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Analysis Of Double Slope Single Basin Solar-Still Using Photo-Catalysts

MD Irfan Ali, S. Madhu Ali, T. Raja Siddhartha.

[1]M.Tech,Energy Engineering, SRM University, Chennai, India, Email: irfanalimech@gmail.com; [2]M.C.A, Information Technology, SRM University, Chennai, India, Email: madhu1506.it@gmail.com; [3]B.Tech, Mechanical Engineering, AnuBose Institute of Technology, Andhra Pradesh, India, Email: siddhutipirneni@gmail.com.

ABSTRACT

This paper presents the effect of two different photo-catalysts (PC's) on solar desalination. A double slope single basin solar-still with basin area 1 m^2 is used for solar desalination. PC's are the chemicals which enhances the evaporation rate of water in solar-still in the presence of sunlight without reacting with water and without getting consumed. In this work, the performance of solar-still was investigated by using two different PC's 1) Granular activated carbon (GAC) and 2) PbO_2, by varying the weight concentration. The performance of solar-still was investigated with 0.5 kg GAC, 1 kg GAC, and by coating the base of solar-still with 0.5 kg PbO_2 and 1 kg GAC. The output from the still was considerably increased by the use of PC's.

Keywords : Solar desalination; Solar-still; Photo-catalysts; Granular activated carbon; PbO_2

1 INTRODUCTION

WATER – A mother, matrix, matter and medium of mankind. Life without water is just unimaginable. A vast growth of human activities and population had its impact in increasing the contamination of water and depletion of ground water levels.

Over 70% of earth is covered with water, majority of that is the oceanic water or saline water, where only 2.5% is fresh water. This amount of freshwater can't definitely meet the requirements for human activities in upcoming days. To meet this crisis in advance people should start depending on salt water or brackish water resources. Well known to us, saline water can't be consumed directly, desalination of saline water is necessary. Conventional ways of desalination uses fossil fuels which are getting depleted at a faster rate, and we need to preserve the fossil fuels for our future generation. Solar desalination using solar-still is one such technique where we exploit the solar energy to harness fresh water from the saline and brackish water. And this method can be easily applicable in the rural areas.

But the efficiency solar desalination using solar-still isn't ample, to enhance the efficiency of solar-still several techniques are employed. One such technique is use of PC's, PC's are the chemicals which becomes active in presence of sunlight producing heat at the base of the solar-still. The best thing in using PC's is they don't react with the basin water and they don't even get consumed, so we can use PC's for a longer period of time.

Suresh G. Patel and Shilpi Bhatnagar et.al [1] conducted experiments with three types of PC's CuO, PbO_2, and MnO_2 and reported that PbO_2 yields better results both in terms of quantity and quality.

Hitesh N Panchal and Manish Doshi [2] used cow dung cakes to enhance the evaporative heat transfer co-efficient of the solar still basin water. They reported 0.5 kg increase in the output from the solar still by using cow dung cakes, the TDS concentration in desalinated water reduced to 80 %.

Radwan A. Al-Rasheed et.al [3] had done chemical analysis of PC's and given the following chemical equation of PC's in presence of sunlight:

$$PbO_2 \longrightarrow e_{cb}^- (PbO_2) + h_{vb}^+ (PbO_2)$$

Where e_{cb}^- and h_{vb}^+ are electrons in conduction band and holes in valence band respectively. They recombine to produce heat without reacting with water. He reported the PbO_2 is from silicon family and inherits semi-conductor oxides properties.

In this work two PC's materials are used in different weight concentrations, they are GAC and PbO_2. First experiments were done on simple solar-still, next solar-still basin water was mixed with 0.5 kg GAC and experiments were conducted. In the next experiments solar-still basin was coated with 0.5 kg PbO_2 and 1 kg GAC was mixed with the still basin water. Experiments were done by recording the hourly temperature of basin water and still condensing glass surface. Hourly output from the still was also recorded.

2 MATHEMATICAL MODELING

Performance of solar-still is based on the internal heat and mass transfer rates. Internal heat losses should be minimized to increase the output from the still. Output from the still can be increased by increasing the evaporation rate in the still.

There are many losses in a still, one such major loss is the convective heat transfer loss. This loss can be minimized by perfectly sealing the still boundaries, the air from surroundings should not enter into the still. Another loss in the still is the radiation loss, this is because the basin water is always at a higher temperature than the cool condensing glass surface.

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This loss results in loss of input solar radiation.

Efficiency of the solar-still can be increased by increasing the evaporation rate in the still. Evaporation rate can be increased by increasing the basin water temperature and lowering the condensing surface temperature. To increase the basin water temperature PC's materials are used.

