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Energy and Exergy Analysis of Dual Purpose Solar Collector

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***Abstract*—**Energy and exergy study of air-water combined solar collector which is called dual purpose solar collector (DPSC) is investigated. The method of $\varepsilon - NTU$ is used. Analysis is performed for triangle channels. Parameters like the air flow rate and water inlet temperature are studied. Results are shown that DPSC has better energy and exergy efficiency than single collector. In addition, the triangle passage with water inlet temperature of 60^{O} C has shown better exergy and energy efficiency.

***Keywords*—**Efficiency, Exergy, Irreversibility, Solar collector.

I. Introduction

TODAY, solar energy is the first selection for substitution of fossil energy sources. This energy is found with very low cost and without any limitation. Air and water solar heaters are current uses of low temperature solar equipment. There are many studies about energy and exergy efficiencies improvement. In this context, Jaisankar et al. [1, 2] studied on the increase in heat delivery of thermosyphon systems. Hazami et al. [3] investigated on the performance of solar storage collector. Karim et al. [4] investigated the evaluation of a V-groove solar collector. In more of many researches, no work on combined air-water solar collector is seen. Dual purpose solar collector (DPSC) is an air and water collector combined to a single collector. This collector can attain high temperature with high heat delivery with a 50% reduction in space and cost [5,6].Kurtbas et al. [7] presented efficiency and exergy analysis of a new solar air heater and studied an absorber having five slices in a collector case. Hepbasli [8] performed a review on exergetic analysis and assessment of renewable energy resources for a sustainable future. Mohseni Languri et al. [9] studied on an energy and exergy of solar thermal collector. Farahat et al. [10] presented exergetic optimization of flat plate solar collectors. In this paper, energy and exergy analysis are studied for DPSC and the water inlet temperature and air flow rate effects are observed.

II. Collector Configuration

Dual purpose solar collector (DPSC) is a kind of solar flat plate collectors that water and air can deliver heat from absorber plate simultaneously. In this collector, water pipes are in top and air channels are in bottom of absorber plate. Water pipes fixed on the absorber plate and air channel are sealed under the absorber plate. In order to prevent the heat losses from sides and back surface of collector, all insulated. Fig. 1 shows design schematic of DPSC. Details design of DPSC described in reference [6,7].

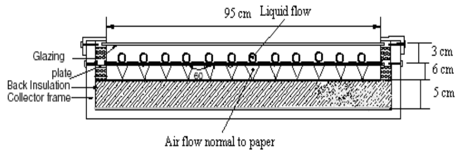

Fig. 1 Detail configuration of DPSC

III. Energy Efficiency

The actual useful energy collected used in the calculation of solar collector can be estimated by using $\varepsilon - NTU$ method [7]:

$$q_u = F_R\left(A_p S - U_L A_p\left(T_{fi} - T_{amb}\right)\right) \tag{1}$$

The heat removal factor can be written as:

$$F_R = \left(\frac{\varepsilon_f \dot{m}_f c_{p.f}}{U_L A_p + \varepsilon_f \dot{m}_f c_{p.f}}\right) \tag{2}$$

Where Effectiveness ε defines as heat delivery to maximum heat delivery that can transfer to fluids and obtained from following equation:

$$\varepsilon_f == 1 - \exp\left[-\frac{h_f A_f}{\dot{m}_f c_{p.f}}\right] \tag{3}$$

Hence:

$$\eta_{th} = \left(\frac{\varepsilon_f \dot{m}_f c_{p.f}}{U_L A_p + \varepsilon_f \dot{m}_f c_{p.f}}\right)(\tau\alpha)_{av} - \left(\frac{\varepsilon_f \dot{m}_f c_{p.f}}{U_L A_p + \varepsilon_f \dot{m}_f c_{p.f}}\right) U_L \frac{\left(T_{fi} - T_{amb}\right)}{I_T} \tag{4}$$

IV. Exergy analysis

The exergy balance can be written as follows:

$$\dot{E}x_{heat} - \dot{E}x_{work} + \dot{E}x_u = \dot{E}x_{des} \tag{5}$$

$$\dot{E}x_{heat} = \left(1 - \frac{T_o}{T_s}\right)\dot{Q}_u \tag{6}$$

Where $\dot{Q}_u$ the total rate of the energy is received by the collector absorber area from the solar radiation, and T_s is the black body temperature of sun surface, which considers being $6000\,K$. Keeping exergy due to heat only then, the

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irreversibility or the exergy destroyed is the total entropy generated times the ambient temperature:

$$\dot{I} = \dot{E}x_{dest} = T_o \dot{S}_{gen} \tag{7}$$

The final expression for exergy balance in the solar collector will be:

$$\dot{I} = \left(1 - \frac{T_o}{T_s}\right)\dot{Q}_u - \dot{m}_f C_f \left[\left(T_{fo} - T_{fi}\right) - T_o \left(\ln \frac{T_{fo}}{T_{fi}} \right) \right] \tag{8}$$

Exergy efficiency of the solar collector can be defined as the ratio of increased mass exergy to the exergy of the solar radiation, in other word; it is a ratio of the useful exergy delivered to the exergy absorbed by the solar collector [10]:

$$\eta_{ex} = 1 - \frac{\dot{I}}{\dot{E}x_{heat}} \tag{9}$$

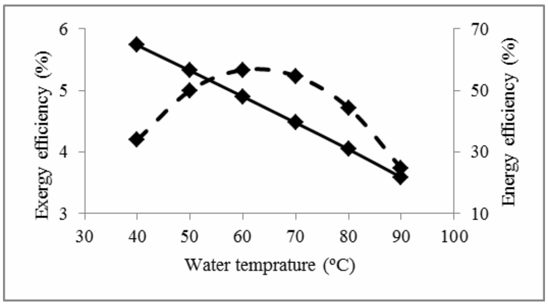
V. Results and Discussions

After the numerical simulation is preformed for energy and exergy by using input data as listed in Table I. The triangle channels with variation of water inlet temperature and air flow rate are used.

