PERFORMANCE ANALYSIS ON HORIZONTAL AND INCLINED BASIN SOLAR DISTILLATION SYSTEM

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ABSTRACT:- *The solar still is most popular green technology used for water distillation. Several design of solar still have been built over the past century. Development of economical solar still with high productivity is a major challenge. The productivity of solar still can be enhanced by improving rate of evaporation and or rate of vapour condensation. Several ways are being tried to improve the productivity of solar still; some of those are, reducing heat loss in the still, augmentation of heat collection by concentrator and reflectors, preheating of inlet water, maintain optimum flow rate, achieving drop wise condensation, reducing condenser surface temperature, use of various heat storage materials, absorber surface texturing, using passive heat transfer augmentation methods etc. In the current work, the evaporation rate is enhanced by basin modifications. An inclined solar still is fabricated. The evaporation rate of solar still improved.*

The experimental study is carried out at Chandrapur (19.9705ºN, 79.3015ºE) during the month of April and May, in this study it has been observed that the thermal efficiency of the modified solar still is increased by around 13.58% over the conventional system of same area.

***Key Words**: Solar Distillation, improvement, solar basin, glass, solar intensity.*

1 INTRODUCTION

The solar still have horizontal flat basin and the water is stored in the basin. To improve the evaporation rate, the inclined basin solar still are proposed. In this system, the basin is inclined and the water is allowed to flow over the basin. Use of inclined basin help to enhance the productivity of solar still because of inclination the solar radiations reaching frequently on absorbing plate. But inclination is not enough to enhance the productivity of solar still, some additional modification are required to basin for enhancement of productivity of solar still.

2 LITERATURE REVIEW

In order to enhance the productivity of solar still (improve rate of evaporation and rate of condensation), various designs and modifications have been incorporated by many researchers. Hitesh Panchal and Indra Mohan explains various methods to enhance the distilled output like fins, energy storage material and multi basin solar still. H.S Aybar et al. carried out both Experimental as well as mathematical studies on inclined solar water distillation (inclined absorption plate 300 to horizontal) system shown in fig 2.1. The experimentation was held on three variants namely - bare plate, Black fleece wick and black cloth wick. He observed that, distilled output was two to three times more in case of wicks instead of bare plate.

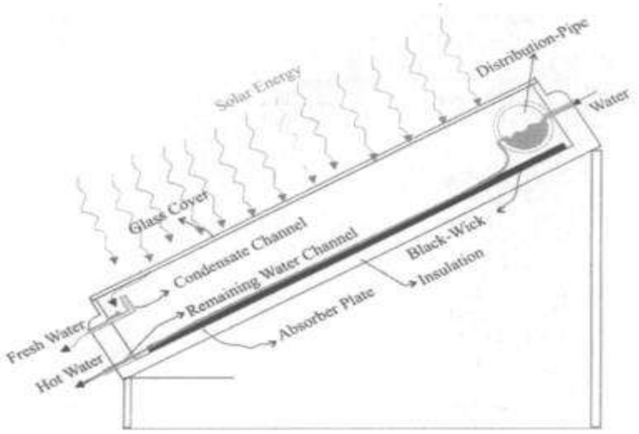

Figure 2.1: Inclined basin solar still

Further in a study by G.N. Tiwari it was ascertained that inclination and the direction of inclination of the cover depends on the latitude of the location.

Summary of literature review

From the literature study following significant conclusions can be made,

1) Inclined basin solar still are preferred instead of horizontal basin solar still for better productivity.

Objective of the present work

The current work is aimed at performance improvement of conventional solar still by improving the rate of evaporation.

Following are the objective of current work

1) Develop an inclined basin solar still

2) To analysis the performance of modified solar distillation system by increase evaporation rate.

3 EXPERIMENTAL DETAILS

A inclined basin solar still is fabricated. One horizontal basin solar still of same dimension is also fabricated. In this chapter we discussed the detailed experimentation and working of incline and horizontal basin solar still.