Hence, evaporative heat transfer is given by following equation

$q_{ew} = h_{ew} \ (T_w - T_g)$ (1)

Evaporative heat transfer coefficient is given by

$h_{evp} = 16.273 \times 10^{-3} \ h_{cw} \ [(P_w - P_g)/(T_w - T_g)]$ (2)

$h_{cw} = 0.884[(T_w - T_g) + ((P_w - P_g)(T_w)/(268.9 \times 10^{-3} P_w))]$ (3)

h_{ew} Evaporative heat transfer coefficient from water to cover, $W/m^2/^oC$

h_{cw} Convective heat transfer coefficient from cover to atmosphere, $W/m^2/^oC$

T_w Temperature of basin water, ^oC

T_g Temperature of glass surface, ^oC

P_w Partial pressure of vapor at water surface, N/m^2

P_g Partial pressure of vapor at glass surface, N/m^2

Hourly yield of solar still is given by:

$m_w = (q_{ew} / L) \times 3600$ (4)

Efficiency of solar still is given by

$\eta = (q_{ew} \ / I(t))$ (5)

$I(t)$ Total solar radiation, W/m^2

L Latent heat of vaporization, J/kg

3 EXPERIMENTAL SETUP

In fig. 1 you can see the solar-still in which the bottom of the still was coated with PbO_2 and GAC is mixed with the basin water. The basin area of the still is $1m^2$ and height of water in the basin is maintained at 0.01m for every experiment done.

Fig. 1. Experimental setup of solar-still. After coating the base with PbO_2 and mixing GAC with water, the still is sealed again.

In the above figure you can see the double slope single basin solar-still getting sealed after coating the base with PC's.

In figures 3 and 4 you can see the instruments used for measuring and recording the temperatures at various locations. Bolt K-type thermocoples are used to meassure the inlet water temperatur to the solar-still. Other type of thermocouples are used to measure the temperatures at the basin water surface and at the glass surface.

Fig. 2. Two types of k-type thermocouples were used to measure the temperatures in the solar still. The left side thermocouple is used to measure the temperature of inlet water to the solar-still, and the right side thermocouple is used for the measurement of temperature of basin water and condensing glass surface.

Fig. 3. Multi-channel temperature indicator, to record the temperature at various locations.

4 RESULTS AND DISCUSSIONS

The experiments were done at the terrace of Sannassi Mess Block, SRM University, Chennai. All the experiments started from 10 am morning and stopped at 7 pm in the evening. Water depth in solar-still was maintained at 0.01m at the beginning of the every experiment. During the experiment, when adding the PC's the solar-still is kept idle minimum for a one day to attain steady state conditions prior to the start of experiments.

The following parameters were measured for every hour.

- Solar-still basin water temperature
- Inner glass cover temperature
- Ambient temperature
- Distillate output
- Solar insolation
- Wind speed

Solar-still basin water temperature and inner glass cover temperature were recorded with help of a calibrated K-type Thermocouple having a least count of 1^oC. The solar insolation and wind speed were recorded using pyranometer and anemometer respectively. Table 1, Table 2, and Table 3 represents the data recorded without any PC's and with different concentrations of PC's respectively.

It is a well known fact in solar desalination that the amount of distillate output gained will be higher for the higher temperature of evaporative surface and also the temperature of the condensing glass surface should be comparatively low, for higher output from the still. In other words, higher value of evaporative surface and lower value of condensing surface temperature leads to rise in distillation output. Experiments were conducted to study the effect of GAC and the combination of GAC and PbO_2 over the productivity of the solar-still.

Hourly measurements were made for various thermocouples put at various locations for temperatures like hot basin water temperature, and inner glass cover temperature. Experiments start from morning 10 am and ends at evening 7 pm. Readings have taken in SRM University, Chennai. Table 1 shows the readings of various thermocouples, mass of distillate output, and time interval of one hour from 10 am to 7 pm shows in simple solar-still. Table 2 shows same variables but contains 0.5 kg GAC, and Table 3 is the recordings by using 1 kg GAC and 0.5 kg PbO_2.

Table 1 Theoretical and actual outputs from the simple solar-still.

