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A theoretical and experimental study of a small-scale barometric sealed flash evaporative desalination system using low grade thermal energy

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HIGHLIGHTS

- Single stage flash desalination system was designed utilizing low grade waste heat.
- Condenser reject warm water at temperature 7 °C more than ambient was utilized.
- Increase in reject seawater temperature and flow rate increases fresh water yield.
- Good agreement was observed between the experimental and theoretical values.

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ABSTRACT

A barometric sealed flash evaporative desalination system was designed to ensure effective utilization of waste heat energy from a process plant. Unlike other conventional system, steam is not used in this desalination process. The plant was constructed in an existing thermal power plant, and experiments were carried out at various temperature differences between condenser reject and surface seawater at various flow rates. The operational and constructional parameters of the plant components were discussed and theoretical calculations for estimating the fresh water yield are presented. The influence of plant operating variables on fresh water generation using low grade thermal energy is experimentally studied. It is found that increase in the power plant condenser reject seawater temperature, feeding to the evaporator, influences the fresh water yield. Increased seawater flow rate to both the flash evaporator and the distillate condenser, decreased distillation plant saturation pressure lead to an increase in the fresh water generation. A maximum yield of 0.086 m^3/h is obtained at 14.8 m^3/h and 25 m^3/h seawater flow rates to the evaporator and condenser respectively, for a flash evaporator system pressure of 49 mbar. The overall agreement between the measured and the theoretical calculations is of the order of 91–96%.

1. Introduction

More than 70% of the earth surface is covered with water, however, not all that is potable. Only 2.5% of the water available on the earth is fresh water, and out of which, only 0.01% is consumable. Remaining water is distributed in rivers, lakes, underground, oceans, ice caps, glaciers, snow, deep ground water, etc. According to World Health Organization report, one out of every six people lacks access to clean drinking water in the developing countries. Water fulfills one of the basic human needs, and in some countries, almost half of the population do not have access to clean and safe drinking water. Water is consumed not only by people, but also by industries for production and manufacturing processes.

India accounts for 2.45% of total land area and 4% of the water resources of the world. However, its population is 16% of the total world population. With a growth rate of 1.9%, the population of India is expected to hit the 1.5 billion mark by 2050 [1]. While the need is growing due to rapid growth of population, an acute shortage of fresh water available results in scarcity of quality water. Moreover, the problem is further aggravated as the existing water bodies are diminishing at a faster rate, despite stringent rules and

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regulations by the regulatory authorities, and also get polluted owing to several external factors. The pressure on the demand for access to clean water increases due to changing demography. With more and more people moving toward cities and towns in India, the urban topography is forever expanding, applying greater stress on the civic authorities to supply higher quantity of clean drinking water, which increases day-after-day. Poor sanitation methods, improper sewage management, contamination of the ground water by industries have adversely affected the availability of fresh water resources. These factors evoke fearful scenarios of the future and measures need to be taken now to look for a technology to produce fresh water from alternate sources such as saline water by desalination processes.

1.1. Conventional desalination processes

The existing conventional desalination technologies are expensive, energy intensive or discharge high salt concentrated water at higher temperature to the ambient, which forms a major environmental concern [2]. The main desalination processes currently available on the market for desalination process are: Multi-Stage Evaporation (MSF), Multi Effect Distillation (MED) and Seawater Reverse Osmosis (SWRO). The cost of desalination processes varies from location to location, as the conditions of the processed water, the nature and the size of the plant are different. Presently, the share of RO plants to produce fresh water in the world is 59%, whilst the thermally-driven desalination methods are about 27% [3,4]. However, in countries where the seawater feed is subjected to changing feed quality, arising from the water salinity, silt, and the harmful algae blooms, the dominant methods employed are usually the thermally-driven methods such as the MSF and the MED [5].

MSF is a reliable technology and has a record accomplishment that other technologies cannot match. MED is the oldest technology, and is more complex. However, in industrial sectors where steam is easily available, MSF and MED are preferred which uses either low or high-pressure steam from power plants. Special and expensive materials are required to withstand the high temperature such as titanium, high grade stainless steel, and duplex steel or copper–nickel alloy steel. To prevent scaling, expensive and hazardous chemicals are required for pre-treating the feed seawater. High temperature discharge from the power plants and/or desalination facility can cause harmful changes in the ecology. This can lead to reduced hatching success of eggs, and serious inhibition in the development of larvae. Presently, the MED and MSF are consuming about 20–40 kW h of thermal energy per cubic meter of fresh water generated [5].

