PERFORMANCE ENHANCEMENT OF PASSIVE SOLAR STILL WITH PARAFFIN WAX

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Abstract- A solar still is a simplest and an economical device for providing potable water in remote and coastal areas. Various techniques such as paraffin wax is present in basin water, proposed to improve the effectiveness of the solar still. An experimental work is carried out to study the influence of the presence of paraffin wax on the performance of solar still. Three different size of paraffin wax i.e. 1kg, 2kg and 3kg are considered for the study. Experiments are conducted on a single slope solar still with condensing cover of 30^o inclination. The study was performed in Indian coastal climatic conditions for 24 hours. The experimental study is carried out on the overall distillate yield and efficiency of the still with different size of paraffin wax. With the increase in heat storage capacity of basin water due to the presence of paraffin wax the distillate production is increased. More distillate production is observed of solar still with 3kg paraffin wax than 1kg and 2kg. It is ascertained that maximum yield is produced at combination of constant water depth of 5cm and 3kg paraffin wax. The increase in yield and efficiency of solar still is due to more heat storage capacity of paraffin wax. It gives 32.8% and 14.87% more yield and 2.68% and 1.27% more distillation efficiency with 3kg when compared with 1kg and 2kg respectively.

Keywords: Distillation efficiency, Solar still, Heat transfer coefficient, Phase change material.

1. Introduction

Many Processes are available for obtaining purified water in which distillation is one of them. During the process water gets heated and evaporated. This evaporated vapour will be condensed and pure water is formed. The required heat for the process is powered from Sun, which one is a renewable energy source and its availability at any location on the earth.

In Indian coastal regions, pure water may not available and the ground water is mostly used as drinking water. By considering the availability of solar energy and ground water, we studied the practical alternative, solar distillation of ground water especially in Indian costal conditions.

This type of solar distillation never demands any hidden fuel costs and is eco-friendly. The solar radiation is available in very large areas compared to usage. So the capacity of distillation can be raised by increasing the area of radiation.

2. Definition of the problem

The internal heat and mass transfer coefficients affect the performance of solar distillation unit. Dunkle[1] proposed a relation between internal heat and mass transfer coefficients. A wide variety of solar stills with different geometries for different climatic conditions have been analysed based on Dunkle relation.

For the selected design, an attempt is made in this paper to find an optimum water depth for maximum daily yield. A single basin solar still unit with a fixed 30^o condensing cover inclination is considered at JNTUK Kakinada, Andhra Pradesh, India. Three different water depths 0.03m, 0.04m and 0.05m are considered for performance prediction of unit. The combined effect of evaporative and convective internal heat transfer are predicted by the relation $Nu=C.(Gr.Pr)^n$

Dunkle[1] suggested the fixed values for C and n as 0.075 and 1/3 respectively Whereas, Kumar & Tiwari [2] used the experimental data to obtain the values of constants from outdoor experimentation. In this work, the values of heat transfer coefficients for solar still unit are evaluated and compared for both Dunkle's and K&T models.

3. Literature Review

Due to the shortcomings in Dunkle's relation, new empirical equations were proposed for determining the constants of C and n for calculating internal heat transfer coefficients by Kumar and Tiwari[2]. Review on the use of renewable energy in various types of desalination systems are found in references [3, 4, 5, 6] Lilian Malaeb et.al [7] examined the effect of using a solar still with three different cover geometries of double-slope, single-slope and curved cover and the effect of cover design on the performance of the still in terms of measured temperature and productivity is considered. A.A.EI-Sebaii et.al [8] investigated the dependence of the still efficiency and productivity on the fin-configuration parameters such as the mumber, height and thickness was studied. A.Muthu Manokara et.al [9] shown that the amount of water produced from the still was increased by more than eight times by maximizing cooling of the condensation surface. R Bharadwaj et.al [10] studied the method of maximizing the water production by increasing the area of condensation surface for solar still. Mansoor Feilizadeh et.al [11] investigated the outdoor performance of a basin type multi-stage solar still as well as the effect of collector over basin area ratio on the distillate production. A .Jahanbakhsh et.al [12] shown that the collector water flow rate and evacuation of the glass cover tubes had little effect on the enhancement of the solar collector thermal performance. F.Saeedi et.al [13] the optimization of Photo Voltaic /Thermal active solar still has been carried out and values of mass flow rate and number of Photo Voltaic/Thermal collectors has been obtained. S.A. EI-Agouz et.al [14] suggested the productivity and efficiency of solar still are influenced by water film thickness, and velocity as well as wind velocity. Naga Sarada, et al [15] reported improvements in the efficiency of solar water distillation by using Phase Change Materials. Durkaieswaran, et al [16], reviewed the work on various special designs of single basin passive solar stills.

