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Thermal Performance of Flat-Plate Collector: An Experimental Study

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ABSTRACT
The analysis of thermal performance of the flat-plate collector includes parameters such as solar intensity, ambient temperature and configuration of flat-plate collectors etc. In this paper, the effect of the parameter $(T_i-T_a)/I_T$ on thermal performance of glazed flat-plate solar collector was experimentally analyzed for water heating application in winter climatic condition. The flat-plate collector consists of the total surface area 2.23 m^2 and the copper tubes are integrated beneath the absorber plate. The plate has a selective coating with high absorptivity of 92% and the heat transfer fluid flowing in the tubes is R-134a. In the paper, evaluation of useful heat gain or collector efficiency has been done. It is based on steady state analysis and by calculating the thermal performance of liquid flat-plate collector. Results show that the flat-plate collector gives good performance and provide a desire quantity of hot water.
Keywords – Flat-plate collector, solar energy, thermal performance, collector efficiency.

I. INTRODUCTION

Most domestic water heaters generate heat by consuming fuel or through electricity. These water heaters are usually simple, but not desirable in view of energy utilization efficiency as well as due to their environmental impact. Whereas the solar assisted heat pump (SAHP) is a promising means of reducing the consumption of none replenish able energy resources. The idea of the combination of heat pump and solar energy has been proposed and developed by many researchers around the world [1] [2] [3] [4]. The SAHPs that were proposed could be differentiated as direct expansion solar assisted heat pump and indirect solar assisted heat pump [5] [6] [7] [8]. The various parameters that could be assessed are solar intensity, ambient temperature, configuration of flat-plate collector etc. [9] [10] [11]. This paper is focused on estimating the effect of parameter, i.e. $(T_i-T_a)/I_T$ on the thermal performance of glazed flat-plate collector. Many theoretical and experimental studies have been reported in the literature [12] [13] [14] [15].

II. NOMENCLATURE

List of symbols
A_c- area of collector, m^2
C_b- bond conductance, mK/W
D_o- tube outside diameter, m
D_i - tube inside diameter, m
F - Fin efficiency
F'- collector efficiency factor
g - width of bond ,m
h_w -wind heat transfer coefficient, W/m^2K
I_T -total incident solar radiation on the collector, W/m^2
k_P- thermal conductivity of absorber plate, W/(m K)
M- number of covers
Q_u- useful heat gain by collector, W
S -net solar radiation on the absorber, W/ m^2 K
T_a- ambient temperature, ^{o}C
T_i -inlet fluid temperature, ^{o}C
T_p -temperature of absorber plate, ^{o}C
U_L -overall heat coefficient loss, W/ m^2K
U_t- top loss coefficient, W/m^2K
U_b- bottom loss coefficient, W/m^2K

U_e- edge loss coefficient, W/m^2K
V -wind velocity, m/s

Greek symbols
α -absorptivity
τ -transmissivity
η -efficiency
β -inclination angle of collector, ^{o}
ε_p -emissivity of absorber plate

ε_c -emissivity of glass cover

Subscripts
a -ambient
c -collector
f -fluid
i –inside/inlet
T- total
o- outside
u- useful

III. EXPERIMENTAL SETUP

The main component of DX-SAHPWH is a single glazed flat plate collector which works as an evaporator, a reciprocating compressor, a condenser cum hot water storage tank and an expansion device. The schematic diagram of the experimental set up is shown in fig1.

