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Performance and Analysis of Solar Desalination System Using Evacuated Tube Collectors

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Abstract: *In the present era getting pure water for drinking is hard in most of the countries. Reverse osmosis and desalination are the two methods of purifying water. The current study uses the desalination process to purify water using evacuated glass tubes as the main tool to remove the water from contaminants in contrast with the other systems which uses the method of removing contaminants from water. The distillation technique takes the advantage of the principle that dissolved substances in water vaporize at different temperatures. Most potential chemical contaminants in water are having higher vaporization point than water. Measurement of Stagnation temperature plays an important role in designing of any distillation unit. Since the water evaporates at 100˚C the heat required for most of the water distillation process ranges from 70˚C - 120˚C. In the present system, by using evacuated glass tube collectors, this temperature can be easily achieved. With the aid of recent advances in vacuum technology, use of evacuated tube collectors which offers high temperature efficiencies will be helpful in the mass production of water purifiers. The experimental results shows that, the quantity of distilled water collected keeps on increasing as the day passes with the radiation level. The result also reveals that, the quality of distilled water is suitable for drinking.*

Keywords: *distillation, evacuated glass, radiation, stagnation temperature.*

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I. Introduction

Worldwide interest for water sources keeps on expanding whilst freshwater sources are becoming rarer due to a constant increase in consumption and the more pronounced effects of climate change, especially in semi-arid and coastal/islandic areas [1].Even though the oceans of the world is filled with 97% water, 2% of water is hiding in the form of ice in the polar regions and only about 1% of the remaining water is fresh water and can be used by humans, animals and plants [2].

Rapid growth of population, industrialization, and urbanization, the use and need of fresh water has become very important. Many countries in Middle East, North Africa, Saudi Arabia and in some parts of India are facing great challenges due to limited natural resources of drinking water. Also the Electrical conductivity (EC) of ground water is greater than 10000mS/cm at 25˚C making the water non potable. Apart from that, high concentration of fluoride (>1mg/l), nitrate (45mg/l) present in drinking water makes it non potable and causes various health problems [3].

In order to supply fresh water in dry regions, several technologies have been developed. Among these developments, Reverse Osmosis (RO), Vapor Compression (VP) and Electro dialysis (ED) are the most common methods [4]. Desalination of saline water is known to be one of the most sustainable alternative solutions to provide fresh water. This resource can play a significant role in socioeconomic development in many developing countries such as Africa, Pacific Asia and countries in the Middle East [5] and Latin America. Desalination is a process in which saline water is separated into two parts: one that has a low concentration of dissolved salts (fresh water), and the other which has a much higher concentration of dissolved salts than the original feed water (brine concentrate) [6].

Various types of solar collectors like flatbed collectors, curved type collectors, tube type collectors have been utilized for the desalination of water [7-10]. Garcia Rodriguez and Gomez Camacho used a distillation system coupled to a parabolic trough collector (PTC) [11]. Hiroshi and Yasuhito [12] suggested a system including a heat pipe solar collector and a Vertical Multiple Effect Diffusion type (VMED) still and predicted to produce 21.8 kg/(m^2·day) which was shown to be 13% larger than that of the VMED still coupled with a basin type still. Dev et al. [13] used a system including concave reflectors with the water depth of 3 cm which led them to obtain 4.3 kg/(m^2·day) of fresh water.

In 2012, Dev and Tiwari [14] investigated the annual performance of a solar still coupled with an Evacuated Tube Collectors (ETC), and reported an average thermal efficiency of 21.3% for the system. An ETC is a type of solar collector that uses evacuated tubes to insulate the inner pipes from the ambient. Sampathkumar et al. [15] also investigated the performance of a solar still coupled with an ETC and obtained higher production rate compared to the similar passive solar still. In 2014, Jahangiri Mamouri et al. [16] introduced a solar still which uses a combination of thermo syphon heat pipes and ETCs. They concluded that the system can reach the maximum production rate of 1.02 kg/(m2·h) and maximum efficiency of 22.9%. Evacuated tube solar collectors (ETC) are also observed to be more beneficial and efficient than flat plate collectors [17].

