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Performance Analysis of Single Pass Flat Plate Recycled SAH Integrated With Use of Thermal Energy Storage Medium

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ABSTRACT
This analysis focused, the thermal behavior of a phase change material (PCM) based single pass recycled flat plate solar air heater is done. Introduced Thermal model is developed for better performance. Experimental observations are made in Indian (25º N, 81º E) climatic circumstances. Novel system were fabricated and designed to analyze performance during day and night. For enhancing rate of thermal conduction, thermal conducting material about 5%, 10% & 15% of PCM is mixed. The maximum instantaneous & average exergy night time is obtained 58.56 % & 41.35%.
Keywords - Solar collector; Fusion; Heat transfer coefficient; Exergy destruction ; Latent heat.

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I. INTRODUCTION

Nowadays, burning fossil fuels causes serious environmental problems in terms of atmospheric pollution and climate change [1].The development of a country depends upon its capability to use of existing sources of energy [2]. In present day's India's progress towards agriculture, transport, & industrial sectors is remarkable. The maximum pare to India's energy consumption are meet by the fossil fuels. The pace of depletion of resources is extremely high & it will not be continued for the long period [3, and 4]. So that the alternative source of energy becomes equally important. The easiest & the most cheapest way to utilize clean energy is by processing the thermal energy for heating application's through solar collectors. Solar Air Heater (SAH) is most widely used due to their easeness, cheap etc [5]. The thermal conduct of solar air collector's is relying upon the material, shape, dimensions & layout of collector's. Upgrading in Performance could be accomplished by varying above parameters. To raise the heat transfer in absorber plate & the air, the modification can be done easily [6].

Thermal investigation is one, that gives an idea to obtain accurate & valuable idea's related energy analysis also destruction because of irreversibility in real situation & state. This includes use of absorbers - (corrugated absorber or matrix based absorber), also (packed bed , baffles, fins) [7]. The first law is mostly used in technological practice & is rely on the heat balance technique i.e. universally adopted in performance investigation. The second law consider the reversibility or irreversibility of process & is a very fundamental aspect of exergy & the energy investigation's [8]. Investigation of exergy analysis predicts a more realistic view of processes, sometimes noticeably different in comparison to the standard energy analysis [9]. Recently, several researchers have undertaken many studies covering the thermodynamic analysis of solar air heater's [10]. Present study made to investigate the performance of novel SAH with the use of PCM in off sunshine hour.

II. EXPERIMENTAL SETUP

A novel single pass recycled flat plate SAH of size (1020x98x 80) mm is fabricated with galvanized iron sheet. It divided in to three floors. It incorporates a black absorber plate above which a transparent glass plate of $1m^2$ is placed and all sides were sealed by silica to prevent leakage. A tray is placed below the absorber plate. The gap in between them is maintained. As a phase change material, paraffin wax is spread throughout the tray. In addition to PCM A thermal conducting material named Aluminum powder is mixed with this. It helps to improve the day & also off day performance of SAH. Use of thermal conducting material charged during day time and discharge at night time. Here the thermal conducting material of

5% 10% and 15% of PCM quantity is mixed to predict the day and night performance of Novel SAH. Thermal conductivity of paraffin wax is very low as compare to aluminum powder. As Aluminum powder thermal conductivity is 200 times more efficient than paraffin wax. On the basis of mass filled cavity of paraffin wax the quantity of blend material comes about 15 %. For this reason 5%, 10% & 15% is taken for the performance analysis.

In addition to this air is supplied to the system with the help of Fan. Air firstly flow above the absorber plate then it turns back from the end and flows over the PCM tray and then it revert to exit through the bottom of the PCM tray. The experimental setup was located at Solar Energy wing in SHUATS, Allahabad. The experiment was conducted in month of September 2017. The experiments were carried from 10am to 8 pm every day. The SAH is insulated using silica at the base & sides, to reduce respective heat losses. Solar intensity & wind velocity is recorded through salary meter & anemometer correspondingly.

Temperature at different point is monitored by k-type of thermocouple. Photo of Novel SAH is given in Fig1. All relevant parameters & dimensions are listed in the table 1.

Fig.1 view of finned SAH.