Time (Hours)	T_g (°C)	T_w (°C)	Theoretical O/P (kg)	Actual O/P (kg)
10-11	18.2	29	0.001254	0.0
11-12	20.6	32.9	0.002664	0.001
12-13	22.4	37.5	0.005485	0.002
13-14	22.6	45.3	0.01223	0.009
14-15	23.5	49.2	0.013457	0.01
15-16	24.7	51.6	0.017460	0.013
16-17	25.2	45.5	0.006092	0.004
17-18	26.8	42.3	0.004431	0.002
18-19	27.3	38.4	0.004112	0.002

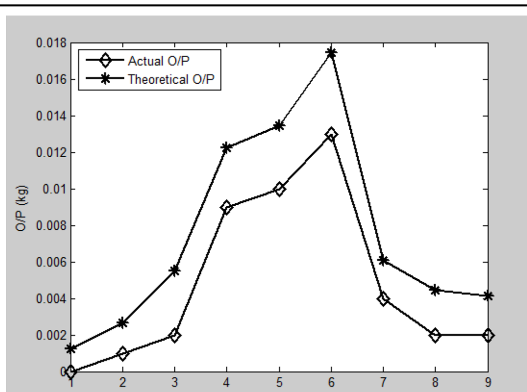

Fig. 4. Comparative analysis of distillate output of simple solar-still.

Figure 4 shows how the mass distillate is varying with duration of day, maximum distillate was obtained from the still between 1 pm to 3 pm, when the basin water temperature is high, this is because at higher temperature of basin water the evaporation rate is maximum, so different PC's are used to enhance the evaporation rate.

Table 2 Output from the still with 0.5 kg GAC.

Time (Hours)	T_g (°C)	T_w (°C)	O/P (kg) with 0.5 kg GAC
10-11	19.3	33.1	0.02
11-12	21.3	38.3	0.039
12-13	22.4	43.6	0.12
13-14	24.5	51.2	0.192
14-15	25.1	54.3	0.269
15-16	26.3	56.1	0.28
16-17	27.4	51.6	0.22
17-18	28.1	46.2	0.19
18-19	28.9	40.5	0.103

Table 3 Output from the still with 1 kg GAC and 0.5 kg PbO_2.

Time (Hours)	T_g (°C)	T_w (°C)	O/P (kg) with 1 kg GAC and 0.5 kg PbO_2
10-11	20.9	35.4	0.096
11-12	21.5	42.1	0.119
12-13	22.7	46.6	0.249
13-14	24.8	53.3	0.351
14-15	25.9	56.7	0.385
15-16	26.7	57.2	0.389
16-17	27.9	54.4	0.321
17-18	28.5	49.8	0.301
18-19	29.3	47.3	0.277

Table 2 and Table 3 are the hourly recordings of different temperatures and mass distillates obtained from the still when

0.5 kg GAC was used in still and 1 kg GAC with 0.5 kg PbO_2 was used respectively.

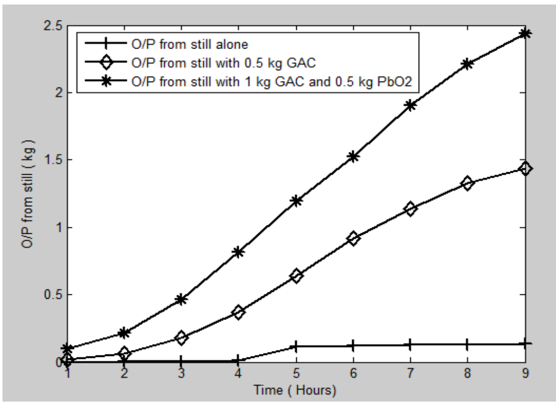

Fig. 5. Comparative analysis of distillate output of simple solar-still,solar still having 0.5 kg GAC, and solar-still with 1 kg GAC,0.5 kg PbO_2.

Figure 5 shows the comparision of the distillates obtained from the solar-still. The output from the simple solar-still was 0.05 kg at average ambient temperature of 34.4 °C. The output from the still increased to 1.44 kg at average ambient temperature of 35.2 °C when 0.5 kg GAC was used in the solar-still. At average ambient temperature of 35.5 °C and with 1 kg GAC, 0.5 kg PbO_2 the output from the still increased to 2.45 kg, nearly 1 kg hike was obtained by mixing GAC and PbO_2. This hike in output was because of the considerable increase in the evaporative heat transfer coefficient.

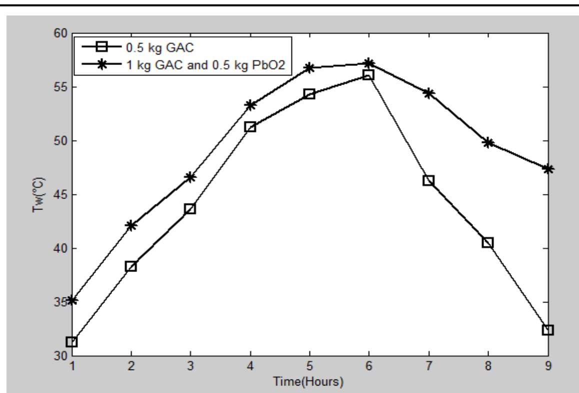

Fig. 6. Comparative study of temperature of basin water of still with 0.5 kg GAC and 1 kg GAC, 0.5 kg PbO_2.

