Experimental Evaluation and Theoretical Analysis of the Long Stills Covered with the GI, Cu and Al Sheets

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Electrical energy is mostly converted from thermal energy drown from the thermal or nuclear power plant for large scale and Diesel generator (DG) sets are used as a backup device. In these, we mostly used water as a working substance and cooling agent for maintaining the operating temperature of the devices. Experimental and theoretical evaluation of three identical reduced scales long still prototypes covered with the different metallic sheets (viz. GI, Cu, and Al) are reported in this manuscript. Hot wastewater at 70±1 ºC is fed to the distiller unit as a discharge of the thermal unit is ranges between 65 to 75 ºC. The theoretical result obtained from the regression analysis gives good agreement with the result obtained from the experimentation. Long still covered with the Cu sheet material is gives better performance as compared with the others (viz. 55.03 and 34.69% higher than the GI and Al sheet cover). It has been observed that the still covered with the Cu sheet gives better distillate yield as compared with the still covered with the Al or GI sheet material.

Keywords: *Metallic sheet cover, Long still, Desalination, Wastewater utilization*

1. INTRODUCTION

The demand for potable water is increasing day by day due to the depletion of potable water mainly due to the rapid enhancement in the population and industrialization. As most of the industries are utilizing water as a cooling agent for the Internal combustion engines. A conceptual model for the performance of a solar still in two different modes(viz. (i) hot wastewater from the thermal power plant to solar still at a constant flow rate and (ii) Hot wastewater obtained from thermal power plant fed once in a day to the solar still) have been reported by Sodha et al.[1]. Mishra et al. [2] have reported experimental evaluation of long still covered with the glass material for utilization of hot wastewater will pave the way for utilization of this waste energy. Sharma et al. [3] have reported the effect of different flow rates on the performance of long still covered with the GI sheet. The effect of the hot wastewater flow through the still in the hot day has been reported by Tiwari et al. [4]. Single basin solar still integrated with the earth have been reported by Sodha et al. [5]. Dumka and Mishra [6,7] have reported Experimental and theoretical evaluation and the way for utilization of ground energy for the desalination using single slope solar still. Elminshawy et al. [8]have utilized low-grade energy for the desalination of water. Fathi et al. [9] have reported enhancement in an overall efficiency of a nuclear power plant by utilization of waste heat. The relation between performance and depth of the water within the solar still has been reported by Tiwari and Tiwari[10] and the influence of water depth on the heat and mass transfer has reported by Tripathi and Tiwari [11]. The effect of different salt concentrations on the performance of the solar still has been reported by Dumka et al. [12]. Experimental evaluation of hybrid solar still integrated with the air compressor has been reported by Hidouri et al. [13]. Exergo-enviro-economic performance evaluation of a single slope distiller unit has been reported by Joshi and Tiwari [14]. Different geometry new absorber configuration (flat, grooved, and fin-shaped absorbers) of single basin solar still for partial utilization of hot wastewater has tested and reported by Hansen and Murugavel [15].

Dumka & Mishra [16] and Dumka et al. [17] have reported the use of ultrasonic fogger without and with cotton cloth tent to enhance the distillate output of solar still. They have reported an increase of 33.26 and 53.12% in the distillate output of modified still in comparison to CSS. Chauhan et al. [18] have reported the use of ANN trained with the LM algorithm to predict the thermo-physical properties of moist air between the condensing and evaporating surface of a still. Dubey and Mishra [19] have theoretically and experimentally examined the impact of glass cover angle on the performance of single basin double slope solar stills. For this sake, they have used 3 cover angles viz. 15, 30, and 45°. They have reported that the maximum yield is obtained from still with 15° inclination with a contribution of 48 and 52% form west and east sides, respectively. Gojak et al. [20] have reported a stepwise simulation of a water heating system that works on solar energy. An extensive review of different solar concentrator designs has been reported by Stojicevic et al. [21].

