Assessment of Annual Yield of Fresh Water from A Hybrid Desalination Scheme Utilizing Solar Parabolic Trough Collector Augmented by Fuel

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Abstract:-The annual production of fresh water that results from desalination of seawater in a hybrid scheme using fuel and concentrated solar energy captured by parabolic trough collector was assessed. Three months; January, March and June, were considered as representative of the scheme annual performance. The results are obtained utilizing in-house developed computer models to solve the conservation equations by the finite difference methods. When considering the production in the month of June as the desired annual production, the investigation reveals that the production of fresh water generated by solar drops for the months of March and January to about 73.9% and to 39.7%; respectively, compared to that of June. The low yield in the month of January is mainly attributed to the low altitude solar angle in addition to lower beam intensity. The low yield in the cold and mild seasons may be augmented by the naturally occurring rainfall as well as by traditional fuel. It is shown that for mild weather only 24.3% of fuel energy compared to the total heat required is necessary to bring production to full capacity, thus indicating the plausibility of the scheme for desalination. The aim of this study is to assist in the implementation of renewable energy resources in the field of seawater desalination.

Key-Words: solar desalination, yield of solar desalination, fuel augmenting solar desalination.

1 Introduction

Parabolic trough collector (PTC) are the most widely used among solar concentrators simply because of their less equipment requirement for control (single axis), utilization of land and modularity. Also, the use of PTC for desalination that are more economical and cost effective [1]. PTC can supply direct solar thermal energy to produce fresh water in desalination plants that uses the evaporation techniques. However, since solar energy is time variant, a plausible usual approach is to have fuel to augment the deficiency in solar energy in order for the system to remain economically feasible [2, 3]. For example, for localities with latitudes above the equator during the month of January the solar altitude angle is considerably lower than what it is during the summer months which influence the PTC performance. The benefits of employing and increasing utilization of renewable energy resources for desalination purposes in addition to lowering cost of water production, will eventually lead to reduction in the amounts of carbon dioxide in the atmosphere and thus remain controlled to an acceptable levels. To illustrate this it is estimated that for producing 1 million m^3 of fresh water per day on annual bases it requires about 8.8 million tons of oil [4, 5]; therefore, the importance of using renewable energy resources is evident.

Employing a simplified scheme for desalination is likely to have less capital cost than elaborate ones. For example some researchers have proposed organic-fluid Rankine cycle driven by a PTC collector whereby the electricity generated is used to drive pumps for reverse osmosis desalination [6]. Such a scheme is most likely will entail more capital and maintenance costs. Therefore, the proposed scheme includes a PTC, fuel-fired boiler and Multi-Stage Flash chambers (MSF). A side-by-side study which to be published soon [7] has shown that the performance of PTC for heating up water directly for the purpose of desalination is dependent on the thermodynamic conditions of the water at the exit of the PTC absorber tube which in turn affect the flow conditions inside the absorber. Namely, for optimal fresh water generation the study recommends the water to be in saturated liquid as it exits the absorber tube. Also, the study revealed that the operating pressure affects the water production rate, although to a lesser degree, whereby rates are seen to approach maximum when operating pressure is above 20 bar for the water as it passes the absorber tube. Therefore, in this investigation the hybrid plant (scheme) assumes the water to leave the PTC absorber tube at saturated liquid while being under 20 bar pressure. The study focuses on three months; January, March and June for obtaining an estimate of the plant annual performance in terms of the fresh water yield and the extra fuel required to maintain constant rate of supply. The months have corresponding daily direct beam incident on horizontal surface equal to 3.9 kWh, 6.7 kWh and 8.9 kWh; respectively.

The intent of this article is to estimate the annual production of fresh water from a hybrid fuel-solar desalination plant and to evaluate the required fuel amounts to keep constant production rate of fresh water supply. The investigation does not account for the effect of sun shading that results from clouding; however, it is important to recall that the sun shading is more apparent in cold season; however, for localities in the northern hemisphere the demand for fresh water from desalination plants is less since mainly of rain availability during the cold season.

2 Methodology

The analysis considered solar data for three months; January, March and June, where the first month is typical of cold weather conditions, the second is more of moderate weather while the last month is representative of relatively hot ambient and high solar fluxes. The solar data was generated for the fifteenth day to represent the above months solar conditions utilizing an in-house developed computer program which is based on outline described by [8, 9]. The locality was chosen such that the latitude is 32° north and the longitude is 36° east. The model for predicting beam intensity is described in detail in [10] and was experimentally verified [7]. The computed direct beam intensity incident on a horizontal surface for January and June are depicted in Figure 1.

To capture the solar energy an PTC was used with its geometrical characteristics based on a similar one used for the SEGS program [8]. The length and width of the aperture opening are 12.25 m and 5.75 m; respectively, thus giving an area of 70.44 m^2 of the opening. The simulation of the heat gained by the water as it passes through the parabolic trough collector was detailed in [7] which involves discretizing the absorber tubes into nodes as depicted in Figure 2.

