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Modelling and performance evaluation of a parabolic trough solar collector desalination system

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Abstract

Renewable energy employing desalination is a fast growing field of research. Solar technology employing water desalination is sustainable solution for dry region with scarcity of water. High potential of solar energy is used for purification of saltwater. The paper is concerned with an experimental study of parabolic trough solar collector desalination setup with tracking system manufactured to facilitate capturing of sunlight with respective sun position. Desalination assisted by parabolic trough collector with horizontally north-south orientation. Concentrating the solar irradiation to the focal line containing receiver tube of parabolic trough, where saline water inside receiver tube is heated up and produce steam. In the condenser, steam condenses and in the outlet of condenser potable water has been formed. During the research evaluation of parabolic trough performance using different receiver tube of stainless steel and glass covered copper tube had done. From the experiments, it is observed that the performance of parabolic trough solar collector strongly depend on solar light tracking and focal receiver. Also physical and chemical analysis of both input saline water and desalinated water had done. Desalination setup has a yield of 2 Litre/m².

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Keywords: Parabolic trough;Desalination;Receiver tube.

1. Introduction

Fresh water is a key element for human beings and animals. However the availability of fresh water is becoming a rare source and decreasing day by day due to unplanned mechanism and pollution created by manmade activities. Major portion of water source contain salinated water and so it’s not used for human consumption. Desalination is one of the suitable process for removing salts and contaminated elements. Among different desalination methods renewable energy using water purification techniques are preferable than conventional methods.

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Large cost of fuels and pollution using fossil fuels leads to the usage of renewable energy source as alternatives in desalination plants [1]. Among different solar thermal concentrating systems, mainly parabolic trough type equipment are chosen for desalination process [2]. Parabolic trough solar collectors have high efficiency for converting solar energy to heat energy and stable performances at high temperature range [3].

Solar desalination systems have poor efficiency because of higher heat loss from large area of collector, but in parabolic trough collectors concentrating sun light in to small area and heat lost should be lower compared to other solar desalination systems [4] and so it can achieve high temperature. Using parabolic trough concentrating solar irradiation in to the focal line contain receiver tube. Inside the receiver tube working fluid is heated. This converted heat energy is used for various purpose like drying of agricultural products, heating of building, industrial process heat, producing electric power and industrial steam generation [5].In this work parabolic trough solar collector associated desalination system is developed. And analyses the temperature variation between one hour intervals with respect movement of sun position. Using stainless and glass covered copper receiver tube hourly variation of temperatures are measured. Also check the yield and quality of output.

1.1. Basic working of solar parabolic trough collector

Solar radiation coming from sun collected over area of reflecting surface of parabolic trough and concentrated in to the focus of parabola. Receiver tube is placed on the focal line axis, so working fluid inside is heated up due to concentrating solar irradiation using collector surfaces. In the receiver tube conversion of solar energy in to thermal energy occur [6].

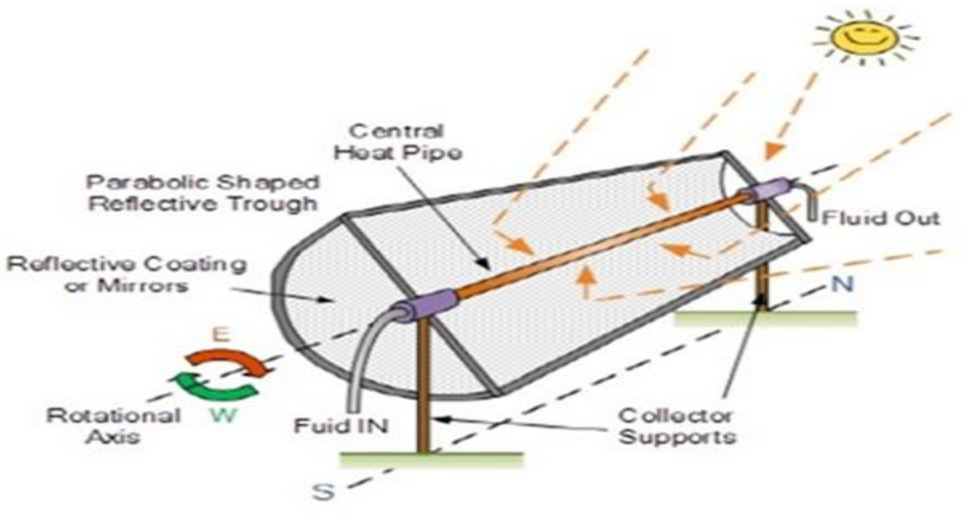

Fig.1 Parabolic trough collector [6]