In this study, a twin-glass evacuated tube collector (TETC) is employed as a basin. The present system can be classified as a passive solar desalination system. However, the conventional basin is eliminated from the setup and the TETC itself serves as a basins. The TETC absorbs the incoming solar radiation, converting it into heat at the inner absorbing surface, and transfers this heat directly to water inside it by means of natural convection and causes it to evaporate. Hence, there is no thermal resistance between the collector and the conventional basin as proposed by previous researchers. Therefore, a higher rate of production is expected.
(10)

II. Description Of Experimental Setup

Components of Solar desalination System
The proposed desalination system is built of the following two main sections.

- Evacuated tubes
- Condensing chamber

2.1 Evacuate tubes

The evacuated tubes are made up of two concentric borosilicate glass tubes. The space between the inner and outer surfaces of the glass tube is evacuated to prevent heat loss to the surroundings. Moreover, the inner surface of the glass tube is blackened to increase the absorption rate of the solar radiation. While the tube length is 1500mm, the inner and outer diameters are 37mm and 47mm respectively with its solar absorptance > 0.93, solar emittance < 0.06 and the vacuum between outer and inner tubes is 5×10^{-3} pascal.

2.2 Distillation chamber

A double walled cylindrical vessel is made up of stainless steel has been fabricated for condensing the vaporized water. The inner chamber contains the vaporized water while the outer chamber contains the cooling water which was circulated continuously throughout the period of experiment. The steam generated from the evacuated tube collector is directly introduced into the condensing chamber and the distillate was collected in a vessel at the other end of the tube.

The entire setup is sealed properly to avoid leakage of water vapor to the ambient. A schematic diagram of the experimental setup is shown in Fig 1. The setup was supported by a stand made of mild steel kept at 30^0 inclinations with the horizontal.

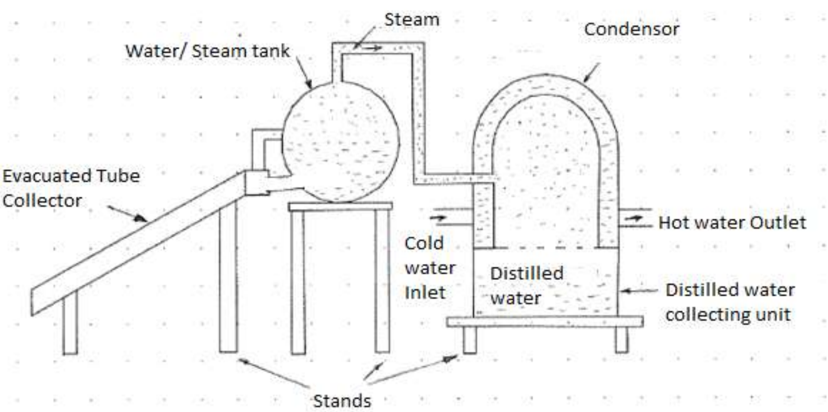

Figure 1 Desalination experimental setup

2.3 Design of the Solar Desalination system

In this evacuated tube coupled solar distillation system, an evacuated tube collector of capacity 100 liters per day having 15 tubes was used. The tubes were at an inclination of 30^0. Water at a temperature of 30 °C was filled into the collector at the start of the experiments and environmental parameters were monitored continuously throughout the day. This was continued till the tank temperature exceeded 90°C and started producing steam. As soon as steam started emanating at the outlet, the condensing chamber was attached to the outlet and the steam was condensed using the condensing chamber.

The condensing chamber was made up of stainless steel material and had two walls. The inner chamber was a straight tube of length 1.5 m and contained the vaporized water. The outer chamber contained the cooling water, which was circulated continuously through two openings in the chamber. Through one opening at the bottom, cold water was supplied and through the other opening at the top, the heated water was drained out. The distillate was collected in a vessel kept at the bottom of the chamber.