3.1 System Description

Inclined basin solar still is fabricated and tested in climatic condition of Chandrapur (India) (19.9705ºN, 79.3015ºE) in the month of April and May. The inclined basin system is shown in fig 3.1. The system consists of conventional basin,. The entire system is described in the subsequent text

Figure 3.1: Experimental system of conventional and inclined basin still

3.2: Components of experimental setup:

3.2.1: Horizontal basin solar still

1) Basin: - Distillation system shown in fig 3.2. Is constructed using Galvanized iron sheet 20 Gauge (1 mm thick) with basin size of 0.5 m X 0.4m which means basin effective area of distillation system is 0.20m^2. Depth of Distillation system is 16cm at one side and 10cm to other side.

2) Glass: - Distillation system is covered with transparent glass of thickness 5mm and inclined to 360 to horizontal surface. The thermal conductivity of transparent glass cover is 0.8 w/m K.

Figure 3.2: Experimental system of conventional or horizontal basin solar still

3) Insulation: - Side wall is insulated with 1cm thermocol sheet as well as bottom wall is also insulated with 1cm thermocol sheet.

3.2.2 Inclined basin solar still.

1) Basin: - The basin dimensions are same as those of conventional still. Only the basin is made by inclined.

Figure 3.3: Experimental system of inclined basin solar still

2) Glass: - Distillation system is covered with transparent glass whose thickness is 5mm and inclined to 19.97 to horizontal surface. The thermal conductivity of transparent glass cover is 0.8 w/m K.

3) Insulation: - Side wall is insulated with 1cm thermocol sheet as well as top and bottom wall is also insulated with 1cm thermocol sheet. To reduce the convective losses from bottom and side walls they are insulated using saw dust.

3.3: Measuring instruments

For the performance analysis, of the solar still. It is required to observed the radiation intensity, temperature at various locations and distillate output. The radiations are measured using solar radiation pyranometer.

To measure temperatures reading, the thermocouple are used. This thermocouple is connected with temperature indicator.

Table 3.1 Thermocouple sequence for solar still system

Locations of thermocouple	**Thermocouple sequence**
Conventional still basin temperature	T1

Conventional still glass temperature	T2
Incline still basin temperature	T3
Incline still glass temperature	T4

Figure 3.4: Pyranometer (solar power meter)

Figure 3.5: Digital temperature indicator

3.4: Working Principle

The conventional and incline solar still are installed as shown in fig 3.1. The inlet water tank. The water is allowed to flow within the space provided beneath the basin surface. Thus the basin of the modified solar still possess more heat as compared to the conventional system.

The raw water which is to be distillate is header circulated over the basin using a pipe fixed at the top. The header pipe has holes drilled at specific interval. The holes and spacing are designed in such a way that the drop by drop water flow can be ensure over the basin. As water flows over the heated basin it evaporates and condense on the top glass. The condensate is collected separately.

3.5 Experimental methodology

The experiments were conducted for entire two months. During experiments, the basin temperature of both the solar stills, glass temperature are recorded throughout the period. The productivity of both the solar still were recorded by measuring the distillate output time to time.

4 PERFORMANCE ANALYSIS OF SOLAR STILL

Experimentation is carried out with the continuous flow of water over the inclined basin surface. The feed water is heated by solar energy. The evaporated water gets condensed on the inner side of the glass cover after releasing the latent heat. The condensed water trickles into the collection channel provided at the lower end of glass, under gravity, while the concentrated feed water is taken out o. The unit temperature thermocouples are used to measure the temperature at various points. Total 4- thermocouples are used on two solar stills. An anemometer with ambient temperature measurement is used to measure the ambient temperature, while pyranometer is used to measure the solar intensity. Two thermocouples are used in conventional solar still and four thermocouples are used in inclined basin solar still. Both the solar stills are in continuous monitoring of distillate output.

