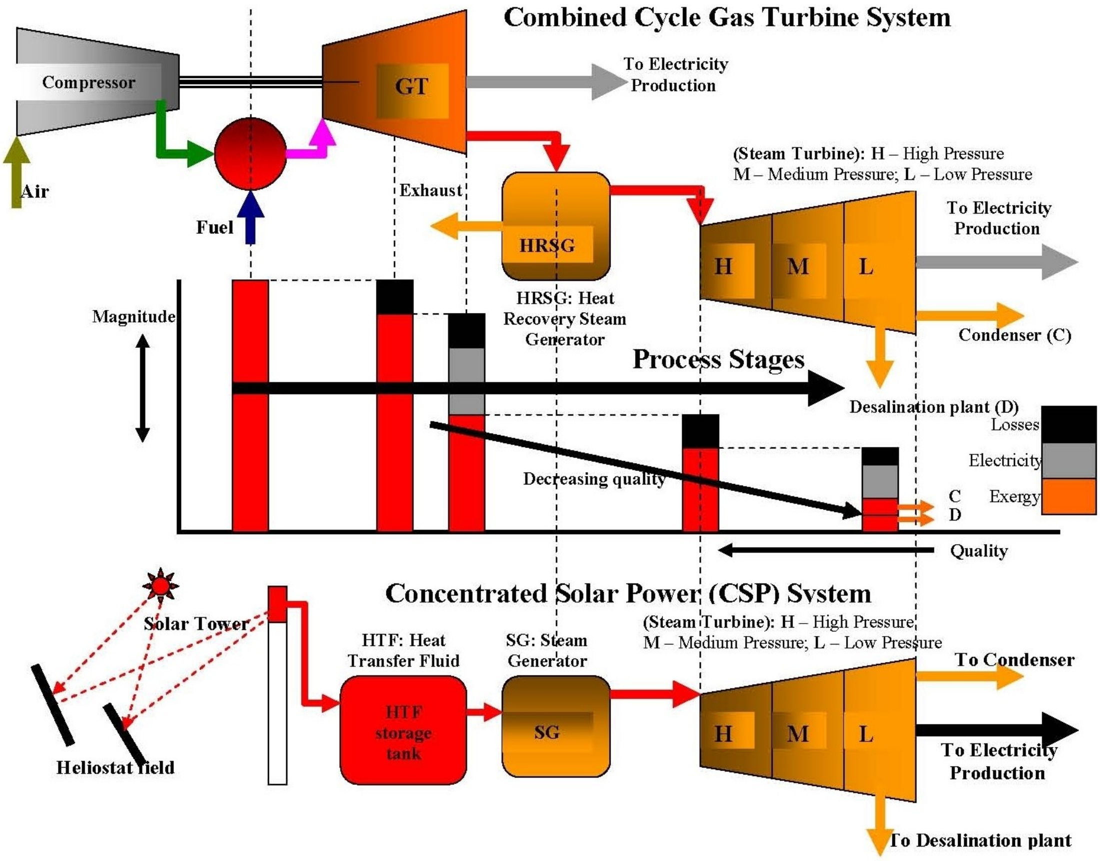

Figure 3(a). A co-generation system (combined cycle gas turbine system or a CSP system coupled with thermal desalination unit) showing energy distribution and (loss of exergy) degradation of energy in stages

Energy 2 that drives the separation process in the desalination section.

The energy required (Energy 2 in Figure 1) to drive the separation process in desalination is to be from a source. In the case of RO it is electricity. In the case of MSF and MED it is heat which can be from a thermal power plant that is preferably coupled to the desalination. Such coupled power and desalination units are well known as cogeneration plants and are shown Figures 2 and 3 (a). It has been asserted in the literature (Tonner, 2008) that cogeneration mode is better than generating electricity and water in separate plants. Figure 3(b) of Wu Lianying etal (2013) clearly shows that cogeneration of electricity and water is more economical than producing water in a stand alone desalination system. Cogeneration is quite simply, make good use of the heat from a thermal power plant fossil fuel or concentrated solar radiation for two purposes: first to drive turbines and generate electricity, and thereafter used in a desalination plant to desalt water and this procedure has been established since several years ago from the history of power plants.