Detailed reviews on the performance of single slope solar stills have been reported by Sharma et al. [22]. A water augmentation technique [23], review on pyramidal still [24], geometric and fin design, and its deployment

Received: April 2020, Accepted: July 2020
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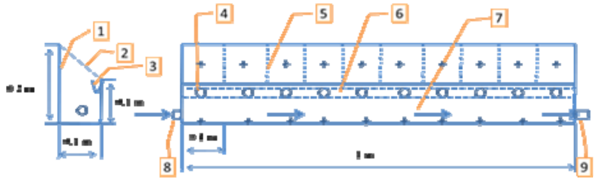
doi:10.5937/fme2004931S

for enhancing the energy storage capacity [25] and application of nano energy [26] have been reported by the various research groups. A detailed review of different glass cover cooling techniques has been reported by Omara et al. [27]. A comprehensive study on PCM material used in solar still has been reported by Kabeel et al. [28]. A theoretical and empirical study of heat and mass transfer inside a basin type solar still has been reported by Madhlopa [29]. Utilization of water as a cooling agent for maintaining the operating temperature of the domestic and industrial thermal equipment is a normal practice worldwide. Cooling water is used to excavate more than 40% of generated heat energy and inject into the ambient with the help of a radiator, Chiller unit, or cooling towers. The utilization of this energy may boost the overall efficiency of thermal units.

Experimental (in control environment) and theoretical evaluation of the reduced scale model after 8-hour experimentation at a one-hour interval is recorded and reported. The proposed model can be utilized in thermal power-based industries; thermal power plants and different capacity of diesel greater units were water is used as a cooling agent in an enlarged scale between the discharge and cooling unit for gating distillate yield by utilizing waste energy. The application of the proposed device will enhance the overall efficiency of the plant or unit.

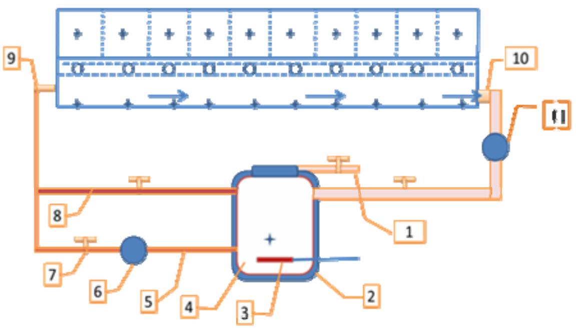
2. EXPERIMENTAL SETUP

The schematic agreement of the experimental setup and the actual photograph is shown in Fig. 1(a), (b), and 2 respectively.



1. Basin of long still, 2.*Al/Cu/GI* sheet covers of 4 mm thick plate 3&6. Condensate gutter,4. Drain to collect distillate yields from ten equidistance locations, 5. Partition of the *Al/Cu/GI* sheet, 7. The flow direction of hot wastewater 8. Inlet of the long still, 9. An outlet of long still, + Thermocouples

Figure 1(a). Schematic representation of the long still



1. Inlet to the storage tank, 2. Thermal insulation of the tank, 3. Electrical water heater 4. Water 5. Feed pipeline to the electric pump, 6. Water pump 7. Control valve, 8. pipeline for the recirculation, 9. Feed pipeline to the long still, 10. Discharge pipeline of long still, 11. Hot water flow meter, + Thermocouples

Figure 1(b). Schematic arrangement of the experimental setup of a long still

Three identical stills with basin area (1m × 0.1m) of long are made with the help of Fiber reinforcement plastic (FRP) material. 10 K-Type thermocouples are deployed at equidistance within the basin area of each still for recoding the fed hot wastewater temperature along the length of the distiller unit during the experimentation. The top covers of the distiller units are made with the Cu, Al, and GI metallic sheets. The top cover of each still contains 10 K Type thermocouples at equidistance in each stills for recording condensing cover temperature behavior. Cover materials are sealed with the basin using epoxy resin to ensure it leak proof. Inlet and outlet of the still as are made with the help of PVC pipe nipples as its bad conductor to heat. An insulated water heater tank with 50 *l* capacity was used for getting hot water which has fed to the distiller unit at 70 ±1°C with flow rate of 230 *l/h* from one end and discharges from the other end recirculated through the water heater with the help of a pump. The recirculating valve was used to regulate the flow rate of hot wastewater. All the experiments are carried out within the control environment of the laboratory at a temperature 22±1°C.

