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Experimental Investigation & Comparison of Internal Heat Transfer coefficients of Single Slope Conventional & Hybrid Solar Stills

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INTRODUCTION

- Potable water is the most essential component for sustaining life.

- Accessibility of fresh water is declining from the natural resources due to :

    water pollution

    receding level of underground water all over the world

- In this study, a comparison is been made between the Dunkle's model and Tiwari model, for the calculation of heat transfer coefficients for both hybrid and conventional modes of solar still.

Solar distillation

- A thermal desalination method where solar energy is used to distill fresh water from saline and brackish water.

- It is an easy, small-scale and cost effective technique

- Distilled water can be used for:
  - ➢ routine domestic applications (battery of invertors, automobiles)
  - ➢ Industries and workshops
  - ➢ Dispensaries and hospitals for sterilization purposes

Solar still performance

- Performance of the still basically depends on the amount of heat transfer between solar still and incoming solar radiations.

- Calculation of heat coefficients is also significant in the determination of characteristic equation, required to be solve for complete performance analysis of the single slope solar stills in both conventional and hybrid mode.

- A comparative analysis between the output yield of conventional and hybrid single slope solar stills is also done in the study at different water depths.

Experimental setup

- The area of each solar still is 1 m^2 (length = 1 m, width = 1 m), facing towards the south(to receive the maximum possible solar radiation)

- The body of both solar stills is made of fiber reinforced plastic (FRP) 5 mm thick. The toughen glass is used as a condensing cover (3 mm thick)

- The bottom surface of the solar still was painted black for greater absorptive capacity.

Experimental setup

The inclination angle for both the solar stills was set on 23^o as latitude (23°16' N, 77°36' E) of the Bhopal (India).

Various parameters measured during experiments were:

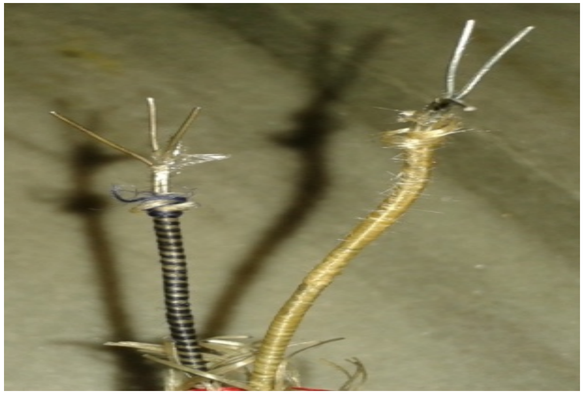
- Water temperature
- Inner / outer glass temperature
- Solar Distillate output
- Total solar radiation on the glass cover and on the collector
- Ambient temperature
- Wind velocity
- Relative humidity

Experimental Setup

Measuring instruments

- Solar power meter (Model no. TM 206) for measuring solar radiation.

- Thermocouple (Aluminium-Chromium) for measuring temperature of water surface and the inner-outer surface of the glass cover.



Measuring instruments

- **Digital anemometer for wind speed measurment**

- **Hygrometer for measuring relative humidity and ambient temperature**

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Thermal Models

- Different thermal models are considered for evaluation of thermal performance of solar still, mainly considered are :

  1.Dunkle's Relation

  2. Kumar and Tiwari model (KTM)

- In this study a comparative analysis is done between:

  - Two different models for thermal analysis
  - Evaporative and convective heat loss coefficients calculated by both methods
  - Thermal efficiency of hybrid & conventional mode of solar still operation

Dunkle's Relation

- ***Convective heat transfer*** **:**

$$h_{cw} = 0.884\left[T_w - T_{ci} + \frac{(P_w - P_{ci})(T_w + 273)}{268.9 \times 10^3 - P_w}\right]^{\frac{1}{3}}$$

Where ,

$$P_w = exp\left[25.317 - \left(\frac{5144}{273 + T_w}\right)\right]$$

- ***Evaporative heat transfer:***

$$h_{ew} = 0.016273 \times h_{cw} \times \left[\frac{P_w - P_{ci}}{T_w - T_{ci}}\right]$$

Where,

$$P_{ci} = exp\left[25.317 - \left(\frac{5144}{273 + T_{ci}}\right)\right]$$

Kumar and Tiwari model (KTM)

- **KTM is based on regression analysis methodology for evaluation of constants C & n in the expressions:**

$$\dot{m}_w = 0.0163 \times (P_w - P_{ci}) \times \left(\frac{k}{d}\right) \times \left(\frac{3600}{L}\right) \times C(R_a)^n$$

$$\dot{m}_w = R.C(R_a)^n$$

Putting values of Ra and applying regression methodology:

$$R = 0.0163\,(P_w - P_{ci})\left(\frac{k}{d}\right)\left(\frac{3600}{L}\right)$$

$$Y = a.x^b \qquad h_{cw} = \left(\frac{k}{d}\right) C.(R_a)^n$$

On solving finally: N = b & C = exp(a)

Thermal efficiency of solar still

- The thermal efficiency of still can be defined as the ratio of the amount of thermal energy utilized to get a certain amount of distilled water to the incident solar energy within a given time interval.
- **Conventional solar still:**

$$\eta_{conventional} = \frac{\sum m_w \times L}{A_s \int I(t)dt} \times 100$$

- **Hybrid solar still:**

$$\eta_{hybrid} = \frac{\sum m_w \times L}{[A_s \int I(t)dt + nA_c \int I(t)dt]} \times 100$$

Results And Discussion

- In this study, a comparative analysis of thermal performance of solar still in both hybrid & conventional mode of operation is been performed at different water depths (5,10,15 cm).

