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Experimental Investigation and Fabrication of Serpentine Flat-Plate Collector to predict the Performance

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***Abstract*— The use of solar thermal energy system is one of the viable system to convert solar energy into thermal energy. This thermal energy is utilized to heat the water. A well-known application is solar water heating systems, in which the main component is the solar flat plate collector. The flat plate collector has many configurations, but it has mainly two types depending on tubes attached to the absorber plate. When the water flows inside a group of parallel tubes (acting as risers) between two bigger tubes (acting as headers), the collector is called tubular collector, while it is serpentine collector, when the flow is only in one tube (usually in zigzag form) from the main source to the outlet of the collector. The serpentine collector has been chosen in present study to evaluate the performance and the heat transfer fluid flowing in the tubes is water. Serpentine flat collector has been fabricated and tests have been conducted for Vijayawada city atmospheric conditions in India to evaluate the heat gain and collector efficiency for different volume flow rates. This systematic study provides useful data to understand the performance of the developed solar collector. This kind of collector is useful to heat small quantity of water.**

Index Terms—**Collector efficiency, Flat-plate collector, solar energy, thermal performance.**

NOMENCLATURE

A	collector area, m²
F_R	collector heat removal factor
I	intensity of solar radiation, W/m²
T_c	collector average temperature, ◦C
Ti	inlet fluid temperature, ◦C
T_a	ambient temperature, ◦C
U_L	collector overall heat loss coefficient, W/m2
Q_i	collector heat input, W
Q_u	useful energy gain,
Q_o	heat loss,

I. 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.

Flat-plate collectors

Flat-plate collectors are the most common solar collectors 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. The water flows in the tube which is bent in a zig-zag form called the serpentine form, which is the main source to the outlet of the collector.

II. SERPENTINE FLAT PLATE COLLECTOR

Fig.1 Flat plate collector used in the experiment

A. flat plate collector has the following components

A blackened or selectively coated flat absorbing plate is normally metallic, which absorbs the incident solar radiation, convert it into heat and conducts the heat to the fluid passages. Tubes, channels or passages attached to the collector absorber plate are to circulate the fluid required to remove the thermal energy from plate. Insulation material provided at the back and sides of the absorber plate whose principal function is to reduce heat loss from the back and sides of the absorber plate. A transparent or translucent cover or covers whose principal functions are to reduce the upward heat losses and provide weather proofing. Enclosed box principal functions are to hold the other components of the collector and to protect the collector plate and insulation material from the weather. In this paper, the study is on a flat-plate collector having collector area is equal to 0.39 m^2. The collector absorber plate is a copper plate, 0.3 mm thick The length of the copper tube is 0.35m and the outside diameter is 12mm.The single-pane 4 mm tempered patterned has been used for this experiment as shown in the figure1.The strength of toughened glass is about eight times of that of the common glass. The aim of this paper is to design, fabrication

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and experimental investigation of a solar flat plate collector (SFPC) for domestic water heating from local raw materials available in Indian-market. Dimensions of collector are shown in Fig 2 and the fabricated model is in Fig 3 and Fig 4. Tube dimensions are shown in Fig 5.

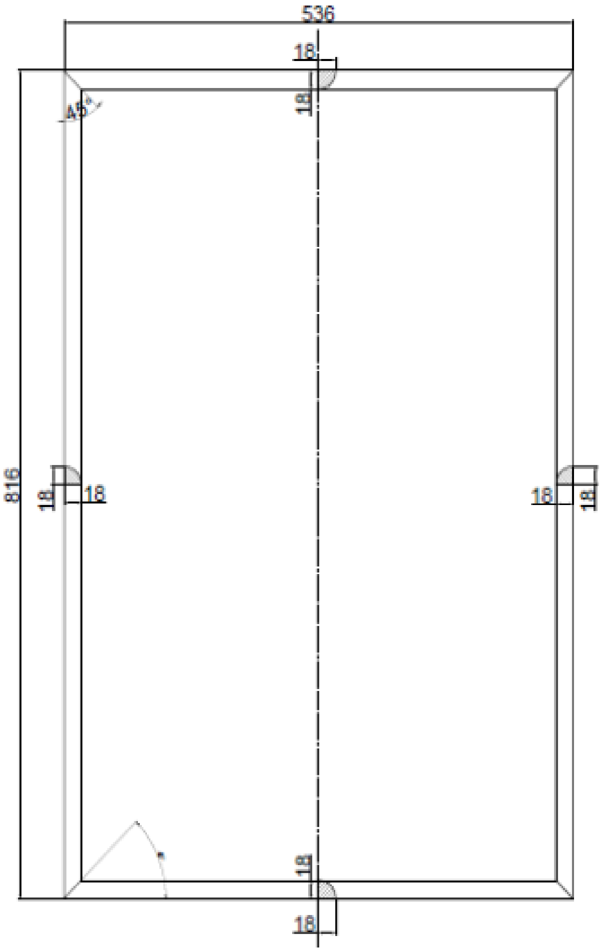

Fig 2 Detailed drawing for fixing the absorber plate of the designed solar flat plate collector