4. Experimental Setup

4.1. Distillation Unit

The schematic line diagram of single-slope passive solar distillation unit is shown in fig. 1a, whereas fig. 1b is the photograph of the setup. The experimental setup consists of a passive solar distillation unit with condensing cover inclination 30^0. The bottom surface of the still is painted Nichrome black for greater absorptivity. The height of lower vertical wall of still was kept at 0.30 m to avoid the spilling of basin water into the distillate channel and to prevent the contact of distillation channel with the condensing cover as well as with the water level. The height of higher vertical wall was kept as 0.88 m. The effective basin area of still is 1m x 1m and it is made of FRP of 6 mm thickness, which provides insulation for heat flow. Condensing cover made of long plain glass of 4 mm is fixed to the top of the vertical wall of the still using a rubber gasket. The yield from the still is collected through a channel, fixed at the height of the smaller vertical wall of the basin. A hose pipe is connected to this channel to collect the yield to a measuring jar.

4.2. Procedure

The experiments were performed in summer climatic condition of 2015 in JNTUK, Kakinada, Andhra Pradesh, India. April & May are usually the hottest months of the year in this region and typical results for 3 days during the period have been reported here. Experiments were conducted from 8.00 A.M. to 8.00 A.M. the next day for 3 different water depths, namely 0.03 m, 0.04 m and 0.05 m. Sufficient care is taken for obtaining steady state condition during the experimentation. The inclination of 30^0 is fixed for all experiments. The parameters , viz, glass outer and inner surface temperatures, vapour temperature, water temperature, ambient temperature, incident radiation, relative humidity(γ) inside still and distillate output are measured on 24 hr basis for all the 3 water depths.

Water, condensing cover and vapor temperatures were recorded with the help of calibrated copper constant thermocouples and a digital temperature indicator having a least count of 0.1^0 C.

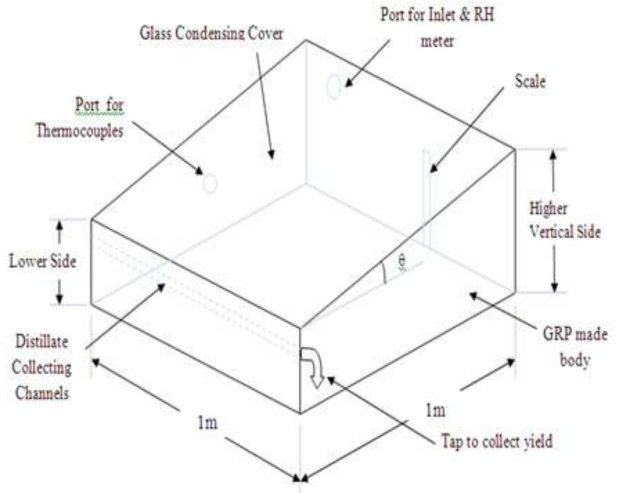

Figure 1a: Schematic diagram of solar still.

Figure 1b: Photograph of the working solar still.

A mercury thermometer was used to record the ambient temperature and outer glass temperature. The yield was measured using of a measuring flask at time intervals. A solarimeter was used measure the solar radiation intensity falling on condensing cover. The above measured parameters were used to calculate average values of each for further calculations. Table1 gives the measured parameters for a water depth of 0.04m.

Table3 shows 24 hourly average values of h_{cw}, h_{ew}, h_{cwDM} and h_{ewDM} calculated from experimental data using MATLAB for water depth of 0.04m. Similar values for two other water depths were also calculated.