SWRO does not require steam; however it requires electrical power to operate. It also needs large amount of chemicals for treatment and frequent maintenance of membranes/filters which are non-biodegradable. Hence, it indirectly contributes to greenhouse gas emissions. It has its own limitations such as higher pumping power requirement proportional to feed pressure, frequent replacement of the filtering membrane, pre-treatment of feed water to remove particulates (to prolong the life of membrane) and high quality plant material requirements [6,7]. Due to the recent development of the energy recovery systems, the specific energy consumption is between 2.5 and 3.5 kW h/m^3 [8,9]. However, these technologies are expensive for smaller quantity of fresh water generation and cannot be used in locations where there is limited access to maintenance activities. In addition, the use of conventional energy sources to drive these technologies has a negative impact on the environment [10]. Highly concentrated brine discharged from the desalination facility could be harmful to the micro-organisms which are crucial for maintaining the marine eco-system. Considering these environmental issues, it is obvious that there is a need to develop a technically viable and eco-friendly desalination process. Besides these technological advantages, there is also motivation for the development of novel desalination cycles/technologies that can perform better than the existing ones.

1.2. Advanced desalination processes

The new emerging methods for desalination are the adsorption desalination (AD) and membrane distillation (MD). The key objectives of the emerging desalination methods are (i) to reduce the specific energy consumption, (ii) to minimize the use of chemicals for water treatment, and (iii) to achieve low carbon dioxide emission [11]. The authors have used huge hydrophilic silica gel and highly porous surface area as the adsorbent materials in the desalination process. The high vapor affinity of the adsorbent enables the water vapor adsorption on the pore surfaces making the saline solution evaporated. Here the temperatures of the heat source and cooling water are maintained at 85 °C and 30 °C, respectively. This cycle is dependent on the sorption capacity of the adsorbent material, and is usually coupled to the last effect of the MED system as the hybridization cycle and thus accommodates additional MSF/MED stages. This further increases the number of effects/stages of the MSF/MED system [12,13]. As the capital investment and operation costs are directly proportional to the number of effects and stages, these processes are expensive. Since the recovery of fresh water from the saline water is more, the salinity level of the water discharged to the sea is also more.

Membrane distillation (MD) is also a thermally driven process utilizing a hydrophobic micro-porous membrane to produce high quality water from a heated saline liquid stream. A number of issues yet remain before this technology can be fully deployed commercially. There are two major criteria that hinder the application of membrane distillation. One is the kind of membrane suitable for membrane distillation and the second is energy efficiency improvement by controlling the process parameters or membrane properties. Further, many leading cost components of the MD system are not yet known, since the process has not been demonstrated in commercial size to have the cost benefits of mass production. Further, fouling and scaling can cause pore clogging which can lead to reduced membrane area available for water vaporization and hence reduces the flux or otherwise causes severe membrane damage [14,15].

1.3. Renewable energy for desalination

Recognizing the greenhouse effect and environmental pollution associated with conventional energy sources and due to the limited availability, one cannot rely on fossil fuels as a long term energy resource. Hence there is a need to look for clean renewable energy source for production of drinking water by desalination. Gude et al. [16] discussed several alternatives to address fresh water generation from energy sources on the basis of availability, applicability and cost factors. These alternatives include renewable energy sources such as wave, wind, ocean current, ocean and solar energy or inventing low-cost and low-energy desalination processes.

These alternate solutions decrease the dependence on fossil fuels, yet possess own limitations and threats. Wave energy is a random source of energy and is seasonal by nature. Wind energy is also a highly variable energy source to power the desalination process. The wind power coupled desalination plant need to be designed in such a way that it should be flexible to operate in a repeated start-up and shut down cycles, caused by the frequent changes in wind direction and velocity. Using the ocean current devices may be harmful to certain species that live near the ocean