- Whole study is performed by conducting three days experiment with hourly readings in clear day sky condition by ensuring that the ratio of daily diffused to daily global radiation comes out to be less than or equal to 0.25, i.e. the sunshine hour is more or equal to 9 hours daily during experimentation.

Data table for Depth of 5 cm

Time	Radiations (W/m^2)		Ta (°C)	Wind Vel. (m/s)	R_h (%)	Hybrid still (°C)			Yield (ml)	Conventional still (°C)			Yield (ml)
(h)	I_g	I_d		v		T_w	T_e	T_g	m	T_w	T_e	T_g	m
09:00	520.10	83.31	36	0.21	40.9	24	28	30	0	25	28	28	0
10:00	586.71	110.22	36.2	1.32	42.4	28	32	35	4	27	33	35	1.8
11:00	712.53	95.87	40.8	0.31	31.4	32	34	38	7	31	33	37	4
12:00	738.44	92.28	39.8	0.25	30.1	35	36	38	7.2	35	35	39	5
13:00	709.76	107.53	39.3	0.56	28.1	38	44	37	9.2	31	42	36	5.5
14:00	681.08	122.78	40.9	0.14	25.2	36	51	38	24	36	45	38	14.5
15:00	336.92	75.24	38.4	0.27	28.1	42	45	36	25	39	43	35	14
16:00	286.04	70.75	39.7	0.35	26	40	46	35	19	37	45	35	12
17:00	171.32	64.47	35.1	0.15	29.5	38	36	33	24	36	34	34	21

Data table for Depth of 10 cm

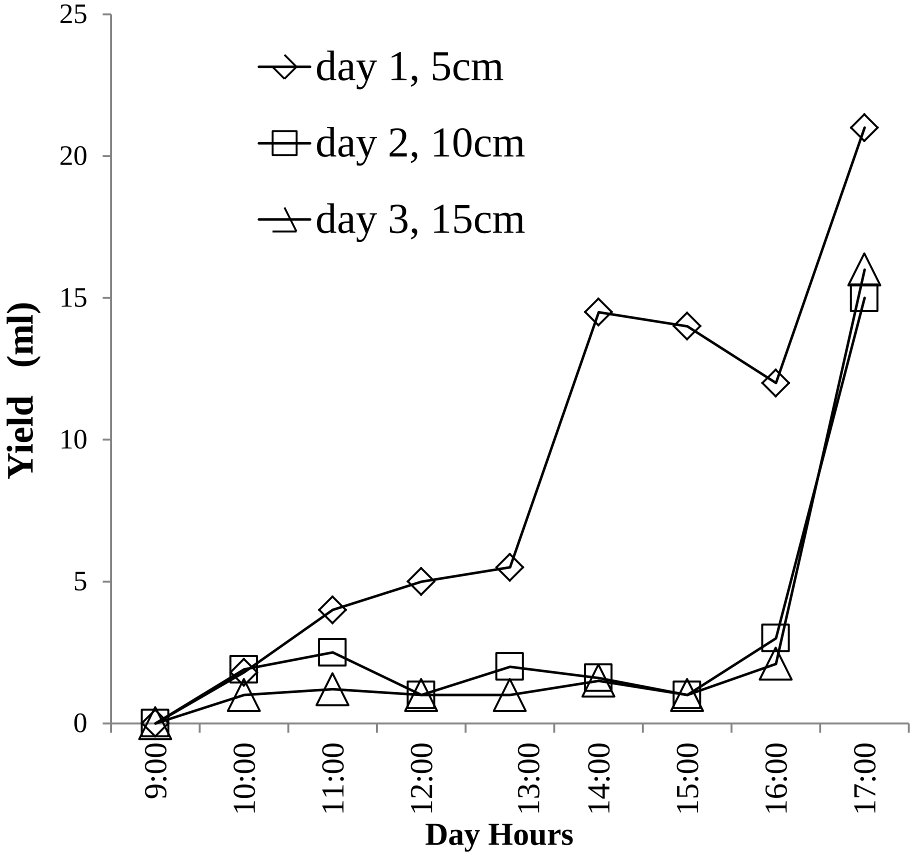
Time	Radiations (W/m^2)		Amb Temp (˚C)	Wind Velocity (m/s)	R_h (%)	Hybrid still (˚C)			Yield (ml)	Conventional still (˚C)			Yield (ml)
(h)	I_g	I_d	Ta	v		T_w	T_e	T_g	m	T_w	T_e	T_g	m
09:00	521.95	79.72	40.8	0.32	27.2	30	28	29	0	22	25	29	0
10:00	550.45	53.71	38.4	1.73	27.9	37	32	28	3	23	25	28	1.9
11:00	847.61	120.99	37.6	0.31	27.6	36	34	34	3.2	29	32	25	2.5
12:00	860.68	90.12	40.6	0.28	21.7	36	36	36	2	31	35	20	1
13:00	798.76	85.11	46.1	0.58	17.7	69	44	38	4	32	40	28	2
14:00	736.77	92.28	38	0.14	30.7	45	48	39	3	33	44	29	1.6
15:00	512.70	82.41	43.1	0.17	17.3	45	50	37	3.3	35	47	30	1
16:00	289.74	68.96	40.4	0.24	21.5	39	45	34	5	36	40	33	3
17:00	103.53	20.12	37.9	0.35	22	38	35	33	20	37	35	28	15

