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Integration of renewable energy based multigeneration system with desalination

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HIGHLIGHTS

- New integrated multi-generation system using renewable energies is proposed.
- Integrated system is designed to heating, space cooling, electrical power and fresh water.
- Energy and exergy efficiencies of the overall system and its subsystems are calculated.

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ABSTRACT

The present paper comprises of an integrated system in which industrial heating, space cooling, electrical power and fresh water are produced by multigeneration system using solar, geothermal and ocean thermal energy inputs. Fresh water is produced using a multi stage flash desalination (MSF), and the direct steam generator (DSG) is used to produce power from solar. The geothermal system, with double stage flashing, is incorporated to assist solar due to its intermittent nature. The ocean thermal energy conversion (OTEC) is interconnected with desalination system while producing 30.49 kW with 0.73% energy efficiency. The proposed system is analyzed energetically and exegetically, and it is found that the energy and exergy efficiencies of the overall system are 13.93% and 17.97% respectively.

1. Introduction

Our planet has been facing pollution problems due to excessive use of fossil fuels. Power generation and transportation applications have been contributing to make our environment worse. That is why the need for clean and renewable energies has significantly increased. The main source of renewable energy for this planet is sun. Almost 170,000 TW of solar radiation falls on the Earth each year [1]. This energy from the sun is stored in earth's crust which is known as geothermal energy. Ninety nine percent of earth's volume has temperature more than 1000 °C [2]. Similarly, this energy from sun is collected by sea water. Ocean Thermal Energy Conversion (OTEC) systems are developed to harvest this energy to convert it into useful work.

Fossil fuel degradation, pollution issues and increasing oil prices are diverting attention towards renewable energy resources. Many studies are conducted on the combination of renewable resources to eliminate fossil fuel consumption. Solar energy is not enough for power production throughout a day. That is why more sources are merged to overcome this problem. The previous studies show production of multiple outputs from one system improves overall efficiency of plant [3–7]. Ozturk and Dincer [3] studied a system in which power, heat, hot water, cooling and hydrogen are produced using energy input. They combined organic Rankine, Rankine, absorption and hydrogen cycles in one system. Their obtained exergy efficiency was higher than the sub-systems efficiencies. Sinan and Dincer [4] proposed multigeneration system to produce hydrogen, electricity, heating and cooling using wind and solar energy inputs. They found that the overall efficiency of the system was higher than the individual systems. Khalid et al. [5] studied a multigeneration system with two renewable energy resources to produce multiple outputs. The calculated energy and exergy efficiencies for overall system were found higher than the efficiencies of biomass and solar systems. Suleman et al. [6] investigated a multigeneration system with solar and geothermal energy inputs to produce multiple outputs. Their study showed the advantage of using multigeneration

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system over single separate energy systems. Yang et al. [7] combined ground source heat pump with fuel cell and determined that less energy consumption by hybrid system than ground source system. This shows that multigeneration systems are advantageous and gaining popularity throughout the world [8–9].

On the basis of above studies, a system is proposed with renewable resources to produce fresh water, electricity, industrial heating and space cooling. Geothermal and OTEC systems are added to assist solar energy input. No heat transfer fluid (HTF) is used in solar collectors as direct steam generation (DSG) has higher cycle temperature and thermal efficiency than indirect steam generation systems [10]. Addition of HTF will make cycle more complicated, and the efficiency will drop down. DSG plants produce 11% cheaper electricity than conventional oil heating systems [11]. To enhance power input, geothermal double flash system is incorporated in the system. Double flash geothermal can generate 20–25% more power than single flash cycle [12–14]. Around 25% of world's geothermal energy systems are based on double flash system [15].

Production of fresh water by desalinating sea water is adopted by several countries specifically in countries which have water shortage. Almost 80 countries in the world face the scarcity of fresh water [13]. Note that worldwide 27% desalination plants are thermally driven [16]. MSF plant operates at relatively lower temperature (under 100 °C) [17]. Multi-Stage flash desalination system consists of several stages. In each following stage, pressure is kept lower than the previous stage to flash the steam. In this paper MSF with three stages are selected. It is running with the combination of both solar and geothermal energy.

OTEC is a technique to harvest tidal heat energy. It is basically the temperature difference in water column of sea at different depths which could be up to 5 °C, [18] and standard depth difference is usually 1000 m [19]. The idea of OTEC, to generate electricity, was first proposed by D'Arsenoval in 1881 [20] and this concept is sometimes considered as virtually free of environmental impacts [21]. Vapor absorption cycle is interconnected with MSF plant to produce air conditioning. Coefficient of performance for single effect absorption cycle typically varies from 0.7 to 1.2 for refrigeration temperatures above 0 °C [22].

