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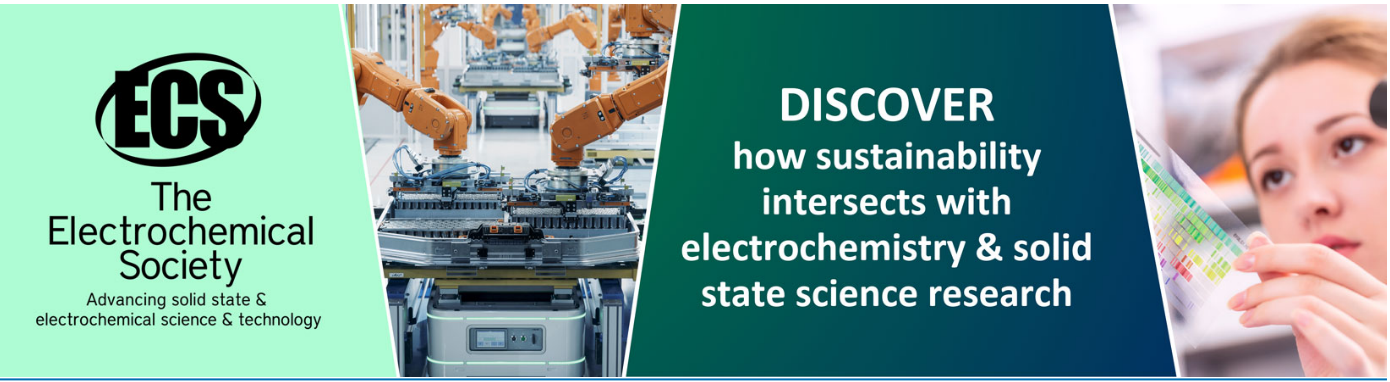

Experimental Analysis of a Solar Still Coupled with Heat Pipe, Evacuated Tubes and Compound Parabolic Concentrators

Vivek G[1], Ratheesh R[1], Mukesh R[1], Sajan G[1], Haritha R[1], Yashaswini C[1] and Vinod Kotebavi[2]

[1]Student, [2]Assistant Professor

Dept. of Mechanical Engineering
Amrita School of Engineering Bengaluru
Amrita Vishwa Vidyapeetham
India.

Abstract. Rural enclosures usually present themselves with poor access to clean and practicable water, despite this drawback, they still do receive a generous amount of sunlight. This sunlight can be used to purify the water. In this work, a pyramid type solar still is built and is coupled with heat pipe placed inside the evacuated tubes. To increase the area of solar energy collection compound parabolic concentrators (CPC) are used. To increase the solar radiation absorption, coating is done on the inner side of the basin and black stones are placed inside the basin. Using tap water as feed, the performance analysis is analyzed under three modes of operation, (i) Still alone, (ii) Still with heat-pipe and evacuated tubes and (iii) Still with Heat-pipe, evacuated tubes and Compound Parabolic Concentrators. The overall thermal efficiencies for the three above mentioned modes of operations are observed to be 23.14%, 23.48% and 23.87% respectively. The salt content is reduced by 98.3%.

1.Introduction

The basic necessities for a man to sustain are food, air and clean water. Fresh water resources available are rivers, glaciers, lakes and underground water reservoirs. Barely 2.5% of the water available on earth is fresh and the remaining water is in the form of sea or ocean [9]. This water is salty and needs treatment to convert it in to drinkable water. The demand of drinking water increases day by day due to the industrial development, advanced agriculture, improved standard of living and increase in population growth. The dearth of fresh water is a prime factor in inhibiting regional economic development. Often water sources contain dissolved salts and harmful bacteria and hence needs some treatment.

There are many ways to purify this water and one of the options available is distillation. This requires an energy input. We cannot think of using the conventional energy like fossil fuels to supply this energy. Solar energy, a renewable one is the right choice for this application. This form of energy is inexhaustible and pollution free. In this process, water is heated and evaporated and is condensed back, which will be free from dissolved substances. As mentioned above, fresh water is not evenly distributed on earth; hence the need for renewable methods has gained prominence. And solar distillation is one of the preferred techniques as it involves simple construction, no high skilled labor required, it is low maintenance and most importantly, it can be used anywhere without any hassles.