Data table for Depth of 15 cm

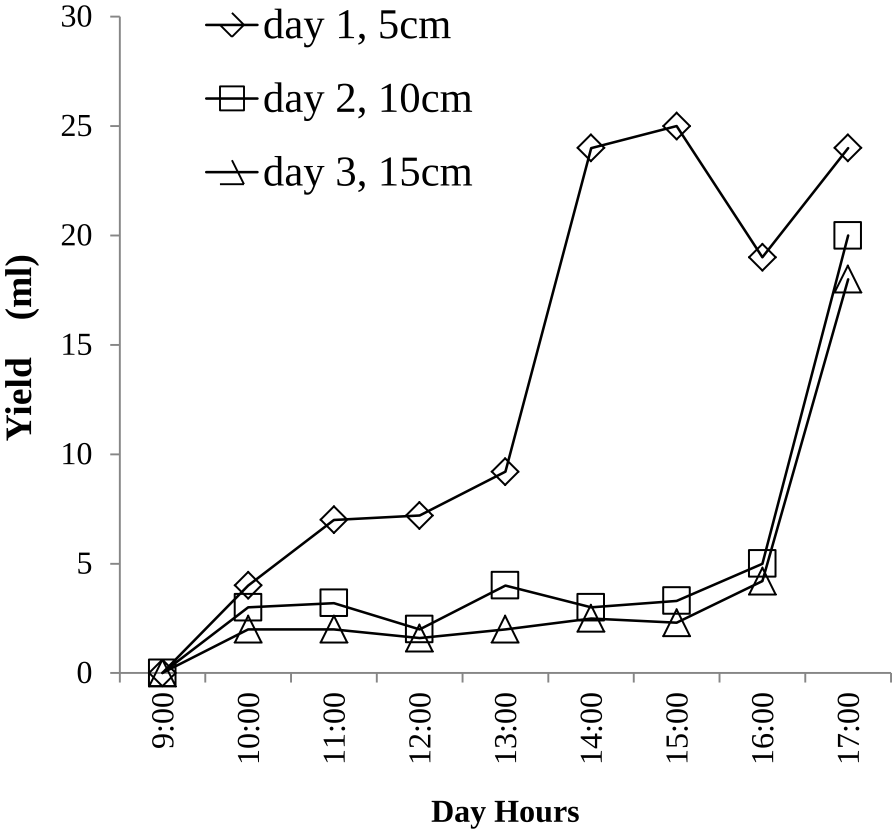
Time (h)	Radiations (W/m^2)		Ta (°C)	Wind Velocity (m/s)	R_h (%)	Hybrid still (°C)			Yield (ml)	Conventional still (°C)			Yield (ml)
	I_g	I_d		v		T_w	T_e	T_g	m	T_w	T_e	T_g	m
09:00	552.48	70.75	36.6	1.37	26.8	30	28	29	0	22	25	29	0
10:00	634.82	56.40	40.1	0.35	22.7	34	29	33	2	25	30	34	1
11:00	748.61	74.34	35.2	0.91	28	35	32	38	2	25	31	37	1.2
12:00	830.03	78.83	36.3	0.96	29.4	36	35	38	1.6	28	31	38	1
13:00	719.12	91.38	34.6	0.8	29.1	38	39	36	2	32	37	36	1
14:00	694.03	77.03	35.5	0.76	30	44	48	39	2.5	33	44	38	1.5
15:00	553.41	65.37	36.5	0.23	28.4	45	48	36	2.3	35	45	37	1
16:00	358.20	47.43	36.6	0.12	24.9	44	48	33	4.2	35	36	31	2.1
17:00	193.52	50.12	35.3	0.21	28.4	31	35	32	18	30	35	32	16

Effect of the water depth on output yield of solar stills

- As the water depth increases from 5cm to 15 cm , the solar still productivity decreases both in conventional & hybrid mode.