In the heat to electricity conversion processes turbines are designed to operate efficiently with steam at about 540°C as input. After extraction of part of the energy in the form of electricity the outlet steam of turbines still carries considerable amount of energy but at low grade. In a power plant that is not connected to a desalination plant, this low grade heat steam from the turbine remains unused for any further conversion but sent to condenser in which a part of that heat is recovered and used to heat feedwater into the boiler . Thermal energy at such reduced grade can be used in an MED system to obtain fresh water; it cannot be used any further in an RO system. This is one of the limitations of RO in the utilization of energy. If low grade heat is available for use in a thermal desalination process, the coupling of power and desalination processes will enable us to operation desalination process without additional cost and therefore cogeneration is highly recommended for energy economy. Integration of desalination and power plants is to exploit the low grade thermal energy still remaining after power generation.

2.1. Specific Electricity Consumption of Reverse Osmosis Plants with and Without Energy Recovery System as Function of Raw Water Salinity

Specific Energy Consumption (SEC) is the related strongly to the salinity level of SWRO desalination. High salinity increases energy demand, whereas the temperature effect on energy consumption is not entirely clear. High-efficiency Energy Recovery Systems can reduce SEC, but the overall SEC cannot be explained by these factors alone. SEC is also affected by target water quality and quantity (See Figure 5).

Energy savings with ERDs can be in the range of 25–40% compared with standard SWRO systems (Peñate and García-Rodríguez, 2011)

Figure 3(b) The Minimum Energy requirement for a Reversible Separation of Pure Water from Saline, Water of Various Feedwater Salinities as a Function of Percent Recovery at Constant Temperature.43 (Right), Minimum Energy Requirements for 25^{o}C and 100^{o}C feedwater as a Function of Percent Recovery at, Constant Salinity.

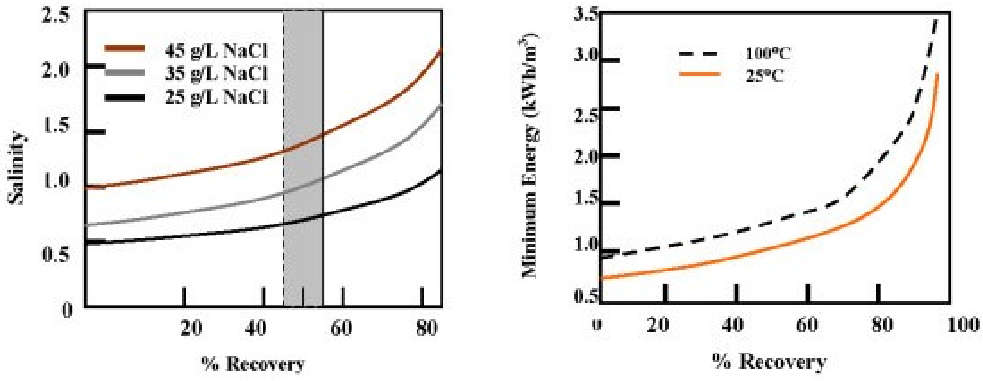

Figure. 3(b). The Minimum Energy requirement for a Reversible Separation of Pure Water from Saline Water of Various Feedwater Salinities as a Function of Percent Recovery at Constant Temperature.

From Figure 3(c). one can see that the cost of production from Combined Power and Water desalination (Cogeneration) is much cheaper than Separated Thermal Power and Water desalination. This is what the proponents of SWRO are trying to underplay in promoting the rather false concept of decoupling Water and Desalination and then use SWRO system which is unnatural uneconomical, of poor reliability and is not a mature process for high salinity Arabian Gulf Seawater. One needs to remember that thermal desalination plants are superior in terms of reliability , availability and maintainability.

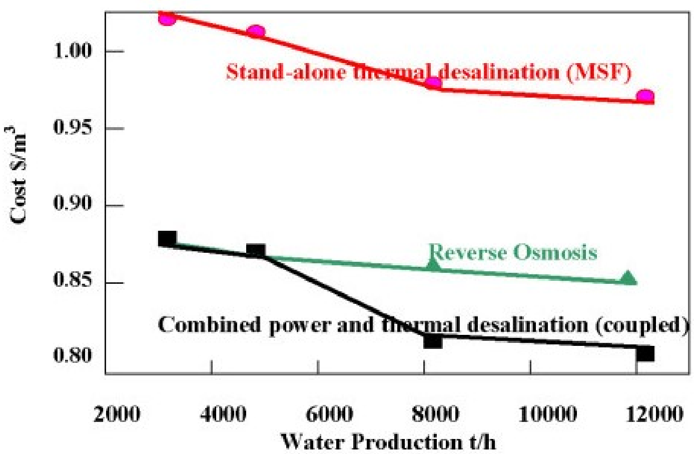

Figure 3(c). Water Cost of Combined Power and Thermal Desalination System VS. Thermal Desalination (MSF) and Reverse Osmosis (RO). (Wu Lianying et al , 2013)

