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Experimental Investigation on the Performance Characteristics of Double Condensing Chamber (DCC) Over Conventional Solar Still (CSS)

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Abstract **Review Article**

The study of performance on double condensing chamber solar still (DCC) and conventional solar still (CSS) at different level of water is presented experimentally in this work. Overall Output of both conventional solar still and double condensing chamber solar still with different water quantities has been found. It is seen that output of chamber-II of DCC is zero till noon almost for every day, because the partial vapor pressure difference is not high enough to drag enough vapours from condensing chamber- I to chamber- II. After that at every time interval the resultant water from condensing chamber- II is obtained. Output during night in both solar still increases with water quantities because of heat storage capacity of water. The maximum output during night is found for double condensing chamber solar still for 15 litres of water. Comparing the overall efficiency between the CSS and DCC, it is seen like overall output the overall efficiency is also more for CSS in the case of 5 litres of water, but for 10 and 15 litres DCC's overall efficiency is more. After comparing both solar stills it is concluded that there is no significant difference in performance of both the solar stills, while cost of DCC solar still is about 30% higher than CSS solar Still.
Keywords: solar energy, double condensing chamber (DCC), conventional solar still (CSS).

INTRODUCTION

In the last few decades the water pollution has led the world to the crisis of drinking water due to the modern technological practices and their scrap dumping along with the societal negligence with respect to time. The polluted water has contaminated the surface as well as under-ground water. The demand of fresh water has been increased drastically due to the rapid increase of human population. In order to meet the demand of fresh drinking water several technologies have been evolved by the researchers like electrodialysis, vapour compression and reverse osmosis. The purification methods for fresh water are highly energy exhaustive and costly [1]. It has been observed that the electrical energy which is used in desalination plants has both environmental and economical disadvantages and depend on conservative fuels. So a method is required to use renewable energy, less efforts and less costly for the production of drinking water.

Although many researchers have already reported on the performance characteristics of single condensing chamber solar still to improve the performance and productivity of distilled water. Tiwari and Tiwari1 mentioned that water is the most abundant and important substance in nature and also the principal component of life, health and sanitation. It is essential for life and vegetation. The continuing shortage of drinking water is the most important issues in the developing countries and using water for survival from contaminated sources causes serious harm to health. With the growth of population, the availability of drinking water per capita is shrinking. A purification method using solar energy can be economical, environment friendly and renewable energy-based technology. It is a method which can be applicable in both rural and remote areas of developed and developing countries where the availability of solar radiation is high with certain limitations. With different features of ''solar stills'', the experimental and numerical investigations dealing are carried out by many researchers. In this section some investigations are presented in short. They investigated the performance for different water levels in a single slope passive solar still of cover inclination of 300on annual and seasonal basis. The 1st patent on solar distillation in America is on the name of Wheeler and Evans.

Aybar *et al.*[2,3] has performed experimentation on the inclined solar water distillation (ISWD). Many of the experiments are done to increase the distillate production and efficiency. Several improvements have been proposed.

Badran[4] suggested that there will be a decrement in productivity with the rise in water level due to the increase in the heat capacity of basin water. He also proposed that there will be a significant improvement in productivity with the use of combination of asphalt-sprinkler as compared to asphalt alone. Feilizadeh *et al*.[5] presented a radiative model of a single-slope solar still which considered the falling solar energy on the water surface with all the walls into account for the first time. Sahoo *et al*.[6] concluded that the effectiveness of the solar still can be improved by using thermocol insulation along with the blackened surface. Abdallah and Badran[7] deployed a system for tracking the sun position in order to improve the productivity of solar still.

