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Thermal analysis for system uses pressurized hot water for seawater desalination (pressurized multistage)

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HIGHLIGHTS

- The system consists of pump, heat exchanger and discharge tank.
- The heat adds to pressurized water in form of sensible heat.
- Thermal analysis was done to estimate the productivity of the system.
- The analysis shows promising energy consumption for each kilogram of fresh water.
- The optimum operating is pressure of 30 bar with final stage pressure of 3 bar when system consists of 45 stages.

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ABSTRACT

The present work is a description of a proposed system for seawater desalination. The suggested system operates basically the same as the MSF system operates but uses high pressurized saturated water. The system operating pressure through all stages of the system and the final stage pressure are higher than atmospheric pressure. The system is simple and easy to construct. No need for high operation maintenance or high technical stuff in operation. No need for vacuum pumps because it operates at pressure higher than atmospheric pressure which also makes the system starts to operate fast and easy. The seawater could be with any quality or grade even brackish water could be used so no need for seawater pretreatment. The system could also be run by solar energy through replacing heat exchanger with a solar collector according to operating pressure and assigned saturated temperature. Energy consumption and production cost are promising even if system uses electricity as heat source.

1. Introduction

According to the type of energy, desalination systems are divided into two main types, thermal and non-thermal. Thermal-type desalination plants such as multistage flash (MSF), multiple effect evaporation (MEE), single-effect evaporation (SEE), humidification–dehumidification (HDD), solar distillation and freeze desalination use heat either by direct heating or indirect heating. Other systems are classified as non-thermal system such as reverse osmosis (RO), capacitive deionization technology (CDT). This type uses electrical energy. There are three types of energy used, thermal energy, mechanical energy (pumping work), and electrical energy (electric potential).

A description of several desalination technologies in commercial and pilot stages of development is introduced in Ref. [3]. The primary focus is on those technologies that are suitable for use in remote areas, especially those which could be integrated into solar thermal energy systems.

A state-of-the art review on membrane processes associated with renewable energies for seawater and brackish water desalination is introduced Ref. [6]. The membrane processes include reverse osmosis, membrane distillation and electro dialysis. They are coupled with renewable energies such as solar, wind, wave, and hydrostatic pressure. This article presents the main results in this field including principles, plant design and implementation, mathematical models and economic feasibility.

The economic performances expressed in terms of cost of water production have been based on different system capacity, system energy source, system component, and water source. These differences make it difficult, if not impossible, to assess the economic performance of a particular technology and compare it with others. Reverse osmosis

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is becoming the technology of choice with continued advances being made to reduce the total energy consumption and lower the cost of water produced [9].

An overview of R&D activities and outlines of future prospects for the state-of-the-art seawater desalination technologies is provided. The present review is made with special emphasis on the MSF and RO desalination technologies because they are the most successful processes for the commercial production of large quantities of fresh water from seawater [4].

A study presenting a detail engineering and economics of an MVC system operating at 172 °C is introduced by Ref. [11]. The literature that performed through the study indicates that high overall heat transfer coefficients for the evaporator are possible at high temperatures with dropwise condensation on the steam side and pool boiling on the liquid side.

Energy is a critical parameter for economic development and of vital importance in social and industrial development, as well as quality of water. Numerous low-density population areas lack not only fresh water availability, but in most of the cases electrical grid connection or any other energy source as well, except for renewable energy sources, mostly referring to solar radiation. For these regions desalination is a moderate solution for their needs. In using RE desalination there are two separate and different technologies involved: energy conversion and desalination systems. The real problem in these technologies is the optimum economic design and evaluation of the combined plants in order to be economically viable for remote or arid regions. Conversion of renewable energies, including solar, requires high investment cost and the intensive R&D effort technology is not yet mature enough to be exploited through large-scale applications [10].