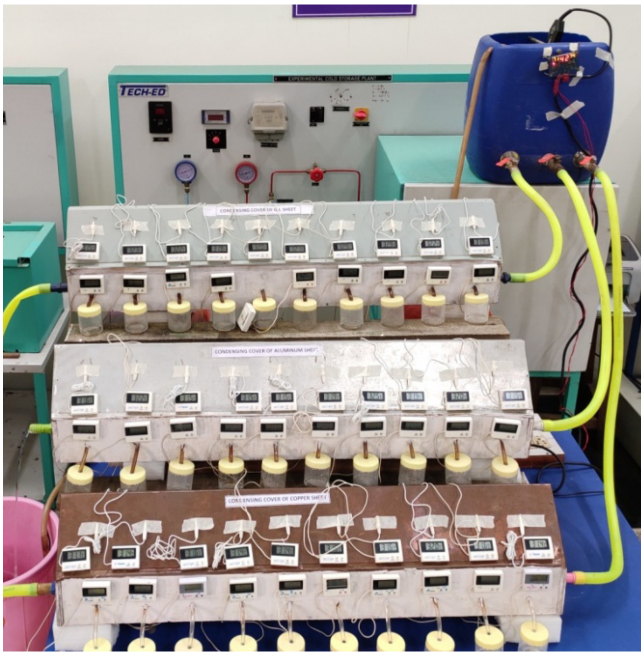


Figure 2. Actual photograph of the three identical experimental setup

Following data were recorded while the experimentation for the theoretical evaluation of the distillate output:

- Ten equidistance condensing cover & basin water and room temperatures.
- Distillate yield from all ten points.

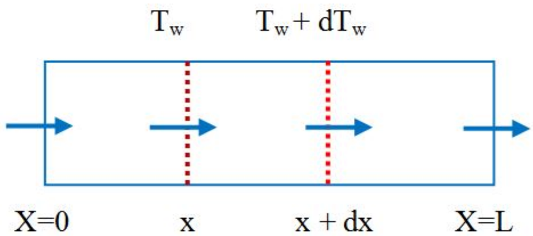


Figure 3(a) Cross-sectional view of flowing water through a single slope still

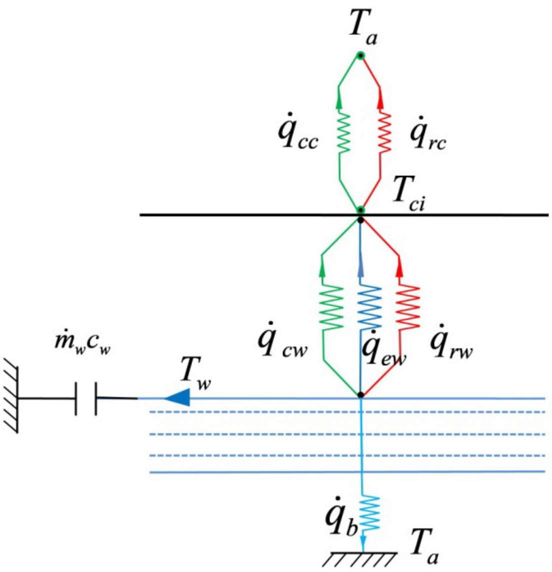


Figure 3(b) Thermal circuit of long still

3. THEORETICAL BACKGROUND

From a cross-sectional view of small flowing water through the single slope solar still at small elemental area and length L Fig. 3(a), thermal circuit diagram Fig. 3(b), and Following assumptions:

•Still is leak proof.

•Metallic cover heat capacity is neglected.