Experiments are carried out from 1000 to 1700 local time. The data are collected during experimentation for inclined basin solar stills and one conventional single basin solar still. This chapter includes only the sample readings, while the detailed experimental data are in the appendices.

Table 4.1: Observation table for temperature, distillate output and radiation intensity for 2nd April

Time (hrs)	Solar Intensity (W/m^2)	Ambient Temp. (Ta) (°C)	Conventional Solar Still			Inclined Solar still		
			T_w (°C)	T_g (°C)	O/p (ml/hr)	T_w (°C)	T_g (°C)	O/p (ml/hr)
10	981	37	39	35	86	50	37	123
11	1082	38	49	39	141	52	39	201
12	1120	42	53	39	173	66	41	225
13	1212	43	55	40	204	66	41	232
14	1013	42	54	36	200	50	40	222
15	951	39	42	35	135	55	39	142
16	801	31	39	35	78	52	37	84
17	604	30	37	34	46	44	34	63

Table 4.1 shows temperature and distillate output values for conventional and incline solar still for particular day. Distillate output increases from 1000 to 1300 for both solar still. The maximum distillate output is observed at 1300 for both conventional and incline solar still and it is 165 ml/hr and 209 ml/hr.

Table 4.2: Observation table for temperature, distillate output and radiation intensity for 2 May

Time (hrs)	Solar Intensity (W/m^2)	Ambient Temp. (Ta) (°C)	Conventional Solar Still			Inclined Solar still		
			T_w (°C)	T_g (°C)	o/p (ml/hr)	T_w (°C)	T_g (°C)	O/p (ml/hr)
10	930	36	36	35	90	44	38	101
11	970	38	48	37	130	48	40	146
12	1078	39	55	39	145	63	41	195
13	1099	41	56	40	165	64	42	209
14	872	42	51	39	157	55	39	179
15	799	43	49	38	121	54	39	148
16	602	41	48	38	92	53	38	109
17	423	41	44	36	51	53	38	72

Table 4.4 shows temperature and distillate output values for conventional and incline solar still for particular day. Distillate output increases from 1000 to 1300 for both solar still. The maximum distillate output is observed at 1300 for both conventional and incline solar still and it is 204 ml/hr and 232 ml/hr.

4.1: Data analysis

Methodology: -

Following methodology is used to estimate the thermal performance system

1) Calculate radiative loss coefficient (h_{rw})

2) Calculations for saturated vapour pressure at the water P(w) and glass temperature P(g).

3) Calculate Convective loss coefficient (h_{cw})

4) Calculate evaporative loss coefficient (h_{ew})

5) Calculate the rate of radiative and convective heat loss in watt

6) Calculate latent heat of vaporization

7) Calculate Solar flux absorbed by water and glass

8) Calculate the rate of evaporative heat loss in watt for solar still.

9) Calculate productivity of solar still including losses.

10) Calculate experimental and theoretical instantaneous efficiency.

4.1.1 Estimation of instantaneous efficiency:

The instantaneous efficiency is calculated with the help of following equations:

Calculations of actual instantaneous efficiency:

$$\eta_i = \frac{Mw \times L}{I \times As}$$

Where,

M_w – Distillate output in kg/s

L – Latent heat of vaporisation in J/kg0 C

I – Radiation intensity in w/m^2

A_s – Solar still basin surface area in m^2

Calculations of theoretical instantaneous efficiency:

Here the distillate output mass flow rate is

calculated theoretically:

Calculations Radioactive loss coefficient (h_{rw})

$$h_{rw} = \epsilon_{eff}\, \sigma\, ((T_w+273)^2+(T_g+273)^2) \times (T_w+ T_g+546)$$

Calculating Convective loss coefficient (h_{cw}):

$$h_{cw} = 0.884 \times [\, T_w - T_g + \frac{(Pw - Pg)(Tw + 273)}{268.9 \times 103 - Pw}\,]^{1/3}$$