Advantages of Concentrating Collectors [7]

- Reflecting surfaces require less material and are structurally simpler than flat plate collectors.
- The absorber area of a concentrator system is smaller than that of flat plate system for same solar energy collection.
- Heat lost to the surrounding per unit of solar energy collecting area is less than that of flat plate. And working fluid achieve maximum temperature.

Main losses in collector are, [7]

- Conductive losses: Heat transfer takes place through adjacent surfaces by conduction; this can be minimized by placing insulating materials in place of good conductors of heat.
- Convective losses: Heat losses due to air from receiver tube. This can be minimized by closing all the air gaps.
- Radiative losses: Radiative losses from the absorber can be prevented by the use of spectrally selective absorber coatings. That decrease heat losses and increase collector efficiency.

1.2 .Components of experimental setup

- Parabolic trough with reflecting surface
- Stainless steel absorber tube
- Glass coated copper absorber tube
- RTD
- Flowmeter
- Pyranometer
- Condenser
- Pump
- Water container and Collecting tank

1.3. Parameters of the experimental setup

Table 1. Specification of experimental setup

Feature/parameters	**Value**
Collector dimension	2.5m x1.75m
Collector area	4.375 m^2
Absorber diameter	25 mm
Glass tube diameter	40 mm
Length of receiver tube	2.5 m
Tilt factor	1
Specific heat of salt water	3900 J/Kg K

1.4. Assembly of parabolic trough desalination system

The trough is made up of high fibre having a weight of about 55 kg. It has a trough length of 2.5 m and a width of 1.75 m. It is covered with any of the reflecting materials or sheet. In this experiment it is polished with aluminium or alanod. The completed trough is mounted on the stands which has a height of about 2 m. The receiver tube placed on the focal line of parabolic trough.