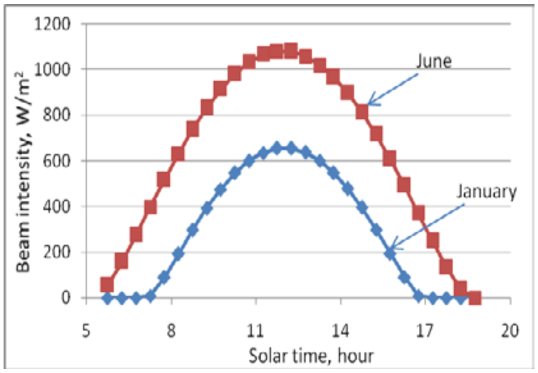

Figure 1. Solar beam intensity incident on a horizontal surface for the months of January and June.

The modes of heat transfer between the water, steel pipe and glass are highlighted by the dashed lines, which are repeated for the remaining nodes. For the water nodes, the heat transfer between the adjacent nodes is represented by arrows since convection is the mode by which heat is transferred as water flows downward in the absorber tube. Finite difference method was employed to generate the solutions. However, in this article the model was modified to allow for the variation of solar data over the entire year. The mean ambient temperatures were taken to be 8 °C, 11.75 °C and 23.6 °C for January, March and June; respectively [11].

The investigation assumes a hybrid plant is sized to have full production of fresh water based on the solar energy availability for the month of June, hence for this month no fuel is required except for the early and the late periods of the day since solar intensity is low. The analysis then estimates the amount of fuel heat required to bring the level of production during the lower solar-energy months; i.e., January and March to the full production of June. Furthermore, the estimated amount of fuel heat does include energy recovery from the generated vapor as it condenses, which is a typical procedure used in desalination plants.

3 Results

Figure 3 shows the generated fresh water for the three selected months January, March and June. It is revealed that for the month of January the rate of production dips during most of the diurnal hours; specifically, before 10:00 AM to past 3:00 PM which is a consequence of the low solar altitude angle for this month compared to that of June; recall that the parabolic trough collector is placed horizontally and oriented north-south direction. The dip is also present for the March month, although to a lesser degree, and is absent for the June month. The effects of these dips lead to the low total daily rate of production as shown in Table 1 compared to that of the month of June.

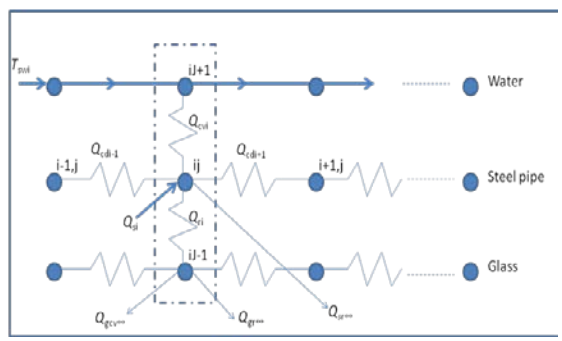

Figure 2. Discretized nodal circuit for the absorber; water, steel pipe and the enclosing glass [7].

The total incident solar heat, gained solar heat by the PTC and the required amount of fuel heat to bring fresh water production to a constant rate is shown in Figure 4. The solar heat is the total incident on the plane of the PTC where for example for the month of June the total incident solar heat is 3067811 kJ of which only 2009152.0 kJ is absorbed by seawater, thus yielding an efficiency of

65.5 % for the PTC. The same data along with other details for the other months are given in Table 1. The amount of fuel heat was computed with regard to taking advantage of the heat that results from condensing the vapor, which is a typical procedure followed in desalination plants. The amount of heat from the fuel is calculated by the appropriate water specific heat, the required water rise temperature and required mass flow rate of seawater to bring it to the desired level. The figure reveals vividly how the sharp drop in heat captured by the parabolic trough collector during the cold season represented by the month January which is reflected on the low production of fresh water by solar energy, a drop of 60.3% when compared to the production in the hot season represented by June.

Summary of the results are shown in Table 1. The gained heat is the heat that is gained by the seawater as it passes through the PTC and leads to partly vaporizing it while the efficiency of the PTC is computed by dividing the gained heat to the total incident solar heat. The two columns before last represent the percent of fuel heat to the sum of gained solar heat and fuel heat. The last column indicates the total production of fresh from solar energy compared to the desired total production.

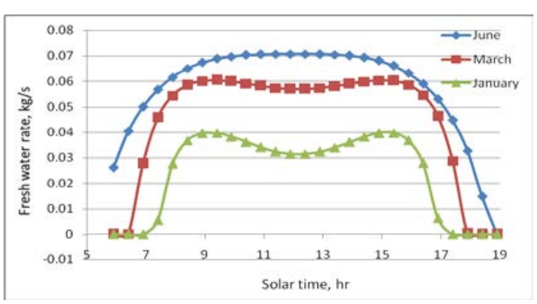

Figure 3. Figure Fresh water production rate from solar energy alone.

