Desalination 380 (2016) 29–42

Contents lists available at ScienceDirect

Desalination

journal homepage: www.elsevier.com/locate/desal

Effects of tracking modes on the performance of a solar MED plant

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HIGHLIGHTS

• Effects of tracking modes on the performance of a solar MED plant are investigated.
• Due to economic issues, full tracking mode is not the best choice.
• On spring and fall equinoxes, polar axis mode is the best choice.
• On winter solstice, polar axis mode is the best choice.
• On summer solstice, N–S mode is the best choice.

ARTICLE INFO

Article history:
Received 22 May 2015
Received in revised form 17 November 2015
Accepted 18 November 2015
Available online 1 December 2015

Keywords:
Desalination
MED
Solar energy
Parabolic trough
Tracking system

ABSTRACT

Solar energy as an energy resource is vastly available and its applications are growing. Due to lack of fresh water resources, sea water desalination is known as a suitable solution all over the world. This paper investigates the effects of quintuple tracking modes on the fresh water production of a solar MED plant, for the first day of seasons known as characteristic days. Solar field and MED system under consideration are modeled using thermodynamic and heat transfer correlations. The system model has been validated according to experimental data. Results show that, using tracking systems has been very effective, for instance, at the winter solstice the solar MED plant with full tracking system, polar axis tracking system, N–S tracking system, and E–W tracking system respectively produce 341%, 291%, 135% and 246% more fresh water in comparison with a plant using only fixed collectors. It is also found that, polar axis mode has better performance in the first day of spring and fall. Moreover, N–S mode demonstrates its best performance in the first day of summer while both polar axis and E–W modes obtain their best performance in the first day of winter.

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1. Introduction

The lack of fresh water will become a major global problem in the years ahead. According to the UN factsheet released in 2013, 'By 2025 1.8 billion people will be living in countries or regions with absolute water scarcity, and two-thirds of the world population could be under stress conditions'. Desalination of brackish waters can be a good solution to this problem. Various desalination systems are designed and exploited in recent decades. The construction and operationalization of desalination systems were very costly processes at the beginning inhibiting the development of this technology in developing countries. On the other hand, these systems consume huge amount of energy; however, during the last 50–60 years, desalination industry has largely grown which is mainly due to its reduced cost of construction [1]. This cost decrease is because of reduced size of equipment, advances in material science, application of more corrosion resistance materials, minimization of energy consumption, and finally achieving plant factor of almost 90% [2]. There are various methods for desalination, one of which is distillation. Distillation is a process through which brackish water is heated until it is changed into vapor, and is then condensed to produce fresh water. There are various distillation-based desalination systems such as multi-stage flash distillation (MSF), multi-effect distillation (MED), and vapor compression distillation (VCD). MED is the oldest process of distillation and its advantageous. For instance, MED plants have less power consumption and higher performance ratio in comparison with MSF plants so it is more efficient in terms of thermodynamic and heat transfer [3,4]. There are different energy sources to fulfill the energy need of these systems including fossil and renewable resources. Using fossil energy is not an appropriate solution, due to lack of resources and environmental pollutions. Using renewable energies for supplying energy needs of desalination plants is a good substitution. Belessiotis and Delyannis [5] investigated the application of renewable energies in water desalination for some dry islands in Greece as case studies and proposed some solutions. In their paper, first, they compared islands water supply alternatives, namely, transportation and desalination. They came to the conclusion that transportation is not a good solution due to its high cost, storage system requirements,

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http://dx.doi.org/10.1016/j.desal.2015.11.015
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and inflexibility which makes it difficult to fulfill future demands. Finally, according to a few factors such as availability and the type of water, type of alternative energy available to the site, geographic location of the region, and needed capacity, they suggested suitable desalination systems for different renewable energy resources. A feasibility study was carried out on the application of multi effect evaporation forward-feed (MEE-FF) seawater desalination system using hybrid solar and wind energies in on-shore regions of Turkey. Mathematical models of MEE-FF seawater desalination system, flat-plate collector, and wind turbine were proposed and simulation was done using visual basic programming language. The simulation model showed good agreement with the reference data. It was found that solar energy is more stable than wind energy, due to the wind vectorial nature and wind speed fluctuation which is higher than solar radiation variations during an operation period [6]. Among solar technologies, using concentrators in plants is a very suitable approach, due to its high efficiency and capability of working at high temperatures. Solar collectors are specific kinds of heat exchangers that absorb the sun's heat energy to heat a fluid medium. The energy stored in the fluid is used through direct or indirect contact in order to supply the energy required by thermal equipment. In addition, this energy can be stored in a tank to be used when required. In this regard, parabolic trough collectors are among well-known and very useful technologies. Features such as high operating temperature (50–400 °C), relatively high efficiency, low cost, and light weight construct have made parabolic trough collectors as one of the best solar technologies. This type of collector is widely used in a plant located in southern California, which is known as Solar Electric Generating Station (SEGS). Using parabolic trough collectors is one of the safest technologies to be used in plants, industrial thermal processes, water desalination units, freezing, HVAC systems, and irrigation, instead of fossil fuels. If the collector's position is perpendicular to the sun, the amount of absorbed energy increases. In other words, collector's efficacy is enhanced. To achieve this, tracking systems can be used. These systems are categorized according to motive modes. The one-axis tracker is oriented along east–west or north–south direction, or parallel to the earth axis. In addition, in two-axis systems, collector position can vary horizontally and vertically [7].