•The still is in steady-state.

•There are no side losses from still.

the energy balance equation for water and metallic cover one can get:

Water:

$$\dot{m}_w c_w \frac{dT_w}{dx} dx = -\left[\dot{q}_{ew} + \dot{q}_{cw} + \dot{q}_{rw}\right] bdx - \\ -U_b\left(T_w - T_a\right) bdx \tag{1}$$

Metallic covers:

$$\left[\dot{q}_{ew} + \dot{q}_{cw} + \dot{q}_{rw}\right] bdx = [\dot{q}_{cc} + \dot{q}_{rc}] dx \frac{b}{cos\theta} \tag{2}$$

where, evaporative convective and radiative heat transfer rates from water to condensing cover are:

$\dot{q}_{ew} = h_{ew}\left(T_w - T_{ci}\right)$; $\dot{q}_{cw} = h_{cw}\left(T_w - T_{ci}\right)$, and $\dot{q}_{rw} = h_{rw}\left(T_w - T_a\right)$

and, convective $(\dot{q}_{cc})$ and radiative $(\dot{q}_{rc})$ heat transfer rates from metallic covers of *Cu, GI,* and *Al* to the atmosphere here are collectively written as overall heat transfer rate $(\dot{q}_{1c})$, which can be calculated as follows:

$$[\dot{q}_{cc} + \dot{q}_{rc}] = \dot{q}_{1c} = h_{1c}\left(T_{ci} - T_a\right) \tag{3}$$

where, $h_{1c} = 5.7 + 3.8V$.

For the natural convection the *Nu* can be written as:

$$Nu = C\left(Gr.Pr\right)^n \tag{4}$$

Evaluation of *Pr* and *Gr*, using humid air physical properties relations are given by Tsilingiris [30] and theoretical model based on linear regression analysis proposed by Kumar and Tiwari which uses experimental yield to generate the values of *C* and *n* of a still is used. The relations of *C* and *n* from the model can be written as:

$$n = \frac{N\left(\sum x.y\right) - \left(\sum x\right).\left(\sum y\right)}{N\left(\sum x^2\right) - \left(\sum x\right)^2} \tag{5}$$

$$C = \exp\left(\frac{\sum y}{N} - n\frac{\sum x}{N}\right) \tag{6}$$

Convective heat transfer coefficient from water to condensing cover can be evaluated as:

$$h_{cw} = 0.884\left[T_w - T_{ci} + \frac{\left(P_w - P_{ci}\right)\left(T_w + 273\right)}{2.689\times10^5 - P_w}\right]^{1/3} \tag{7}$$

by knowing the value of h_{cw}, h_{ew} can be evaluated as:

$$h_{ew} = 0.016273.h_{cw}\cdot\left(\frac{P_w - P_{ci}}{T_w - T_{ci}}\right) \tag{8}$$

whereas radiative heat transfer rate from water to the inner condensing surface is calculated as [31,32]:

$$\dot{q}_{rw} = h_{rw}.F_{12}.\left[\left(T_w - T_{ci}\right)\right] \tag{9}$$

where,

$$h_r w = \varepsilon_{eff}.\sigma.[(T_w + 273.15)^2 + \\ +(T_{ci} + 273.15)^2].[T_w + T_{ci} + 546.2] \tag{10}$$

The total heat transfer rate from water to the inner condensing surface is given by:

$$\dot{q}_1 = \dot{q}_{cw} + \dot{q}_{ew} + \dot{q}_{rw} = \left(h_{cw} + h_{ew} + h_{rw}\right)\cdot \\ \cdot\left(T_w + T_{ci}\right) = h_{1w}\left(T_w + T_{ci}\right) \tag{11}$$

Distillate yield from the long still can be calculated as:

$$\dot{m}_{ew} = \frac{\dot{q}_{ew}\cdot A_s\cdot 3600}{L} = \frac{h_{ew}\cdot A_s\cdot\left(T_w - T_{ci}\right)\cdot 3600}{L} \tag{12}$$

Evaporative, convective, and radiative heat transfer fractions are evaluated as: $F_{ew} = \frac{\dot{q}_{ew}}{\dot{q}}$, $F_{cw} = \frac{\dot{q}_{cw}}{\dot{q}}$ and $F_{rw} = \frac{\dot{q}_{rw}}{\dot{q}}$ to predict the strength of individual mode of the heat transfer within the distiller unit.

