Performance analysis of a solar still coupled with evacuated heat pipes

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Abstract. In developing countries the need for better quality drinking water is increasing steadily. We can overcome this need by using solar energy for desalination purpose. This process includes fabrication and analysis of a pyramid type solar still coupled with evacuated heat pipes. This experiment using evacuated heat pipes are carried in mainly three modes namely 1) Still alone 2) Using heat pipe with evacuated tubes 3)Using evacuated heat pipe. For this work single basin pyramid type solar still with 1m² basin area is fabricated. Black stones and Black paint are utilised in solar still to increase evaporation rate of water in basin. The heat pipe’s evaporator section is placed inside evacuated tube and the heat pipe’s condenser section is connected directly to the pyramid type solar still’s lower portion. The output of distillate water from still with evacuated heat pipe is found to be 40% more than the still using only evacuated tubes.

1. Introduction

The Energy and water are the most essential things for the sustainment of life on earth and it needs to be conserved for the sustainable development of the world. Even though water is a nature’s gift but clean and potable water is still not available for forty-percent of the world population. This is because about 97% of the water is salt water, about 2% of the water is in the form of ice in polar region, and about 1% fresh water is available to fulfill the need of the animals, plants and human beings. Hence the purification of water is most essential. To purify this we need energy and the renewable energy like solar energy is a better option for this.

The process of filtering salts and other impurities using solar energy to get fresh and potable water is called solar distillation. In comparison with various other methods this method is simple and within the range of economy. Solar distillation resembles the method of natural rain. Water first evaporates into water vapour. Water vapour rises, condenses on glass surface for collection removing salts and microorganisms. Final product is pure water.

Few relevant works related to solar distillation using evacuated tubes have been carried out to increase the distillation output. Jahanbakhsh et al. [1] performed experimental analysis on solar collector with heat pipe using water-ethanol solution in various concentrations as working fluid and found that 50-50% of water-ethanol is optimal and also performed experiments with various tilt angles, among them...
Put of 2.8 litres per day designed to study and analyze the performance of a solar still coupled with heat pipes with different working fluids for different fill ratios at different tilt angles and concluded that performance with methanol and acetone was better compared to water. They also concluded that 25% fill ratio is optimal and 60° tilting angle is better compared to 35°. Rajaseenivasan et al. [7] integrated flat plate collector with solar still. They obtained 60% higher distillation output when compared to the solar still alone for the same basin area. Kalidas Murugavel et al. [8] conducted experiments on double slope single basin solar still year around performance and concluded that the output for summer is 4 litres per day. Kalaivani et al. [9] experimented with double slope solar still with basin area of 1m² and top glass cover making an angle 10°. They got an average distillate output of 2.8 litres per day. Tris et al. [10] conducted experiment by coupling two flat plate collectors with a single basin solar still. The distilled water obtained with flat plate collector was double than the still alone. The main purpose of this work is to study and analyze the performance of a solar still coupled with heat pipes and evacuated tubes. In order to increase the effectiveness, the basin is coated with black paint from inside and black stones are placed in the basin. This helps in increasing the radiation absorption rate.

2. Experimental setup

The setup is installed at the location, latitude: 12.97°N, longitude: 77.59°E and an altitude of 900m above sea level. The readings were taken during the period of June to July 2015 from 9:00 am to 5:00 pm. The set up consists of a basin made up of Galvanized iron sheet. The basin is of rectangular shape and area of basin is 1m². The inside surface of the basin acts as absorber plate. In order to absorb the maximum amount of incident solar radiations the inner side of the basin is coated with black paint. The height of the basin is 0.13m. This basin is enclosed in a wooden box structure. The gap between the still and box is 0.05m and this gap is filled with saw dust to minimize the heat losses. The basin is covered with borosilicate glass in the shape of pyramid. This glass allows the radiation to pass through it, reduces the losses due to re radiation and convection and it also helps in condensation. The glass makes an angle of 15° with the horizontal. The water used for the distillation purpose is tap water and is filled in the basin.