III. MATHEMETICAL MODELING

(a) ENERGY ANALYSIS:

Energy analysis is use to understand the basic design & performance of any developed thermal system, first law of thermodynamic (TD) through which energy balance is calculated. It involves the measured value obtained from experiments. The characteristics of SAH integrated with PCM cavity is obtained by writing the overall thermal energy balance equation through the following assumptions: [11]

1. The system performed at steady state.
2. The sky as black body
3. The cover plates don't absorb any part of solar energy.

Thermal energy balance at charging & discharging phases:

$$Q_A = Q_u + Q_{st} + Q_{loss} \tag{1}$$

The useful heat gain through collector: Duffie et al.

$$Q_u = \dot{m} C_p \left(T_{out} - T_{in}\right) \tag{2}$$

Where $\dot{m} = \rho V_{av} S$

Absorbed radiation by absorber surface is defined as:

$$Q_A = A_{abs}\left(\alpha\tau\right) I_T \tag{3}$$

During the charging phase stored heat flux:

$$Q_{ch} = m_{pcm}\left[\int_{ini\_ch,pcm}^{F} C_{p,s}\left(T\right)dT + L_F + \int_{F}^{fin\_ch,pcm} C_{p,l}\left(T\right)dT\right] \tag{4}$$

During the discharging phase delivered heat flux:

$$Q_{dis} = m_{pcm}\left[\int_{ini\_dis,pcm}^{F} C_{p,l}\left(T\right)dT + L_F + \int_{F}^{fin\_dis,pcm} C_{p,s}\left(T\right)dT\right] \tag{5}$$

Heat flux loss is measured, U_{loss} is overall heat lost through collector to surroundings by conduction, convection & infrared radiation.

$$Q_{loss} = U_{loss} A_c \left(T_{abs} - T_a\right) \tag{6}$$

The PCM filled cavity sizing: The PCM mass, m_{pcm}, during charging phase .

$$m_{pcm} = \frac{Q_A}{\left[\int_{ini\_ch,pcm}^{F} C_{p,s}(T)dT + L_F + \int_{F}^{fin\_ch,pcm} C_{p,l}(T)dT\right]} \tag{7}$$

Daily thermal efficiency: Daily thermal efficiency of novel SAH with PCM cavity is termed as the ratio of desired energy output during discharging to the total energy input charging :

$$\eta = \frac{\int_{disch} Q_{disch}}{\int_{ch\arg} A_c I_T} \tag{8}$$

(b) EXERGY ANALYSIS:

By applying exergy equilibrium in SAH shown in Fig.1, Exergy balance in flat plate SAH can be expressed as Chamoli (2013):[12]

$$\Psi_{in} - \Psi_{out} - \Psi_{loss} - \Psi_{change} - \Psi_{des} = 0 \tag{9}$$

Patella's efficiency for transforming solar radiation in to work discussed by Bejan (1988):

$$\eta_p = \frac{4T_a}{3T_s} + \frac{1}{3}\left(\frac{T_a}{T_s}\right)^4 \tag{10}$$

As Considering inlet & exit exergy , the exergy efficiency expressed:

$$\eta_\Psi = \frac{\dot{m}}{I_T A_p \eta_p}\left[C_p\left(T_o - T_i - T_a l_n \frac{T_o}{T_1}\right)\right]$$

(11)

EXERGY DESTRUCTION: Exergy destruction caused by irreversibility's in the system. Rate of exergy destroyed incorporate below three terms: [13,14 and 15]

One because of temperature difference (absorber plate surface & sun):

$$\Psi_{des,abs} = \eta_o I_T A_p T_a\left(\frac{1}{T_p} - \frac{1}{T_s}\right)$$

(12)

Second because of duct pressure drop:

$$\Psi_{des,\Delta_p} = \frac{\dot{m}}{\rho} \times \frac{\Delta_p T_a l_n\left(\frac{T_o}{T_a}\right)}{(T_o - T_{in})}$$

(13)

Third term is due to temperature difference between surface of absorber plate & agent fluid:

$$\Psi_{des,conv} = \dot{m} C_p T_a\left(l_n\left(\frac{T_o}{T_{in}}\right) - \frac{(T_o - T_{in})}{T_p}\right)$$

(14)