Fig 3 Wooden frame at the time of making

Fig 4 A photographic view of the outside frame

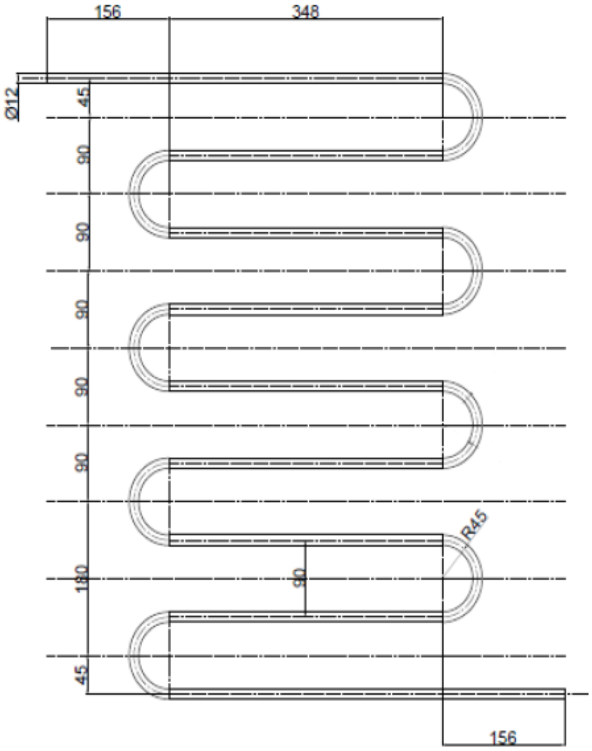

Fig 5 A detailed drawing for copper tubing of the designed solar flat plate collector

Fig 6 A photographic view of the Copper Tubes

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Fig 7 A photographic view of the Serpentine copper tubing of the designed solar flat plate collector

III. ENERGY FLOW IN THE COLLECTOR

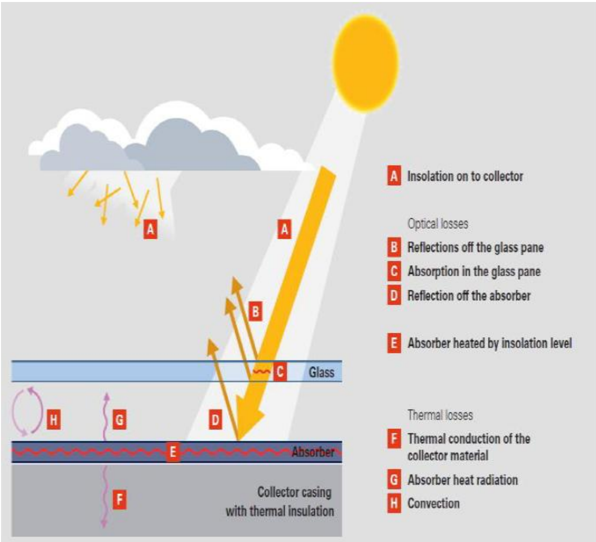

Fig.8 Energy flow in the collector

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. 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 same is absorbed by absorber plate as shown in Fig 8. Firstly the short wavelength radiation enters through the cover, then the convection losses occur between the plate and the glass cover, 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.

IV. THERMAL PERFORMANCE OF FLAT-PLATE COLLECTOR

If I is 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:

$$Qi = I \cdot A \tag{1}$$

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,

$$Q_i = I\,(\tau\alpha)\,A \tag{2}$$

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. The rate of heat loss (Qo) depends on the collector overall heat transfer coefficient (U_L) and the collector temperature.

$$Q_o = U_L\, A\, (T_c - T_a) \tag{3}$$

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.