Murugavel *et al*. [8] optimized the inclination as well as orientation to receive the maximum solar energy and reduced the loss due to condensation. They also used different materials for enhancing the productivity. Dev *et al*. [9] presented an experimental comparison of inverted absorber solar still (IASS) with single slope solar still (SS) at different depths of water as well as total dissolved solid (TDS). Kumar and Bai [10] enhanced the productivity by adding condensing surface on the sidewalls and also studied the effectiveness of solar still for different samples of water. Rubio-Cerda *et al*. [11] described the thermal performance of the condensing covers in a triangular solar still. Madhlopa and Johnstone [12] explained the Numerical analysis on a passive solar still along with additional condenser. Abdallah *et al*. [13] implemented various possible designs in order to improve performance of the single slope solar still by increasing the rate of production of distilled water. Fath and Hosny [14] carried out a theoretical study on the thermal performance of a basin still by increasing evaporation rate with an additional condenser. Al-Karaghouli and Alnaser[15] explained the experimental comparative study of the performances of single and double basin solar-stills. They concluded that the double besin still has 40% higher average production than that of the single basin every day. Khawaji *et al*. [16] studied the advances in seawater desalination technologies. Omar Bait and Si–Ameur[17] reviewed a comprehensive outlook in many fields especially in solar energy desalination technologies about the role of nano fluids. Fathy *el at*.[18] investigated experimentally the performance of double slope solar still with coupling parabolic trough collector. They illustrated that the solar still shows poor performance in winter than in summer for all cases and systems.

It is evident from the above literature survey that the performance characteristics of distillation of water using single condensing chamber solar still has already been performed by the many researchers. To the best of author's knowledge no work has been presented on the efficiency of double condensing chamber solar still (DCC) in order to improve the productivity of distilled water. Moreover, the present work is about the comparison of performance for double and single condensing chamber solar still. Overall Output of both conventional solar still and double condensing chamber solar still with different water quantities has been found. It is seen that output of chamber- II of DCC is zero till noon almost for every day, because the partial vapor pressure difference is not high enough to drag enough vapours from chamber- I to chamber- II. After that at every time interval the output from chamber- II is found.

Experimentation

Experimental system

The figure 1 shows the experimental system of the double condensing chamber and conventional solar stills. The installation of experimental set up was done on top of the roof in department of mechanical engineering, M.N.I.T, Jaipur (26°55′N latitude, 75°52′E longitude).To receive the maximum solar radiation, both the solar stills are south facing. Double condensing chamber solar still is simply a basin made up of galvanized iron sheet. The 5mm thick glass is used to cover the still which is inclined at the angle of 26° with horizontal. The enclosure of a double condensing chamber solar still was divided into chamber – I and chamber – II, which are separated by a partition wall. The partition wall is made of GI sheet and consists of thermocol. The chamber –II is shaded with GI sheet so that the solar radiations are not received by it directly. The partition wall is fitted with a 4 mm thick vertical mirror, facing chamber – I and two more mirrors are also fitted on the side walls, for reflecting back most of the radiations falling on it to the basin water. In order to reduce the side heat loss to the ambient all sides of the still are insulated by foam. The upper and lower surfaces are blackened with black epoxy paint whereas the outer structure of the DCS is painted with white enamel paint for increasing the absorption of solar radiation. The basin is insulated with thermocol from all sides with bottom to minimize the heat loss in between the basin and ambient. A provision of a channel is made at the bottom of the chamber – II and under the bottom of glass cover for collecting the condensed water. The channels are connected with a plastic pipe, in order to drain out the fresh water into two external small plastic buckets. A provision to fill water into the tray is also made. The experiment has been conducted with another arrangement of conventional solar still (CSS) and compared with the double condensing chamber solar still. Twelve T-type thermocouples and one RTD are used in the experiment to measure the temperature at different locations. Seven thermocouples are used for double condensing chamber solar still. Thermocouple no.1 and 2 are kept under the glass top inside the basin such that they are not in contact with the glass to read the water vapour temperature. Thermocouple no.3 is pasted on upper surface of the glass cover in the centre of the glass to measure the glass upper surface temperature. To measure the glass inner surface temperature thermocouple no.4 is pasted in the inner surface of the glass and in the centre of the glass. Thermocouple no.5 and 6 is submerged in water to measure water temperature. Thermocouple no.7 is pasted on the second chamber to measure the vapor temperature. Five thermocouples are used for conventional solar still. The water vapour temperature is measured with the help of thermocouple no.8 and 9. Thermocouple no.10 and 11 are used to measure the glass inner and upper surface temperature. Thermocouple no.12 is used to measure the water temperature. One RTD is kept in shadow in the atmosphere to read the ambient temperature. A solarimeter is used to find solar radiations falling on the glass. One measuring cylinder was used to measure the distillate. Experiment was started at 9:00 AM and ended at 6:00 PM by taking readings at 1 hour interval for different combinations.