Free convection of water vapor takes place due to the density variations, which occur because of thermal potential difference.

Fig 4.9 Photograph of wooden tetrahedrons

Fig 4.10 Photograph of solar still with wooden tetrahedrons

5. Governing Equations and Thermal Models

The following equations are applicable for obtaining convective heat transfer coefficient.

$Q = h_{cw} . A. (T_s – T_a) = h_{cw} . A .\Delta T$ (1)

Where Q is rate of heat transfer, A is surface area , T_s is surface temperature, T_a is ambient temperature and $.\Delta T$ is temperature difference.

From the relation $Nu = C (Gr. Pr)^n$, the convective heat transfer is written as

$h_{c\,w}= (K_v/L_v) . C. (Gr . Pr)^n$ (2)

Where, C & n are constants, K_v is thermal conductivity of humid air ,L_v is characteristic length, Gr is Grashoff number and Pr is prandtl number

5.1. Present Work

In the present work, the effect of water depth on maximum yield and distillation efficiency for a single basin solar still are experimentally studied. Further, the constants C and n of both K& T model as well as the Dunkle's model are used for calculating the various parameters h_{cw} and h_{ew} etc., and the comparative performance of the solar still is also presented.

6. Results and discussion

In the present work, the performance of a single slope and single basin passive solar still with 30^0 condensing cover inclination for three different size of paraffin wax i.e. 1kg, 2kg and 3kg is reported. The measured values for a size of paraffin wax 3kg on a typical day are presented in Table 1. The C and n values obtained as per K&T model for all the three water depths are indicated in Table 2. The comparative values of h_{cw} and h_{ew} obtained through K&T model and Dunkle's model are presented in Table 3.

The hourly water and inner condensing cover temperatures for various size of paraffin wax have been shown in figures 2a and 2b respectively. The temperatures rise in the morning, fall in the evening and variations followed similar trend for various size of paraffin wax. This is due to the variations in the intensity of sun radiation over the observation period. The variation of the hourly difference in temperature for water and inner surface of the condensing cover i.e. Δ T is shown in the figure 2c for the still with various size of paraffin wax. It can be concluded that during morning hours condensing cover encounters the radiation first and its temperature rises very fast when compared to the rise in water temperature and as a result, ΔT becomes negative. This will continues upto water temperature supersedes the cover temperature. It is seen from the figure 2c that for morning hours, the negative value of ΔT increases with increasing size of paraffin wax as the water temperature takes more time to surpass the cover temperature. When the water temperature crosses the condensing cover temperature, it will continue higher till next sunrise. It was observed that, for a paraffin wax size of 3kg, ΔT becomes positive at around 11 am, whereas the same condition is attained for 1kg and 2kg size of paraffin wax after 12 noon, i.e. 1 to 1.5 hrs later. After becoming positive, ΔT increases rapidly with increase in water temperature. Hence the ΔT plays an important role in maximising the yield and ultimately the convective mass transfer coefficient and partial pressure difference as well.

For the size of paraffin wax of 3kg, highest yield is obtained as shown in fig. 3a for the entire period of 24 hrs. Figure 3b shows the variation of the daily yield for the three size of paraffin wax. A maximum yield 2.64 kg is obtained at a paraffin wax size of 3kg whereas the yield is 1.45 kg for 1kg paraffin wax and 1.85 kg for 2kg paraffin wax respectively. It is clear from the above that the paraffin wax size 3kg is the optimum size among the three. This is due to the reasons that mor heat storage capacity & less heat drop for the paraffin wax size of 3kg.

Figure 3c shows the variation of distillation efficiency for the three sizes of paraffin wax. The variation is similar to the daily yield, shown in fig. 3b.The efficiencies of still at 1kg and 2kg size of paraffin wax are 18.97% and 20.38% respectively. The maximum efficiency of 21.65% is obtained at the optimum paraffin wax size of 3kg.