Where, P_w and P_g are the saturated vapour pressu re at the water and glass temperature

correspondingly. The values of P_w and P_g can be obtained from the expression,

$$P(T) = \exp\,(25.317 - \frac{5144}{T+273})$$

calculating evaporative loss coefficient (hew)

$$h_{ew} = 16.273 \times 10^3 \times hcw\, [\, \frac{(Pw - Pg)}{Pw - Tg}\,].$$

The rate of evaporative heat loss in watt for solar still,

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

calculating distillate output in kg/s

$$M_{wth}=\frac{qew}{L}$$

Theoretical Instantaneous efficiency

$$\eta_{ith} = \frac{Mwth \times L}{I \times As}$$

4.1.2 Estimation of overall thermal efficiency:

Overall thermal efficiency for passive solar still is calculated as;

$$\eta = \frac{\Sigma Mwth \text{ x } L}{\int I \text{ x } As}$$

Overall thermal efficiency for active solar still is calculated as;

$$\eta = \frac{\Sigma Mwth \text{ x } L}{\int I \text{ x } As + \int I_* \text{ x } Ac}$$

4.1.3 Calculation for productivity of solar still:

An energy balance of steady state around the water basin can be written as,

$$Q_{ew} + Q_{losses} = (\alpha'w + \alpha'b)\ I.\ A_s + Q_{water}$$

But

$q_{ew} = m \text{ x } L$

Where,

L- Latent heat of vaporization

$L = 2.4935\text{x}10^6\ [1-9.4779 \text{ x } 10^{-4}\ T + 1.3132 \text{ x } 10^{-7}\ T^2 - 4.7974 \text{ x } 10^{-9}\ T^3]$

Solar flux absorbed by water

$$\alpha'_w = (1-\alpha_g).(1-R_g)(1-R_w).\ A_w$$

Solar flux absorbed by the basin liner

$$\alpha'_b = \alpha_b\ (1-R_g).(1-\alpha_g).\ (1-R_w) \text{ x } (1-\alpha_w)$$

Solar flux absorbed by the basin liner and water

$$(\alpha'_w + \alpha'_b) = (\alpha\tau)_w$$

For glass

$R_g = R_w = 0.05$, $\alpha_w = 0.831$

Solar flux absorbed by water

$\alpha'_w = 0.749977$

Solar flux absorbed by basin

$\alpha'_b = 0.7199$

Therefore,

$(\alpha\tau)_w =$

1.469955

Calculations for optimum flow rate of water inlet into the inclined basin solar still.

Let

Water surface temp. is 66°C

Glass covered temp. is 41°C

Ambient temp. is 42°C

Vapour Temp. is 66°C

L- Latent heat of vaporisation

$L= 2.4935x10^6 [1-9.4779 \times 10^{-4} T +1.3132 \times 10^{-7} T^2 – 4.7974 \times 10^{-9} T^3]$

= 2338945.025 J/ kg ° C

Radioactive loss coefficient (h_{rw})

$h_{rw} = \epsilon_{eff} \sigma ((T_w+273)2+(T_g+273)2) \times (T_w+ T_g+546)$

= 9.07 W/m^2 °C

Saturated vapour pressure

$P(T) = \exp (25.317 - \frac{5144}{T+273})$

P(w) = 25411.540 N/ m2

P(g) = 7591.87 N/ m2 $_{cw}$

Convective loss coefficient (h_{cw}):

$h_{cw} = 0.884 \times [T_w - T_g + \frac{(Pw - Pg)(Tw + 273)}{268.9 \times 103 - Pw}]^{1/3}$

= 3.02 W/m2 °C

evaporative loss coefficient (hew)

