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Experimental Investigation on Series Solar Flat Plate Collectors with Variable Mass Flow Rates

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ABSTRACT---Energy obtained from the sun can be converted in to useful work in many ways. Out of which most efficient method to convert cold water in to hot water for domestic purposes is by means of passing working fluid water through the flat plate collectors. Various research works are made as a mean to improve the performance of solar flat plate collector. But obtaining of higher temperature of water and higher flow rate of water at the outlet is still a mystery. In this work we gone through three different flow rates and suggested the economical one for domestic purposes. In addition experiments are made in conventional series flat plate collector and new mixed mode series flat plate collector. Experimental investigation on such new mixed mode collector had already been made as a mean to prove its performance with unit flow rate.

KEYWORDS: SFPC, Mixed mode, Working fluid, Flow rate etc…

I. INTRODUCTION

A. Solar Water Heater

Solar energy is very large, inexhaustible source of energy. The power from the sun intercepted by the earth is approximately 1.8*1011 MW which is many thousand times larger than the present consumption rate on the earth of all commercial energy sources. Thus in principle source of energy could supply all the present and future energy needs of the world on a continuing basis. The liquid flat plate collector one of the main solar energy conversion device is most widely used because it is simple in design, has no moving parts and requires a little maintenance.

S.P.Sukhatme and J.K.Nayak [1] classifies solar water heaters in to two types as flat plate collector and the parabolic collector. Besides while converting cold water in to hot water using one collector is known as single system and while using multiple collectors it is called as series collectors. Single system is suitable for domestic purposes and not for industrial purposes while series system suits to both.

G.N.Tiwary [2] performed varieties of experiments on series flat plate collectors by connecting 2 to N^{th} number of collectors both as partially and fully covered (mixed combination).But the experiments he made are using identical collectors which means he used up to N numbers of same design configured collectors. As a mean of which he proved series flat plate collectors provide higher outlet temperature as compared to single system via variety of experiments.

M.Sridharan [4] [5] modeled and fabricated a new type solar water heater of area 2035*1035*100mm as a mean of improving efficiency of a single system. It consists of 3 header tubes & 8 riser tubes along with slight changes in the flow pattern (Zig-Zag pattern). He makes use of the mixed mode concept as a mean to improve the performance of solar series flat plate collector.As a mean of which improved outlet temperatures as compared with conventional series flat plate collectors was obtained.

Soteris A. Kalogirou [6] surveyed various parameters associated with solar thermal collector's performance. In addition to the environmental problems related to the use of conventional sources of energy and the benefits offered by renewable energy systems are discussed. He founds that mass flow rate one of the important parameter which plays a major role in the variation of outlet temperature. In this work three different mass flow rates(1 kg/min, 1.5 kg/min and 2.0 kg/min) i.e (60 kg/hr , 90 kg/hr and 120 kg/min) are used to monitor the impact of such property over outlet fluid temperature. In addition it verifies theoretical fact of reduction in flow rate results in increase in outlet temperature and beyond certain reduction in flow rate results in steam formation and pressure drop. This paper converts such theoretical facts in to actual or real time values.

A. Assumptions

- Flow inside tube is viscous.
- Flow of the heat is does not vary with time.
- One dimensional flow.
- Heat transfer between storage tank & surroundings are negligible.
- During entire cycle system remains closed.

B. Specification of mixed mode Collector

The design of a new collector was entirely based on universal standard specifications but with slight difference in tubular arrangements. Sivakumar.P,Christ Raj.W , M.Sridharan, N.Jaya malathi [4].The parent material copper with thermal conductivity (k=385W/m-k) remains the same for both collector tubes. The basic dimensions of newly designed FPC are as follows:

- Area of new collector = 2035*1035mm
- Number of Header tubes=3 (Changes made)
- Number of riser tube=8
- Diameter of Header tubes=25.4mm
- Diameter of riser tubes=12.7mm
- Center to center distance between copper tubes=100mm
- Thickness of glass cover =0.003mm
- Emmisivity of glazing cover=0.1
- Absorptivity of glazing cover=0.1
- Reflectivity of glazing cover=0.9
- Thermal conductivity of tube = 385 W/m-k
- Thickness of insulation = 0.05m of polyurethane.
- Mass flow rate per minute = 1 Kg/min, 1.5 Kg/min, 2 Kg/min.
- Mass flow rate per hour = 60 Kg/hr, 90 Kg/hr, 120 Kg/hr.