Figures 4a and 4b show the variation of h_{cw} and h_{ew} for 1kg size of paraffin wax. It can be observed that the values obtained by the K&T model [2] are almost constant within 24hrs whereas the values obtained for Dunkle’s model have non uniform variation. However Dunkle’s model gave higher values when compared to that of the K&T model [2].

Figures 4e and 4f indicate the variations of h_{cw} and h_{ew} for 2kg size of paraffin wax. It can be observed that the values obtained for h_{cw} by the K&T model are almost constant within 24hrs whereas the values obtained for Dunkle’s model have non uniform variation. However Dunkle’s model gave lower values for both h_{cw} and h_{ew} when compared to that of the K&T model. This may be due to the reason that the constants C and n used in Dunkle’s model are same for all the sizes and hence are not realistic.

Figures 4c and 4d show the variation of h_{cw} and h_{ew} for 3kg size of paraffin wax. It is observed that both convective and evaporative heat transfer coefficients have maximum value at a water temperature of around 53^0 C for both the models. However Dunkle’s model gave higher values when compared to that of the K&T model [2]. A maximum deviation of around 9% and 96% is observed for the values of h_{cw} and h_{ew} respectively with the K&T model. Table 2 also indicates the average values of h_{cw} and h_{ew} obtained through calculations.

Figure 5a shows the values of h_{cw} for three paraffin wax sizes and the variation is uniform throughout the day. The average values of h_{cw} for the three sizes are 1.41 w/m².°C, 1.81 w/m² °C and 2.09 w/m^2 °C respectively.

Figure 5b shows the values of h_{ew} for three sizes and the variations within the 24 hours are uniform. The maximum values of h_{ew} are 49.96 w/m² °C, 74.85 w/m² °C and 60.78 w/m² °C for the three sizes respectively.