The application of tracking systems has been widely investigated. For instance, Koussa et al. [8] presented a study on the effect of various tracking systems on the performance of photovoltaic panels and compared the results with traditional fixed ones. Results demonstrated that, generally, using tracking systems results in higher PV performance; furthermore, tracking systems are very beneficial during clear sky days, unnecessary during cloudy sky days and for partially clear sky days, their performance depends on daily clearness index K_T and the season when the system operates. Masoudzadeh et al. [9] reviewed different models of tracking systems, and investigated their weaknesses and strengths. The most efficient and well-known types of solar tracking systems are polar-axis and azimuth/elevation. Although, E–W tracking system receives the maximum amount of solar radiation in solar noon, its absorption severely decreases in the beginning and ending hour of day, due to cosine losses. In contrast to E–W tracking system, N–S tracking system has cosine losses in solar noon, and its radiation reception increases in the beginning and ending hour of day. On the other hand, contrary to N–S axis tracking system, the amount of received radiation by E–W axis tracking system is slightly higher in winter than summer. Tang and Yu [10] introduced one-axis three positions sun-tracking system (one axis three positions sun-tracking polar-axis aligned CPCs). Polar-axis sun-tracking system is adjusted eastward, westward, and southward in the morning, noon, and evening, respectively. Comparing it with one-axis one-position tracking system (1p-CPCs), it can be concluded that the received sun's heat increases by 61–71%, annually. One-axis systems track the sun only by adjusting zenith angle, and thus they need only one motor while in two-axis tracking systems, the zenith and tilt angles are both changed, and thus they need two motors. Two-axis tracking systems are more complicated and costly than one-axis tracking systems. Investigations into two-axis tracking systems have shown 20–50% efficiency increase in comparison with fixed mode [10–12]. Peng et al. [13] investigated the effects of rotatable-axis tracking solar parabolic trough collector system in solar hybrid coal-fired power plants. Results showed that solar field area could be decreased by 4% in case of using rotatable-axis tracking system. Lubitz [14] calculated the radiation received by collector, equipped with one-axis solar zenith angle tracking system, through the optimization of the tilt angle. Results showed that this system receives more radiation in comparison with fixed-southward collector; while, the amount of radiation received by full tracking collectors is slightly larger than that of one-axis solar zenith angle trackers. Al-Soud et al. [15] experimentally investigated the effects of using two-axis tracking system on a solar cooker. It was found that the proposed cooker is able to heat water inside the cooker's tube to 90 °C in typical summer days, considering the maximum ambient temperature of 36 °C. It was also concluded that, towing to automatic two-axis tracking system, foods inside the cooker can be kept in place all day long without being burnt which is one of the troubles using concentrating solar cookers. Peragon et al. [16] evaluated the energy advantage of two-axis solar tracking system in comparison with fixed devices, in Spain. They came to the conclusion that two-axis devices are more energy efficient (higher than 20%) for most of the Spain national territory.

The majority of papers released about solar tracking systems talk about the effects of these systems on PV systems performance and there are less papers pointing to the effects of tracking systems on the performance of desalination units and even these papers are mostly conducted using small-scale experimental setups and their results only applies to the latitude of their experiments. In the present study, the effects of tracking systems on the amount of fresh water production in a large-scale solar desalination plant is investigated. For this purpose, computational codes are generated in MATLAB by which the amount of received radiation, useful energy, heat loss of parabolic collectors, and fresh water production of the MED water desalination plant have been calculated. Finally, according to the criterion of maximum fresh water production the most suitable tracking system for different latitudes is suggested.

2. System description

The system under consideration is located in Tehran (35° 41′ N, 51° 25′ E) and its schematic plan is demonstrated in Fig. 1. This system consists of two parts; solar field and MED system. In solar field, the heat transfer fluid (HTF) is fed into the parabolic trough collectors and absorbs the sun's heat.

It then transmits this energy to the water within MED cycle, through series of heat exchangers. Then the water changes into steam and acts as motive steam in the first effect of MED system. It should be noted that, due to thermodynamic concerns, the steam generated by the solar field and some of the steam from the last effect of the MED system flow into the vapor compressor, as motive steam. After the completion of isobaric process, superheated steam turns into saturated vapor, by desuperheater. This steam, as the heat source of the first effect, evaporates feed water (sea water), and is also released from the first effect in form of saturated liquid, due to the heat loss. Then the produced steam in the first effect enters the second effect as heat source, and evaporates feed water of the second effect and is condensed as fresh water. The produced brine in the first effect is also released into the next effect. Then, similar to the prior stage, some of seawater is evaporated and some flows into the next effect as brine. In the last effect, the produced steam enters the condenser and preheats inlet seawater then leaves the condenser as fresh water.

3. Governing equations

Two sets of equations govern the unit under consideration. One set governs the solar field, another govern the MED water desalination

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