II.EXPERIMENTAL SETUP

In case of series connected test rig two or more collectors are connected & exposed to a same environmental condition.

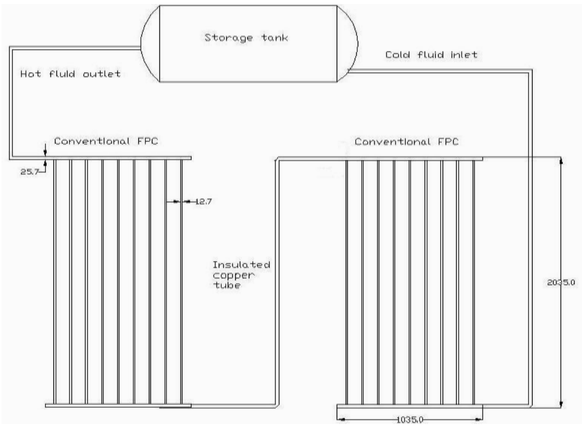

Fig. 2.1. Sectional view of Existing series FPC consists of two identical SWH's.

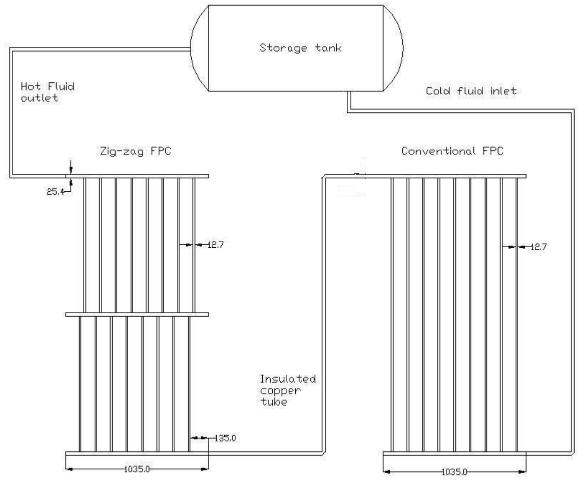

Fig. 2.2. Sectional view of new series FPC consists of Zigzag & Conventional type SWH's.

In this process inlet water temperature is maintained with a controlled flow rate. The inlet and outlet temperatures are continuously monitored for each of collector separately. A large bank of collectors can be formed by series, parallel, or mixed combination of collectors in one or multiple rows. As a mean of improving the efficiency of the conventional SFPC a mixed mode combination was used.

A. Formula for Performance Calculation of SFPC

From G.N.Tiwary[2] , it is convenient to define array characteristics for the series connected modules that are analogous to $F_R(\tau_0\alpha_0)$ and F_RU_L for single module. If two sets of collectors 1& 2, are connected in series the useful heat output of the combination is

$$Q_{um1}+Q_{um2}=A_{m1}F_{Rm1}[(\tau_0\alpha_0)_1I(t)-U_{Lm1}(T_{fi}-T_{fa})]+A_{m2}F_{Rm2}[(\tau_0\alpha_0)_2I(t)-U_{Lm2}(T_{fi}-T_{fa})] \quad (1)$$

From [4] and [12] we have formula to determine useful heat energy collected by N numbers of collectors,

$$Q_{UN}=m*C_f*0.1*(1-\exp\{-(NA_cU_LF^1/mC_f\})*(q_{ab}{}^1-U_L(T_{fi}-T_a)) \quad (2)$$

Formula to determine efficiency of solar series flat plate collectors in N numbers,

$$\eta_{SFPC} = Q_{UN} / Ac*I \quad (3)$$

III. READINGS AND OBSERVATIONS

TABLE 1: READINGS OF DIFFERENTLY CONFIGURED SOLAR WATER HEATERS AT A MASS FLOW RATE OF 1 Kg/min (sq. m).