Fig-1: Experimental Set up

Calibration of Thermocouples (TC)

A thermocouple is made of two dissimilar electric conductors, which has two electric connections between them called junctions. Using a thermocouple circuit there are two commonly used approaches for measuring temperature. In first, in the thermocouple circuit there are two junctions and one of the junctions is maintained in an ice bath at constant temperature at 0 0C. As temperature of one junction is constant, in the thermocouple circuit the potential difference generated. Only one junction is visible in second attempt and the second junction formed at the temperature indicator automatically. The temperature is measured using temperature indicator which takes the temperature of the junction formed and the type of the thermocouple used into account. For errors thermocouples calibration was needed. Two points calibration were done. In an insulated bath one is measured as 0 0C in the mixture of water and ice while the other point is the boiling point of distilled water. The boiling point of water is fixed at 99.96 0C whereas the corresponding barometric pressure is obtained as 1.0102 bars at the time of calibration.

Using temperature indicator readings for both ice and boiling points were taken. Table 1shows the readings for all the twelve thermocouples and one RTD. Corresponding conversion factors for each thermocouple are ‘a’, and ‘b’.

$$T\ (actual) = a + b*T\ (tc)$$

In the above equation ‘a’ and ‘b’ are conversion factors. T (tc) denotes the temperature measured by thermocouples. Measured temperature of thermocouples can be converted into actual temperature from the above given equation.

Experimental Procedure

Experimental set up is installed on the roof of mechanical engineering department, M.N.I.T, Jaipur (26°55′N latitude, 75°52′E longitude). To receive the maximum solar radiation, both the solar stills are south facing. Double condensing chamber solar still (DCC) and conventional solar still (CSS) were instrumented with copper-constantan thermocouples connected to both digital temperature indicators. The temperature readings were taken at the following points:

- Water to be distilled
- The lower surface of glass
- The upper surface of glass
- The vapour temperature
- Ambient temperature

Ambient temperature is measured with the help of RTD. The glass of the still is cleaned properly at the time of performing the experiment. A solarimeter is used on the glass cover which sensor is facing the sun directly to measure the global solar radiations. The water quantity in the still was maintained to 5 liters, 10 liters and 15 liters for the experiment. Water was filled daily to maintain the certain quantity. The distilled water was collected in three buckets and the graduated cylinder was used to measure the amount of distilled water. The steps taken for hourly readings are as below:

- Glass upper and inside surfaces, ambient, vapour and water temperatures were measured.
- Intensity of solar radiation was measured.
- Distilled water was measured.

Table-1: Calibration of Thermocouples

TC	T(tc)	T(tc)	T(actual)	a	b	T(actual)
T1	0.5	95.3	99.96	-0.5	1.05	0.03
T2	0.6	95	99.96	-0.6	1.06	0.04
T3	0.6	95.9	99.96	-0.6	1.05	0.03
T4	0.8	96.2	99.96	-0.8	1.05	0.04
T5	0.6	95.5	99.96	-0.6	1.05	0.03
T6	0.8	96.1	99.96	-0.8	1.05	0.04
T7	1.2	96.4	99.96	-1.2	1.05	0.06
T8	1.1	96.2	99.96	-1.1	1.05	0.06
T9	1.3	96.6	99.96	-1.3	1.05	0.06
T10	1.4	96.4	99.96	-1.4	1.05	0.07
T11	1.4	96.3	99.96	-1.4	1.05	0.07
T12	1.3	96.2	99.96	-1.3	1.05	0.07
TRTD	0.1	98.2	99.96	-0.1	1.02	0.00

Results and Discussions

Appendixes, if needed, appear before the acknowledgment. Performance analysis for double condensing chamber and conventional solar still are presented and discussed in the following paragraphs. A total of 3 sets of experiments are being shown here, by changing quantity of water.

Figures 2, 3 and 4 show the effect of quantity of water in the basin on distillate output during sunshine and night for both solar still. It is observed that day's output decreases with water quantity while night's output increases almost in every cases for both solar still. Amount of heat stored in the water increases with water quantity which is released in the night as increased condensation of water vapours. During sunshine the output of the CSS is more than the DCC'S output but during the night DCC'S output is more.

