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Thermal Analysis of Solar Flat Plate Collector

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Abstract- *In the solar-energy industry the major component unique to active systems is the solar collector. The Solar collector absorbs solar radiation, converts it into heat at the absorbing surface, and transfers this heat to a fluid flowing through the collector. The heated d fluid carries the heat either directly to the hot water or space conditioning equipment or to a storage subsystem from which can be drawn for use at night and on cloudy days. In a detailed thermal analysis of a solar flat plate collector, many factors are involved. Efforts are made to combine these factors into a equation. The formulation of a mathematical model describes the thermal performance of the collector in a efficient manner.*

Index Terms- collector heat removal factor, intensity of solar radiation, collector average temperature, collector overall heat loss coefficient, collector heat input, useful energy gain, collector efficiency, transmission coefficient of glazing, absorption coefficient of plate.

1 INTRODUCTION

Solar Collectors

Solar collectors are the key component of active solar-heating systems. They gather the sun's energy, transform its radiation into heat, then transfer that heat to a fluid (usually water or air). The solar thermal energy can be used in solar water-heating systems, solar pool heaters, and solar space-heating systems. There are a large number of solar collector designs that have shown to be functional. These designs are classified in two general types of solar collectors:
Flat-plate collectors – the absorbing surface is approximately as large as the overall collector area that intercepts the sun's rays.

Concentrating collectors – large areas of mirrors or lenses focus the sunlight onto a smaller absorber.

Flat-plate collectors

Flat-plate collectors are the most common solar collector for solar water-heating systems in homes and solar space heating. A typical flat-plate collector is an insulated metal box with a glass or plastic cover (called the glazing) and a dark-colored absorber plate. These collectors heat liquid or air at temperatures less than 80°C.

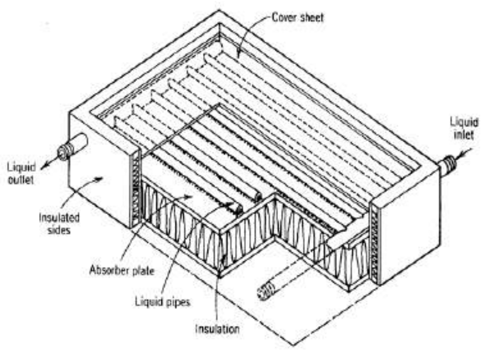

Fig. 1 A typical liquid Flat Plate Collector

Flat-plate collectors are used for residential water heating and hydronic space-heating installations.

2 PROBLEM STATEMENT

Figure 2 shows a schematic diagram of the heat flow through a collector. The work focused on how to measure its thermal performance, i.e. the useful energy gain or the collector efficiency.

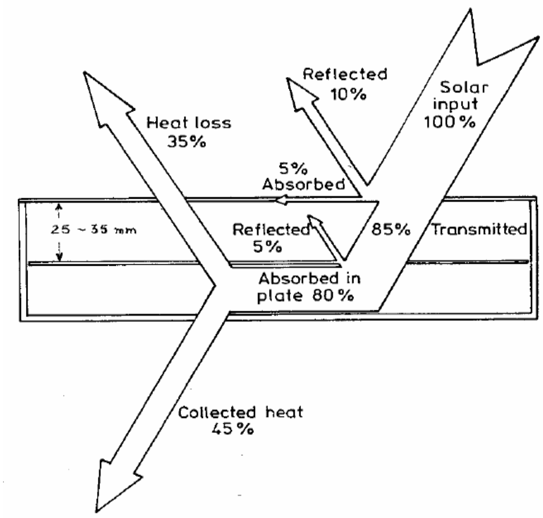

Fig. 2 Heat flow through a Flat Plate solar collector

Thus it is necessary to define step by step the singular heat flow equations in order to find the governing equations of the collector system.

3 LITERATURE SURVEY

The experimental results to predict the effect of different parameters on system thermal performance and efficiency, for flat plate collector in double flow mode with and without using a porous media have been conducted. It is found that increasing the mass flow rate through the air heaters results in higher efficiency. The double flow is more efficient than the single flow mode due to the increased heat removal for two channels compared to one flow channel, and the using of porous media increase the system efficiency and the outlet temperature hence the use of porous media increases the heat transfer area.