$h_{ew} = 16.273 \times 10^3 \times h [\frac{(Pw - Pg)}{Pw - Tg}]$

=35.02 W/m2 °C

$Q_{water} = m \times cp \times (T_w- T_g)$

= 104.675 W

An energy balance of steady state around the water basin can be written as,

$Q_{ew} + Q_{losses} = (\alpha'_w + \alpha'_b) I. A_s + Q_{water}$

Q_{losses} = 302.25 w

$(\alpha'_w + \alpha'_b) I. A_s$ = 615.712 W

i.e Q_{ew} = 910 W

$q_{ew} = m \times L = h_{ew} (T_w – T_g)$

m = 9.8 ml/min = 10 ml/min

Therefore, optimum flow rate of water m = 10 ml/min

The productivity of solar still is 600 ml/hr when heat losses are not considered, whereas productivity of solar still will be 297.75ml/hr when the losses are considered

4.2: Sample data for conventional and incline basin solar still

The sample data for average theoretical instantaneous efficiency and average experimental instantaneous efficiency for conventional and incline solar still based on table 4.1 and table 4.2

Table 4.5: Average theoretical instantaneous efficiency and average experimental instantaneous efficiency for conventional and incline solar still, for 2^{nd} April

Time	Solar Intensity (W/m^2)	Conventional Solar Still		Inclined Solar still	
		Theoretical Instantaneous Efficiency in %	Experimental Instantaneous Efficiency in %	Theoretical Instantaneous Efficiency in %	Experimental Instantaneous Efficiency in %
10	930	9.36	11.56	12.93	12.97
11	970	23.51	15.90	25.24	17.86
12	1078	25.56	15.94	25.88	21.38
13	1099	31.02	21.32	34.06	29.29
14	872	23.08	18.14	30.07	24.24
15	799	21.29	17.41	25.98	21.98
16	602	20.47	16.05	24.78	21.72
17	423	17.69	14.63	23.12	20.25

Table 4.5, shown all the average values of theoretical and experimental instantaneous efficiency for inclined basin solar still and conventional solar still. It can be observed that the theoretical and experimental instantaneous efficiency of both still are maximum at 1300.

Table 4.6: Average theoretical instantaneous efficiency and average experimental instantaneous efficiency for conventional and incline solar still, for 2^{nd} May

Time	Solar Intensity (W/m^2)	Conventional Solar Still		Inclined Solar still	
		Theoretical Instantaneous Efficiency in %	Experimental Instantaneous Efficiency in %	Theoretical Instantaneous Efficiency in %	Experimental Instantaneous Efficiency in %
10	930	7.98	12.88	14.92	17.88
11	970	25.63	18.69	27.63	20,28
12	1078	26.83	20.22	27.72	24.93
13	1099	28.28	23.62	35.67	32.97
14	872	25.26	21.98	33.98	27.83
15	799	22.93	19.67	26.53	25.27
16	602	21.56	19.14	25.66	24.68
17	423	18.22	15.22	24.12	24.12

Table 4.6, shown all the average values of theoretical and experimental instantaneous efficiency for inclined basin solar still and conventional solar still. It can be observed that the theoretical and experimental instantaneous efficiency of both still are maximum.

5 RESULTS AND DISCUSSION

The experimental investigation is carried out in month of March and April. The experimentation is conducted from 1000 hrs to 1700 hrs. In these experiment, the performance of inclined basin solar still have been investigated and compared with conventional basin solar still. The results are discussed,

5.1: Experimental results

The experimental results are discussed in the subsequent text.