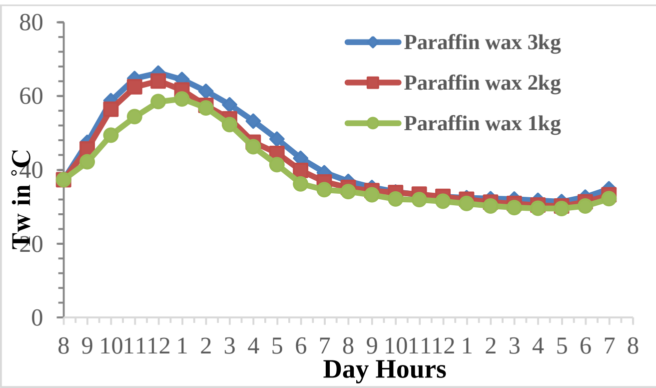

Figure 2 a : T_w for the solar still with various sizes of paraffin wax

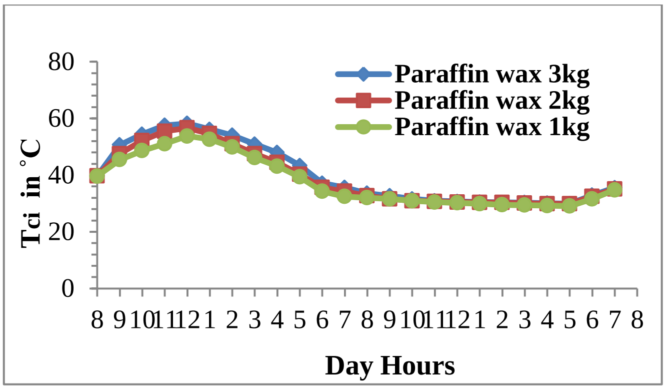

Figure 2 b: T_{ci} for the solar still with various sizes of paraffin wax

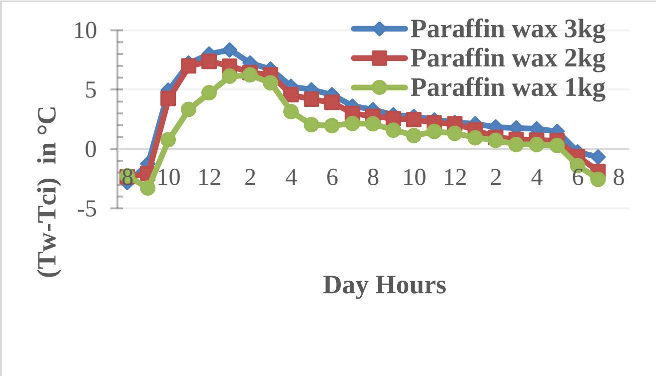

Figure 2c: ΔT for the solar still with various sizes of paraffin wax

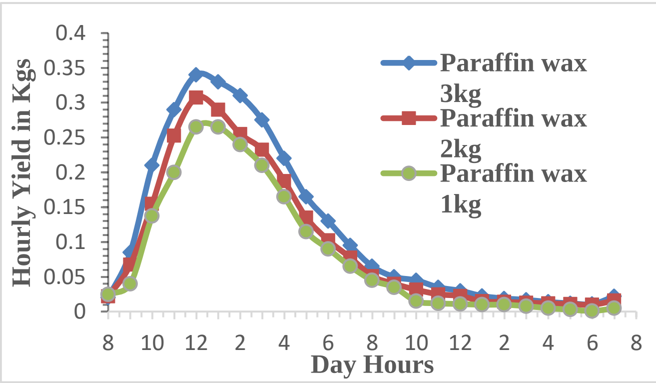

Figure 3 a : Variation of m_{ew} with various sizes of paraffin wax

Table1: Measured values for Solar still with 5kg size of paraffin wax on a clear sunny day of March 30th, 2022

S.No	I(t) W/m^2	Time	T_w °C	T_{ci} °C	T_{co} °C	T_v °C	T_a °C	m_{ew} kg	γ %
1	490	8	30.43	34.19	32.58	36.42	31.95	0.00	86
2	580	9	36.85	46.51	36.61	48.61	32.56	0.012	75
3	870	10	43.92	50.63	39.28	51.79	36,20	0.014	66
4	930	11	49.31	49.77	39.85	49.81	36.92	0.038	69
5	980	12	53.54	52.82	45.21	48.51	38.75	0.082	76
6	1080	13	55.18	50.58	46.68	51.86	39.28	0.112	82
7	830	14	56.82	48.41	45.89	53.98	39.89	0.165	82
8	650	15	54.61	45.23	41.75	50.57	38.34	0.210	84
9	370	16	52.54	44.34	40.32	49.23	37.56	0.175	84
10	90	17	49.45	43.68	37.52	45.25	35.41	0.162	85
11	50	18	46.23	40.97	34.71	42.17	33.34	0.134	93
12	0	19	42.78	38.65	32.62	39.21	32.18	0.118	95
13	0	20	39.57	35.56	31.52	36.58	30.81	0.08	97
14	0	21	36.44	33.88	31.00	34.50	30.45	0.082	98
15	0	22	35.92	32.99	30.70	33.88	30.00	0.060	99
16	0	23	33.47	31.87	28.90	32.62	29.21	0.058	100
17	0	24	31.50	30.15	28.00	31.41	28.82	0.052	100
18	0	1	30.41	29.62	27.12	30.22	28.18	0.039	100
19	0	2	30.00	29.10	26.85	29.42	27.92	0.028	100
20	0	3	29.75	28.68	26.23	29.15	27.51	0.021	100
21	0	4	29.31	28.05	25.90	28.37	27.28	0.018	100
22	0	5	29.00	27.85	25.38	28.05	27.12	0.015	100
23	60	6	28.81	28.91	27.18	29.17	27.00	0.014	100
24	240	7	30.52	34.16	30.55	36.11	28.58	0.014	97
25	540	8	32.12	36.28	33.28	41.52	30.62	0.012	92

Table 2**: V**alues of constants C& n and average values of h_{cw} & h_{ew} from K & T model

Paraffin wax size	C	n	h_{cw}(W/m^2 °C)	h_{ew}(W/m^2 °C)
1kg	42.285	-0.031568968	1.41	12.95
2kg	46.772	-0.024300133	1.81	15.52
3kg	40.557	-0.008932585	2.09	14.77

Table3**:** Hourly Average values calculated using 24hrs experimental data for 5kg size of paraffin wax .