In the present investigation, two types of experiments were conducted. While the first experiment was conducted to find the stagnation temperature of an evacuated tube, the other test was conducted after filling the system with water to study the thermal characteristics.

III. Stagnation Temperature Test

An evacuated tube was placed facing towards south in the outdoor atmosphere. The opening of the tube was closed with airtight cork, and was fitted with a thermometer. Solar radiation was recorded for every five minutes under clear sky conditions. The ambient temperature and the tube temperature were simultaneously measured.

IV. Efficiency Of The Evacuated Tube Coupled Desalination System

Experiments were carried out from 10.00 am to 3.00 pm under clear sky conditions and the parameters like solar radiation, ambient temperature, inlet temperature of the liquid and outlet temperature of the liquid were measured at an interval of fifteen minutes throughout the experimental period. The collected distillate was measured using a measuring jar. Using the generated database, the efficiency of the novel system was calculated.

To calculate the efficiency of the evacuated tube, the following parameters were determined.

Q_t (l/m^2 day) - the solar insolation incident on the evacuated tube

Q_e (l/m^2 day) - the amount utilized in vaporizing the water

M_e (Kg/m^2 day) - the daily output of the distilled water

i.e,

$$M_e = Q_e / L \qquad \text{(Eqn.1.0)}$$

Where L is the latent heat of vaporization of water (2.489×10^6 l/kg)

The efficiency of the evacuated tube desalination system is given by:

$$\eta = Q_e / (A * l * t) \qquad \text{(Eqn.1.1)}$$

$$\eta = (M_e * L) / (A * l * t) \qquad \text{(Eqn.1.2)}$$

Where,

A- area of the evacuated tube ($1.64m^2$)

l - average insolation (W/m^2)

t - time taken for collecting M_e kg of water (18000s)

V. Collection Of Experimental Data

During the period of study, the variables such as solar radiation, ambient temperature, inlet temperature and outlet temperature were recorded every fifteen minutes. Solar radiation was measured with pyranometer. The range of measurements of this instrument was 0-1300 W/m^2 and its precision was 0.1 W/m^2. A dry and wet thermometer was used for measuring ambient temperature. The range of measurements of this instrument was 0-100^0C and its precision was 1^0C. The pH values were measured with the benchtop pH meter with an accuracy of pH ±0.01.

VI. Results And Discussion

In the present investigation the stagnation temperature was measured using the reading taken from morning 10.00am to evening 4.30 pm at the interval of every 5 minutes and the observations are tabulated. The temperature versus time plot drawn is presented in Fig 2. According to the observation and the figure 2, the maximum temperature attained by the system is 127^0 C which is also known as the stagnation temperature. Since this stagnation temperature is above the range of temperature for low temperature applications, the evacuated tubes can be used efficiently for low temperature applications in domestic, commercial, agricultural and industrial sectors. Variation of solar radiation with respect to time is presented in Fig 3. It is evident from the figure that the maximum radiation attained in that particular day is 948 W/m^2, which is attained at the mid of the day when the ambient temperature is 37^0 C.