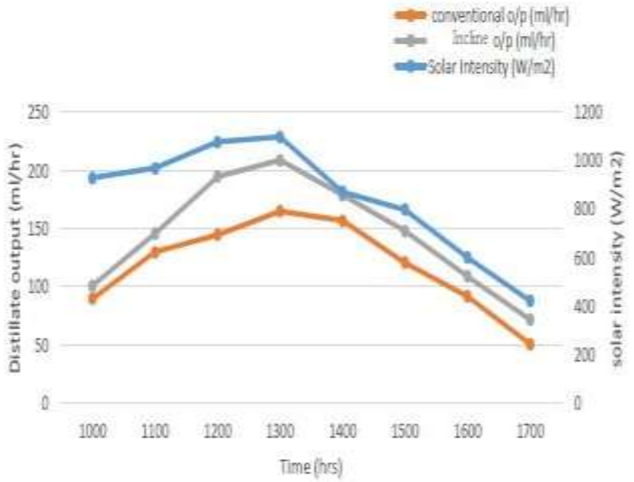

Figure 5.1: Distillate output of conventional and Incline solar still at a particular radiations intensity and time of the day, For 2nd April.

The variation in distillate output of conventional solar still and inclined basin solar still with respect to time is shown in fig. 5.1. It can be observed that the distillate output of solar still and conventional solar still have highest output is 209 ml/hr and 165 ml/hr respectively at 1300 hr.

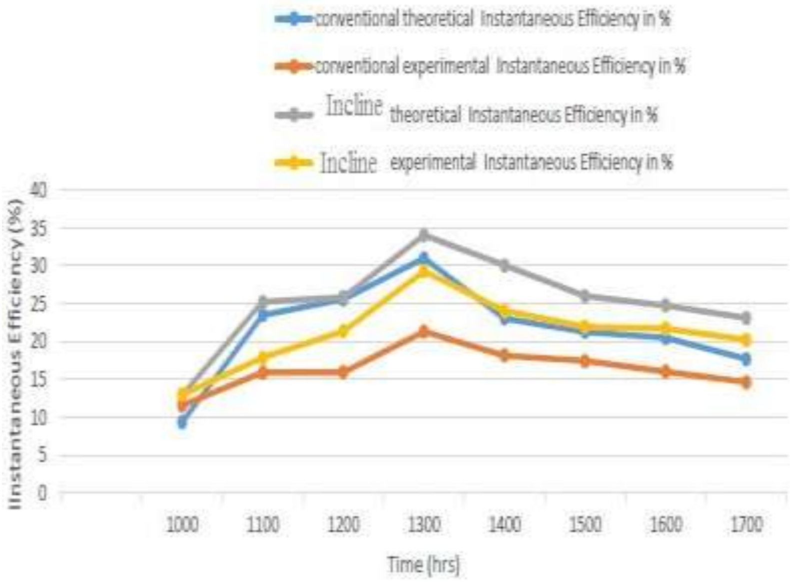

Figure 5.2: Instantaneous experimental and theoretical efficiency of conventional and incline solar still, For 2nd April.

The variation in instantaneous experimental and theoretical efficiency of conventional solar still and inclined basin solar still with respect to time is shown in fig. 5.2. It can be observed that the Instantaneous experimental and theoretical efficiency of incline solar still and conventional solar still are highest at 1300 hr. The highest experimental efficiency for incline and conventional solar still is 29.29% and 21.32 % respectively

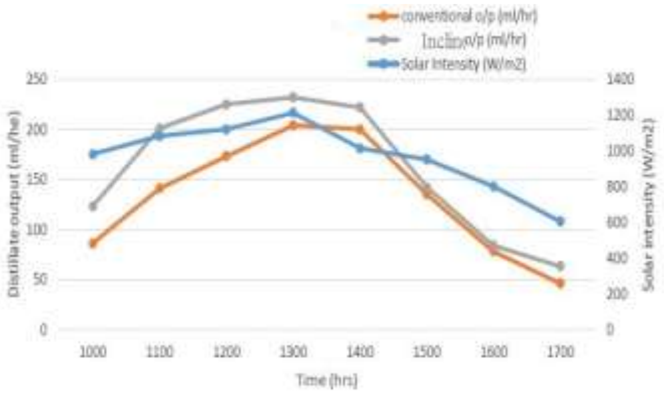

Figure 5.3: Distillate output of conventional and Incline solar still at a particularradiations intensity and time of the day, for 2nd May.