S.no	Time	T_{ci} °C	T_v °C	T_w °C	m_{ew} kg	h_{cw} W/m^2 °C	h_{ew} W/m^2 °C	h_{cwDM} W/m^2 °C	h_{ewDM} W/m^2 °C
1	8am-9	40.35	42.51	33.64	0.006	1.72	3.26	4.42	8.38
2	9-10	48.57	50.19	40.38	0.013	1.75	1.81	4.74	4.89
3	10-11	50.2	50.80	46.61	0.026	1.81	15.97	3.44	30.33
4	11-12	51.29	49.16	50.14	0.06	1.87	74.33	2.30	91.14
5	12-13	51.7	50.18	54.36	0.097	1.85	51.05	2.94	81.14
6	13-14	49.49	52.92	56.00	0.138	1.81	29.03	3.84	61.71
7	14-15	46.82	52.29	55.71	0.187	1.79	23.85	4.19	55.95
8	15-16	44.78	49.90	53.57	0.192	1.78	21.35	4.18	50.32
9	16-17	44.01	49.26	50.99	0.168	1.78	21.01	3.94	46.54
10	17-18	42.32	43.73	47.34	0.148	1.78	18.73	3.59	37.87
11	18-19	39.81	40.69	44.50	0.126	1.76	14.58	3.53	29.16
12	19-20	37.10	37.89	41.19	0.103	1.75	12.08	3.40	23.40
13	20-21	34.72	36.40	38.65	0.085	1.74	10.15	3.36	19.60
14	21-22	33.43	34.19	36.18	0.071	1.75	9.19	3.02	15.91
15	22-23	32.43	33.25	34.69	0.059	1.75	8.22	2.85	13.40
16	23-24	31.01	32.10	32.48	0.053	1.76	7.28	2.49	10.34
17	24-1	29.88	30.81	30.96	0.045	1.76	6.85	2.26	8.78
18	1-2	29.36	29.82	30.21	0.033	1.77	6.66	2.09	7.88
19	2-3	28.89	29.28	29.87	0.024	1.76	6.50	2.19	8.09
20	3-4	28.36	28.76	29.53	0.019	1.75	6.32	2.32	8.39
21	4-5	27.95	28.21	29.15	0.016	1.75	6.19	2.34	8.30
22	5-6	28.87	28.61	28.91	0.015	1.74	6.84	0.76	2.75
23	6-7	31.57	32.63	29.67	0.012	1.74	5.81	2.80	9.37
24	7-8am	35.22	38.81	31.32	0.012	1.72	5.51	3.62	11.56