4. RESULTS AND DISCUSSIONS

Variation in evaluated partial pressure at condensing covers of long stills covered with the *Cu, Al,* and *GI* sheet cover material and on the basin water surface from the entrance to exit is shown in Fig.4. Partial pressure on *Cu* condensing sheet cover has maintained its lead throughout the length of still in comparison with the other two stills, whereas, it goes on reducing throughout the length of the long stills. Partial pressure on the water surface also shows a reduction from the entrance to the exit in all three cases. Long still which covered with the *Cu* sheet material shows higher pressure difference (i.e. the pressure difference between water and condensing surface) as compared to the other two identical long distiller units. The higher gradient will lead to better performance and gives higher distillate output from the long still covered with the *Cu* Variation of heat transfer coefficient of evaporative, radiative and conductive heat transfer rate along the length of stills are shown in Fig.5.

sheet material.

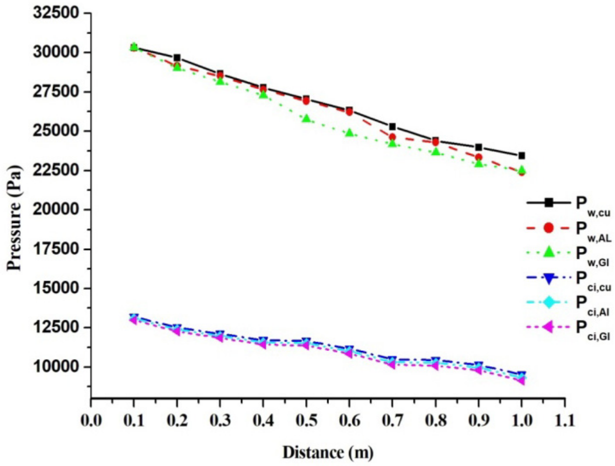


Figure 4: Variation of the partial pressure on the water surface and condensation surface of *Cu, Al,* and *GI* sheet cover material along the length of the still.

Evaporative mode of heat transfer shows dominance over the convective and radiative as coefficients for the evaporative heat transfer is higher as compared to the radiative and convective heat transfer rate at all the stages of long still along its length.

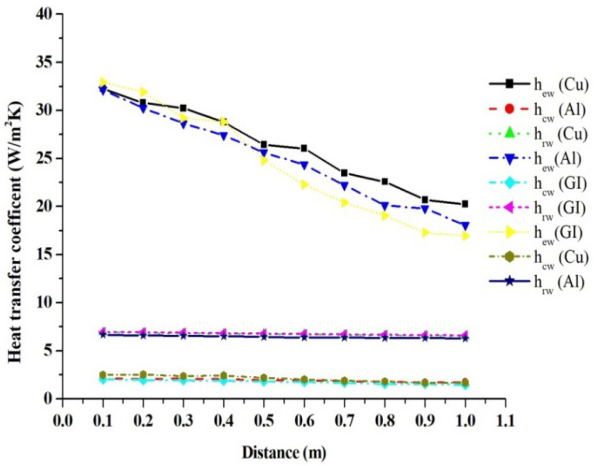


Figure 5: Variation in different modes of heat transfer coefficient as a function of time

The evaporative heat transfer coefficient of still covered with the *Cu* sheet has maintained its lead throughout the experimentation along the length of the still in comparison with the still covered with the *GI* and *Al* sheets. Variation of the influence of the different metallic covers is used as a condensing cover in long stills on the total heat transfer rate is shown in Fig.6. The total heat rate in all the cases decreases along the length of the long still. Long still covered with the *Cu* sheet maintains its lead throughout the experimentation in comparison with stills covered with the *Al* and *GI* sheet. Maximum and minimum values of heat transfer rates are 691.027, 751.16, & 1114.99 W/m^2 and 425.71, 518.03, 645.62 W/m^2 for the long still covered with the *GI, Al,* and *Cu* sheet respectively.