This increment will result in the increase of the pressure drop thus increasing the pumping power expanded in the collector. Thermal performance of the collector is improved by integrating a porous matrix in the absorber plate of the system. Thus, finally concluded that the efficiency will be maximum only by using the sand as a porous medium. Also,this will be economic when compared to non porous medium of the solar flat plate collector[1].

A numerical and experimental investigation of the flow and temperature distribution in a solar collector was performed. The influence of the tube shape and the absorber plate effect on flow and thermal distribution was investigated with CFD simulations. The CFD model was validated by measurements with the solar collector with circular tube and absorber configurations. Comparison between CFD simulation and the experimental measurements showed that the simulations were quite satisfactory in predicting the outlet temperatures. It shows only 5% deviation. This enhanced heat absorption by the working fluid reduces the overall temperature of the absorber plate while improving the efficiency of the collector [2].

The use of solar collectors in combination with heat pipes is rapidly growing in recent years.
Heat pipes, as heat transfer components, have undeniable advantages in comparison with other alternatives.
The most important advantage is their high rate of heat transfer at minor temperature differences.
Although there have been numerous studies on the heat analysis or first thermodynamic analysis of flat plate solar collectors in combination with heat pipes, the exergy analysis of these collectors is needed to be investigated.
In this work, energy and exergy analysis of a flat plate solar collector with a heat pipe is conducted theoretically.
Next, the exergy efficiency of pulsating heat pipe flat plate solar collectors (PHPFPSC) is compared with conventional collectors by using the experimental data. The results indicate that the use of heat pipes for heat transfer from the absorption plate to the water reservoir has significantly higher availability and exergy efficiency than the case with conventional collectors with intermediate fluid [3].

A comprehensive theoretical study was carried out to evaluate the thermal performance of flat plate solar collector using altered nano fluid as absorbing medium. The assumptions can be drawn that the efficiency of the collector advances with growing nano particles volume concentration due to an improved heat transfer to the nano fluid flow. The exergy loss of the system reduces subject to the increase of the collector efficiency.

With increasing nanoparticles volume concentration, exergy can be enhanced with reducing exergy loss. From the analyses, it is revealed that by inserting a small amount of graphene nanoparticles in water, exergy efficiency could be enhanced by 21%, comparing to conventional fluids the entropy generation, however, is decreased by 4% [4].

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Flat Plate Collector (FPC) is widely used for domestic hot-water, space heating/drying and for applications requiring fluid temperature less than 100oC. Three main components associated with FPC namely, absorber plate, top covers and heating pipes. The absorber plate is selective coated to have high absorptivity. It receives heat by solar radiation and by conduction; heat is transferred to the flowing liquid through the heating pipes. The fluid flow through the collector pipes is by natural (thermosyphon effect) or by forced circulation (pump flow). For small water heating systems natural circulation is used for fluid flow. Conventionally, absorbers of all flat plate collectors are straight copper/aluminum sheets however, which limits on the heat collection surface transfer area. Thus, higher heat collection surface area is optimized by changing its geometry with the same space of conventional FPC. The objective of present study is to evaluate the performance of FPC with different geometric absorber configuration. It is expected that with the same collector space higher thermal efficiency or higher water temperature can be obtained. Thus, cost of the FPC can be further bring down by enhancing the collector efficiency. A test setup is fabricated and experiments conduct to study these aspects under laboratory conditions (as per IS standard available for the flat plate collector testing)[5].

A theoretical study to investigate the effect of mass flow rate, flow channel depth and collector length on the system thermal performance and pressure drop through the collector with and without porous medium. The solution procedure is performed for flat plate collector in single and double flow mode.