The variation in distillate output of conventional solar still and inclined basin solar still with respect to time is shown in fig. 5.3. It can be observed that the distillate output of incline solar still and conventional solar still have highest output is 232 ml/hr and 204 ml/hr respectively at 1300 hr.

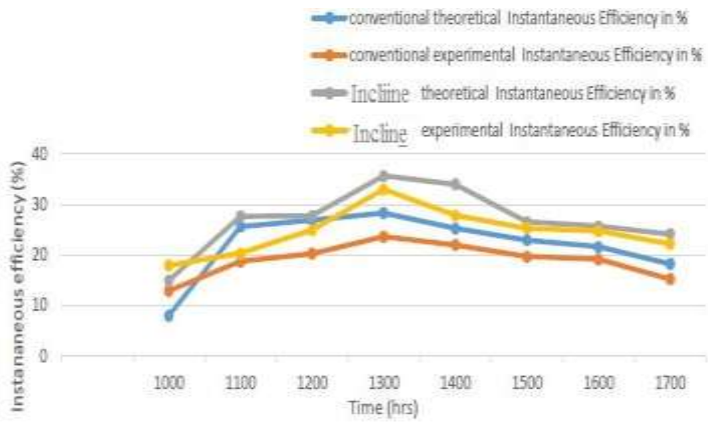

Figure 5.4: Instantaneous experimental and theoretical efficiency of conventional and incline solar still, For 2^{nd} May.

The variation in instantaneous experimental and theoretical efficiency of conventional solar still and inclined basin solar still with respect to time is shown in fig. 5.4. It can be observed that the Instantaneous experimental and theoretical efficiency of solar still and conventional solar still are highest at 1300 hr. The highest experimental efficiency for incline and conventional solar still is 32.97% and 23.62 % respectively

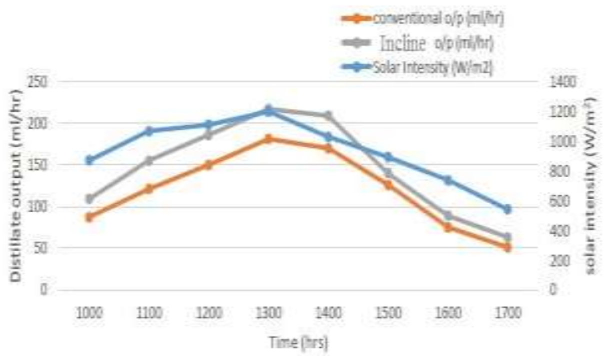

Figure 5.5: Average distillate output of conventional and Incline solar still at a particular radiations intensity and time of the day.

The variation in average distillate output of conventional solar still and inclined basin solar still with respect to time is shown in fig. 5.5. It can be observed that the average distillate output of incline solar still and conventional solar still have highest output is 217ml/hr and 181 ml/hr respectively at 1300 hr.

6 CONCLUSION FUTURE SCOPE

6.1 Conclusion

In the current work, the evaporation rate is enhanced by basin modifications. An inclined basin solar still is fabricated. Thus the basin is heated by circulation of hot water and direct radiation both. The raw water is allowed to flow over the basin from the top. Thus in all, the evaporation rate of solar still improved. The experimental study is carried out at Chandrapur during the month of April and May.

Based on the experimental and simulation studies following conclusion can be drawn,

1. Based on the average value of productivity recorded during experimentation, for the conventional solar still the productivity was around 1002 ml/day and for modified 1205ml/day.

2. For the conventional still instantaneous thermal efficiency was 48.43% and for modified still 62.01%.

6.2 Future scope

1) Use of various glass cooling arrangements, additional condenser, selective coatings for the inclined basin solar still are recommended.

2) Solar still arrangement for maintaining low water feed can be used for better productivity

3) Additional mirror like vertical external or vertical inclined mirror can be used.

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