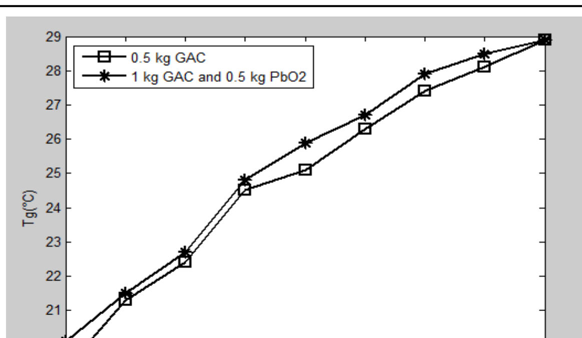

Figure 6 and figure 7 shows how the basin water temperature and inner glass surface temperature of still changes with time. Figure 3 shows that there is a increase of 5 °C of basin water at every hour when you increased the quantity of GAC to 1kg and coated the base with PbO_2, at the same time there is not much difference in the temperature of the inner glass surface. Hence with 1 kg GAC and 0.5 kg coating of PbO_2 the difference between basin water temperature and inner glass surface increased leading to increase in the output from the still.

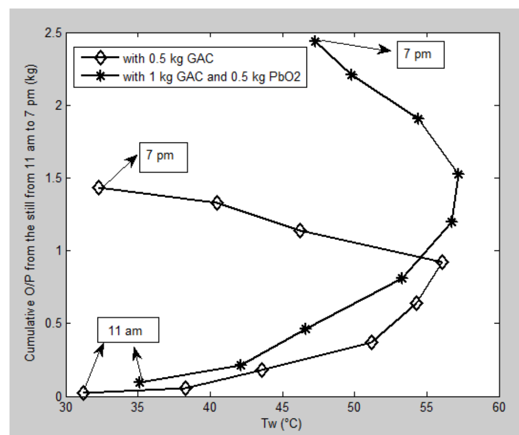

Fig. 8.Comparative study of output from the solar-still with 0.5kg GAC and 1kg GAC, 0.5 kg PbO_2 with basin water temperature.

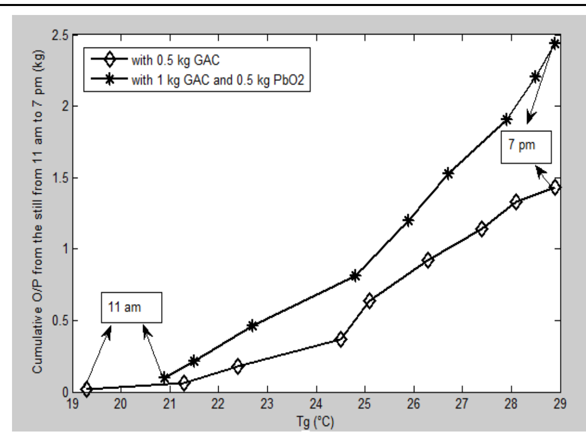

Fig. 9. Comparative study of output from the solar-still with 0.5 kg GAC and 1kg GAC, 0.5 kg PbO_2 with inner glass cover temperature.

Figure 8 and Figure 9 are the comparisions of the cumulative ouputs from the still at different basin water and inner glass surface temperatures. We know that if the basin water temperature is higher then the output from the still is more, PC's with different concentrations were used to increase the basin water temperature.If the inner glass surface temperature is lower then the output from the still is more. Higher basin water temperature were obtained with 1 kg GAC and 0.5 kg PbO_2 increasing the output to 2.45 kg from 1.44 kg. This hike in the output also infers the evaporative heat transfer coefficient has increased considerably.

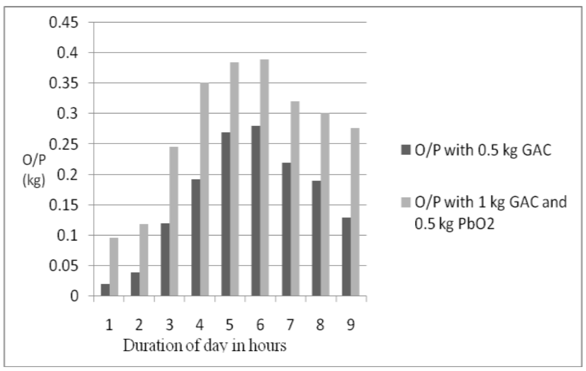

Fig. 10. Hourly output from the solar-still with different concentrations of PC's.

