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Sustainable desalination using ocean thermocline energy

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ABSTRACT

The conventional desalination processes are not only energy intensive but also environment un-friendly. They are operating far from thermodynamic limit, 10–12%, making them un-sustainable for future water supplies. An innovative desalination processes are required to meet future sustainable desalination goal and COP21 goal. In this paper, we proposed a multi-effect desalination system operated with ocean thermocline energy, thermal energy harnessed from seawater temperature gradient. It can exploit low temperature differential between surface hot water temperature and deep-sea cold-water temperature to produce fresh water. Detailed theoretical model was developed and simulation was conducted in FORTRAN using international mathematical and statistical library (IMSL). We presented four different cases with deep-sea cold water temperature varies from 5 to 13 °C and MED stages varies from 3 to 6. It shows that the proposed cycle can achieve highest level of universal performance ratio, UPR = 158, achieving about 18.8% of the ideal limit. With the major energy input emanated from the renewable solar, the proposed cycle is truly a "green desalination" method of low global warming potential (GWP), best suited for tropical coastal shores having bathymetry depths up to 300 m or more.

1. Introduction

Currently, more than 150 countries producing 38 billion m^3 desalination water per year by operating 18000 desalination plants. By 2030, this production is expected to increase 54 billion m^3 per year consuming 0.4% of global electricity, 75.2 TWh per year. The main factors of this demand increase are population growth and economic development. In Saudi Arabia, water demand is estimated to increase 8.5 million m^3/day in 2025 as compared to 6.8 million m^3/day in 2010, increasing desalination share to 63%. Saudi Arabia is not only leading in GCC countries but also in the World in desalination capacities installation as shown in Fig. 1[1–15].

All conventional desalination processes are not energy intensive but also a major source of CO_2 emission. Presently, the CO_2 emission associated with global fresh water demand of 92 million m^3/ day is in excess of 100 million tons per year and it is estimated to reach to new high level of 218 million tons per year in 2040. Desalination emission is a major contributor in consuming the limit of CO_2 emission to achieve COP21 goal, maintaining environment temperature increase below 2 °C [16–32].

Presently, two major desalination processes are membrane based and thermally driven desalination processes. Membrane based reverse osmosis processes operate at 60–70 bar pressure to overcome osmotic pressure consuming 3–5 kWh/m^3 electric energy. On the other hand, thermally driven processes based on evaporation and condensation phenomenon consuming 70–80 kWh/m^3 low grade thermal energy for process and 2–3 kWh/m^3 electric energy to operate circulation pumps. All existing desalination processes are operated far from thermodynamic limit of performance ratio (PR) calculated by the minimum work input of 0.78 kWh/m^3. This theoretical minimum work is independent of the desalination processes used but it is a function of initial concentration and temperature of feed water. The conventional PR definition is based on derived energies (electricity and thermal), instead of the primary energy of fuel input. The derived energy based PR is only acceptable for a single useful effect output, i.e., stand-alone power plant or desalination system. However, with today's widespread use of cogeneration processes to produce power and water simultaneously, the derived energy based assessment is not accurate and need a more accurate method to distinguish the fraction of primary energy input consumed by the processes for their generation.

Abbreviations: RO, Reverse osmosis; MED, Multi effect desalination; MSF, Multi stage flashing; AD, Adsorption desalination; TL, Thermodynamic limit; PR, Performance ratio; UPR, Universal performance ratio; ST, Seawater thermocline; GWP, Global warming potential; CCGT, Combined cycle gas turbine; GT, Gas turbine; ST, Steam turbine; HRSG, Heat recovery steam generator; CF, Conversion factor; HAB, Harmful algae blooms; GDP, Gross domestic product; LTTD, Low temperature thermally driven; LPM, Litters per minute

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Nomenclature

Subscripts

Pe	Primary energy
Ther	Thermal
Elec	Electrical
Ex	Exergy

$$UPR \cong \frac{2326\left\{\frac{kJ}{kg}\right\}}{3.6x\left[\left\{\frac{kWh_{elec}}{m^3}\right\}CF1 + \left\{\frac{kWh_{ther}}{m^3}\right\}CF2 + \left\{\frac{kWh_{Renewable}}{m^3}\right\}CF3\right]}$$
$$CF = conversion factor$$
$$1 = electrical,\ 2 = thermal\ \&\ and\ 3 = renewable \quad (1)$$