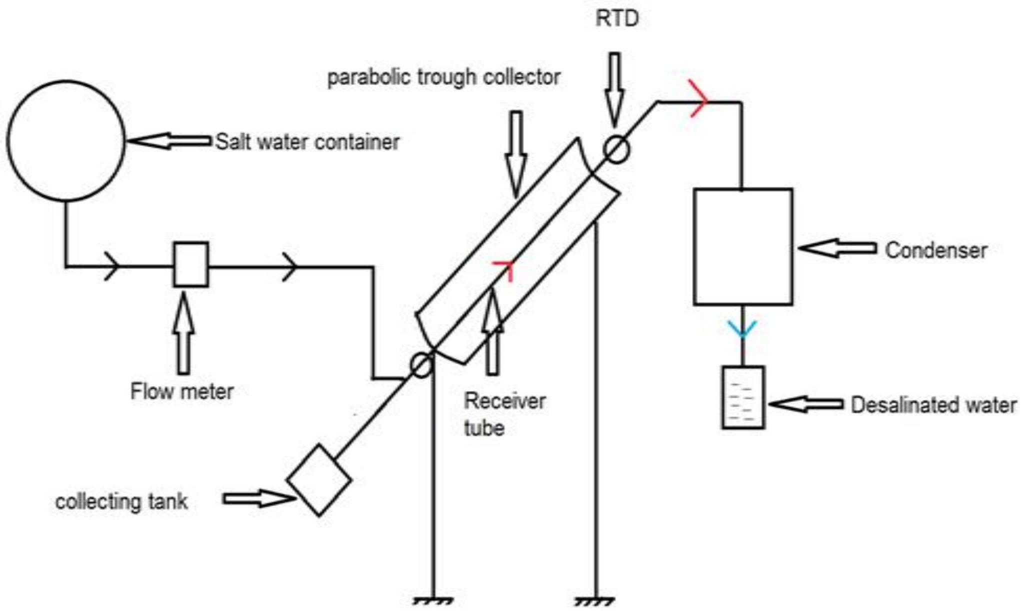

Fig.2 Schematic flow diagram

RTD is inserted at the inlet and outlet of the receiver tube to sense the inlet and outlet temperature of the working fluid. The end of RTD is connected to the virtual lab (lab view) monitor for measuring temperature. From the arrangement, temperature at each interval of time can be found. The north side of parabolic trough arrangement is lifted up height of 0.5m using bricks and south side placed in ground level. Receiver tube south end is connected with collecting tank and other side is connected with condenser setup. Condenser is copper tube with 1cm diameter coiled and it placed in water for cooling the output. Receiver tube is partially filled by working fluid used as sea water by placing working fluid contain container at a height of 1.75 m in a stand. Concentrating solar irradiation in to the focal line of parabolic trough contain receiver tube by proper tracking with respect sun position. Schematic diagram and detailed parts are shown in the figure 2. Experiments are done with using stainless steel and glass covered receiver tube with same dimension. Experiment setup shown in figure 3.

2. Experiment setup

All the experiments were conducted at Amritapuri campus of Amrita school of engineering Kollam, Kerala (latitude 9.1° and longitude of 76.49°). Experiments are carried out on month of February 2016. The parabolic trough solar desalination system is oriented in north-south direction. Glass covered copper tube used as receiver tube. Experiments are done on sunny days from 09:00 hours to 17:00 hours.Thus the performance of a solar heating panel strongly depends on the solar radiation received throughout a day [8]. The inlet temperature and outlet temperature from the RTD is measured with the help of virtual lab technique. Based on the movement of the sun using tracking system solar irradiation is concentrated in to the focal line contain receiver tube. Tracking is done from East to west.

Fig.3 Experiment setup of Desalination system

Sun tracking system consist of gear drive, motor and for controlling, output from the lab view software given to lab jack (data acquisition device) and signal from lab jack passed via motor card to the motor for moving system with sun position. Receiver tube partially filled with working fluid by placing sea water container at height of 1.75m. Concentrating the solar irradiation in to the receiver tube sea water is heated up and form vapour by settling the salt and minerals.

Vapour formed is move to the condenser side and it cooled in the condenser in to pure water as output. Flow rate from the sea water container to receiver depend upon the evaporation rate inside the receiver tube. Salts and impurities due to phase change of sea water under go gravity settlement in to the collecting tank placed south side of receiver tube. Outlet forming water is measured in each hour. The intensity of irradiation measured using the pyranometer and solar irradiation intensity in Kollam is 700 W/m².

3. Result and Discussion

Solar intensity on the experiment days of February are measured using pyranometer from time of 09:00 hours to 17:00 hours and on the table 2 shows intensity measured in each hours. Maximum solar intensity measured is 715 W/m² at peak noon time. At that time desalination system show more performance. At morning and evening time irradiation intensity is very poor.

Table 2. Solar intensity measured on the Experiment day

Time (24 Hour format)	Solar Intensity (W/m²)
9	460
10	566
11	625
12	680
13	715
14	700
15	673
16	567
17	415