The basin is provided with one inlet and two outlets. The inlet pipe is used to fill the basin with tap or brackish water. One of the outlets is used to remove the waste particles in the water and is fixed at the bottom of the basin. The other outlet is used to collect the pure or distilled water and is fixed at left side of the basin. The galvanized iron sheet is folded in U shape which is fixed in the lower side of the still in order to collect the purified or distilled water which is condensed from the glass. The U shaped collection tray is connected to left side outlet which in turn connected with rubber pipe to collect the distilled water in the measuring jar.
The evacuated tubes and heat pipes are used to improve the performance of the still. The experimental arrangement is shown in the figure. The condenser section of the heat pipe is placed inside the still and the evaporator section of the heat pipe is kept inside the evacuated tube. Aluminium sheet is wound on the evaporator section of the heat pipe to enhance the heat transfer rate between glass tube and heat pipe. In order to receive maximum solar radiation the evacuated tubes are aligned at 20° with respect to the horizontal. The silicon sealant is used in order to prevent vapour leakage from the still. The selective absorber coating on the inner glass surface helps in increasing the absorptivity of the glass. The evacuation in the tube reduces the convective heat losses. The heat transferred to the working fluid inside the pipe is absorbed by the evaporator section. The working fluid gets vaporized and it flows towards the condenser section. The vapour is condensed by exchanging the heat of vapour to the water in the basin.

Figure 1. Pyramid Type Solar Still Coupled With Evacuated Heat Pipes.

In order to measure the radiation intensity, a solar flux meter of a range 0 -1200W/m² is used. For measuring various temperatures, like temperatures of water, vapour, basin, ambient K-type thermocouple with a range of (0-1200°) are used.

3. Results and discussion

3.1 Performance of the still in different modes

The experiments were conducted in three different modes like 1) Solar still alone 2) Solar still coupled with evacuated tubes and 3) Solar still coupled with evacuated tubes and heat pipes

Initially experiments were conducted on pyramid type solar still without any attachments. It was observed that this setup produced an average hourly distilled output 370ml/m²h. The factors affecting the performance of the solar still were studied and recorded by various parameters. Experiments were carried out for the Still during June 2016 to July 2016 for the period of 9:00 am to 5:00 pm (hrs) and the results for various parameters recorded for some typical days in the mentioned period are shown in Figure 2. The hourly variation of various parameters like solar radiation, ambient temperature, inner surface temperature of the glass cover, basin temperature and water temperature are plotted in the graph. We can observe the rise in temperatures with time. This is because initially the water
absorbs heat and it will be stored in the form of sensible heat. The temperature of water in the basin for all three modes are shown in figure 3 and figure 4 for different days. It can be observed that the temperature of water is maximum in case of heat pipe with evacuated tube and its minimum in case of still alone.

![Figure 2. Variation of Water, Basin, Vapour and Glass temperature with time.](image)

![Figure 3. Variation of water temperature with time for Heat Pipe and Evacuated tubes.](image)

Analysing the performance plot, it is seen that the general trend is that initially the temperature increases with time and reduces gradually after the peak hours. Throughout the experimental duration, highest temperature is maintained by the vapour inside the still, followed by the glass surface. The similar trends were shown by basin and water inside the basin with a slight variation of 2-3°C.
Figure 4. Variation of vapour temperature with time for Heat pipe and Evacuated tubes.

3.2 Thermal efficiency of solar still

Table 1. Thermal efficiency of Solar still.

| Mode of operation         | Average Solar radiation flux (W/m²) | Thermal Efficiency |
|---------------------------|-------------------------------------|--------------------|
| With Still only           | 752                                 | 21.53%             |
| Still coupled with evacuated tubes | 1314                                 | 28.90%             |
| Still coupled with evacuated heat pipes | 1335                                 | 33.02%             |

Table 1 shows the thermal efficiency of the solar still, still coupled with evacuated tubes and still coupled with evacuated tube and heat pipe. By using nine evacuated tubes alone we were able to get a distillate output of 4.5 litres and thermal efficiency calculated is around 28.90%. At the same time by using only five heat pipes coupled with evacuated tube we got a distillate output of 3.5 litres. Here the thermal efficiency calculated is around 32.06%. Still coupled with nine evacuated tubes gave a distillation output of 4.5 litres per day whereas the five heat pipes with evacuated tubes gave an output of 3.5 litres. The still alone gave an output of 2 litres per day.

4. Conclusions

From present experimental study it can be concluded that pyramid type solar still coupled with evacuated heat pipe has better performance and more productivity rate of distilled water when compared to the solar still alone. The thermal efficiency of the solar still coupled with heat pipe and evacuated tubes was found to be 33.02%, that of still coupled with evacuated tubes was around
28.96% and that of solar still alone was 21.53%. The efficiency of the still coupled with heat pipe and evacuated tube was 12.5% more when compared to still coupled to evacuated tube and it was 34.8% more when compared to still alone. The distillate output of the still coupled with heat pipe and evacuated tubes was 28% more compared to still coupled with evacuated tubes and 43% more when compared to still alone.

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