Figure 10 shows how the hourly output increased by increasing the concentration of PC's. First 0.5 kg GAC was used in the solar-still and then the GAC concentration increased to 1 kg and 0.5 kg PbO_2 was also coated on the base of the solar-still. By doubling the concentration of GAC and by adding PbO_2 the output from the still reported nearly 65 % hike in the hourly output. This shows the GAC and PbO_2 conciderably increases the evaporative heat transfer coefficient.

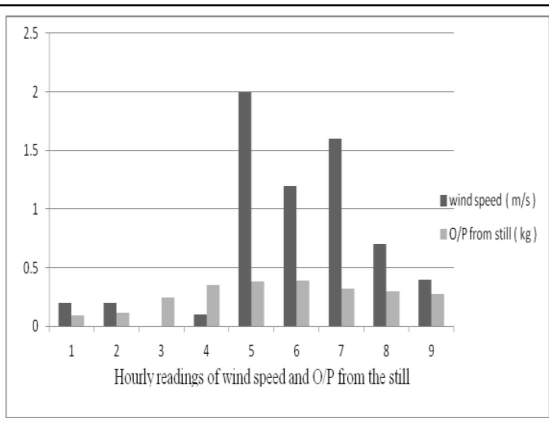

Fig. 11. Hourly variation of output from the solar-still with 1 kg GAC and 0.5 kg PbO_2 with wind speed.

Figure 11 shows the how the output from the still fluctuates with wind speed. If the wind speed is high the output from the still decreses. But our solar-still was completely sealed giving no chance of air currents entering into the solar-still. If air currents enters into the solar-still the basin water temperature decreases and the output from the still decreases.

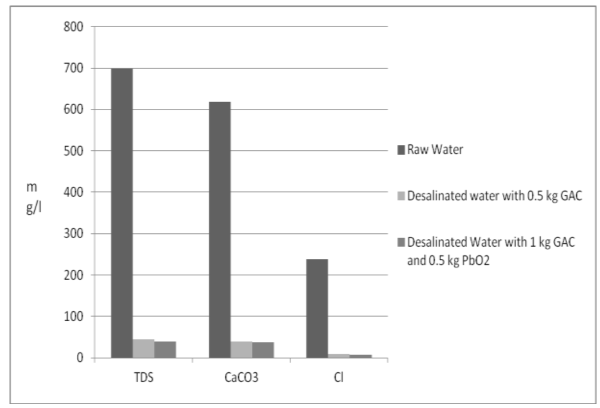

Fig. 12. Hardness test results of water.

Figure 12 shows the result of hardness test. The pH of raw water @ 25 °C was 7.42 and for the desalinated water with 0.5 kg GAC was 6.57 and with 1kg GAC, 0.5 kg PbO_2 it was 6.5. The TDS in raw water were 698 mg/lit but in desalinated water by using PC's the count reduced to 44 mg/lit, 93 % TDS were reduced. Total hardness as $CaCO_3$ for raw water was 618 mg/l, which got reduced to 40 mg/lit resulting in 93.5 % decrease in desalinated water. . Chlorides as Cl in raw water were 238 mg/lit and in desalinated water it got reduced to 8.4 mg/lit resulting in 96.4 % decrease.

5 Conclusion

The performance of solar-still with two different photo-catalysts, granular activated carbon (GAC) and PbO_2 was investigated. The output from the solar-still with 0.5 kg GAC was recorded to be 1.44 kg, and the output with 1 kg GAC and 0.5 kg PbO_2 was recorded to be 2.45 kg. By increasing the concentration of GAC to 1 kg and by adding 0.5 kg PbO_2 the efficiency of the still increased to 40 %. It was found that the output from the still in the night hours is 30-40 % of the output obtained in the day hours.

The pH of desalinated water decreased to 6.5 from 7.42. The total dissolved solids concentration in desalinated water decreased from 698 mg/lit to 44 mg/lit resulting in 93.6 % decrease. Total hardness as $CaCO_3$ in the desalinated water decreased from 618 mg/lit to 40 mg/lit, resulting in 93.5 % decrease. Chlorides in the desalinated water decreased from 238 mg/l to 8.4 mg/lit resulting in 96.4 % decrease. Hence the use of PC's increased the efficiency of the solar-still considerably, by increasing the evaporation rate in the solar-still.

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