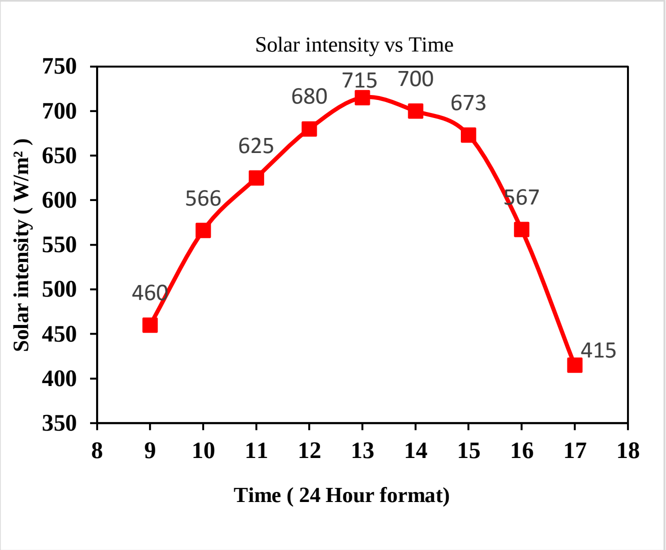

Fig.4 Solar intensity vs Time

Concentrating the solar irradiation in to receiver tube leads to conversion of salt water in to vapour and it move to condenser section were it condensed in to pure water. Rate of distilled water is measured hourly. Figure 5 shows the yield of desalination system

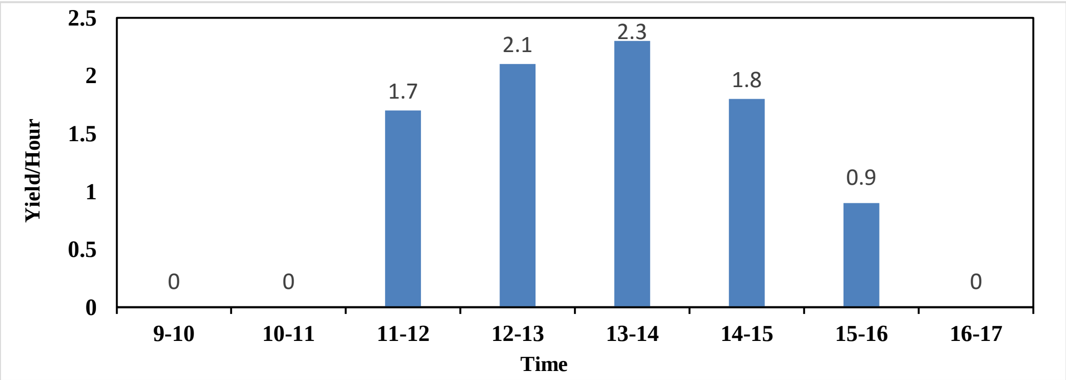

Fig.5 Yield per hour

For analysing the performance of the parabolic trough desalination system inlet and outlet temperature are measured in each hour on the experiment conducting sunny day. Initially experiments done with stainless steel used as receiver tube in the experiment set up. The measured temperature readings are shown table 3.

Table 3. Inlet and outlet temperatures of the salt water using stainless steel reciever tube.

Sl.No	Time (24 Hour Format)	Inlet Temperature (°C)	Outlet Temperature (°C)
1	9	35	44
2	10	37	49
3	11	40.5	57
4	12	43	64
5	13	45	75
6	14	44	67
7	15	42.5	61
8	16	40	55.5
9	17	39	53

Table 4. Inlet and outlet temperatures of the salt water using glass coated copper reciever tube

Sl.No	Time (24 Hour Format)	Inlet Temperature (°C)	Outlet Temperature (°C)
1	9	32	40
2	10	34.5	70
3	11	42	98
4	12	46	101
5	13	52	103
6	14	50	100
7	15	47	99.85
8	16	45	75
9	17	43	58

Using stainless steel receiver tube salt water is maximum heated up to 75°C and for phase change of salt water this much of heat is not sufficient for formation of vapour. Using stainless steel receiver tube in the desalination experiment set up poor performances. Stainless steel receiver tube is replaced with glass covered copper receiver tube with same dimension. Experiment was done and measured readings are shown in table 4. Using stainless steel receiver tube in the desalination experiment set up poor performance. For the calculation of efficiency [9] of the parabolic trough solar desalination system,

Efficiency, $\eta = Q/ [I * A] * 100$ (1)

Where,

Q= Net useful heat gained by fluid
$Q= m*H_{fg}+m*C_{p*}(T_f–T_i)$
H_{fg}= Latent heat of vaporisation = 334kJ/ kg for sea water.
m =Rate of desalinated water
Cp=Specific heat of working fluid = 3900J/kgKfor seawater
T_f= Maximum temperature attained by the fluid (°C)
T_i = Initial temperature of fluid (°C)
I= Solar irradiation intensity =700 W/m² for Kollam
A = Area of collector = 4.375 m²

