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Thermal analysis for system uses solar energy as a pressure source for reverse osmosis (RO) water desalination

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Abstract

As Natural resources are becoming limited and energy price dramatically increased, energy utilization with efficient systems is essentially required to be used in desalination technologies. The use of solar energy in desalination processes is one of the most promising applications of renewable energies. The primary focus on desalination by solar energy is suitable for use in remote areas. A proposed desalination system uses solar radiation, which concentrated by parabolic dish to heat up the working fluid in a closed space. Then the generated pressure in this space used to push salt water into RO module.

Daily production rate of fresh water quantity for suggested system compared with other solar techniques is a promising rate for each m^2 of solar radiation collecting surface. The production rate for one operation cycle could reach to 1800 L/cycle of fresh water at low water salinity (Brackish water with 5000 ppm) and 55 L/cycle at highest water salinity (sea water salinity with 42,000 ppm). The required energy needed to produce 1 kg of fresh water is also promising even when in case of using another type of energy, also operating cycle has ability of repetition according to salinity concentration through sunny hours.

Keywords: Desalination; Solar energy; Reverse osmosis (RO); Thermal desalination; Solar desalination

1. Introduction

Desalination systems are divided into two main types thermal and non-thermal. Thermal type desalination plants such as multi stage flash (MSF), vapor compression (VC), solar distillation and freeze desalination uses heat either direct heating or heat moving. Other systems are classified as non-thermal system such as reverse osmosis (RO), capacitive deionization technology (CDT). Actually cost for each method depends mainly on 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 and also on the purity of the required water.

Solar energy will play a critical role in sea water desalination. A great attention should be given to develop new techniques for improving efficiency and productivity of solar desalination systems. Solar desalination techniques can either be direct or indirect. Direct system uses solar energy to produce distilled water directly from solar distiller. Indirect system combines conventional desalination techniques such as vapor compression (VC), reverse osmosis (RO), membrane distillation (MD), and electro dialysis (ED) with solar collector as source of heat or photovoltaic as source of electricity.

An enhancement for traditional solar energy in desalination process by developing multi-stage distiller connected with an evacuated tube heat pipe solar collector. A multi-stage solar still water desalination system was designed to

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Nomenclature

A	collector area (m^2)	m_{wf}	Charge amount of working fluid (kg)
E	constant (radiation losses constant) $E = \delta * (A = 1m^2) * 5(\text{minutes}) * (60\ \text{sec})$ (J/K^4)	h_i	initial enthalpy of working fluid (kJ/kg k)
δ	(Boltzmann constant) $= 5.76 \times 10^{-8}$ ($W/m^2\ K^4$)	m_{copper}	mass of metals of working fluid housing includes boiling bubble, piping and first part of pressure tank (kg)
I_O	solar constant 1336 (W/m^2)	h_f	fluid enthalpy of working fluid at certain saturation temperature (kJ/kg k)
η_{ref}	Reflection efficiency for Dish concentrator surface (–)	h_g	vapor enthalpy of the working fluid at certain saturation temperature (kJ/kg k)
θ	the angle of incident between the solar radiation beam and the imaginary line normal to surface (°)	v_f	fluid specific volume of working fluid at certain saturation temperature (m^3/kg)
φ	latitude angle (°)	v_g	vapor specific volume of working fluid at certain saturation temperature(m^3/kg)
δ	declination angle of the celestial sphere measured northward or southward from the celestial equator plane (°)	v_t	specific volume of working fluid at certain saturation temperature (m^3/kg)
ω	hour angles (°)	m_v	mass of working fluid that founded in vapor form (kg)
β	Inclination angle of the collector (°)	m_f	mass of working fluid that founded in liquid form(kg)
γ	surface–azimuth angle (how far the solar collector deviates from the north–south axis (°)	x	dryness fraction of the working fluid at certain saturation temperature
n	day number according to Julian days (–)	W	work done (J)
Q_{in}	Total heat coming from the collector (W)	w	specific work done (J/kg)
Q_{used}	actual energy used (W)	P	pressure (N/m^2)
C_p	specific heat for metals of (J/kg K)		
I	solar radiation (W/m^2)		
t_t	initial temperature of the system (°C)		
T_a	ambient temperature (°C)		

recover latent heat from evaporation and condensation processes in multi stages (Shatat and Mahkamov, 2010). Using solar in RO system is done using photovoltaic cells, which converts solar radiation into electricity. The output electricity used to operate the salty water pump into RO module. An economic analysis for the RO and the power supply system is presented. Also system simultaneously exploits the waste heat of photovoltaic cells to desalinate water (Tzen, 1998; Mittelmen et al., 2009). Also, a scheme exploits the vapor pressure difference between fluids of different salinities and temperature to produce fresh water from seawater. In this scheme, heat is injected into sea water use solar energy to produce distillate directly in solar distiller.

2. System description

The proposed system consists of solar collector (parabolic dish concentrator type with spherical tank (boiling bubble) in its focal point), pressure tank (which, divide into two parts-separated by movable piston- first and second part) and RO module. The solar radiation has been concentrated on focal point where boiling bubble, which containing working fluid exists. With accumulation of heat during day hours the temperature and pressure increases inside boiling bubble due to working fluid evaporation in a closed space. The pressure increases till reaches to operating pressure of RO module. During this time the generated pressure in boiling bubble applied on movable piston through pipe connected to first volume of pressure tank. The movable piston pushes the salt water that fills second volume of pressure tank into RO module. The fresh water comes out from fresh water side of RO module with the movement of movable piston in pressure tank. The volume swapped by the movable piston is equal to fresh water production rate. At the end of the day piston moves come back again to original position by reducing pressure through condensing steam. The condensation process is done by allowing cooling water to flow around pressure tank.

The piping system, boiling bubble, and first part of pressure vessel form continuous volume. The formed volume (first volume) contains specified amount of working fluid (mostly pure water) which will evaporate in closed space (heat add at constant volume process) causing pressure and temperature raise. In pressure vessel the movable piston separates working fluid in first volume and salt water that fills second volume. The second volume connected to RO module through pipes with flow control valves. The piston designed to reduce heat lost from hot pressure side