Experimental study and analysis of single slope solar still integrated with Phase Change Material

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Abstract. Solar thermal systems are playing important role to encounter environmental issues like global warming, in the last two decades they replace conventional systems to create an eco-friendly environment. Lot of research have been undergone on solar thermal systems to improve their performance and efficiency, but still the area is wide open for improvement because of demand on renewable sources increase. As their is need for increasing the performance of solar thermal systems, phase change materials could serve as energy storing device during abundant available of energy. For solar thermal systems the major challenge is energy availability will not be round the clock, in order to clear this hurdle phase change materials backing served as a better support. The biggest challenge of developing countries today is to provide clean drinking water, as there are many conventional systems to convert saline water into drinking water their main disadvantage is pollution of environment due to harmful emissions. Hence, solar thermal systems with phase change materials are considered as best option in production of clean drinking water due to their operation by renewable energy, compactness and zero emissions. Phase change materials are coupled with solar system experimentally, and their behaviour and performance were characterized with results and observation, here the phase change material paraffin wax is embedded in copper tubes coupled with solar system is employed in production of clean drinking water; their performance and efficiency are compared with single slope solar still without phase change material. The thermal stability, corrosive resistance and impressive properties of paraffin wax and thermal conductivity of copper were tied together to single slope solar still for improving performance and efficiency of clean drinking water production. It is observed solar still without phase change material could generate drinking water from saline water only during day time, but the solar still coupled with phase change material embedded in copper tubes showed better results with 11 percent increase in production of drinking water even during dark hours.

1. Introduction

In most of developing countries the major challenge is their access to clean drinking water because of salinity in their water bodies, only 3 percent of water is suitable for drinking purpose from the 100 percent availability of water, the remaining 97 percent is not suitable for drinking because of higher percentage of dissolved salts in it [1-3]. In order to meet the demand of developing countries for clean drinking water, identifying new sources would be a not clearable task; whereas converting saline water to clean drinking water would be appropriate; one such method to facilitate the need is desalination of
saline water. There are various methods for desalination of saline water, but the current scenario demands for a usage of clean and renewable energy sources for the process of desalination due to their emission and environment friendly characteristics, in search for the above need; refinement to one of the ancient technique solar still method to convert saline water to clean drinking water would serve the purpose [4-6]. In solar still two methods are employed namely passive and active methods to increase the distillation of saline water to obtain clean drinking water; various models of solar still like cone, pit and domo are used; however, for all these models basin design mostly would be single sloped or double sloped. Flat plate solar energy coupled with solar still of single basin yielded 24 % higher production of clean drinking water than the uncoupled one. Phase change materials are the key to increase production of drinking water in solar stills, so the ancient method is revived with new scope for efficient way because of phase change materials, solar stills embedded with PCM yielded 31 % percent more than the method without PCM and also with PCM solar stills were able to provide clean drinking water even during dark hours [7-12]. Phase change materials with high capacity of latent heat gives more productivity and there is a subsequent increase in basin temperatures after sunrise, maximum water obtained in a day by distillation in solar still embedded with phase change material with double slope design is 3.1 L/m² [13]. Exergy efficiency is one of the important parameter which plays dominant role in water production rate, whenever exergy efficiency is more, coupled with phase change materials and proper insulation would give better results. Paraffin as a phase change material in cascade solar still provided exergy efficiency of about 75 %, several experiments have indicated that usage of phase change materials decreased productivity in day time whereas overall productivity increased by the complement from productivity of clean drinking water even during dark hours [14-19]. Recent studies say when solar distillation systems coupled with thermal energy storage materials is one of the best solution to meet the balance between energy demand and supply, hence solar still with thermal energy storage systems would be the best option to convert saline water into clean drinking water with low maintenance and cost [20-24]. In this work paraffin wax is made as a choice for thermal energy storage because of its high latent heat capacity and non-corrosive property, in order to study its performance and role in production of clean drinking water; various modes are experimented such as paraffin wax embedded in copper tubes compared against ordinary solar still in the production of clean drinking water from saline water, copper tubes of diameter 6 cm are chosen to embed paraffin wax into it. The paraffin wax is melted and filled into copper tubes with help of syringe, copper tubes are placed over the black coated aluminum plate, inlet pipe and outlet pipe are fixed and sealed in the appropriate places; temperature sensors are fixed in needed places to obtain data for exergy calculations. Figure 1 shows the
experimental setup of PCM integrated solar still. In order to lower heat loss the aluminum container is covered externally with thermocol sheet and further with saw dust to maximize exergy efficiency which would in turn increase the production of clean drinking water from saline water.