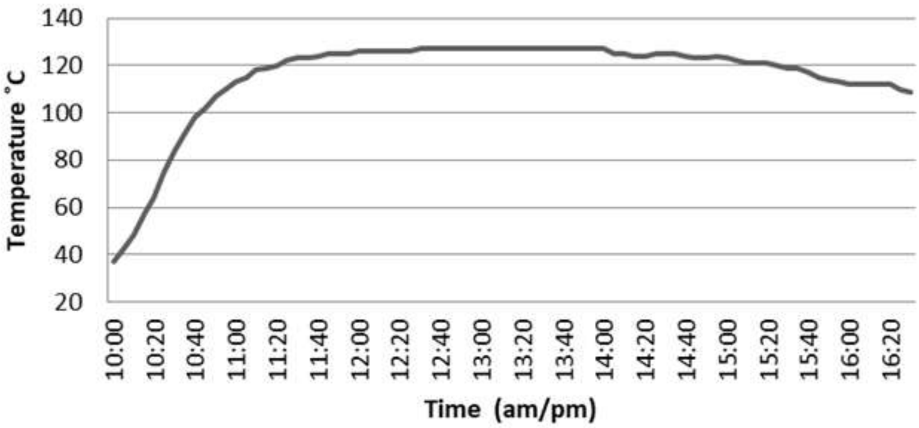

Figure 2: Variation of stagnation temperature with time

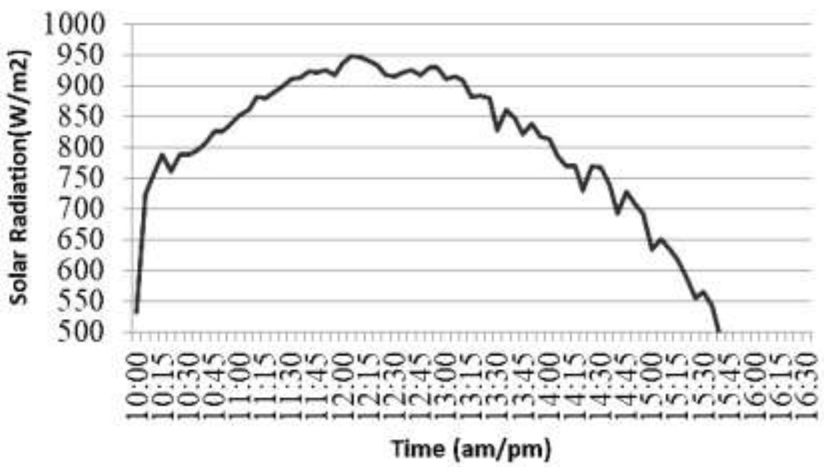

Figure 3: variation of solar radiation with respect to time

In the present experimentation the readings are noted down between morning 10.00am to evening 3.00 pm at the interval of every 15 minutes and are tabulated. Table 1 shows the summarized result of seven days data collection. Figures 4 and 5 shows the variation of amount of water collected and efficiency of the system with respect to number successive days of experimentation.

Figure 6.3 reveals that, the amount of water collected goes on increases as the days passing. This is because of the increasing in the temperature of the water which is present in the water tank. Since the water tank is an insulated one, the water which got heated up whole day will retains its temperature for the next day circulation and causes the increment in the temperature which is entering the evacuated tube which enhances the yielding and as well as efficiency of the system as shown in figure 5.

Table 1: Comparison of the observed data and results.

Day	Solar radiation (W/m^2)	Mass of water collected per day (ml)	Efficiency %	Average ambient temperature °C
1	782.5	2000	21.6	34.3
2	834.3	2200	23.2	32.6
3	669.0	2200	25.0	32.1
4	752.7	2500	28.0	31.6
5	787.0	2800	30.0	33.9
6	770.7	2900	31.7	34.0
7	856.0	3100	32.6	33.7