There are two types of solar still namely, active and passive solar stills. Active solar stills require external energy and passive solar stills, solar energy alone is enough to evaporate the water and no other devices are used. Though it produces a lower yield, the objective to evaporate the water in the basin is achieved and no electric devices are used. And hence, these solar stills are preferred.

Ganesh et al. [1] worked on the conversion of saline water to clean potable conditions by solar distillation. They built a solar still of pyramid shape and connected evacuated tubes to preheat the water. They observed a high increase in production rate as well as a high reduction in the $CaCO_3$ content. Shobha et al. [2] conducted experiments on single slope type solar system. They connected the solar still to a water heater to increase the output. Productivity increased from 39% to 59% connecting the solar still to water heater. They also studied the effect of water depth (in basin) on the efficiency of the unit. The maximum efficiencies obtained for 1cm, 1.5cm and 2cm depths were 52%, 48% and 41% respectively. They concluded that increase in water depth in the basin reduces the efficiency of the still. Senthilrajan [3] did a study on single basin solar still and to increase productivity he used biomass water heater. During the day time still was making use of solar energy as a heat source whereas in night it was using biomass energy as heat source. The efficiency of the still was increased by 47.2 % by using biomass energy. Praveen et al. [4] developed a solar still using evacuated tube. They also studied the effect of water height on the performance of the still. They also found that efficiency of the still increases with decrease in water height in the basin. And upon chemical analysis of the distillate, the chemical compositions were well within the Indian Drinking Standard. Pankaj et al. [5] analyzed the effects of many geometric and operating parameters on the performance of a solar still. They concluded that arrangement of the solar still is not the lone parameter to decide the performance. It also depends on the absorber plate made with different materials and internal modifications of the absorber plate. They found that the effects of reflectors, condensers, vacuum technology and sun tracking systems played a major role in maximizing the yield of the solar stills. HariKrishnan et al. [6] conducted experiments with heat pipe using different fluids and for different fill ratio. They concluded that acetone and methanol perform better than water as a heat pipe fluid, 25% fill ratio is better for solar applications during their study on heat pipes. Dinesh Raju et al. [7] conducted experiments with hemispherical basin Solar Still. They couples the solar still with two evacuated tubes and heat pipes. They obtained a thermal efficiency of 27.72% during their experiments. Shivaraman et al. [8] varied L/di ratio of heat pipes to study the performance of heat pipe solar collector. They obtained a system efficiency of 68% and L/di ratio of 52.63 was found more efficient.

2. Experimental Setup

The experimental setup consists of solar still, heat pipes placed inside the evacuated tubes and cylindrical parabolic concentrators. The experiments were carried out during April to May at Bengaluru. The radiation flux is measured by flux meter.

2.1Pyramid type solar still

The still consists of basin and pyramid shape glass cover. Basin is rectangular in shape having an area of $1m^2$. The inner side of the basin acts as absorber plate and is coated with black to enhance the absorptivity. A similar rectangular box structure was made of plywood (having an area of 1.05m × 1.05m) to enclose the still. A gap of 0.05m was given between the still and the enclosing box. The insulating material was placed compactly to reduce the loss of heat from the basin. On the top of the basin glass cover is placed in the shape of a pyramid. This glass cover transmits the solar radiation into the basin and it prevents the re-radiation from the basin, thereby it traps the heat inside the basin and glass cover. This glass cover also helps convective losses and helps the water to condense on the inner surface. The glass cover is placed at an angle of 15^0 with the base. This angle helps the condensed water to slide down on it and prevents the water droplet falling in the basin. The still has one inlet through which the water to be purified is fed in to it. The water which condenses on the glass is collected in U shape channel and is taken out.