Thus exergy destruction rate:

$$\Psi_{des} = \frac{\Psi_{des,abs} + \Psi_{des,\Delta_p} + \Psi_{des,conv}}{\Psi_{in,r}}$$

(15)

Since the duct pressure drop is neglected in the present case so that the rate of exergy destruction is:

$$\Psi_{des} = \frac{\Psi_{des,abs} + \Psi_{des,conv}}{\Psi_{in,r}}$$

(16)

EXERGY IN: According to Petela's exergy in through collector :

$$\Psi_{in,r} = I_T A_p \eta_p$$

(17)

(c) PARAMETER RANGE:

Table 1: Input parameters used:

S.No	Input Parameter	Range	S.No	Input Parameter	Range
1	Glazing	Single glass	8	Transmttance-absoptance	0.84
2	Mass of	5 Kg	9	δ	0.002m
3	Tray Dimension	(0.99x0.96x0.10)m	10	εp	0.92
4	Length	L=(1.02)m	11	εg	0.88
5	Width plate	W=(0.98)m	12	σ	5.67x10-8 W/m2 K4
6	Depth of channel	s=0.08m	13	Space between plates	0.025m
7	Sun Temperature	5760K	14	Mass flow rate	0.057kg/sec

Table 2: Thermo physical properties of used PCM

Material	Melting Temperature (˚C)	Heat of fusion (J/Kg)	Thermal Conductivity (W/mK)	Cp Liquid	Cp Solid	Density (Kg/m³) Liquid	Density (Kg/m³) Solid
Paraffin Wax	37-60	$214.4\text{x}10^3$	0.21	3890	2940	775	850
Aluminum powder	600-660	$0.321\text{x}10^3$	205.0	-	923	-	2830

HEAT TRANSFER COEFFICIENTS: Rate (Heat transfer) for convective & radiative, analyzed by the following ways: [16,17] for calculating the radiative heat transfer:

$$h_{r,abs-g} = \frac{\sigma\left(T_{abs}^2 + T_g^2\right)\left(T_{abs} + T_g\right)}{\left(\frac{1}{\varepsilon_{abs}} + \frac{1}{\varepsilon_g} - 1\right)}$$

(18)

$$h_{r,g-a} = \varepsilon_g \sigma\left(T_g^2 + T_{sky}^2\right)\left(T_g + T_{sky}\right)$$

(19)

Sherwin suggested in laminar flow, can be modeled for flat plate & proposed relations as (Heat transfer) coefficient:

$$R_{eL} \le 5\times10^5 \, and \left(P_r \ge 0.5\right)$$

(20)

$$N_u = 0.664 P_r^{\frac{1}{3}} R_{eL}^{\frac{1}{2}}$$

(21)

For turbulent flow, (Niles et al.) Propose relationship:

For $5\times10^5 < R_{eL} < 10^8$ and $0.6 < P_r < 60$

(22) $N_u = 0.333 R_e^{0.8} P_r^{0.33}$

(23)

Where $N_u = \frac{h_c L}{k}$

(24)

For convective heat transfer coefficients,

$$R_e = \frac{\rho VD}{\mu} = \frac{\dot{m}D}{A_c \mu}$$

(25)

Where $A_c = s \times W$ the c/s area

Hydraulic diameter, D of channel

$$D = 4\left[\frac{W \times s}{2W}\right] = 2s$$
(26)

The convective heat transfer coefficients (absorber PCM cavity & the air fluid) can be analyzed from empirical relation: $h_{c,abs-g} = \frac{N_u \lambda}{b}$

$$h_c = \left(\frac{k}{L}\right) \times 0.664 \times (P_r)^{\frac{1}{3}} \times (R_e)^{\frac{1}{2}}$$
(27)

LOSS COEFFICIENTS: The top loss coefficients between the novel (SAH) & the outside is:

$$U_t = \left(\frac{1}{h_{c,abs-g} + h_{r,abs-g}} + \frac{1}{h_w + h_{r,g-a}}\right)^{-1}$$
(28)

$$h_w = 5.7 + 3.86 \times V_a$$

The energy loss through the bottom U_b & the edge U_e equation is given by:

Bottom loss coefficient: $U_b = \frac{\lambda_i}{\delta_b}$

$$U_e = \frac{(L_1 + L_2) L_3 \lambda_i}{L_1 L_2 \delta_e}$$

Total loss: $U_L = U_t + U_b + U_e$
(29)

IV. RESULT AND DISCUSSION

Experimentation was done during winter in Indian climatic conditions at SHUATS, Allahabad. Reading noted throughout the month & best a particular day value is considered. Fig. 2 reflects the performance of solar intensity w.r.t. time of the day. Solar intensities are almost close for all the observation day at same mass flow rates and show the intermittent behavior.