Heat, $Q = m*H_{fg} + m*C_p (T_f – T_i)$
T_f= Final temperature = 103°C
T_i=Initial temperature = 32°C
m=Rate of desalinated water = 2.3L/Hr = $6.38*10^{-4}$ kg/s
$Q= 6.38 *10^{-4}*(334*10^3 + 3900*(103-32))$
= **390.292 J/s**

Efficiency, η

$$\eta = \frac{390.292}{(700 \times 4.375)} = \mathbf{0.1274 = 12.74\%}$$

The maximum temperature attained by salt water is 103°C and efficiency is 12.74%.

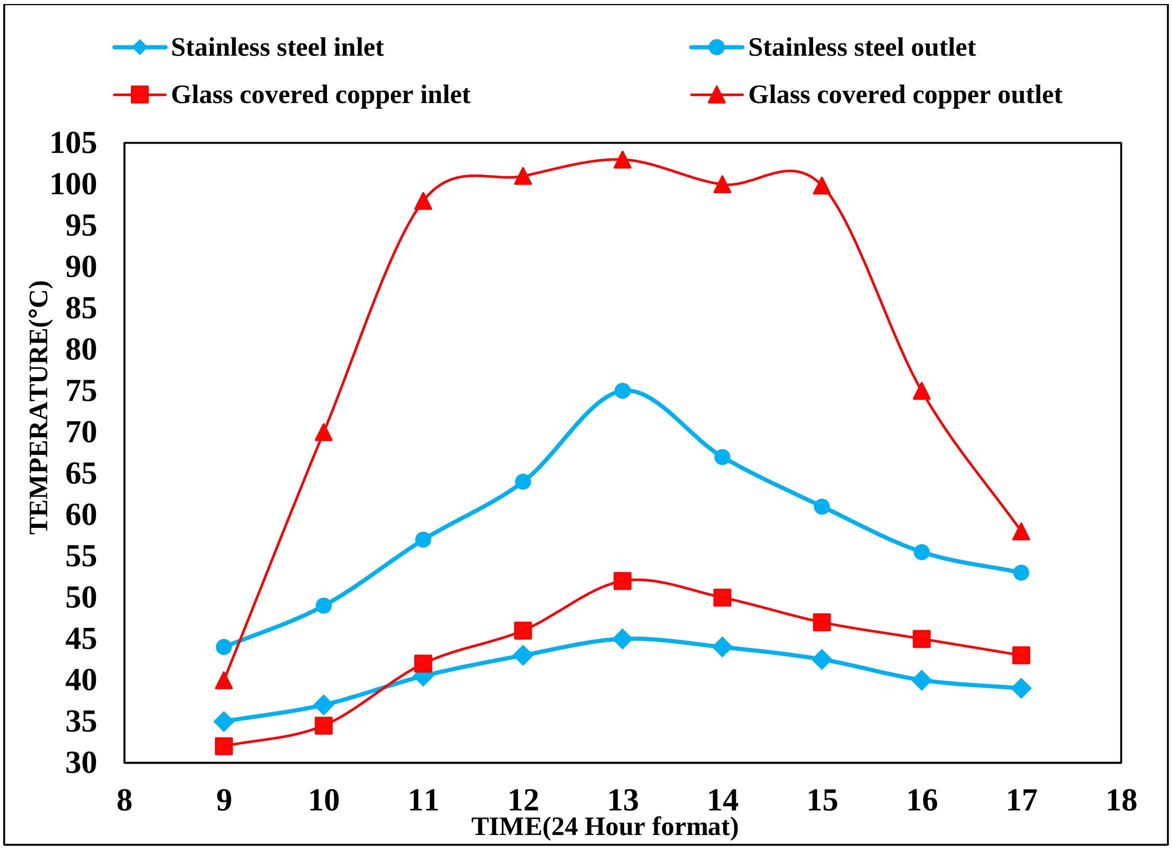

Fig.6 Inlet and outlet temperature of working fluid

The analysis of both input saline water and desalinated water from the parabolic trough solar desalination system had done. The physical and chemical analysis are done at Kerala water quality control district lab at Ernakulum. The quality of extracted water tested based on a standard BIS-10500/2012. Obtained result are shown table 5.