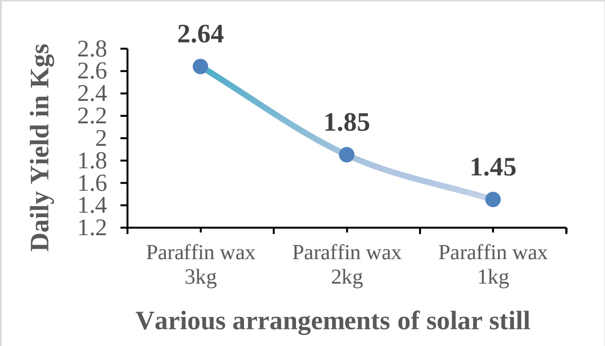

Figure 3b : $\sum m_{ew}$ with various sizes of paraffin wax

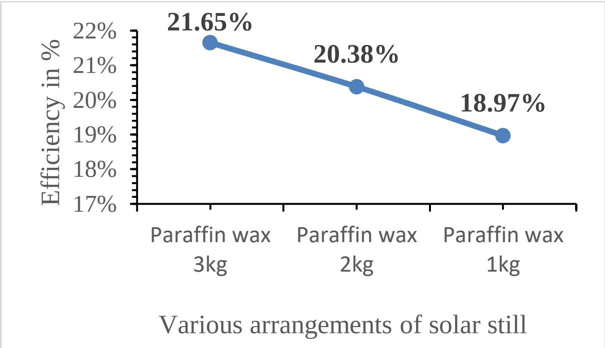

Figure 3c: Variation of η_D with various sizes of paraffin wax

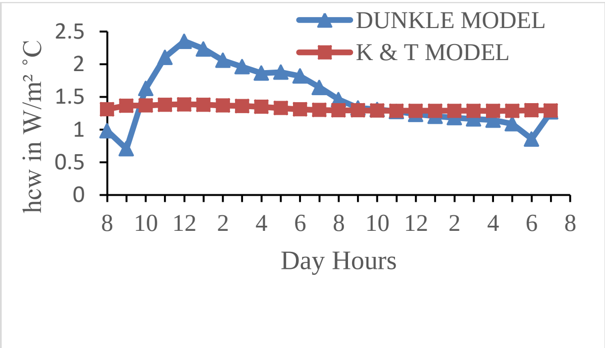

Figure 4 a: Variation of h_{cw} for 1kg sizes of paraffin wax

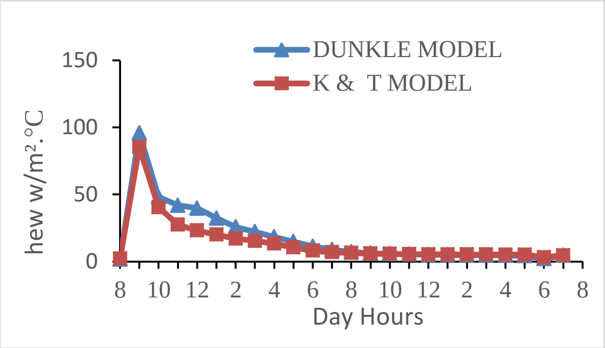

Figure 4 b: Variation of h_{ew} for 1kg sizes of paraffin wax

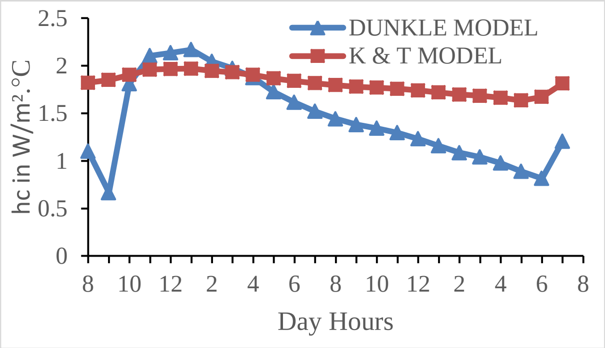

Figure 4 c : Variation of h_{cw} for 2kg sizes of paraffin wax

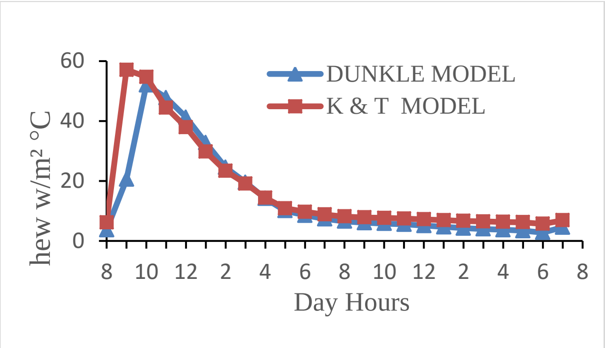

Figure 4d: Variation of h_{ew} for 2kg sizes of paraffin wax

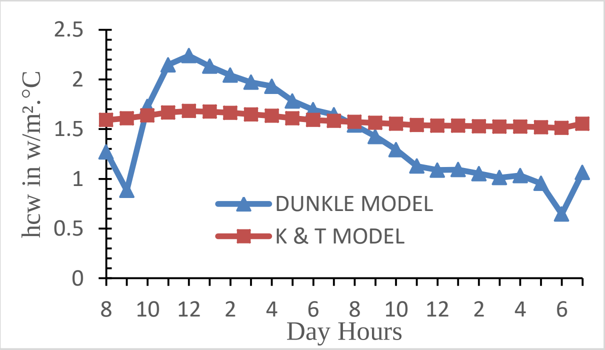

Figure 4e : Variation of h_{cw} for 3kg sizes of paraffin wax

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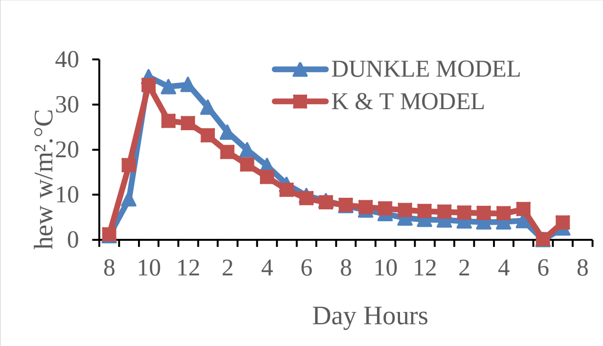

Figure 4f: Variation of h_{ew} for 3kg sizes of paraffin wax

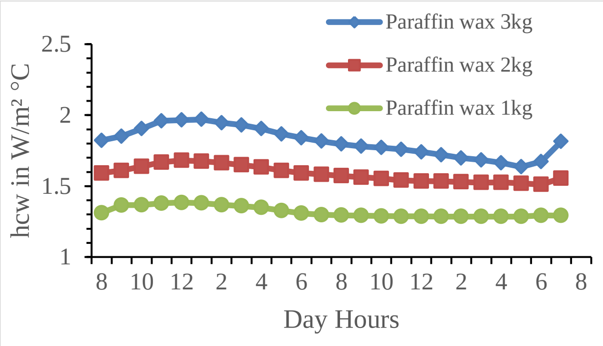

Figure 5 a: Variation of h_{cw} with various sizes of paraffin wax using K&T Model

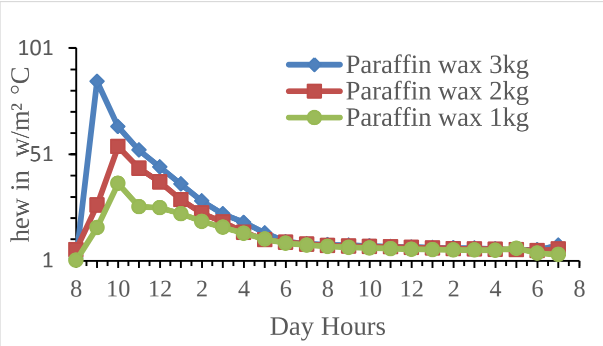

Figure 5b: Variation of h_{cw} with various sizes of paraffin wax using K&T Model

7. Conclusions

The present experimental study is related to the optimization of the paraffin wax size for efficient distillation using a single slope, single basin passive solar still in Indian coastal climate in peak summer conditions. The important conclusions from the present work are summarized below.