Time	**Solar Intensity**	**Case1 conventional FPC**	**Case2 Zig-Zag FPC**
IST (Hrs)	*I (w/m^2)*	*T_{fo} (K)*	*T_{fo} (K)*
10.00	722.6	318	323
11.00	859.4	323	331
12.00	937.5	327	338
13.00	917.9	334	355
14.00	820.3	333	350
15.00	761.7	323	343
16.00	605.5	318	332

TABLE 2: READINGS OF DIFFERENTLY CONFIGURED SOLAR WATER HEATERS AT A MASS FLOW RATE OF 1.5 Kg/min (sq. m).

Time	**Solar Intensity**	**Case1 conventional FPC**	**Case2 Zig-Zag FPC**
IST (Hrs)	*I (w/m^2)*	*T_{fo} (K)*	*T_{fo} (K)*
10.00	722.6	314	316
11.00	859.4	319	322
12.00	937.5	322	325
13.00	917.9	330	333
14.00	820.3	327	330
15.00	761.7	318	324
16.00	605.5	312	320

TABLE 3: READINGS OF DIFFERENTLY CONFIGURED SOLAR WATER HEATERS AT A MASS FLOW RATE OF 2 Kg/min (sq. m).

Time	**Solar Intensity**	**Case1 conventional FPC**	**Case2 Zig-Zag FPC**
IST (Hrs)	*I (w/m^2)*	*T_{fo} (K)*	*T_{fo} (K)*
10.00	722.6	309	311
11.00	859.4	314	316
12.00	937.5	318	321
13.00	917.9	323	325
14.00	820.3	317	322
15.00	761.7	311	317
16.00	605.5	308	314

IV. RESULTS & DISCUSSIONS

The performance of these both conventional SFPC and mixed mode SFPC was determined at Tiruchirappalli, Tamilnadu, India, (longitude 78°43', latitude 10°46'). From the experiments conducted it is observed that the outlet temperature of the fluid is a function of intensity of solar irradiation and mass flow rate. For all the two cases of FPC, the maximum collector efficiency was obtained at 13.00 hrs in all three different mass flow rates. Graphs are plotted for variation of outlet temperature with respect to the time with mass flow rates of different values.

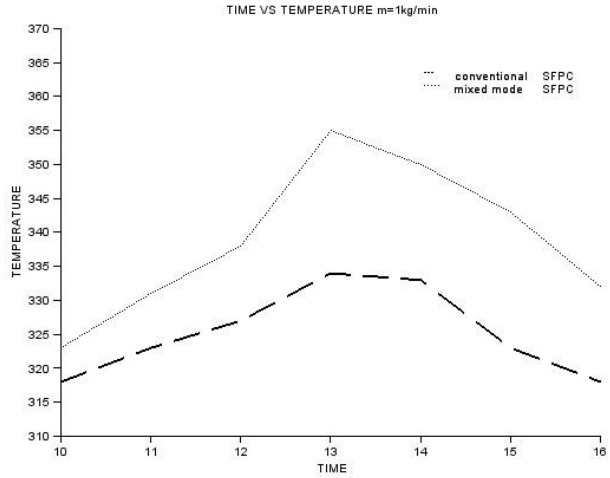

Fig. 4.1: Time vs. Outlet Temperature for conventional and new series system at a mass flow rate of 1kg/min.