![Experimental Set up of PCM integrated Solar Still](image)

2.2 Methodology

The two solar still setup; one without PCM and another integrated with paraffin wax embedded in copper tubes is placed in a proper location, where there will not be any disturbance to absorption of sunlight, because from sunrise to sunset glass surface should be exposed to sunlight in order to absorb maximum of light energy as it is only source of energy. Then all the temperature sensors from both the experimental setup (with PCM and without PCM) are connected to the Arduino controller for obtaining temperature values of components like glass, saline water and copper tube. After both the solar still setup is ready for experiment, saline water is poured through the input tube to the required level, the values are not recorded immediately after commencement of experiment; readings are recorded from the next day because a day is provided for tuning of both the experimental setup. The solar radiation is absorbed by solar still through glass cover through radiation, which heats up aluminum plate, saline water and copper tubes, due to convection saline water molecules start to evaporate and pure water molecules are retained under the bottom of glass cover, as the glass cover is inclined pure water molecules roll down which is collected in a separate tank. The heat absorbed by copper tubes helps to melt stuffed paraffin wax which is encapsulated into it, there will be sufficient heat energy to keep it melt during day hours, whereas during dark hours the absorbed heat is liberated from the paraffin wax into the saline water due to this it starts to evaporate for providing clean drinking water. Saline water evaporates continuously to produce clean drinking water with help of solar energy due this salts are deposited on the surface of the aluminum plate it is removed through the drain pipe. The heat absorbed by the salt water and aluminum plate is almost the same as with PCM without PCM, but we will have clean water output with PCM setup even during night hours, temperature sensors continuously records the data in the data logger which can be used for exergy calculation.

2.3 Energy Balance Equation

Saline water in the basin can be represented by energy balance equation as shown

\[ I + Q_{sw} + c_{bw} \frac{dT_{bw}}{dt} = Q_{cw} + Q_{rw} + Q_{sw} + I_2 \]  

\[ 1 \]
In the equation 1 $Q_{bw}$ indicates convective heat transfer from basin to water, heat capacity of water in the basin is represented by $C_{bw}$, whereas basin water temperature is represented by $T_{bw}$, evaporative heat transferred from water to glass is indicated by $Q_{ew}$, heat radiated from water to glass is $Q_{rw}$, convective heat transfer from water to glass, solar irradiation received in the still by the water after penetrating through glass cover is $I_1$ and solar irradiation reaching the basin liner surface after passing through glass and water $I_2$ in the still, can be determined as follows:

\[ I_1 = (1 - \alpha_g)I - \quad (2) \]

\[ I_2 = (1 - \alpha_g)(1 - \alpha_w)I - \quad (3) \]

In two modes heat is transferred from basin saline water to the glass through radiation and convection. The heat transferred through convection from basin saline water surface to glass cover happens through humid air, it is expressed by the following equation

\[ Q_{cw} = h_{cw}A_w(T_{bw} - T_g) - \quad (4) \]

Coefficient for convective heat transfer from basin saline water to glass cover is indicated by $h_{cw}$. Cross sectional area of water basin liner is $A_w$, and glass cover temperature is indicated by $T_g$. The difference in temperature of saline water in basin liner and glass cover arises because of radiative heat transfer, which can be estimated using Stefan – Boltzmann’s law

\[ Q_{rw} = h_{rw}A_w(T_{bw} - T_g) = \varepsilon_{eff}A_w\sigma(T_w^4 - T_g^4) - \quad (5) \]

\[ h_{rw} = \varepsilon_{eff}\sigma(T_w^2 - T_g^2)(T_w - T_g) - \quad (6) \]