This is expressed as follows:

$$Q_u = Q_i - Q_o = I\,(\tau\alpha)\,.\,A - U_L\, A\,(T_c - T_a) \tag{4}$$

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:

$$Q_u = mC_p(T_i - T_o) \tag{5}$$

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:

$$F_R = \frac{mC_p(T_o - T_i)}{A[I\tau\alpha - U_L(T_i - T_a)]} \tag{6}$$

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 (FR) by the maximum possible useful energy gain. This allows the rewriting of equation (4):

$$Q_u = F_R\, A\, [I\, \tau\alpha - U_L\, (T_i - T_a)] \tag{7}$$

Equation (7) is a widely used relationship for measuring collector energy gain and is generally known as the "Hottel-Whillier-Bliss equation".

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

$$\eta = \frac{\int Q_u\, dt}{A \int I\, dt} \tag{8}$$

The instantaneous thermal efficiency of the collector is:

$$\eta = \frac{Q_u}{AI} \tag{9}$$

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

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

V. THEORETICAL CALCULATIONS

Reflectance (ρ)
$\rho = \{(1.526-1)/(1.526+1)\}^2$
= 0.04336
Transmittance (τ)
K = 16.1/m
L = 5*10-3 m
τ = e-16.1*5*10-3{(1-0.04336)/(1+0.04336)}
= 0.845
Absorptance (α)
α+ τ + ρ =1
α+0.845+0.04336=1
α=0.11164
In Vijayawada city the I_{avg} per day =4.88kw-hr/m^2
(Reference11)
Q_{in} = 4.88*3600*10^3*(л/4)*0.012*0.012*5*0.845*0.11164
= 937.176 W
Efficiency Calculations

1. For 1Litre /minute
Volume = (1/(1000*60))
= 1.6667*10-5 m^3/sec
m= ρ*volume = 1000*volume
=0.0166 kg/sec
Q_{out} = 0.0166*4186*(37.5-33)
= 312.6942 W
ɳ= (312.6942/937.176)*100 =33.36%

2. For 2 Litres /minute
V =3.333*10-5m^3/sec
m= ρ*volume
= 0.0333 kg/sec
Q_{out}=0.0333*4186*2
= 279.0666
ɳ= (279.0666/937.176)*100= 29.77%
3. For 3 Litres /minute
V=5*10^{-5} m^3/sec
m=0.05 kg/sec
Q_{out}=0.05*4186*1
=209.3W
ɳ=(209.3/937.176)*100=22.33%
4. For 4 Litres /minute
V=6.6667*10-5 m^3/sec
m= ρ*volume
= 1000*6.6667*10-5
= 0.0666 kg/sec
Qout=0.0666*4186*0.5
=139.393 W
ɳ = (139.393/937.176)*100 = 14.873%

VI. RESULTS

The variation of the collector efficiency with volume flow rate has been shown in Fig 9. The experimental study reveals that when the volume flow rate of the water that is flowing through the tubes increases the collector efficiency decreases. The results of a sample test through it, the collector is tested, are tabulated in Table 1. The temperature measured clearly shows that at low mass flow rates, the collector working effectively and the outlet temperature is high among all the tested cases.

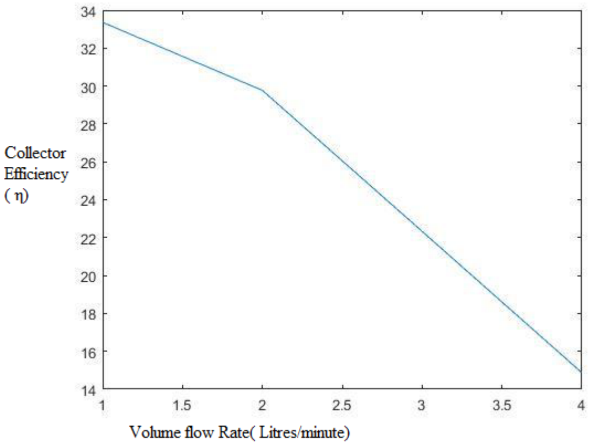

Fig.9 Variation of Collector efficiency with volume flow rate

Table1: Temperatures measured at outlet of collector for different flow rates.

Volume flow rate (Litres/minute)	Inlet Temperature Ti(°C)	Outlet Temperature To(°C)	Efficiency (%)
1	33	37.5	33.36
2	31	33	29.77
3	32	33	22.33
4	32	32.5	14.873

VII. CONCLUSIONS

A flat Plate collector has been fabricated and its performance for the Vijayawada city operating conditions has been experimentally studied. Results obtained from this study shows that Flat plate collector's efficiency is high at low volume flow rate. Collector performance is good at 1 litre per minute flow rate. As the flow rate increases from 1 to 4 litres per minute, collector efficiency decreases. Collector efficiency varies from 33%-14% with single glazed flat-plate collector when solar intensity is 4.88kw-hr/m^2.

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