The thermal desalination process almost is the process that uses heat to separate water from salts. This separation mostly happens through evaporation of water then condensing it again in a separate zone and rejecting the remaining brine water. Thermal methods are used mainly in medium- and large-sized systems, while membrane methods, mainly RO, are used by medium- and low-capacity systems. Yet, during the last years, RO is the optimal choice in even larger units. RO methods, which are dominant in the desalination of brackish water, have the lowest cost, mainly due to much lower energy consumption and the recent technological advances that have been achieved in membranes. Under special conditions hybrid systems can offer increased and more stable production of fresh water [5],

The single-effect evaporation desalination (SEE) system has very limited industrial applications. The system is always used in marine vessels. This is because the system has a thermal performance ratio of less than one, i.e.; the amount of water produced is less than the amount of heating steam used to operate the system. The multiple effect evaporation (MEE) system is formed from sequence of single-effect evaporators, where the vapor formed in one effect is used in the next effect. The vapor is reused in the multiple effect system which allows reduction of the brine and low temperature values and prevents rejection of large amount of energy to the surrounding, which was the main drawback of the single-effect system. MSF processes always use waste heat from power plants either traditional or nuclear. So the level of temperature is not higher than 110 °C or 120 °C. This is related to the cooling system of power station. MSF system does not include moving parts, rather than conventional pumps. Construction of the MSF plants is simple and contains a small number of connection tubes, which limit leakage problems and simplify maintenance works. In the light of the above, they strongly believe that the MSF system will remain the main desalination process, especially in the Middle East [8].

Desalination plants integrated with compression heat pumps along with steam compression desalination plants can be considered to produce distillate from seawater. They can maintain water supply of high quality for small fixed and mobile consumers of fresh water [1].

There are also a lot of methods still under development as stated by Ref. [2]. EDI is a combination of ion exchange and electro dialysis. MD uses a temperature difference that occurs on opposing sides of the membrane. In CDI salt water passes through plates coated with carbon aerogel material. Carbon aerogel absorbs ions, thus producing potable water applicable to special needs. In RSE saltwater is sprayed through nozzles at high velocity. As it exists, it is vaporized and salt is not, thus producing potable water, potential to process brine and high salinities, can use waste energy. Freezing with hydrates a saltwater vapor/gas mixture is cooled. Hydrates are formed and separated from the brine. Hydrates are decomposed to form potable water and the hydrate former gas, potential for future use because of research of hydrates developing. In vacuum distillation the saltwater is subject to vacuum, the boiling temperature is reduced. Saltwater is vaporized at lower temperatures and is condensed to form potable water. Low amounts of energy, ability to run off of waste energy, no scaling because of low temperatures.

An overview of the studies performed on the gained output ratio (GOR), specific energy consumption (EC) and the water production costs (WPC) of different MD systems is presented together with comparisons to other desalination processes [8].

Actual cost for each method depends mainly on the type of physical process of salt removal (i.e. evaporation, filtration, freezing or electrostatic potential difference). The efficiency of each type depends on the total energy required to remove the salt particles which depends on some extent on the method of operation, the purity of the required fresh water and also on the type of saline water used.

In thermal desalination MSF, the applied pressures on water surface play a critical role where all the water properties are related to it. Most thermal desalination plants especially MSF plants work at low pressure. Low pressure is related to low saturation temperature which is the mean phenomena of parts of heat that rejected from thermal power and nuclear power plants, which ranges between 100 °C and 120 °C. So the MSF plants are always designed to work at pressure lower than atmospheric pressure.

With the increase of using solar energy (photovoltaic) as source of electricity and trends to use renewable energy, the rejected heat from thermal plant will not satisfy the required quantity to produce required fresh water especially with the population growing. Also with constrains on CO_2 emissions, we should find another trend to increase the productivity and reduce fresh water production cost for MSF plants.

The main idea of the suggested system depends on raising the inlet pressure of the MSF plant to be higher than atmospheric pressure. This will increase the percentage of dryness fraction at plant stages which will cause an increase in productivity and consequently reduce the production cost for each kg of fresh water.

2. System description

The system is similar to MSF but replacing vacuum pump by traditional water pressure pump. The pump raises the pressure of seawater to the required operating pressure. The heat added to seawater through the boiler raises its temperature to saturation temperature of inlet pressure of first stage. After that seawater is injected into the first stage which is always kept at pressure lower than injection pressure. The first stage outlet is used as injection into next stage. This sequence is repeated for the next stages. The pressure of the final stage may be higher than or equal to the atmospheric pressure.

In each stage injection pressure is higher than stage pressure. Part of seawater is divided into two parts, vapor phase and water phase at stage saturation pressure and temperature with dryness fraction according to ratio of injection pressure to stage pressure (dryness fraction). Each stage is supplied by a condenser section at the upper part which condensed the vapor phase, that forms fresh water production rate for stage. This condensate (fresh water) is collected by the upper tray of stage and then fed to the upper tray of the next stage. The