Heat transfer coefficient of radiative heat transfer from basin saline water to glass cover is $h_{rw}$, Stefan-Boltzman’s constant $\sigma = 5.67 \times 10^{-8}$ W/m²K⁴, the effective emittance of saline water surface to the glass cover is $\varepsilon_{eff}$. A part of heat energy is utilized for evaporating saline water from the basin that is can be represented by the following equation

\[ Q_{ew} = h_{ew}A_w(T_{bw} - T_g) - \quad (7) \]

3. Results and Discussion

3.1 Time vs Solar Radiation

As the process of distillation of saline water to produce clean drinking water using solar stills require heat energy to drive the process as a backbone; because of that focus on solar radiation intensity and their absorption increases, the experimental works were carried during month of January to March 2020, so we observe close values in the solar intensity. The required values are noted and plotted as a graph against time, in X axis time is taken and in Y axis calculated solar radiation is plotted, from the graph it is evident that in the month of March solar radiation is higher in the range of 900 W/m² during high intensity time of 2 to 3 pm in comparison with other two months, this effect plays a role in distillation of saline water to produce clean drinking water.

3.2 Glass Water Temperature vs Time

Temperature difference of glass and saline water in the basin is an important parameter in distillation of saline water, hence temperature of glass and saline water are recorded to have a clear view in the production of clean drinking water from saline water. Figure 2 is plotted between temperature of glass and water with time interval of 2 hrs. In X axis time interval is take with 2 hours difference and in Y axis temperature of glass cover and saline water is taken, from the plots it is observed that temperature of glass cover is in the range of 310 K in the experimental setup without PCM and the range 315 K in
the experimental setup with PCM, temperature of saline water in the basin is of the range 350 K in the setup without PCM and the range 360 K is observed in the setup with PCM during 2 pm to 3 pm. When the temperature difference between saline water and glass cover is more, the distillation of saline water will be more, when the setup is integrated with PCM this difference tends to increase leading to more clean water production from saline water and also from the graph it is observed total water production is higher when PCM is integrated with solar still this is because it supplies heat energy even in the absence of solar radiation.

Figure 2: Glass Temperature Vs Time

3.3 Water Yield vs Time

Clean water production from saline water by using solar still depends on various parameters, the major contributor for the production of clean drinking water is solar radiation and the exergy efficiency in order to increase its various techniques are employed in solar still. In the view of implementation of this setup in distillation solar radiation is very important, hence the setup should be placed in the area where solar radiation is uninterrupted for better yield. To have the yield even during dark hours solar still is integrated with phase change materials which act as energy storing device, in this work phase change material is encapsulated in copper tubes in order increase the exergy efficiency so that the yield of clean drinking water will be more. From the Figure 3 it is observed that yield of clean drinking water in day time during intense radiation timing from solar still without phase change material because copper tubes absorb small amount of heat to melt the wax, so yield from solar still with phase change material is slightly lower during peak time of radiation. It is observed that in month of March, higher intensity of radiation is recorded and it resulted in 2264 ml of clean water production from the setup with PCM when accounted for 24 hours, whereas from the setup without PCM it yielded 2080 ml; 11 % hike in the yield from setup with PCM. In the month of January, radiation is slightly which influenced the yield of clean drinking water, 2196 ml was yielded from the setup with PCM and 2004 ml from the setup without PCM. Hence from the plots it’s very clear phase change materials increased yield of clean drinking water from saline water in the solar still by a margin of 11 %.
4. Conclusion
The need for clean drinking water arises in several developing countries, to meet that demand is an essential one; viable solution to this need is employing solar still in distillation of saline water as it depends on renewable energy source. The only problem of solar still is its efficiency and inability to produce clean drinking water during night, to overcome these problems solar still is integrated with thermal storage devices. Hence the experimental works on solar still in production of clean water with thermal storage devices is essential to have a clear view in the process, various techniques are employed to increase the yield of water through distillation of saline water. When phase change materials are used certainly there was increase in the yield of clean drinking water but on the other several efficient heat storage and transfer techniques would yield more yield, several techniques are employed and tuned to optimize the parameters those play important role in production of clean drinking water. In this work solar still insulated with thermocol and saw dust; integrated with paraffin wax encapsulated in copper tubes increased the production by 11 percent in comparison with solar still without phase change material. Hence to improve the production various techniques can be employed in future to increase exergy efficiency so that production of clean drinking water would increase from saline water to meet the demand of developing countries.

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