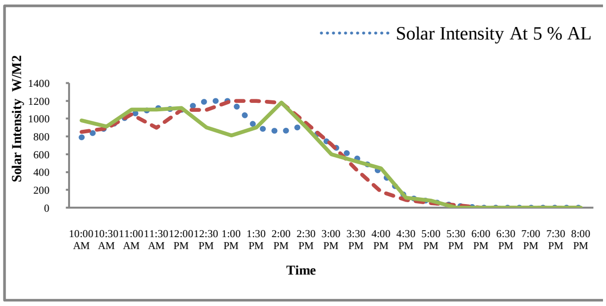

Fig.2 Variation (Solar intensity) w.r.t. (Day time)

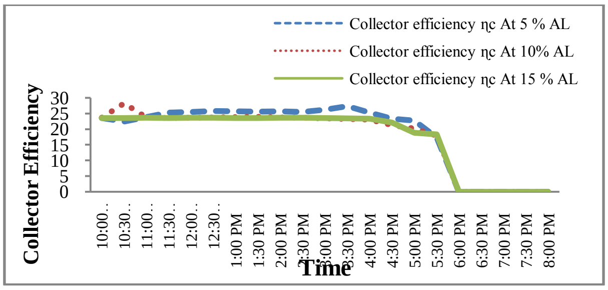

Fig.3 Variation of Collector efficiency w.r.t. to time of day .

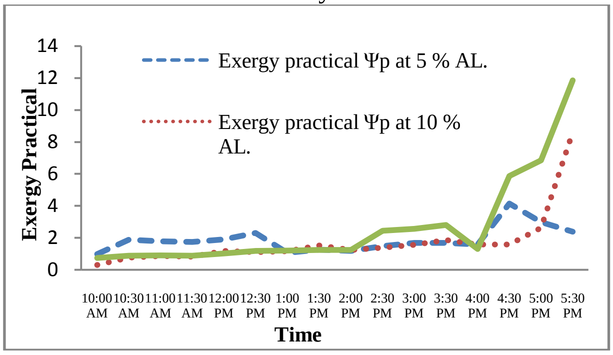

Fig.4 Variation of exergy practical w.r.t. time of day.

Behavior, collector efficiency with respect to day time is elaborated in fig. 3 as expected average collector efficiency comes out 23.11%, whereas 28.96% maximum instantaneous collector efficiency is obtained. Experimental & Theoretical (exit air) temperature used to obtain exergy efficiency. Fig.4 & 5 depicts variation of exergy efficiency of system corresponding to time of a day practically and theoretically. As solar intensity goes on decreasing as the day progress, exergy efficiencies are decreasing & reaching to its lowest value at the end of the day. Exergy loss & destruction is observed more in the SAH. Because of PCM when the day ends exergy practical increases. Average practical & theoretical exergy efficiency is found to be 4.38% & 0.34 %.