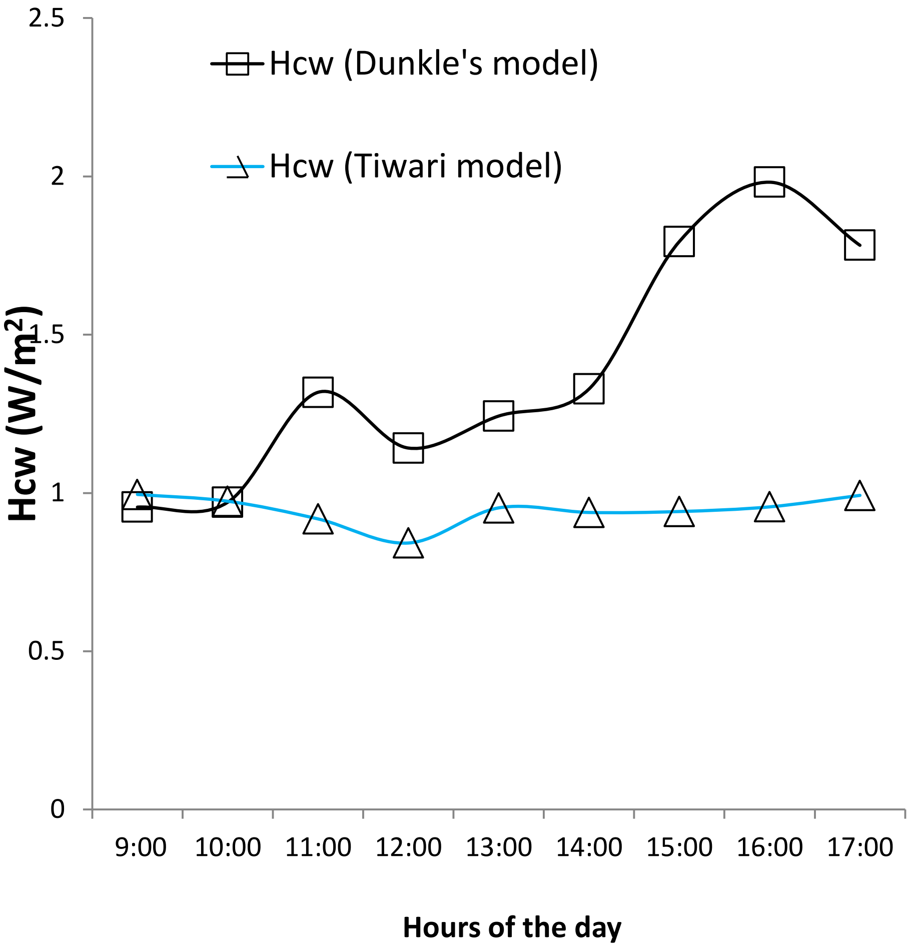


Conventional Still

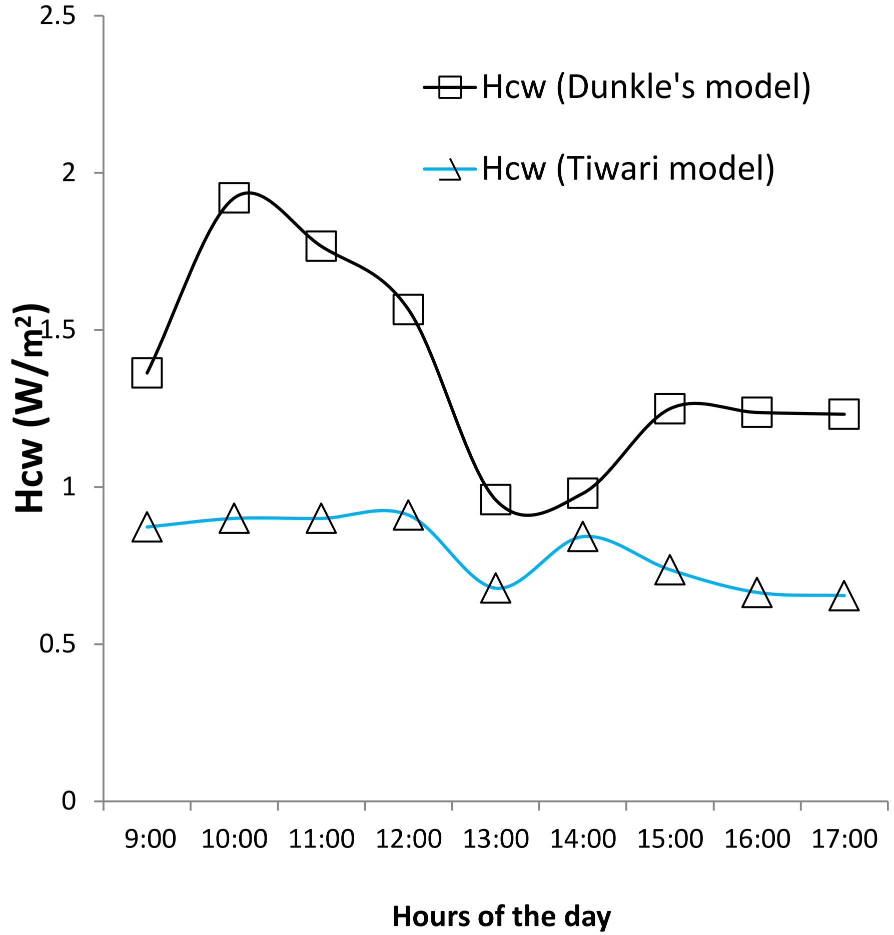


Hybrid Still

Convective heat transfer coefficient

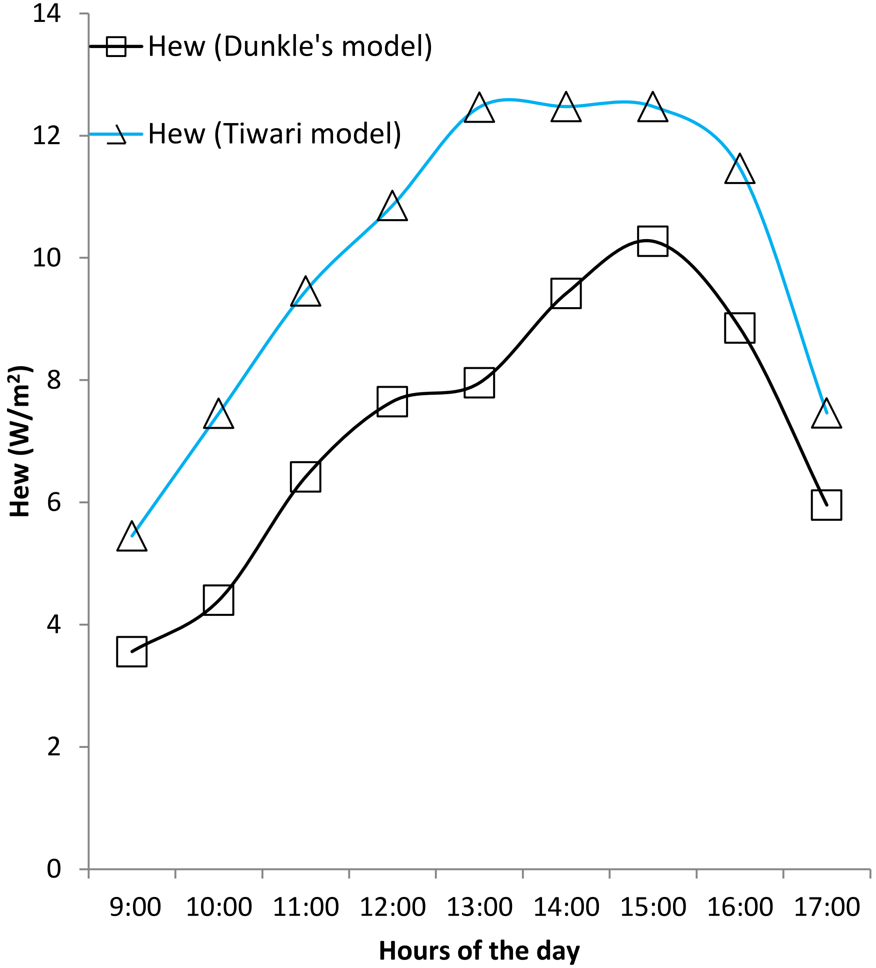


Hybrid Solar Still

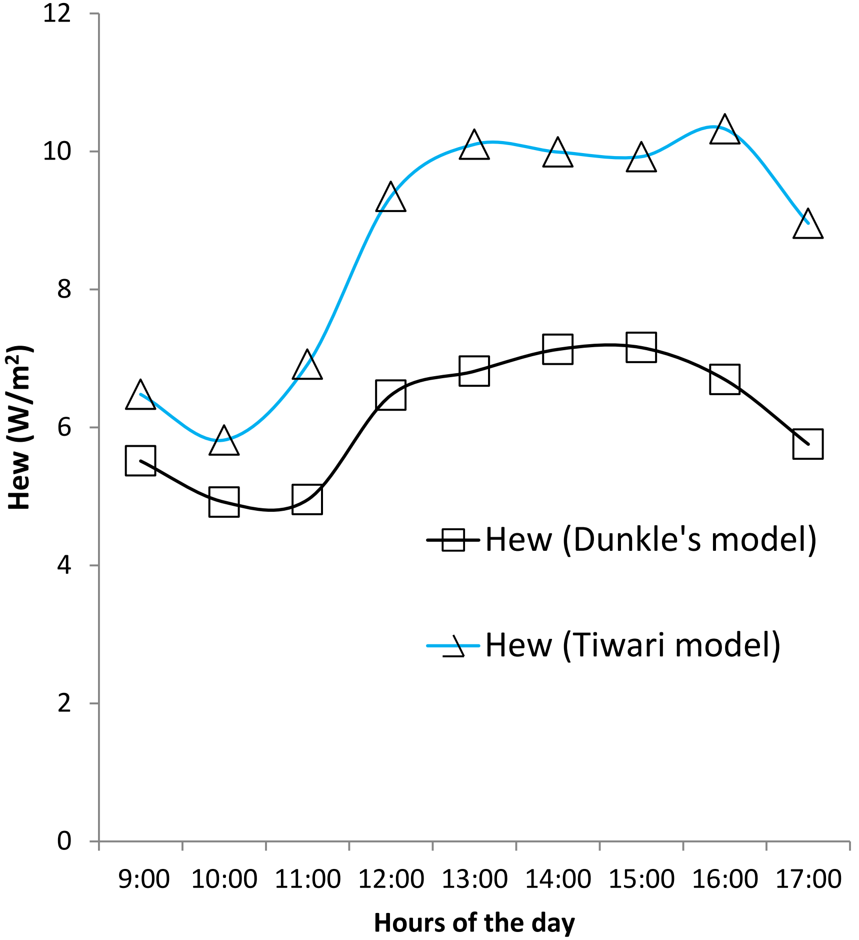


Conventional Solar Still

Evaporative heat transfer coefficient

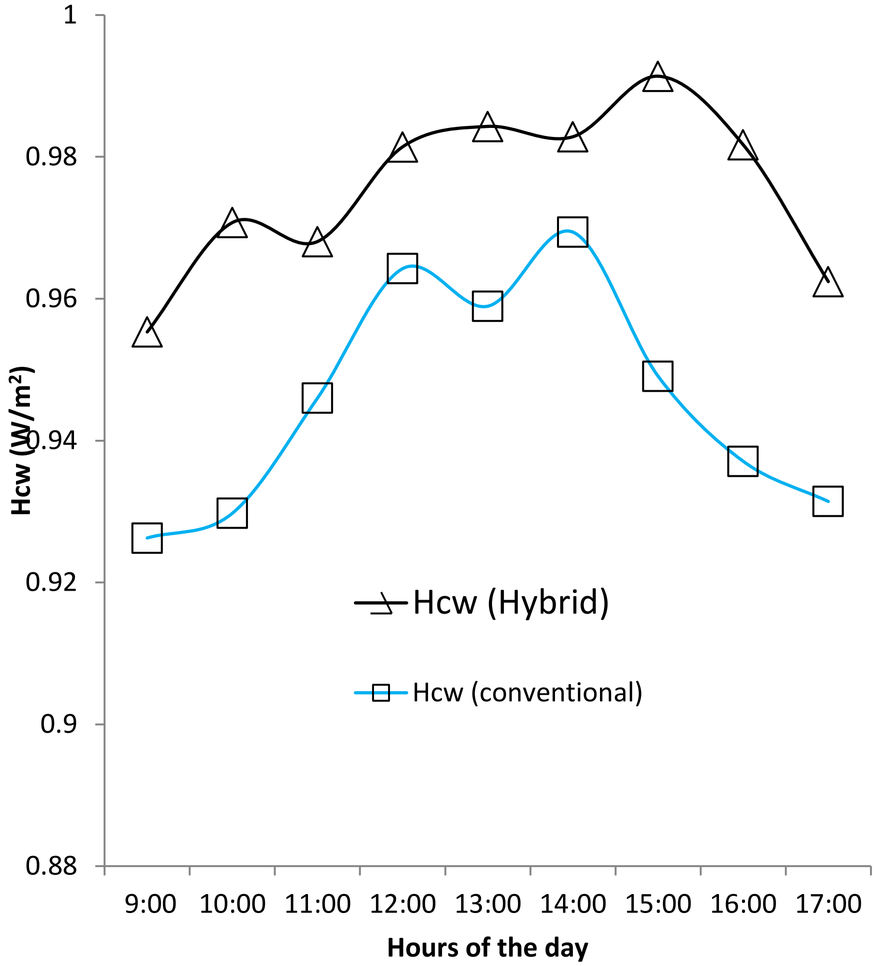


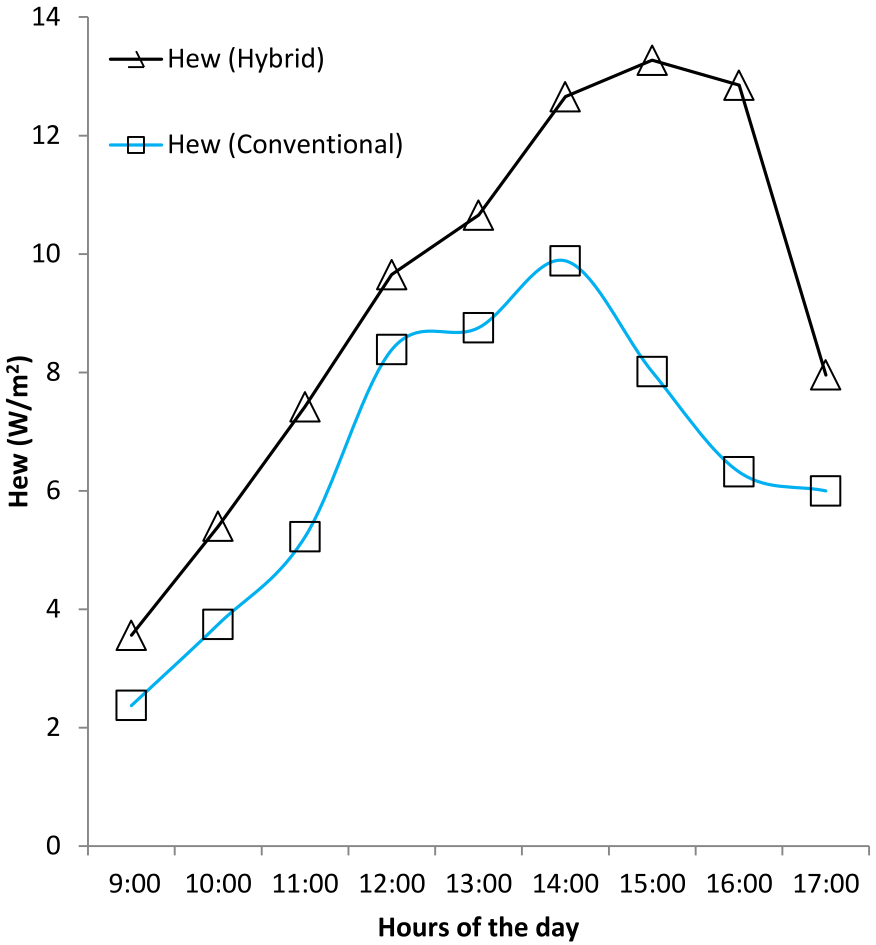