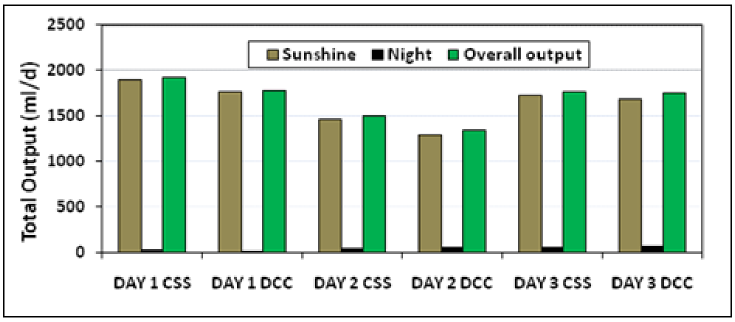

Fig-2: Distillate output during Sunshine, Night, and overall output for 5 Liters of water

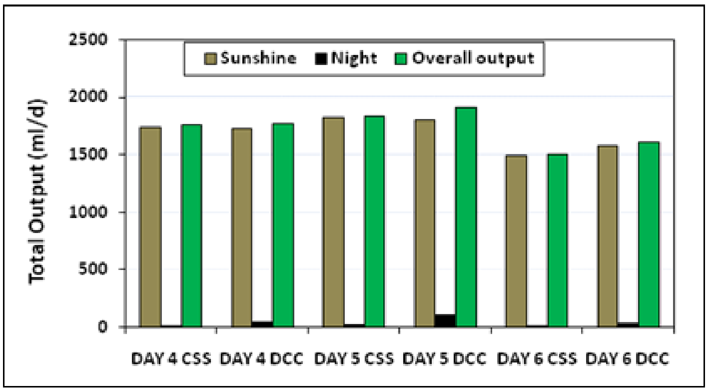

Fig-3: Distillate output during Sunshine, Night, and overall output for 10 Liters of water

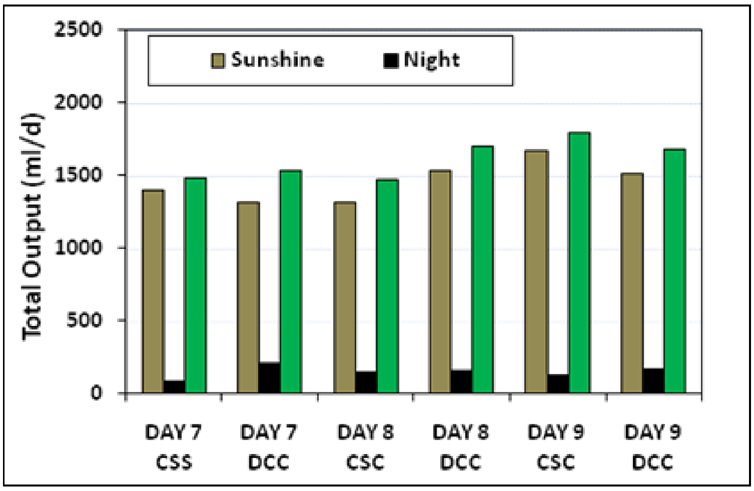

Fig-4: Distillate output during Sunshine, Night, and overall output for 15 Liters of water

Figures 2, 3 and 4 also show the overall output for different quantity of water for both still. It can is observed that the overall output of DCC is more than the CSS's except for 5 liters of water. This is perhaps due to higher thermal mass of DCC and higher leading to less of heat taken up by water for evaporation.

Figures 5 to 7 show the plot of efficiency with time for different quantities of water. It is observed that the instantaneous efficiency is minimum at the starting and increases with output, reaches the maximum value and then declines. It can be observed that efficiency of both the stills increases with increase in quantity of water in the basin because the heat capacity increases with increase water depth whereas heat loss from the basin is merely constant. Output during night is also increased with depth of water. So the overall efficiency increases with water depth.