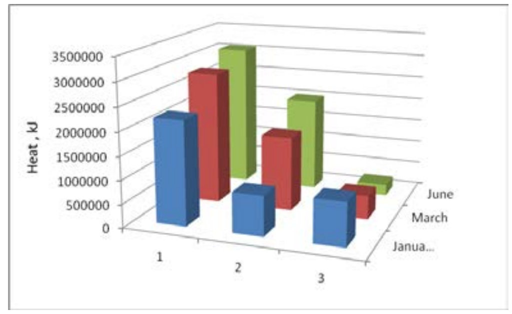

Figure 4. Total incident solar heat (row 1), gained heat by PTC (row 2) and required fuel heat (row 3) for maintaining constant production rate.

Table 1. Summary of results for the Hybrid Fuel-Solar Desalination

Month	January	March	June
Total Solar Incident (kJ)	2214992	2816662	3067811
Gained Solar, (kJ)	850491.7	1581686.8	2009152.0
PTC Efficiency, %	38.4	56.2	65.5
Fuel Heat, kJ	922657.6	507695.8	236491.2
Fuel to total heat (%)	52.0	24.3	10.5
Fresh water (m^3/day)	1.17/2.95	2.18/2.95	2.77/2.95

The results clearly indicate that this kind of seawater desalination hybrid plant may be suitable for most of the year for the production of fresh water. The data in Table 1 indicates that only 15% of fuel heat required to bring the production to a constant level. It is important to recall that the sun shading effect that result from clouds was not accounted for in the current investigation hence the results, especially for the month of January, is optimistic; however, considering the fact that the rainy season for northern localities occur during the cold months, thus decreasing the demand for fresh water from desalination plants. In other words, maintaining high production rate during the cold season is not necessary.

4 Conclusions

The annual yield of a seawater desalination hybrid plant utilizing solar energy augmented by fuel heat was evaluated by examining the plant performance during the months of January, March and June, which are taken to represent cold, mild and hot seasons; respectively. The solar energy was concentrated using a parabolic trough collector that has length and width of 12.25 m and 5.75 m; respectively. The results indicated that the production of fresh water from solar energy drops to 73.9% of the total required during the mild season (March) and drops to about 39.7% of full capacity for the cold season (January). However, when utilizing fuel to augment solar energy only about 10.5% of fuel heat to that of the total required was necessary to bring the production to the full capacity of June or 2.95 m^3/day, thus indicating the adequacy of the scheme for generating fresh water for most of the year. The low efficiency in the January month is due to lower beam intensity and more importantly due to the low altitude angle. The deficiency in the output of fresh water during the cold season may be augmented by the rain fall which normally occur during the cold season; thus reducing the demand of fresh water from the desalination plant as well as using fuel heat.

References:

1. V.K. Jebasingh, G.M. Joselin Herbert. A review of solar parabolic trough collector. Renewable and Sustainable Energy Reviews, 54(2016)1085–1091.
2. El-Nashar AM. The economic feasibility of small solar MED seawater desalination plants for remote arid areas. Desalination 2001;134:173–86.
3. El-Nashar AM. Economics of small solar-assisted multiple-effect stack distillation plants. Desalination 2000;130:201–15.
4. Kalogirou, S, Use of Parabolic Trough Solar Energy Collectors for Seawater Desalination. Applied Energy, Vol. 60: 65-88.
5. Kalogirou SA. Seawater desalination using renewable energy sources. Progress in Energy and Combustion Science 2005;31:242–81.
6. Bruno Joan Carles, Lopez-Villada Jesus, Letelier Eduardo, Romera Silvia, Coronas Alberto. Modelling and optimization of solar organic rankine cycle engines for reverse osmosis desalination. Appl Therm Eng2008;28:2212–26.
7. A.K. Ababneh, A. Jawarneh, H. Tlilan, N. Duke, 'Performance Evaluation of Solar Parabolic Trough Collector for the Application of Sea Water Desalination'
8. Energy Conversion, D. Y. Goswami, F. Kreith, Taylor and Francis Group.
9. ASHREA Handbook, Fundamentals, 1993
10. A. Ababneh 'Energy Conservation Using a Double-effect Absorption Cycle Driven by Solar Energy and Fossil Fuel', JJMIE, Vol 5, No 3, 2011, pp 213-219
11. Heating and Air Conditioning, M. A. Alsaad, M. A. Hammad, 3rd edition
12. Kalogirou, S, Use of Parabolic Trough Solar Energy Collectors for Seawater Desalination. Applied Energy, Vol. 60: 65-88.
13. Parabolic-trough solar collectors and their applications, Renewable and Sustainable Energy Reviews, September 2010, Vol 14(7): 1695-1721, A. Fernandez-Garcia, E. Zarza, L. Valenzuela, M. Perez.