1. The highest yield and efficiency of the still are obtained at a paraffin wax size of 3kg. Hence 3kg paraffin wax size is the optimum size for the selected solar still. For paraffin sizes of 1kg and 2kg, less yield and low efficiency are obtained due to low heat storage effect in the morning and more heat drop in the evening. The partial pressure difference between water temperature and condensing cover temperature is found to be highest for the 3kg paraffin wax size, which directly influences the yield.

2. The distillation efficiencies of still at 1kg and 2kg water sizes are 18.97% and 20.38% % respectively. The maximum efficiency of 21.65% is obtained at the optimum paraffin wax size of 3kg respectively.

3. A maximum yield of 2.64 kg is obtained at a paraffin wax size of 3kg whereas the yield is 1.85 kg for 2kg and 1.45 kg for 1kg respectively.

4. The convective & the evaporative heat transfer coefficients are evaluated using K&T model and Dunkle model. The K&T model is found to be superior when compared to Dunkle's model due to the realistic values for the constants C and n, whose values vary for the respective paraffin wax size.

5. The important parameters in the study are the convective and evaporative heat transfer coefficients, as the maximum yield and the distillation efficiency depend on the convection and the evaporation processes.

6. The study will be useful for designing efficient solar distillation systems for the coastal climatic conditions.

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