2.2Heat pipe evacuated tubes
Heat pipes are placed inside the evacuated tubes and are connected to the still by making 0.025 m diameter hole at the bottom part of the basin. A metal frame is made to place the evacuated tubes and is positioned at an angle 20° with respect to the horizontal facing south.

2.3Compound parabolic concentrators
Compound parabolic concentrators are made up of aluminum sheets of thickness 0.3mm. These are mainly used to increase the area of solar radiation collection. They reflect the radiation falling on them on the evacuated tubes, there by increases the energy input. Evacuated tubes are placed at the focal line of the compound parabolic collectors. The angle of the heat pipe evacuated tubes and compound parabolic concentrators are maintained at 20° with the ground surface. Joint is sealed with a sealant to prevent water vapour leakage. The evacuated tube is coated with selective absorber coating for better absorption of solar radiation. This evacuated tube transfers. This heat is transferred to the water in basin by the heat pipe fluid. The evacuated space prevents the convective heat losses in the evacuated tubes and helps in increasing the efficiency of the still.

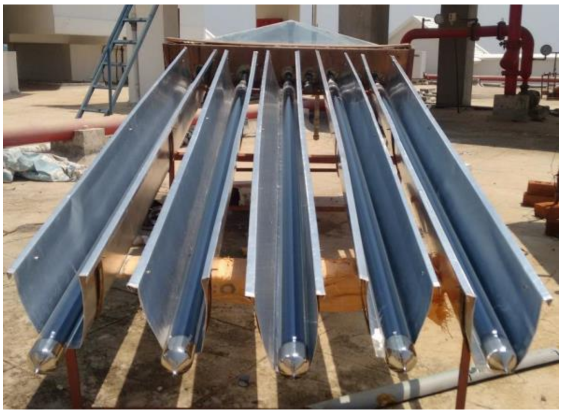

Figure.1. Arrangements of heat pipe, evacuated tubes and compound parabolic concentrators (CPC)

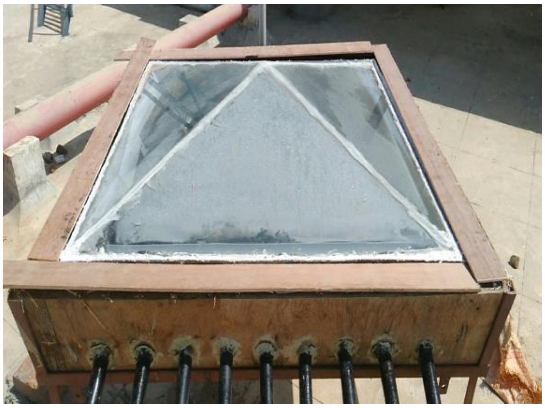

Figure.2. Photographical view of the pyramid type solar still

3. Results and Discussions

3.1Performance of the still
To enhance the output of the pyramid type solar still, evacuated tubes with heat pipes are coupled with to the still. To increase the yield further, compound parabolic concentrators are integrated with these evacuated tubes. Black stones and black coating are used to increase the heat storage capacity and absorptivity of the still. These black stones stores energy and this energy is used during the off sunshine hours. The use of heat pipe evacuated tubes with black stones and black coatings in the basin produced the maximum hourly distilled output as shown in figure below. The experiments were carried out during April 2017 to May 2017 for the period of 9.00 hr to 18:00 hr.

The experiments are carried out in three different modes i) Still only ii) Still coupled with Heat pipe inside evacuated tubes and (iii) Still coupled with Heat pipe, evacuated tubes and Compound parabolic concentrators.

The figure 3 shows the variations of the hourly distilled output of the three modes during day time. We can see increase in the distilled output as the day progresses i.e with the increase in radiation flux. This is because the temperature of water increases in the basin and rate of evaporation increases. Thereby condensation rate also increases.