Clearly, RO cannot participate in cogeneration and it can operate only in isolation by consuming energy of the highest quality that is electricity which is usually the product of plants of considerable investment. Tonner (2008) made it clear that if fossil fuels are burned to provide the heat for thermal desalination, it will never be economically competitive with other desalting processes like RO in terms of energy economics. But if that heat is the byproduct of electricity generation – which is often rejected into the environment via heat exchangers or cooling towers – then the economics and efficiency can fall in favor of thermal desalination. Even in separate plants dedicated to generate only electricity, the reject steam from the turbines has to be condensed and the heat dissipated to the environment, typically via cooling towers or condensers cooled by surface water.

Desalination Process	**Derived energy, kWh/ m^3**		**Conversion Efficiency Exergy Proportion of Primary Energy**		**Primary energy, kWh/m^3**	**UPR**	**% of Thermodynamic Limit (TL)**
	Electrical	**Thermal**	**Electrical**	**Thermal**			
RO	3.5	NA	47%	NA	7.45	86	10.4%
MSF	3.0	80.6	-	5.4%	10	60	7.2%
MED	2.3	71.7	-	3.4%	7.32	88	10.6%

Table 2. Primary energy of MSF, RO and MED processes and universal performance ratio (UPR) (Ibrahim S. Al-Mutaz, 2019)

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Biographical Sketches

Adil Alradif received his higher education in Electrical Engineering from the University of Baghdad, and training as Commissioning Engineer Desalination, in Demag, Germany. For over two decades since 1980 he was with the Water and Electricity Department (WED), Government of Abu Dhabi, UAE in various positions in the Power and Desalination (P&D) Plants division, Advisor in various aspects of activity including planning, development, operation, and maintenance of P&D plants.He was involved in the development of the P&D plants over these years. He has been actively engaged in research and development in an attempt to bridge the gap between theory and practice. Presently he is a consultant related to desalination and water management.

Adil Alradif has authored several papers in the field of desalination and water management. As a Member of its Editorial Board, he has been actively committed to the development of Encyclopedia of Desalination and Water Resources (DESWARE) (https:\\www.desware.net). He is also a member of the UNESCO-EOLSS Joint Committee that is associated with the development of Encyclopedia of Life Support Systems (EOLSS), developed under the auspices of the UNESCO. DESWARE is one of the 21 componet encyclopedias of the EOLSS.

Al Gobaisi, Darwish M.K. received his higher technical education in Electrical Engineering from the United Kingdom where he received his B.Sc. (Engineering) and Ph.D. degrees. For over two decades since 1976 he was with the Water and Electricity Department (WED), Government of Abu Dhabi, in various positions including Director General, Power & Desalination (P&D) Plants, directing all aspects of activity including planning, development, operation and maintenance of P&D plants. He was responsible for the continuing development of the P&D facilities over the years, the capacity of which at present has reached 3000 MW and 200MGD respectively. He is actively engaged in research and development in an attempt to bridge the gap between theory and practice, particularly in the aspect of plant modeling, simulation, optimization, control, fault diagnosis and care.

He has authored/coauthored over 40 papers in the fields of power and desalination, water resources and environment. Presently he is leading a large team of internationally renowned experts, in a monumental project -The Encyclopedia of Life Support Systems (EOLSS), as its Editor-in-Chief and Co-chairman of the UNESCO-EOLSS Joint Committee. This Encyclopedia is the largest online source of state-of-the-art knowledge in the world that was inaugurated at the World summit on Sustainable Development, Johannesburg, South Africa in September 2002. Encyclopedia of Desalination and Water Resources (DESWARE) appeared in November 2000 and augmented and updated annually as another unique online publication in the field of desalination and water resources.