TABLE I
Input Parameter and their Values in the Study

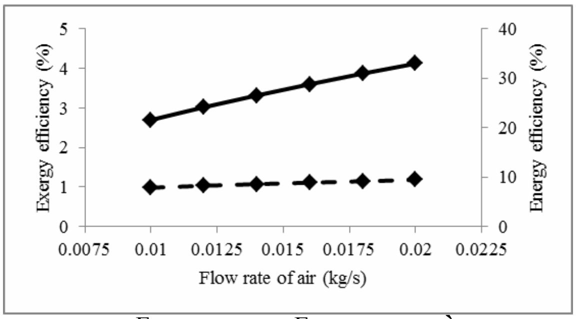
Range	Input parameters
1000 W/m^2	Solar radiation
45°C	Ambient temperature
1.5 m/s	Wind speed
40-90°C	Water inlet temperature
0.01-0.02 kg/s	Air flow rate
-	Air channels area
8.12 m^2	Triangular fin
0.01 kg/s	Mass flow rate of water

Fig. 2 shows energy and exergy efficiencies for water part. By increasing water inlet temperature, ability of heat absorbing and efficiency of water section decreases extremely. Efficiency decreases from 64.66 percent in 40^O C to 21.68 percent in 90^O C. Such case occurs in thermosyphon systems that with increase of water heat storage temperature, potency of heat delivery slake. exergy efficiency increases with increasing water inlet temperature up to 60^O C. Then, exergy efficiency decreases. The maximum point is shown to be 5.33%.

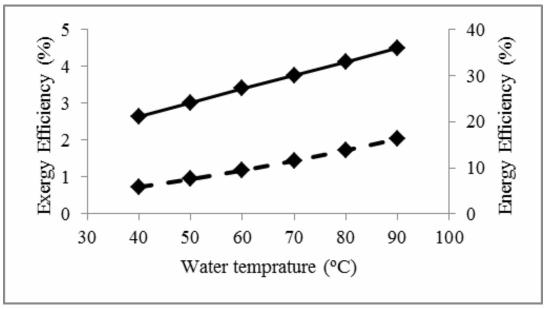


Energy —— Exergy - - - - -`
Fig. 2 Energy and exergy efficiencies of water part at flow rate of water= 0.01 kg/s

Air part in DPSC can cash part of energy that water can't deliver it. This heat delivery changes by changing of air flow rate and water inlet temperature. Fig. 3 shows air part efficiencies by varying the air flow rate at water inlet temperature of 60^O C. It's clear that with increase of air flow rate, heat delivery and efficiency of air section increases. It seems that with increasing of air flow rate, exergy efficiency of air part increases.



Energy —— Exergy - - - - -`
Fig. 3 Comparing energy and exergy efficiencies of air part at inlet water temperature=60^{O}C



Energy —— Exergy - - - - -`
Fig. 4 Comparing Energy and exergy efficiencies of air part at flow rate of air = 0.02 kg/s

Fig. 4 shows effect of air section efficiency with air flow rate of 0.02 kg/s for different water inlet temperature. In this case, with rise in water inlet temperature, exergy efficiency increases. The increase in energy efficiency is from 21.13% to 36.05% and the exergy efficiency is from 0.73% to 2.03 % for water inlet temperature ranging from 40 to 90 ◦C at air flow rate of 0.02 kg/s.

VI. Conclusion

In this study, energy and exergy analysis of DPSC was performed. Results indicated that air section of DPSC increases heat delivery and efficiency of collector significantly at higher water inlet temperature. Exergy analysis indicated that air part can increases exergy efficiency of DPSC.

NOMENCLATURE

A_p	Collector gross area, m^2	T_{fi}	Inlet fluid temperature, K
$\dot{E}_x$	Rate of exergy transfer, kJ/s	U_L	Overall loss coefficient for water part, W/m^2-K
F_R	Collector heat removal factor	η	Solar efficiency
$\dot{I}$	Irreversibility, kJ/s	**Subscript**	
I_T	Instantaneous/hourly flux incident on top cover of collector, W/m^2	$dest$	Destruction
$\dot{m}$	Mass flow rate, kg/s	ex	Exergy
q_u	Rate of useful heat gain by fluid, W	f	Fluids (air or water)
$\dot{Q}_u$	the total rate of the energy is received by absorber area, W	i	Inlet
S	Incident solar flux absorbed in the absorber plate, W/m^2	o	Outlet
$\dot{S}_{gen}$	Entropy generation, kJ/kg	th	thermal
T	Temperature, K	u	useful
T_{amb}	Temperature of ambient, K	0	Dead state

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