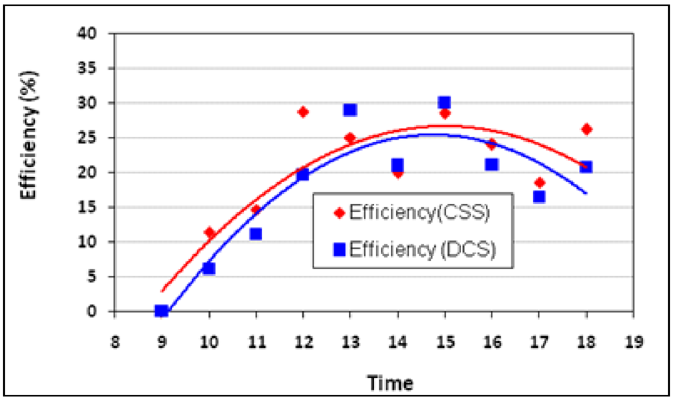

Fig-5: Efficiency with time for 5 liters of water

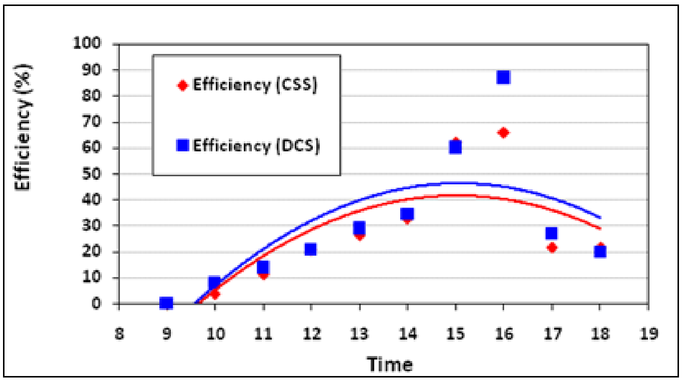

Fig-6: Efficiency with time for 10 liters of water

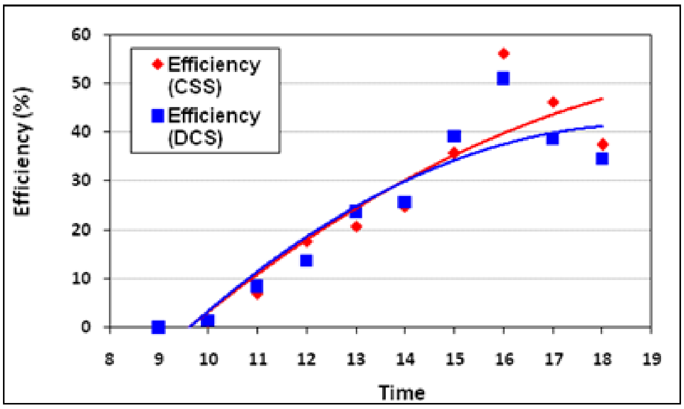

Fig-7: Efficiency with time for 15 liters of water

From Figures 8 to 10 it can be seen that maximum water temperature occurs after maximum solar intensity has occured. The temperature of water keeps on rising until heat input (i.e. solar radiations) is more that heat losses including loss of heat due to evaporation of water. Similarly temperature of water starts falling when heat input is less than heat losses including loss of heat due to evaporation of water. Thus water temperature keeps rising until the peak of solar radiations is reached as heat input is increasing and it is more than the total heat losses. It keeps rising further as after peak of solar intensity while heat input starts falling; it still remains more than total heat losses. Further heat input continues to fall and peak of water temperature is reached when two losses become equal. After peak of water temperature has reached, heat input continues to fall rapidly while heat losses fall slowly and temperature of water starts falling. Graphs also show the variation in water temperature, solar radiation and the distillate output collected through typical clear summer day from 9: 00 am to 6:00 pm. It can also be seen that the maximum water temperature occurs among all readings because of clear day and less thermal losses of solar stills at the mid-noon period. This is attributed to the increase of the surrounding ambient temperature of both the stills and higher solar intensity.