The analysis of the results at the same configuration and parameters shows that the system thermal efficiency increases by 10-12% in double flow mode than single flow due to the increased of heat removal, and increase by 8% after using porous medium in the lower channel as a result of the increase of heat transfer area. At the same time the pressure drop will be increased. All collectors show improved efficiency obtained when the collector operates at relatively high flow rates, and at relatively low collector temperature rise since the collector losses will be less in low temperature difference [6].

A numerical analysis was used to investigate the effect of different parameters on thermal efficiency of flat plate solar collectors. Various geometries were examined in order to assess the influence of geometrical characteristics and operating conditions on thermal efficiency of solar collectors. Important parameters such as absorber thickness, riser position, shape of tube cross section, absorber material, absorber absorptivity, glass transmissivity, and mass flow rate have been investigated. Results show that the efficiency of collector with risers on top of the absorber plate is 4.2% more than that of the collector with risers on bottom. Also the tube cross-sectional geometry shows strong effect on the efficiency e.g. the efficiency of collectors with circular tubes is 38.4% more than that of collectors with triangular cross sections. Thermal efficiency of solar collectors increases with increasing the fluid flow rate, plate absorptivity, absorber thickness, and glass transmissivity [7].

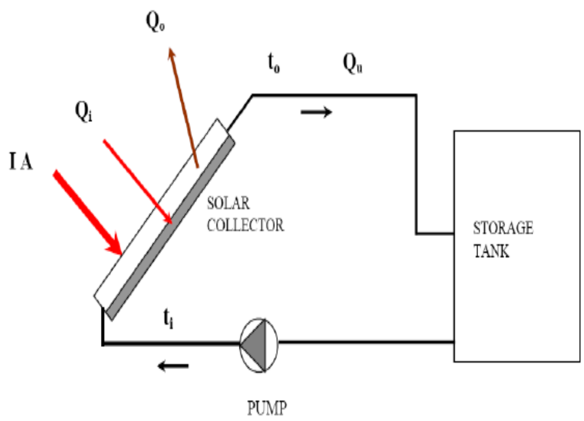

Fig. 3 Typical solar energy collection system

Figure 3 shows the schematic diagram of a typical solar system employing a flat plate solar collector and a storage tank.

Taking I as the intensity of solar radiation, in W/m^2, incident on the aperture plane of the solar collector having a collector surface area of A,m^2, then the amount of solar radiation received by the collector is:

$$Q_{in} = I \cdot A \quad (1)$$

However, as it is shown Figure 2, a part of this radiation is reflected back to the sky, another component is absorbed by the glazing and the rest is transmitted through the glazing and reaches the absorber plate as short wave radiation.
Therefore the conversion factor indicates the percentage of the solar rays penetrating the transparent cover of the collector (transmission) and the percentage being absorbed.

Basically,it is the product of the rate of transmission of the cover and the absorption rate of the absorber.
Thus,

Qin = I (τ α) A (2)

As the collector absorbs heat its temperature is getting higher than that of the surrounding and heat is lost to the atmosphere by convection and radiation heat transfer. The rate of heat loss (Qo) depends on the collector overall heat transfer coefficient (U_L) and the collector temperature.

Qo = U_L A (Tc-Ta) (3)

Thus, the rate of useful energy extracted by the collector (Qu), expressed as a rate of extraction under steady state conditions, is proportional to the rate of useful energy absorbed by the collector, less the amount lost by the collector to its surroundings.1 This is expressed as follows:

Qu = I (τ α) A - U_L A (Tc-Ta) (4)

It is also known that the rate of extraction of heat from the collector may be measured by means of the amount of heat carried away in the fluid passed through it, that is:

Qu = mCp (Ti- To) (5)

Equation 4 proves to be somewhat inconvenient because of the difficulty in defining the collector average temperature. It is convenient to define a quantity that relates the actual useful energy gain of a collector to the useful gain if the whole collector surface were at the fluid inlet temperature. This quantity is known as "the collector heat removal factor (F_R)" and is expressed as:

F_R = mCp (Ti- To)/ A[I (τ α) - U_L (Ti-Ta)] (6)