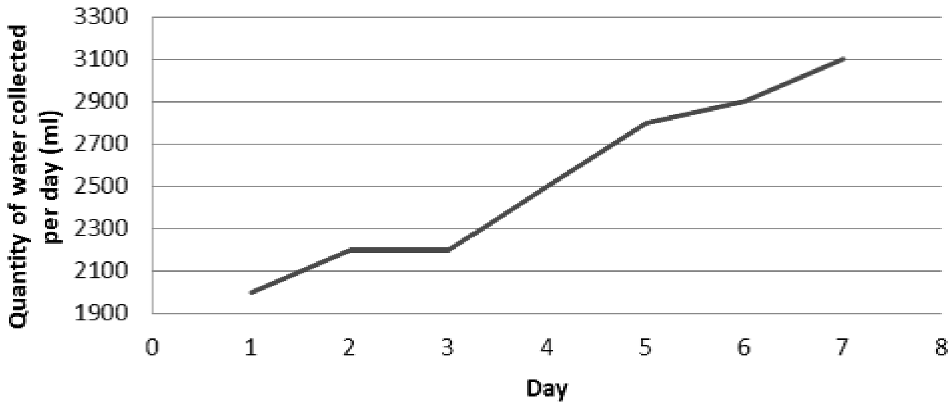

Figure 4: Quantity of water collected

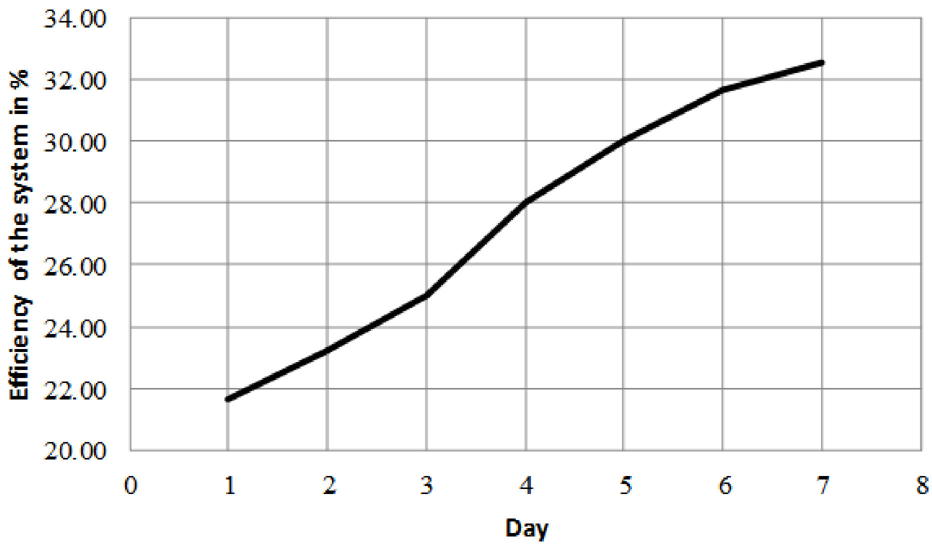

Figure 5: Variation in the efficiency of the system with day

Table 2 shows the properties of the distillate. The table reveals that, the water which is distilled by the present system has pH value close to the pure water and amount of total dissolved solids are very less in comparison with ordinary tap water. Hence it is clear that, the water which is yielding by the present system is pure and suitable for drinking purpose.

Table 2: Properties of the distillate

Sample number (day)	pH	Total dissolved solids (ppm)
1	6.79	92.5
2	6.80	90.1
3	6.78	75.9
4	6.86	91.6
5	6.80	97.0
6	6.83	96.0
7	6.90	93.4
Tap water	**7.92**	**343.0**

VII. Conclusions

The idea of using evacuated tube collector (ETC) to transfer the heat directly to the salty water improves the performance of the desalination system. Implementing ETCs for direct heat transfer to the water reduces the heat loss to the environments and improves the efficiency of the absorbed solar radiation. The earlier studies shows that amount of water processed is directly proportional to the incoming solar radiation. In the present system, since the collector is an evacuated tube, it maintains the heat absorbed and it is utilized for the next fill up of the water and gives the better yielding even though there is a reduction in the amount of radiation on the next day. The efficiency of the collector also gets increases with the incident radiation and making the desalination process as a continuous. On the other hand, it was measured and observed that the ambient temperature and the wind speed have not produced any significant changes in the yield and the working of the system. The variation of the wind speed was minimal and however it can be varied with higher values and used for the future studies. The ETC was placed at a particular fixed inclination angle of 30˚ with the horizontal can be varied depending on the location to get maximum output and efficiency of the collectors.

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