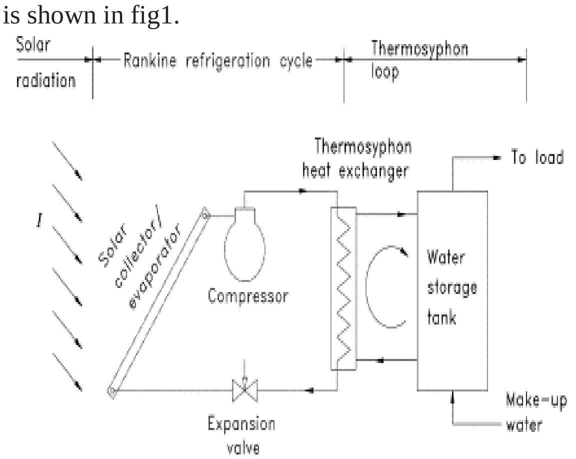

Fig.1: Direct Expansion Solar Assisted Heat Pump System

IV. GLAZED FLAT-PLATE COLLECTOR

In this paper, the study is on a flat-plate collector having collector area as equal to 2.23 m^2. The geometric dimensions for the collector are 1.83m × 1.22m. The collector absorber plate is a copper plate, 0.3 mm thick, with its surface painted with high absorptive matt-black paint.

Fig. 2: Flat-Plate Collector Used in Experiment

The length of serpentine copper tube was 6.4 m. and outside diameter of 11 mm was soldered to the backside of the copper plate, with a pitch between tubes as 100 mm as shown in Fig 2. The absorber plate is encased in 50 mm resin bonded glass wool, retaining the collector's heat. The single-pane 4 mm tempered patterned or clear solar glass has a high solar transmittance up to 92% and excellent durability. The strength of toughened glass is about eight times of that of the common glass. The collector has faced south at an angle of inclination of 45°.

V. ENERGY FLOW IN THE COLLECTOR

The efficiency of a solar collector depends on the ability to absorb heat as well as on the loss of heat from the absorber plate to ambient.

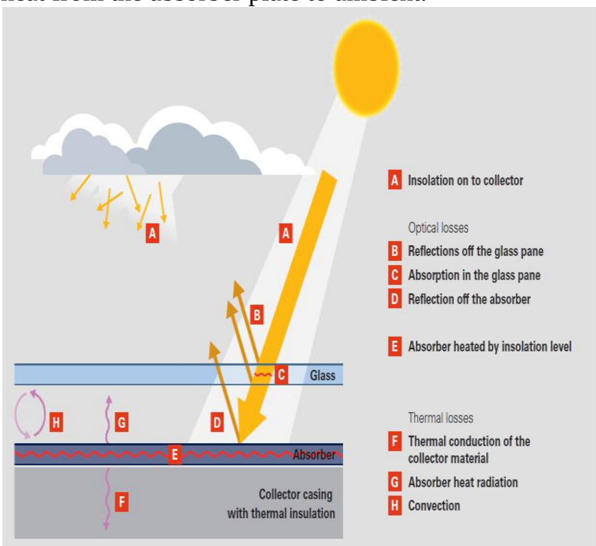

Fig.3. Energy Flow in the Collector [19]

The solar radiations are incident on the collector cover and then on absorber plate. Thus transmittance of heat is through the collector cover (glass cover) and the very same is absorbed by absorber plate as shown in Fig 3. Firstly the short wavelength radiation enters through the cover, then the convection losses occur between the plate and the glass cover, and after which conduction occurs due to the thickness of glass cover and finally radiation losses occur from the cover to the ambient. The distance between absorber and cover glass is important to minimize the heat losses due to convection and conduction.

VI. THERMAL PERFORMANCE OF FLAT-PLATE COLLECTOR

The flat-plate collector, without any sun tracking utilizes beam and diffuse radiation. Thermal performance of flat plate collector can be evaluated by

$$Q_u = F' A_c \left[(\tau\alpha) I_T - U_L (T_i - T_a) \right] \quad (1)$$

Where A_c is the area of collector, F' is collector efficiency factor, τα transmittivity-absortivity product, I_T total solar intensity on flat plat collector, U_L overall heat loss coefficient, $(T_i-T_a)$is the temperature difference between inlet fluid temperature of collector and ambient temperature [16] [17].

$$U_L = U_t + U_b + U_e \quad (2)$$

The empirical relation of U_t is given by the klein [17].