The maximum possible useful energy gain in a solar collector occurs when the whole collector is at the inlet fluid temperature. The actual useful energy gain (Qu), is found by multiplying the collector heat removal factor (F_R) by the maximum possible useful energy gain. This allows the rewriting of equation (4):

Qu = F_R A[I (τ α) A -U_L (Tc-Ta)] (7)

Equation (7) is a widely used relationship for measuring collector energy gain and is generally known as the "Hottel- Whillier-Bliss equation".
The useful energy gain depends strongly on the energy losses from the top surface of the collector both due to convective and radiative heat transfer processes. The losses from the bottom and from the edges of the collector do always exist. Their contribution, however, is not as significant as the losses from the top [8].

A measure of a flat plate collector performance is the collector efficiency (η) defined as the ratio of the useful energy gain (Qu) to the incident solar energy over a particular time period:

$$\eta = \frac{\int Q_u dt}{A\int I dt} \quad (8)$$

The instantaneous thermal efficiency of the collector is:

$$\eta = \frac{Q_u}{AI} \quad (9)$$

$$\eta = \frac{F_R A[I\tau\alpha - U_L(T_i - T_a)]}{AI} \quad (10)$$

$$\eta = F_R\tau\alpha - F_R U_L\left(\frac{T_i - T_a}{I}\right) \quad (11)$$

4 PROJECT DESCRIPTION

If it is assumed that F_R, τ, α, U_L [9] are constants for a given collector and flow rate, then the efficiency is a linear function of the three parameters defining the operating condition: Solar irradiance (I), Fluid inlet temperature (Ti) and Ambient air temperature (Ta).

In practice, U_L is not a constant as heat losses will increase as the temperature of the collector rises further above ambient temperature (thermal conductivity of materials varies with temperature) [9].

The results from the plot will be a straight line only if conditions are such that F_R, U_L and (τ α) are constants . Thus, the performance of a Flat-Plate Collector can be approximated by measuring these three parameters in experiments [10].

The result is a single line (ΔT/I – Curve) shown in Figure 4.

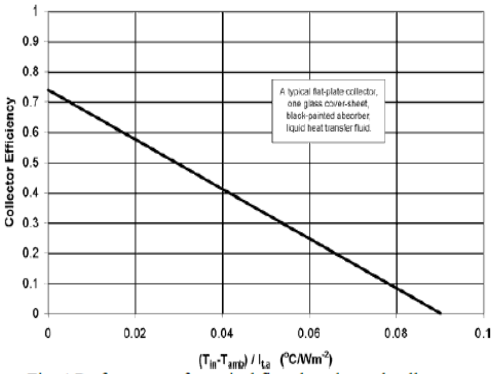

Fig. 4 Performance of a typical flat-plate thermal collector (ambient temperature 25°C)

The collector efficiency η is plotted against (Ti – Ta)/I**.** The slope of this line (- F_R U_L) represents the rate of heat loss from the collector. For example, collectors with cover sheets will have less of a slope than those without cover sheets.
There are two interesting operating points on Figure 4.

1) The first is the maximum collection efficiency, called the optical efficiency. This occurs when the fluid inlet temperature equals ambient temperature (Ti= Ta). For this condition, the ΔT/I value is zero and the intercept is $F_R(\tau\ \alpha)$.

2) The other point of interest is the intercept with the ΔT/I axis. This point of operation can be reached when useful energy is no longer removed from the collector, a condition that can happen if fluid flow through the collector stops (power failure). In this case, the optical energy coming in must equal the heat loss, requiring that the temperature of the absorber increase until this balance occurs. This maximum temperature difference or "stagnation temperature" is defined by this point. For well-insulated collectors or concentrating collectors the stagnation temperature can reach very high levels causing fluid boiling and, in the case of concentrating collectors, the absorber surface can melt.

CONCLUSION

A method to describe the thermal performance of a Flat Plate Solar collector has been presented. The collector efficiency is an important parameter. A detailed analysis shows the fact, that the overall heat loss coefficient (U_L), heat removal factor (F_R) and other factors are not constant values.

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