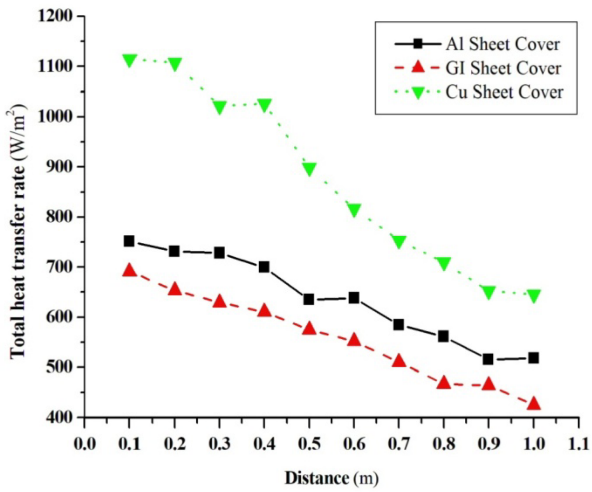


Figure 6: Variation of the total heat transfer rate of long stills with different metallic cover as a function of time.

Overall heat transfer rate at the entrance (0.1 m distance) of the long still having a condensing cover of *Cu* sheet is 61.25 and 48.43% higher than the still covered with the *GI* and *Al* sheets. At intermediate position long still covered with Cu sheet maintain its lead in terms of overall heat transfer rate by 56.35 and 41.49% with the long stills covered with the *GI* and *Al* sheets. At the exit (viz. 1.0 m distance) *GI* and *Al* sheet covered long stills are lagged by 34.06 and 19.76% in comparison with the long still covered with the *Cu* sheet, as overall heat transfer has great influence of thermal conductivity. Heat transfer rate goes on reducing along the length of long still.

Variation of theoretical and actual observed distillate output from the still units in control environmental conditions from reduced scale identical models covered with the *GI, Al,* and *Cu* sheet materials along the length are shown in Fig.7. Long still utilized *Cu* sheet as a condensing cover maintain its leads along the length of the still, whereas still covered with the *GI* sheet gives lowers output and still covered with the *Al* sheet gives an intermittent performance in comparison to the other two stills. The measured distillate output from the long still covered with the *Cu* sheet gives 39.78 and 58.53 % higher distillate output in comparison with the long stills covered with the *Al* and *GI* sheet materials respectively. At 0.5 *m* away from the entrance, it is 51.47 and 35.52 % higher than the *GI* and *Al* sheet condensing cover long still. At exit section long still covered with the *Cu* sheet leads by 40.91 and 16.98 % in comparison with the *GI* and *Al* sheet cover material of the long stills respectively. Total distillate output obtained from the long still covered with the *Cu* sheet material gives 55.03

and 34.69 % higher distillate output as compared with the long stills covered with the *GI* and *Al* sheets respectively.

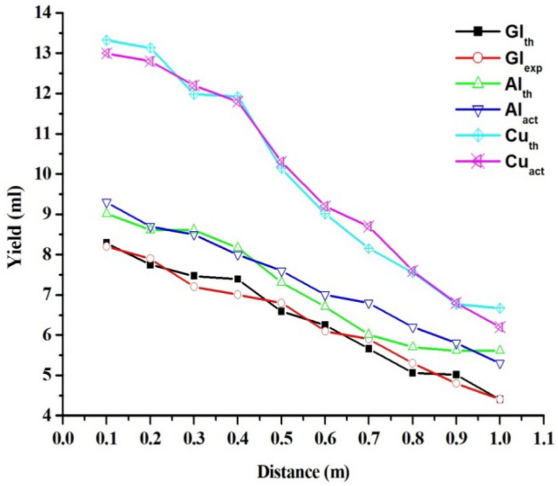


Figure 7: Variation of the experimental and theoretical distillate output from the long stills covered with *GI, Al,* and *Cu* sheet material along the length.