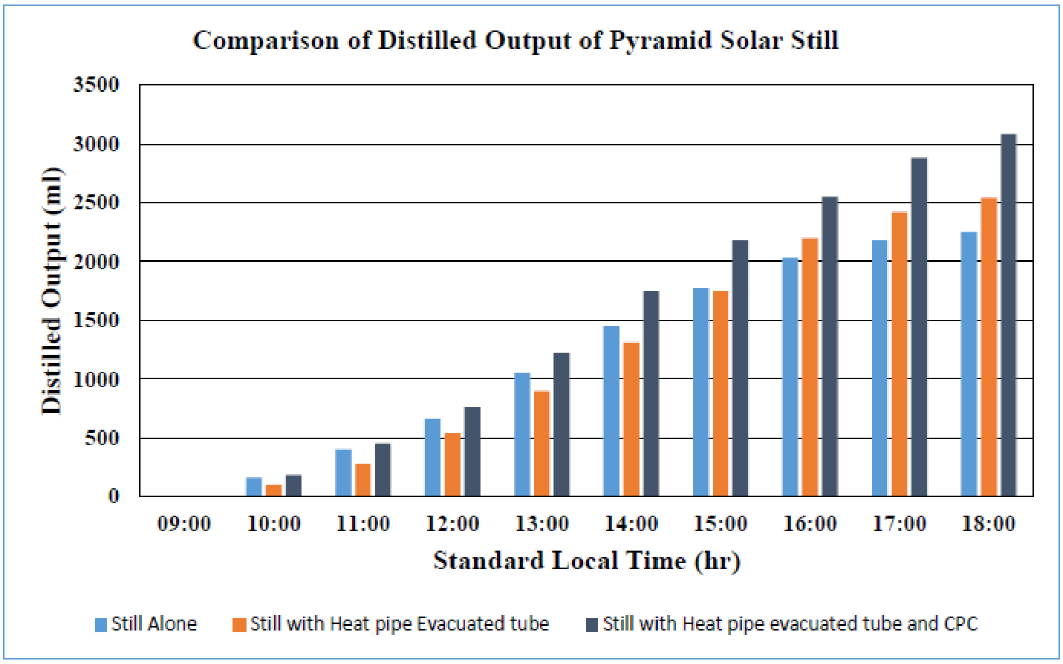

Figure.3. Comparison of Distilled Output of the Solar Still

3.2Thermal efficiency of still

Table 1 compares the daily distilled output, solar radiation and the thermal efficiency of the three different modes. From the table it is observed that, still with heat pipe evacuated tubes and CPC is most thermal efficient.

Modes	Distillation output per day in ml	Radiation flux (w/m^2)	Thermal Efficiency
Still only	2550	7326	23.14%
Still with heat pipe evacuated tube	3260	6066	23.48%
Still with heat pipe evacuated tube and CPC	3960	5535	23.87%

Table.1. Daily distillation output, Radiation flux and efficiency of the Still

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4. Conclusion

This work focuses on the construction and testing of Solar still for different modes of operation in real life conditions. The experimentation is run on three modes to improve the efficiency and the distillation output of the still. The different modes on which the experiments conducted here are 1) still only 2) still connected to heat pipe evacuated tubes and 3) still connected to heat pipe evacuated tube and compound parabolic type concentrator.

The drawn up conclusions are:

- An increased output of distilled water is obtained by the method of integrating solar stills with evacuated tubes. Utilization of compound parabolic concentrators gives a higher output.
- The solar still exhibits an overall thermal efficiency of 23.14% for still only, 23.48% for Still connected to Heat-pipe evacuated tubes and a 23.87% for Still connected to Heat-pipe evacuated tubes and Compound Parabolic Concentrator.
- Testing out three different configurations with a constant basin area of 1 m^2, still alone type was found to give an output of 2.25 litres, still connected to heat pipe evacuated tubes to give a maximum output of 3.080 litres and still connected to heat pipe evacuated tubes type produces a maximum of 3.96 litres of distilled water at the water level of 0.04m in the basin.

A reduction of 98.3% in the salt content was observed when the water quality analysis was run.

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