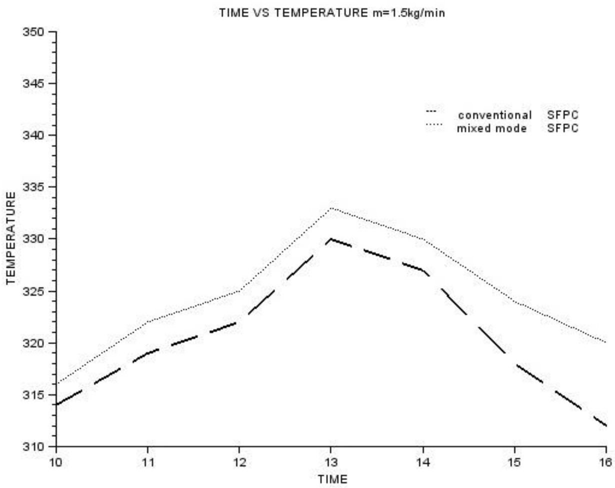

Fig. 4.2: Time vs. Outlet Temperature for conventional and new series system at a mass flow rate of 1.5 kg/min.

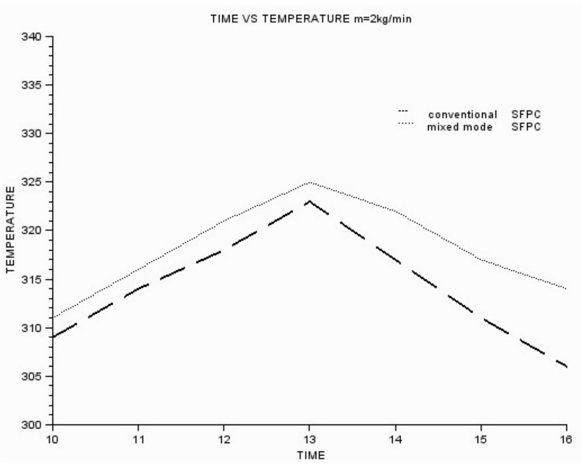

Fig. 4.3: Time vs. Outlet Temperature for conventional and new series system at a mass flow rate of 2 kg/min.

The maximum efficiency is observed at the time 13.00 hours. Overall efficiency in two cases are obtained as 54.12% and 52.92 % respectively. From the results shown above cleared the optimal and efficient results are obtained with mass flow rate of 1 kg/min. Hence it shows that efficiency improvement can be made by increasing the contact surface area as well as maintaining a constant flow rate of 1 kg/min.In case of mixed mode series flat plate collectors outlet temperatures with a mass flow rates of 1.5kg/min are comparable with conventional series flat plate collectors with a mass flow rate of 1 kg/min.

It is cleared from the Figure 4 that the maximum temperature is observed at the time 13.00 hour in all the two cases. Similarly from the Figure 5 that the maximum solar flat plate collector efficiency is observed at the time 13.00 hour in all the two cases.

V. CONCLUSIONS

From the experiments it is cleared that beyond that of increasing performance of series solar flat plate collector by means of increasing contact surface area, changing tube materials of higher conductivity and that of using nano-materials. It is suggested and necessary to maintain mass flow rate as a mean to obtain optimal mass transfer rate and higher outlet temperature. Further increase or decrease in mass flow rate beyond the values of 2kg/min results in decreased outlet temperature and pressure drop inside the flow tubes of the collector which in turn results in generation of steams.

In all these 6 different sets of readings taken mixed mode series flat plate collector proves its higher performance when compared with conventional SFPC.

Fig. 4.1. Photograph of new set of series system taken at Tiruchirappalli, Tamilnadu, India, (longitude 78°43’, latitude 10°46’).

NOMENCLATURE

A_{p}- Area of absorber plate, m^2

A_{c}- Area of collector, m^2

β -Collector tilt angle, degrees

N-Number of covers

T_{c}-Thickness of cover, m

U-Overall heat transfer coefficient, W/m^2K

K_c -Thermal conductivity of cover, W/m^2K

Q_{UN}-Useful energy gain, W

S- Flux absorbed by collector, W/m^2

FR- Heat removal factor

I-solar radiation, W/m^2

S- Flux absorbed by collector, W/m^2

SFPC-Series Flat plate collector.

m-Mass flow rate, kg/min.

C_f –Specific heat of the working fluid, kJ/Kg-K.

F^1- Collector efficiency factor.

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