$$U_t = \left[\frac{M}{\left(\frac{C}{T_P}\right)\left\{\frac{T_P - T_a}{M + f}\right\}^e} + \frac{1}{h_w} \right]^{-1} + \left[\frac{\sigma\left(T_P^2 + T_a^2\right)\left(T_p + T_a\right)}{\left(\varepsilon_p + 0.059 M h_w\right)^{-1} + \left\{\frac{\left(2N + f - 1 + 0.133\varepsilon_p\right)}{\varepsilon_g}\right\} - M} \right] \quad (3)$$

$$f = \left(1 + 0.089 h_w - 0.116 h_w \varepsilon_p\right)\left(1 + 0.07866 M\right)$$

$$e = 0.43\left(1 - \frac{100}{T_P}\right)$$

$$C = 520\left(1 - 0.000051\beta^2\right) \quad for\, 0 < \beta < 70°$$

$$h_w = 5.7 + 3.8V \quad (4)$$

$$F' = \left[\frac{\frac{1}{U_L}}{W\left[\left(\frac{1}{U_L[D_o + (W - D_o)F}\right) + \frac{1}{C_b} + \frac{1}{\pi D_i h_{fi}}\right]} \right] \quad (5)$$

Where:

$$F = \frac{\tan h\left[m\left(W - D_o\right)/2\right]}{[m\left(W - D_o\right)/2]} \quad (6)$$

$$m = \sqrt{U_L / k_p \delta_p}$$

$$\eta = \frac{Q_u}{A_c I_T} \quad (7)$$

VII. RESULTS

As shown in Fig 4, the solar radiation pattern for clear days increases from morning to noon and after that decreases from noon to evening. The experimental study revealed that with the decrease in parameter $(T_i-T_a)/I_T$ corresponding collector efficiency increases shown in Fig 5.

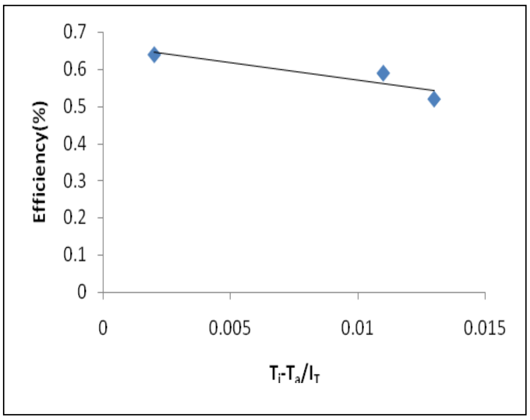

Fig. 4: Solar intensity Versus Time of The Day

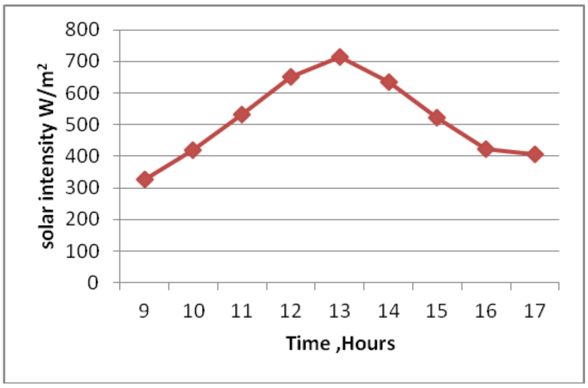

Fig. 5: $(T_i-T_a)/I_T$ versus Collector Efficiency

The collector efficiency η is plotted against $(T_i-T_a)/I_T$. The slope of this line (- F' U_L) represents the rate of heat loss from the collector.

VIII. CONCLUSION

This paper shows that Flat plate collector's efficiency is strongly influences by the parameter $(T_i-T_a)/I_T$, as this parameter increases collector efficiency decreases and in present study collector efficiency varies from 52%-64% with single glazed flat-plate collector when solar intensity varies from 523-710W/m^2.

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