The specific objective of this study is to design and analyze thermodynamically of a new multigeneration system with solar, geothermal and OTEC energy inputs to produce fresh water, electricity, industrial heating and space cooling; and to study the effects of varying operating conditions and system parameters on the overall system performance. The calculations of energy and exergy efficiencies of the present multigeneration system and its subsystems are included in this study.

2. System description and assumptions

Solar, geothermal and OTEC sources are utilized as energy inputs while electricity, fresh water, industrial heating and space cooling are produced as the useful outputs. This system is a combination of steam turbines, pumps, generator, condenser, heat exchangers, solar collectors, mixing chamber, desalination plant, expansion valves, steam separator and cooling tower. Schematic diagram of the said system is presented in Fig. 1. All components work simultaneously to produce desired outputs using clean energy resources. The sea water entering the OTEC system is utilized in desalination plant, saving extra pump work to extract water for desalination plant. The steam injected by low pressure turbine is driving MSF plant and remaining heat is utilized by vapor absorption cycle. As this steam is the sum, of both geothermal and solar system fluids, it splits into two sections after condenser. The extra condensate is drained back to geothermal well while remaining liquid is sent back to solar field to regain energy from sun. The geothermal system is extracting saturated water at high temperature and pressure, which is being converted into steam by flashing it twice in separators A and B. The unconverted liquid drains back to the well. Following assumptions are made in analyzing the system

- The ambient temperature and pressure are assumed to be $T_o = 25$ °C and pressure $P_o = 1$ bar.
- The OTEC cycle has ammonia as the working fluid.
- The salinity of sea water for desalination plant is taken = 48,000 ppm.
- All processes are in steady state with negligible potential and kinetic energy.
- The multi-stage desalinations has three stages.
- The salt, water and saline water are incompressible substances.
- The temperature of sun is assumed to be 6000 K.

3. Thermodynamic modelling

The proposed system is analyzed both energetically and exergetically by assuming appropriate temperatures and pressures at all state points. The exergy balance equations of each component are written to find exergy destructions. Similarly efficiencies of each system, OTEC, geothermal, MSF, are calculated separately based on proposed data. Both energetic and exergetic COPs for vapor absorption cycle are determined. In the end, the overall system is assessed, and the study graphs are plotted to analyze the variation of certain parameters with respect to others. The calculations, by assuming appropriate temperature pressures at all state points, are made using Engineering Equation Solver (EES). Energy efficiencies are defined as the ratio of useful energy output to energy input [3]. The energy input from the sun is calculated as

$$\dot{Q}_{solar} = \dot{m}_1 h_1 - \dot{m}_{11} h_{11} \tag{1}$$

The solar cycle is driving turbine-A and supplying heat for industrial use. The energy and exergy efficiencies of solar cycle are defined as

$$\eta_{en,solar} = \frac{\dot{W}_{turbineA} - \dot{W}_{pump1}}{\dot{m}_1 h_1 - \dot{m}_{11} h_{11}} \tag{2}$$

$$\eta_{ex,solar} = \frac{\dot{W}_{turbineA} - \dot{W}_{pump1}}{\dot{Q}_{solar} * \left(1 - \frac{(T_o + 273)}{6000}\right)} \tag{3}$$

where

$$\dot{W}_{turbineA} = \dot{m}_1 h_1 + \dot{m}_3 h_3 - \dot{m}_2 h_2 \tag{4}$$

$$\dot{W}_{pump1} = \dot{m}_{11} h_{11} - \dot{m}_{12} h_{12} \tag{5}$$

For geothermal system, turbine B is producing output. Even more steam is injected from solar cycle as well. The efficiencies for geothermal cycle are defined as

$$\eta_{en,geo} = \frac{\dot{W}_{turbineB}}{(\dot{m}_8 h_8 - \dot{m}_{13} h_{13}) + (\dot{m}_2 h_2 - \dot{m}_5 h_5)} \tag{6}$$

$$\eta_{ex,geo} = \frac{\dot{W}_{turbineB}}{(\dot{m}_8 ex_8 - \dot{m}_{13} ex_{13}) + (\dot{m}_2 ex_2 - \dot{m}_5 ex_5)} \tag{7}$$

where

$$\dot{W}_{turbineB} = \dot{m}_5 h_5 + \dot{m}_6 h_6 - \dot{m}_{19} h_{19} \tag{8}$$

$$ex = h - h_0 - T_0 (s - s_0) \tag{9}$$

$(\dot{m}_8 h_8 - \dot{m}_{13} h_{13})$ is the amount of heat extracted from geothermal source.