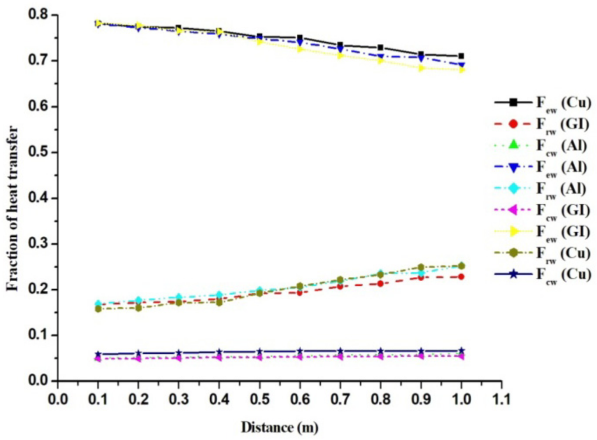


Figure 8: Variation of the fraction of heat transfer along the length of the long stills

Highest and lowest distillate outputs are recorded and evaluated in all the cases at their entrance and exit respectively. Total distillate evaluated for the *Cu, Al*, and *GI* sheet cover long still is 0.07 % higher, 2.53% lower, and 0.43% higher respectively, which will give credence to the results obtained from the theoretical evaluation and shows good agreement with the experimental results. Theoretical models use the regression model for evaluation Gr and Pr numbers for each section. Varation of the fraction of the overall heat transfer coefficient through the different modes of heat transfer took place while the experimentation in long stills covered with the *GI, Al*, and *Cu* sheet cover material is shown in Fig.8. Evaporative mode of heat transfer in all the stills dominating to the heat transfer which took place in radiative and convective mode and it goes on decreasing along the length of still. Convection mode shows its least contribution whereas radiative mode has an intermittent stage. A fraction of energy utilization in radiative mode is increasing along the length of the long stills covered with the *GI, Al,* and *Cu* sheet material.

5. CONCLUSION

Based on obtained experimental results and theoretical evaluation following conclusions are drawn:

- Proposed long still covered with the *Cu* thin sheet can be utilized for desalination.
- The productivity of the long still decreases along its length.
- Condensing cover made with the *Cu* sheet material gives higher distillate output as compared to the *GI* and *Al* sheet cover.
- Long still with *Cu* sheet material as a condensing cover will lead over the *GI* and *Al* sheet covered stills by 55.03 and 34.69 % respectively.
- Both theoretical and experimental results give good agreement to each other.

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NOMENCLATURE

A_s	basin area (m^2)
b	width of still (m)
C	constant
c_p	specific heat of water vapour at constant pressure (J / kg – K)
c_w	Specific heat of water at constant pressure (J / kg – K)
d	Characteristic length of still (m)
F_{cw}	convective heat transfer fraction ($F_{cw} = \dot{q}_{cw} / \dot{q}_1$)
F_{ew}	evaporative heat transfer fraction ($F_{ew} = \dot{q}_{ew} / \dot{q}_1$)
F_{rw}	Radiative heat transfer fraction ($F_{rw} = \dot{q}_{rw} / \dot{q}_1$)
F_{12}	View factor
g	Acceleration due to gravity ($g = 9.81\ m/s^2$)
Gr	Grashof Number ($Gr = \frac{g\beta\rho^2 d^3 \Delta T'}{\mu^2}$)
h_{cw}	Convective heat transfer coefficient $\left(W/m^2K\right)$
h_{ew}	Evaporative heat transfer coefficient $\left(W/m^2K\right)$
h_{rw}	Radiative heat transfer coefficient $\left(W/m^2K\right)$
h_{1c}	Total internal heat transfer coefficient from