Recently Ng et. al. [33] presented an improved PR definition based on primary energy called universal performance ratio (UPR) as presented in Eq. (1). They also analysed a combined cycle power plant integrated with desalination cycle to calculate exergetic proportions of primary fuel to each processes as shown in Fig. 2. Gas turbine cycle consume almost 73% of input fuel exergy and 27% exergy is supplied to heat recovery steam generator in terms of exhaust gases to produce high pressure steam for Brayton cycle. Steam turbines utilize 20% of steam exergy before bleeding to desalination that carry 3–5% depending on bleed temperature and pressure. Based on exergetic proportions of primary fuel. the conventional desalination processes' UPR varies from 70 to 90, 9–11% of thermodynamic limit as presented in Table 1. Despite the common concept that membrane-based RO method is more energy efficient than the MSF/MED, they have attained merely less than 10% of the thermodynamic limit. Since 1995, all desalination processes performance improved slightly but still they are far from sustainable desalination zone as shown in Fig. 3[33].

In GCC countries, thermal desalination processes are dominating with 68% installations due to harmful algae blooms (HABs) in the Gulf seawater near to the Straits of Hormuz caused by the seasonal surge of nutrients and they affected about 70% of the RO plants in the region [34,35]. In 2008 and 2013, RO plants were shut down for several weeks along Gulf due to spread of red tides as shown in Fig. 4 with yellow circles. Since GCC countries have only few days water storage, such long and frequent shut down is not affordable and this the reason that RO processes are not very successful in this region [36,37].

The thermally driven desalination processes performance can be improved in GCC region if thermal energy, the major part of input

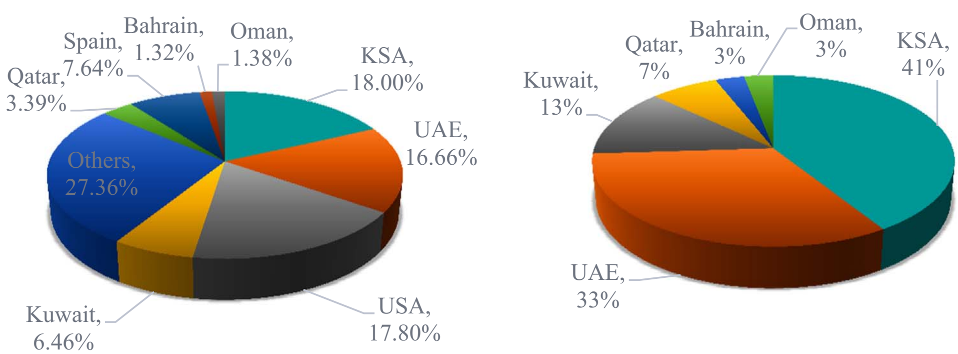

Fig. 1. Saudi Arabia desalination share in the World and in GCC, leading with high percentage.

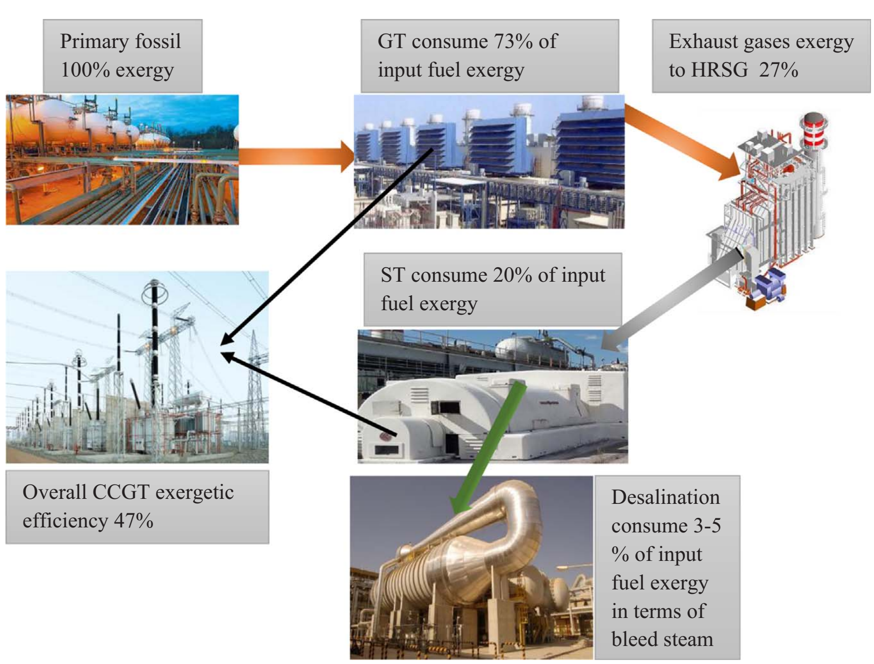

Fig. 2. Primary fuel exergy utilization by the components of combined cycle for power and water production [33].