FUTURE ENERGY BENCHMARK FOR DESALINATION: IS IT BETTER TO HAVE A POWER (ELECTRICITY) PLANT WITH RO OR MED/MSF?

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Power and desalination cogeneration plants are common in many water scarce countries. Designers and planners for cogeneration face tough challenges in deciding the options:- Is it better to operate a power plant (PP) with the reverse osmosis (i.e., PP+RO) or the thermally-driven multi-effect distillation/multi-stage flashed (PP+MED/MSF) methods. From literature, the RO methods are known to be energy efficient whilst the MED/MSF are known to have excellent thermodynamic synergies as only low pressure and temperature steam are used. Notwithstanding the challenges of severe feed seawater of the Gulf, such as the frequent harmful algae blooms (HABs) and high silt contents, this presentation presents a quantitative analyses using the exergy and energetic approaches in evaluating the performances of a real cogeneration plant that was recently proposed in the eastern part of Saudi Arabia. We demonstrate that the process choice of PP+RO versus PP+MED depends on the inherent efficiencies of individual process method which is closely related to innovative process design. In this connection, a method of primary fuel cost apportionment for a co-generation plant with a MED desalination is presented. We show that an energy approach, that captures the quality of expanding steam, is a better method over the conventional work output (energetic) and the energy method seems to be over-penalizing a thermally-driven MED by as much as 22% in the operating cost of water.

Keywords: Co-generation system; hybrid cycles; desalination economic; energetic and exergetic analysis; desalination carbon footprint.

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1. Introduction

China is 20% of the world's population, but only has 7% of freshwater reserves. As 'the world's factory', China is one of the highest consumers and emitters of industrial raw materials. Recent survey shows that major rivers (19%) and key lakes (36%) are severely polluted and are unusable as a source for water supply. In the Yangtze and Songhua rivers basin alone, 107 kinds of toxic and hazardous organic pollutants have been detected. It is estimated that in 2030 net water demand will grow up to 818 billion cubic meters compared to 618 billion cubic meters in 2010. Of this 2030 net water demand, agriculture, industry and domestic utilization is estimated as 50%, 32% and 18% respectively. There will be deficiency of 199 billion cubic meters, about 24% demand-supply gap by 2030 as shown in Figure 1. Chinese government allocated RMB 4 trillion for water infrastructure improvement in 2011-2020¹⁻³.

Fig. 1. Water supply-demand gap in China from 2000-2030.

Most of China cities ($\geq 60\%$) are under extreme water scarcity, less than 500m³/capita/year water available from all sources as shown in Figure 2. In China, there are 57 desalination plants operating presently with different capacities. In the past, Reverse Osmosis (RO) technology was the dominant technology applied in China desalination industry but in 2008 the biggest Multi-Effect Distillation (MED) plant (200,000 m³/day) was installed combined with Tianjin Beijiing Power Plant⁴.

Source: National Bureau of Statistics

Fig. 2. Water scarcity level in different cities of China.

The Chinese government has set ambitious targets to boost desalination capacity from today's modest 800,000 tons to 3 million tons a day by 2020 and this fast expanding desalination industry would consume more energy than China's total installed electricity capacity in 2012, about 1200GW⁵.

Desalination is an energy intensive process with significant environmental costs. Desalination not only emits carbon to environment but also highly concentrated brine back to sea. This has increased the temperature and salinity of sea, with the latter rising by around 2 percent over the last 20 years, with a negative impact on marine life and ecosystems. The increasing salinity makes future desalination even more difficult. There is a need to investigate the best-match for power plant (PP) & desalination systems for energy efficiency to reduce the specific energy consumption in terms of kWh/m³ and carbon emission. Hence, this is the motivation to find efficient power and desalination system combination.

2. Power + Desalination: Best Match

Efficient power and desalination cogeneration system analysis is conducted using real data of a cogeneration system. Exergy approach is used to apportion primary fuel cost to power and desalination systems. Two cases were analyzed; power plant (PP) + reverse osmosis (RO) system and power plant (PP) + multi-effect desalination (MED) system as shown in Figure 3.

Fig. 3. Power + Desalination cogeneration system configuration.

Figure 4 summarized cogeneration system selection. It can be seen that for a specific water production (2813m³/hr) the PP+RO plants are efficient than PP+MED (GOR≤20) system. Efficiency of whole system is depends on individual systems performance. PP+MED can be more efficient approach only if MED system GOR can be increased more than 20. PP+MED (GOR≥20) will not be only efficient approach but also help to prevent hazards algae blooms those are frequently occurring in some region in the world and dangerous for health.

Fig. 4. Cogeneration systems (PP+RO/PP+MED) comparison at different MED GOR for 2813m³/hr water production.

Now the question is, whether MED GOR can be ≥ 20 ? The conventional MED GOR is limited to 10-11 and advanced MED (with vapor re-circulation) GOR can be up to 20. This GOR is limited due to operational limitations namely; top brine temperature, TBT (typically 70°C) and bottom brine temperature, BBT (typically 40°C) of MED system. Conventional or advanced MED systems with power plants cannot beat PP+RO in terms of energy efficiency.

We proposed hybrid MED+AD cycle to overcome conventional MED limitations and hybrid MED+AD system GOR can be more than 20. In this hybrid system multi-effect desalination system is integrated with adsorption cycle to overcome BBT limitations and now MED last stage temperature can be as low as 8-10°C. This hybridization will not only improve water production (2-3 folds) but also reduce corrosion and fouling chances due to low operational temperature.

3. Experimentation and Results Discussion

A three-stage MED system and an AD cycle detail can be found in the literature⁶⁻¹⁵. Figure 5 shows the temperature profiles of conventional MED stages and hybrid MEDAD stages at heat source 50°C. Initially system was started as a conventionally MED and it can be seen that inter-stage temperature difference (ΔT) is about 1°C. After stable results, MED was linked with AD and it can be seen that adsorbent pulled last stage temperature to about 30°C and inter-stage temperature difference increased to 4-5°C. This higher inter-stage ΔT increase heat flux and evaporation rate in each stage.

Fig. 5. Temperature profile of MEDAD components at heat source 50°C.

Fig. 6. Distillate production from MED and MEDAD at heat source 50°C.

The last stage temperature is 30°C is because our system has only three stages. In real plant it can be as low as 10°C and practically 8-10 stages can be inserted with same top brine temperature. This higher operational range is only possible by AD hybridization to the last stage of MED.

Figure 6 shows the water production profile of conventional MED and hybrid MEDAD cycle at heat source 50°C. It can be seen clearly that once MED is linked with AD, water production boosted 2-3 times, GOR increased more than 20.

4. Desalination Systems Economic Analysis

On the basis of above analysis for primary fuel cost and with data from the published literature^{16,17} the life-cycle cost (LCC) of water production is compared for all capital expenditure (Capex) and operation expenditure (Opex), across all proven industrial processes, as shown in Figure 7. Exergy factor calculated above is utilized only for thermal and electricity cost calculations. Energy based analysis has good agreement with GWI¹⁷ data.

Fig. 7. Desalination methods costing by energetic and exergetic approach.

5. Conclusions

An efficient cogeneration (power+desalination) system is investigated and it is found that PP+RO can be an efficient approach if MED GOR is less than 20. An innovative hybrid desalination cycle called MEDAD is investigated experimentally that can achieve GOR more than 20. Hybrid MEDAD+PP can beat PP+RO system in terms of energy efficiency and it is also environment friendly. MEDAD+PP are the only system achieving a lowest life-cycle cost (LCC) of US\$0.5/m³.

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