	condensing cover to air $\left(W/m^2K\right)$
h_{1w}	Total internal heat transfer coefficient $\left(W/m^2K\right)$
k	Thermal conductivity of humid air (W/mK)
L	Latent heat of vaporization $\left(\mathrm{J/kg}\right)$
$\dot{m}_{ew}$	Distillate output (kg/m^2hr)
n	Constant
N	Number of sample
Nu	Nusselt Number ($Nu = \frac{h_{cw}d}{k}$)
P_{ci}	Saturated vapor pressure on inner condensing cover surface (Pa)
P_t	Total atmospheric pressure (Pa)
P_w	Saturated vapor pressure on water surface (Pa)
Pr	Prandtl Number ($\Pr = \frac{\mu c_p}{k}$)
$\dot{q}_{cc}$	Convective heat transfer rate from condensing cover to air (W/m^2)
$\dot{q}_{cw}$	Convective heat transfer rate from water to condensing cover (W/m^2)
$\dot{q}_{ew}$	Evaporative heat transfer rate from water to condensing cover (W/m^2)
$\dot{q}_{rc}$	Radiative heat transfer rate from condensing cover to air (W/m^2)
$\dot{q}_{rw}$	Radiative heat transfer rate from water to condensing cover (W/m^2)
$\dot{q}_1$	Total internal heat transfer rate from water to condensing cover (W/m^2)
$\dot{q}_{1c}$	Total internal heat transfer rate from condensing cover to air (W/m^2)
T_a	Atmospheric temperature ($°C$)
T_{ci}	Inner condensing cover temperature ($°C$)
T_v	average temperature of moist air ($°C$) ($T_v = \frac{T_{ci}+T_w}{2}$)
T_w	Water temperature ($°C$)
V	Wind velocity (m/s)
U_b	Overall heat transfer coefficient from basin area (W/m^2s)

Greek symbols

α	Thermal diffusivity (m^2/s)
β	Expansion factor (K^{-1})
σ	Stefan Boltzmann constant ($\sigma = 5.67 \times 10^{-8}\ W/m^2K^4$)
ρ	Density of humid air $\left(kg/m^3\right)$
$\Delta T'$	Effective temperature difference ($°C$)
μ	Dynamic viscosity of humid air $\left(Ns/m^2\right)$
ε_{eff}	Effective emissivity ($\frac{1}{\varepsilon_{eff}} = \frac{1}{\varepsilon_w} + \frac{1}{\varepsilon_{ci}} - 1$)
ε_w	Emissivity of water surface
ε_{ci}	Emissivity of condensing surface
θ	Inclination of metallic cover

ЕКСПЕРИМЕНТАЛНА ЕВАЛУАЦИЈА И ТЕОРИЈСКА АНАЛИЗА ДЕСТИЛАТОРА ДУГИХ РАЗМЕРА ПОКРИВЕНИХ ЛИМОВИМА ОД Gl, Cu И Al

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Електрична енергија се углавном производи у термоелектранама и нуклеарним електранама, у којима се врши претварање топлотне енергије у великом обиму, док су дизел генератори помоћни уређаји. Вода се најчешће користи као радни флуид и расхладно средство за одржавање радне температуре уређаја.

Рад приказује експерименталну и теоријску евалуацију три идентична прототипа дугих дестилатора, редукованих размера, покривених металним лимовима од различитих материјала (Gl, Cu, Al). Врућа отпадна вода чија је температура 70 ± 1^0 се доводи у дестилатор јер је температура коју испушта топлотни агрегат 65 – 75^0C. Теоријски резултати добијени регресионом анализом се подударају са експерименталним резултатима. Дестилатор покривен лимом од Cu има боље перформансе у односу на друга два лима (55,03 односно 34,69% боље него лимови од Gl и Al). Дестилатор покривен лимом од Cu даје већи принос дестилата у поређењу са дестилаторима покривеним лимовима од Al и GI.