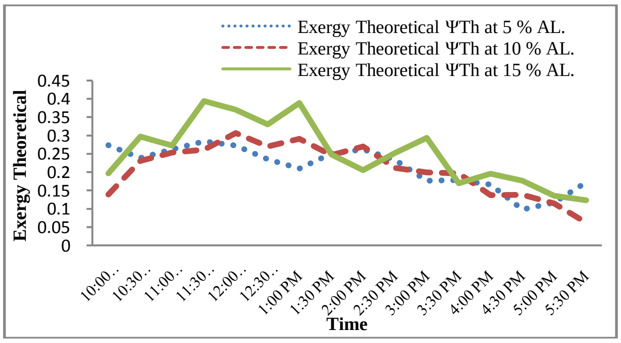

Fig.5 Variation of exergy theoretical w.r.t. time of day

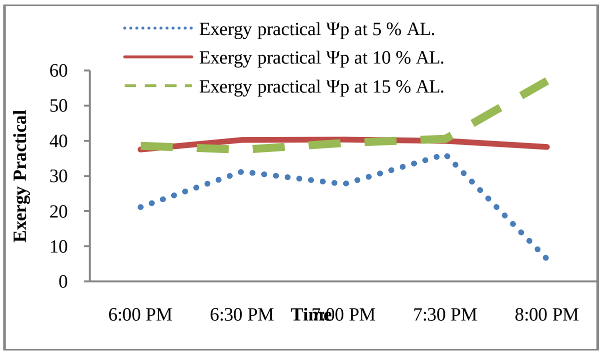

Fig. 6 Variation of exergy practical w.r.t. off time of day.

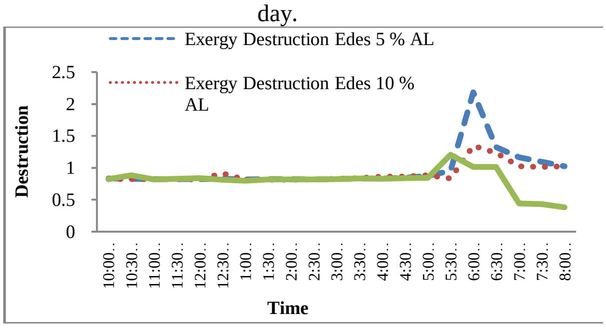

Fig. 7 Variation in Exergy destruction, w.r.t. time

Fig 6, shows the trend of Exergy practical with respect to off sunshine hour. As the heat released by phase change material and solar intensity is zero average practical exergy efficiency is found to be 41.35 % & maximum instantaneous exergy efficiency is found to be 58.56 %. Fig.7 shows variation of destruction with respect to time of the day. As expected the obtained destruction found under the limit. The maximum value in instantaneous destruction is approximately 2.05 where as the average exergy destruction is found to be 1.35 in this experimental analysis.

V. CONCLUSION

This work presents the details about Mathematical model of a phase change material assisted single pass recycled flat plate(SAH) using heat transfer expressions to collector components & empirical relations in order to estimating different Heat transfer coefficients. It predicts the thermal performance in novel SAH over wide range of operating condition namely solar intensity, inlet air temperature & variation in thermal conducting material quantity. Exergy analysis shows moderate exergy loss and the exergy destruction is found in system. Details discuss in result. Due to use of PCM system performed well during the off sunshine hour. Average & instantaneous practical exergy efficiency in the night is found to be 41.35% &58.56% respectively in the study. Use thermal conducting material in the increasing % shows the trend of increasing in the night time exergy accordingly.

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APPENDICES
Nomenclature:
A Area (m^2)
C_p Specific heat capacity of the fluid (K j /Kg k)
F' Finned collector efficiency factor
F_R Heat removal factor
I_T Incident Solar radiation (W/m^2)
U_L Over all heat loss coefficient (W/m^2-K)
T Temperature (K)
Q Heat transfer rate (Watt)
D Hydraulic diameter (m)
U Loss Coefficients(W/m^2-K)
T Temperature ^oK
E,H, Value Contant (W/m^2-K)
h_1, h_2, h_3,hc ,convective Heat transfer coefficient (W/m^2-K)
S Absorbed solar radiation (W/m^2)
R_e Reynolds's No.
N_u Nusselt No
P_r Prandtl No
L Collector length (m)
W Collector width (m)
s Depth of air channel (m)
$\dot{m}$ Mass flow rate (Kg/sec)
h_w Convective heat transfer due to wind.
F Fin efficiency

Greek symbols		**Subscripts**			
ɳ Efficiency	a absorptance	t_h Thermal	a ambient	p plate , petla	r Radiative
τ Transmittance	ψ Exergy	s Sun ,Depth of channel	o,outlet .optical	c collector	t Total ,top
(τα) Transmittance-absoptance	ε emmitance	g Glass	i inlet	u useful	b Back
σ Stefan-Boltzman constant	μ Dynamic viscosity (Kg/m-s)	c onvective	exp exponential	f fin	e End