Hybrid Solar Still



Conventional Solar Still

Dunkle's model heat transfer coefficients

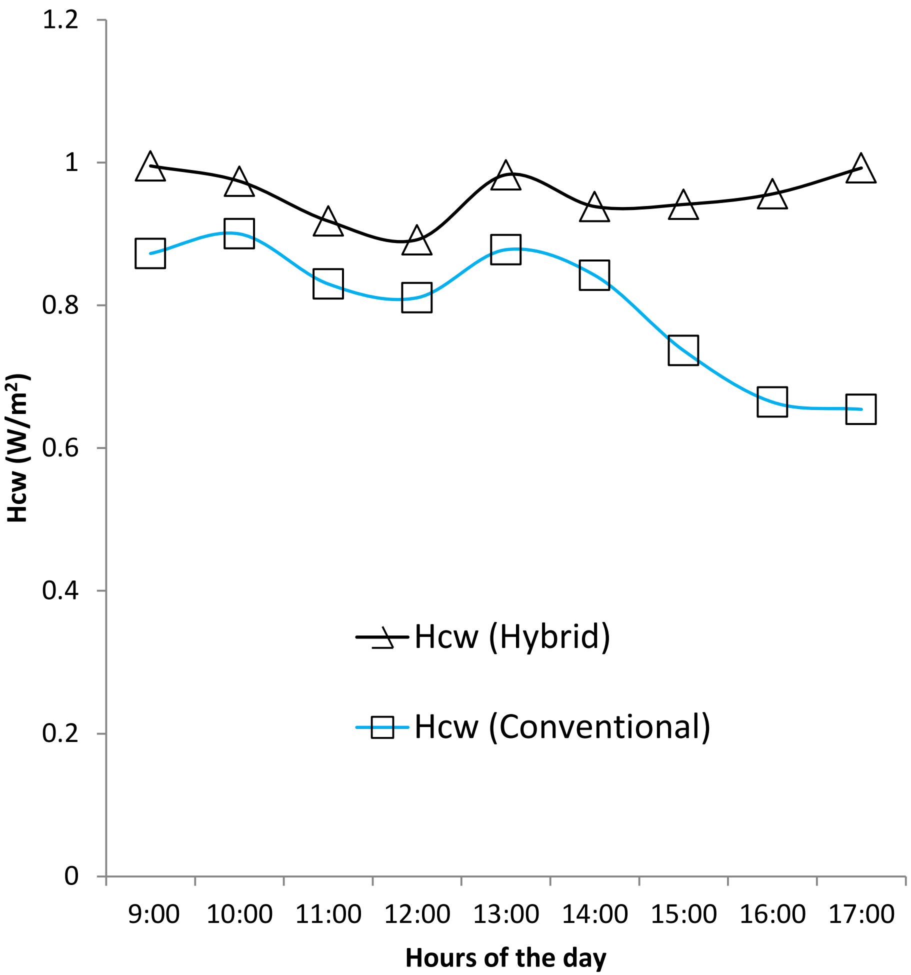


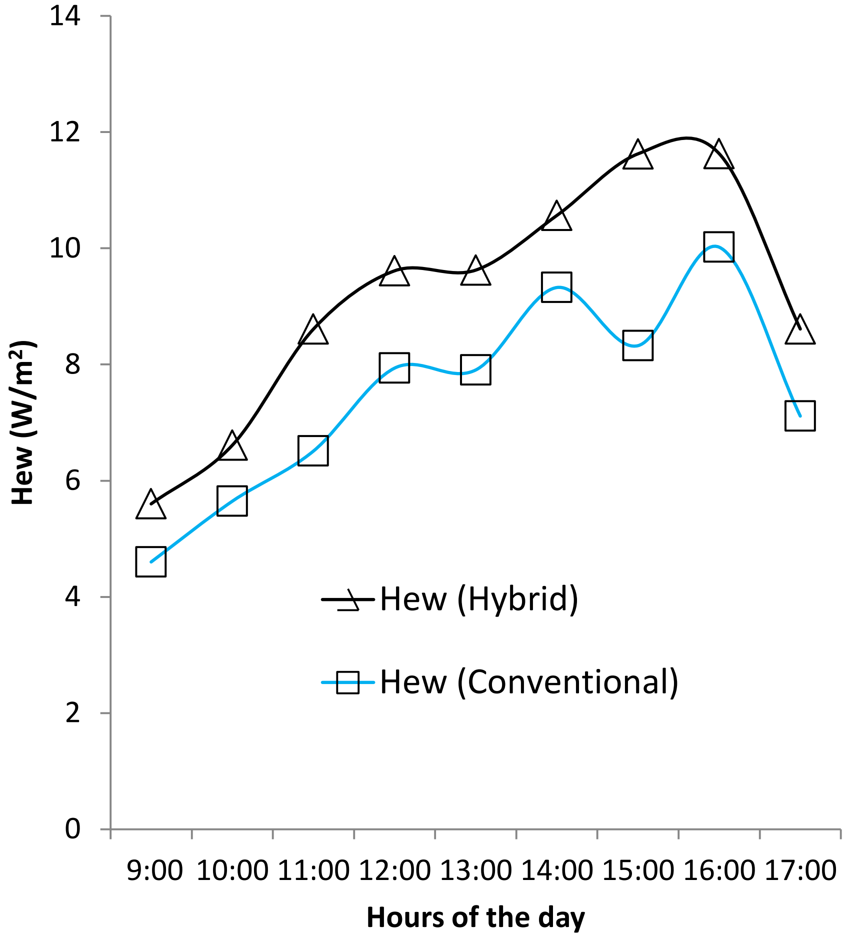


Hybrid Solar Still

Conventional Solar Still

Tiwari model heat transfer coefficients

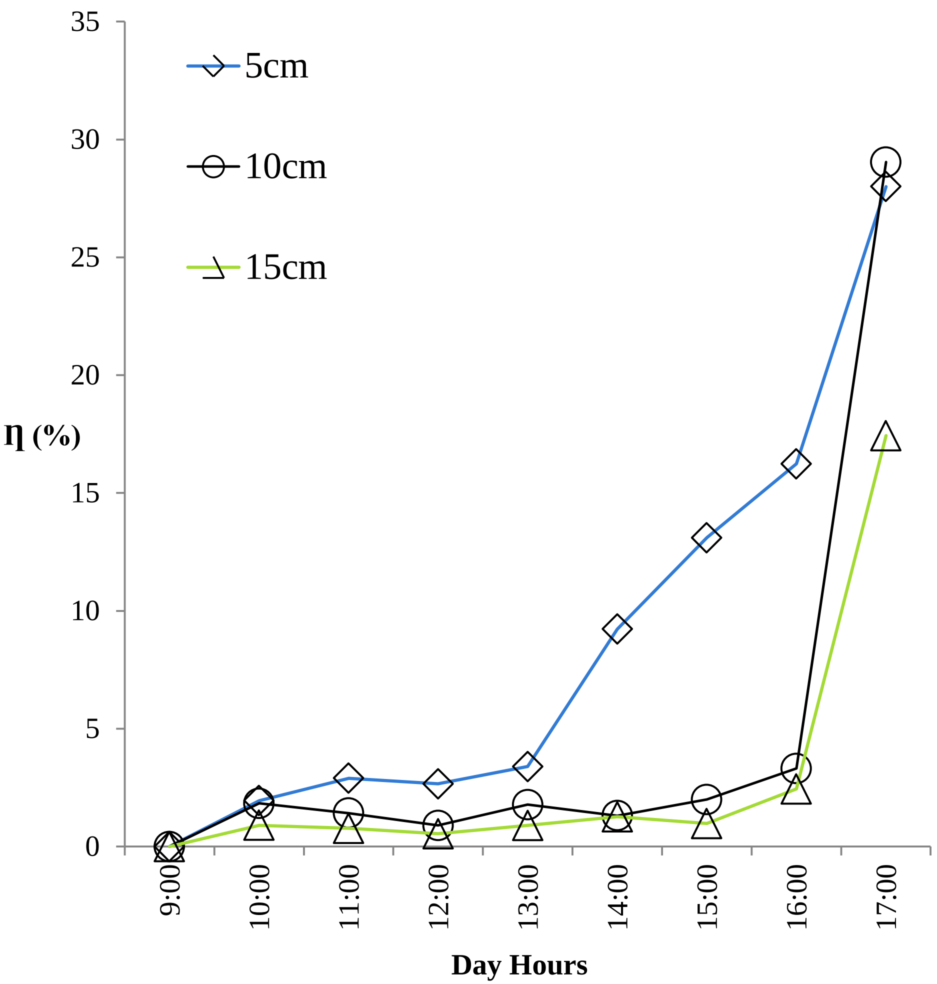




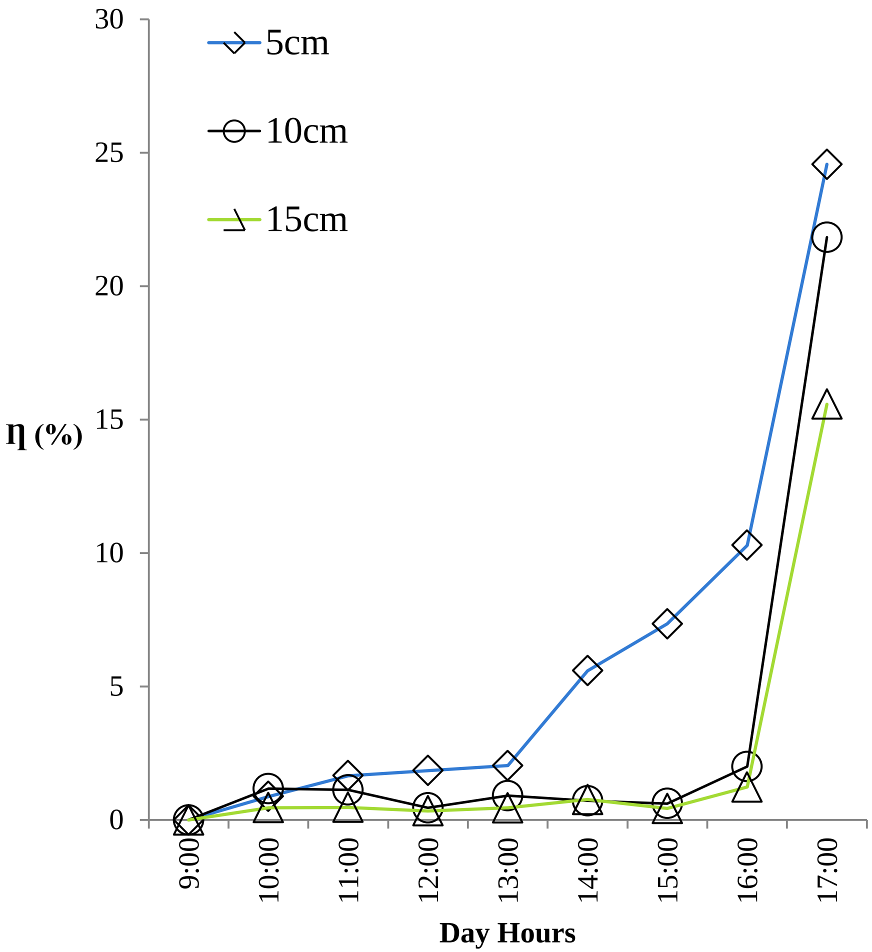
Hybrid Solar Still

Conventional Solar Still

Thermal efficiency



Hybrid Solar Still



Conventional Solar Still

Conclusions

- The lowest basin water depth (5 cm) is the best for greater yields among different water depths of 10 cm and 15 cm. However, it should be 5 cm for maximum yield at a 23° inclination with minimum heat storage from the operational point of view.
- The hourly thermal efficiency of hybrid still is more than conventional solar still by 10% to 15%. It was found that the thermal efficiency is maximum for a water depth of 5 cm.
- It is also evident from the above study that for the lower water depth (5–10 cm) Dunkle's model can be used for determination of internal heat transfer coefficients.

Continue……

- Also with the increase in water depth from 5 cm to 15 cm there is a marginal variation in the values of convective and evaporative heat transfer coefficients. The fluctuations in the value of h_{cw} as observed for lower water depth reduces with the increase in water depth.

- It can be concluded also that the ambient conditions (i.e. wind and temperature) have a direct effect on the still productivity. Also it is evident from the result that as the depth of water decreases the daily still output is increased.

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THANKS