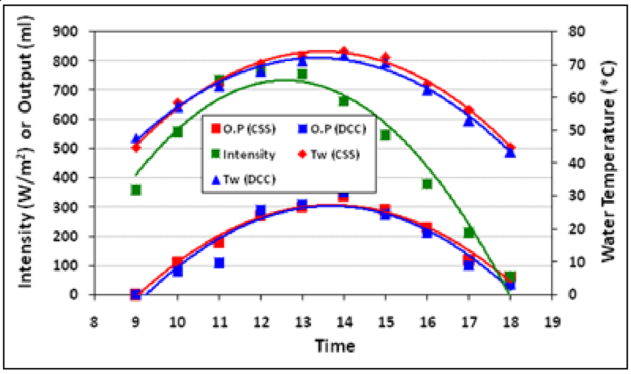

Fig-8: Intensity, water temperature and output with time for 5 liters of water

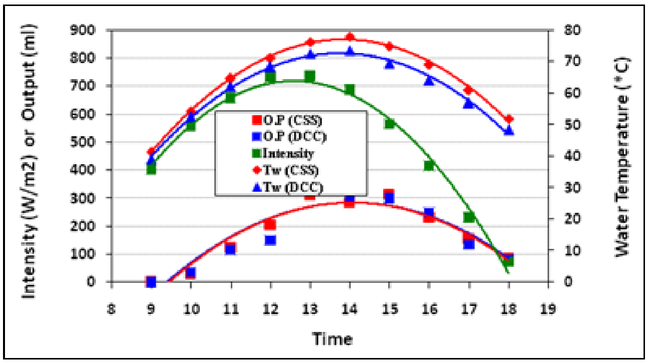

Fig-9: Intensity, water temperature and output with time for 10 liters of water

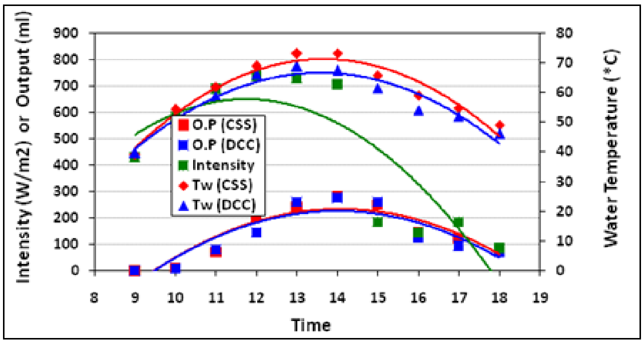

Fig-10: Intensity, water temperature and output with time for 15 liters of water

It can also be observed from the graphs that the distillate output increases with time. At the starting of the day productivity is minimum, and as the day passes it reaches its peak value and then declines. The reason is the intensity of solar radiation is less in the morning time.

Equations

Solar still's overall efficiency of has been calculated as:

Input Energy: $E_i = \int_0^{24hrs} I \times Adt$

Energy of distilled water : $E_o = m \times h_{vap}$

Overall Efficiency: $\eta = \frac{E_o}{E_i} \times 100\%$

Where,

Area of basin (A) = 0.94 m^2 (Double condensing chamber solar still)

= 0.99 m (Conventional solar still)

m = Mass of water condensed in one day in Kg.

h_{vap} =Latent heat of vaporization of water (i.e. 2260 KJ/Kg)

CONCLUSIONS

An experiment has been carried out by changing the quantity of water after every three days that effect on the output and efficiency of both solar still. Following conclusions can be made from the experiments.

- Overall Output 'of both conventional solar still (CSS) and double condensing chamber (DCC) solar still with different water quantities has been found.
- It can been seen that the output of chamber- II of DCC is zero till noon almost for every day, because the partial vapor pressure difference is not high enough to drag sufficient vapors from chamber- I to chamber- II. After that at every time interval the output from chamber- II is found.
- Output during night in both solar still increases with water quantities because of heat storage capacity of water. The maximum output during night is found for double condensing chamber solar still for 15 liters of water.
- It is clear that for 5 liters of water the output of CSS is always more than the DCC's .The output of DCC for 10 and 15 liters of water is more than the CSS almost in every case. It shows that the output of DCC is more than CSS, if water quantities increase, but average improvement is not more.
- Comparing the overall efficiency between the CSS and DCC, it can be seen like overall output the overall efficiency is also more for CSS in the case of 5 liters of water, but for 10 and 15 liters DCC's overall efficiency is more.

After comparing both solar stills it is concluded that there is no significant difference in performance of both the solar stills, while cost of DCC solar still is about 30% higher than CSS solar still.

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