Table 5. Physical and chemical analysis of saline and desalinated water

Parameters	**Sea water**	**Desalinated water**	**Acceptable limit**	**Units**
pH	7.84	7.44	6.5 – 8.5	pH
Turbidity	1.5	1	1	(NTU)
Alkalinity	130	90	200	mg/litre
Hardness	7000	1600	200	mg/litre
Calcium	2733.4	561.12	75	mg/litre
Magnesium	72.144	48.6	30	mg/litre
Chloride	3500	2000	250	mg/litre
Sulphate	301.6	55.85	200	mg/litre
Nitrate	0.3044	0.184	45	mg/litre
Iron	0.3	0.1	0.3	mg/litre
Acidity	7	4	-	mg/litre
Electrical conductivity	443	25.3	-	µmho/cm
Total dissolved solids (TDS)	221	180	500	mg/litre
Odour	Agreeable	Agreeable	Agreeable	-

4. CONCLUSIONS

The parabolic trough desalination system had output formed when solar intensity range is above 600 W/m². From time of 11:00 hours to 15:00 hours, effective performance of system was founded. Using glass covered receiver tube maximum temperature of 103 °C and using stainless steel receiver tube using maximum of 75°C temperature is only reached. Compared to glass covered copper receiver with stainless steel receiver tube have poor performance because of high temperature attained at exit of copper receiver tube due to high thermal conducting property of material and reduced conventional loss using glass covering. Desalination system have production rate of 2 litre/m² and efficiency of 12.74%. From lab reports desalinated water is bacteriologically free and fit for the human consumption. Chemical and physical analysis result shows that hardness, calcium, magnesium, and chlorides levels are more than acceptable limits in both water, however using parabolic trough solar desalination setup hardness and other chemical elements content levels can be bring in to lower levels and acceptable limits.

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References

[1] Fahad A. Al-Sulaiman, M. Ifras Zubair, Maimoon Atif, Palanichamy Gandhidasan, Salem A. Al-Dini , Mohamed A. Antar, Humidification dehumidification desalination system using parabolic trough solar air collector, Applied Thermal Engineering 75 (2015) 809-816

[2] Wolfgang Meinecke, Parabolic trough collectors, Renewable energy systems and desalination – Vol. II.

[3] Soteris Kalogirou, Use of parabolic trough solar energy collectors for sea-water desalination, Applied Energy 60 (1998) 65-88.

[4] FernandezGarcía, Renew. Sust. Energy Rev., 2010, vol. 14, pp. 1695–1721.

[5] Soteris A. Kalogirou, Solar thermal collectors and applications, Progress in Energy and Combustion Science 30 (2004) 231–295.

[6] Mr. Mohd. Rizwan, Mr. Md. Abdul Raheem Junaidi, Mr. Mohammed Suleman, Mr. Mohd. Aamer Hussain, “Experimental Verification and Analysis of Solar Parabolic Collector for Water Distillation”, International Journal of Engineering Research ISSN: 2319-6890) (online), 2347- 5013(print) Volume No.3, Issue No.10, pp: 588-59301 Oct. 2014.

[7] Pradeep Kumar K V, Srinath T, Venkatesh Reddy,“Design, Fabrication and Experimental Testing of Solar Parabolic Trough Collectors with

[8] Automated Tracking Mechanism”, International journal of research in Aeronautical and mechanical engineering, August 2013 ,pgs 37-55.

[9] M.J Brooks, I.Mills, T.M.Harms, “Performance of a parabolic trough solar collector”, Journal of Energy in Southern Africa, Volume 17 No3, August 2006.

[10] H. Jafari Mosleh, S. Jahangiri Mamouri, M.B. Shafii, A. Hakim Sima, A new desalination system using a combination of heat pipe, evacuated tube and parabolic trough collector, Energy Conversion and Management 99 (2015) 141–150.