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Influence of Mass Flow Rate on the Performance of Solar Flat Plate Collector in Forced Convection Mode

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Abstract- A Solar Water Heater (SWH) is a typical device that converts solar energy into thermal energy to heat a heat transfer fluid such as water, non-freezing liquid or air for domestic usage. Solar energy collectors are special kinds of heat exchangers that transform solar radiation energy intothe internal energy of the transport medium.To increase further the thermal performance of solar collectors the interaction between the radiation and mass flow rate was employed in an experimental study on a solar water heater system to evaluate better results. In this research work, experimental analysis has been carried out at different levels of mass flow rate concerning solar irradiance level. Results indicate that efficiency decreases with a decrease in factor x, but it is maximum at a low value of mass flow rate.

Keywords- Solar radiation, thermal performance, solar flat plate collector, efficiency

I. INTRODUCTION

An enormous amount of energy from the sun falls on the earth's surface. The primary concern here is radiation in the wavelength range between 0.3 to 3.0 µm, that portion of the spectrum that includes most of the energy of solar radiation [1]. The average produced over the entire surface of the planet, twenty-four (24) hours per day in a year is approximately 4.2kW/h of energy depending on the earth's location [2]. All the energy stored in the earth's reserve of coal, oil, and natural gas is matched by the energy from just twenty (20) days of sunshine. The energy in sunlight at noon on a cloudless day that falls on Earth's surface is about 1000 kW/m^2 [3].

When a dark surface is placed in sunshine, it absorbs solar energy and heats up. Solar energy collectors working on this principle consist of a sun-facing surface that transfers part of the energy it absorbs to a working fluid in contact with it [4]. To reduce heat losses to the atmosphere and to improve its efficiency, one or two sheets of glass are usually placed over the absorber surface [5]. This type of thermal collector suffers from heat losses due to radiation and convection. Such losses increase rapidly as the temperature of the working fluid increases [6].

Solar Water Heater (SWH) is a typical device that converts solar energy into thermal energy to heat a heat transfer fluid such as water, non-freezing liquid or air for domestic usage [7]. Solar energy collectors are special kinds of heat exchangers that transform solar radiation energy intothe internal energy of the transport medium [8]. A system in which the sun's heat is gathered by a solar collector and used to increase the temperature of a heat-transfer fluid (such as water or a nonfreezing liquid) which flows through the pipes in the collector; the heat contained in this fluid then is conveyed and transferred to the water to be heated [9]. Also, see direct solar water heating system and indirect solar water heating system [10].

Solar water heater is being used worldwide for low-temperature applications mostly in the domestic sector for washing clothes and bathing purposes [11, 12, 13]. Thermosyphon flat plate solar water heater is a solar passive system, which can produce hot water in the temperature range of 60–90℃ [14]. Closed loop or heat-exchanger type or Indirect type solar water heaters are used in which a primary fluid namely pure water or glycol–water mixture is added, to prevent the formation of scaling on the inner surface of the copper tubes due to passage of high saline water and to prevent damage to tubes due to water freezing in cold climates [15]. Due to the low thermal conductivity of water and the heat exchanger's effectiveness, the temperature attained by the secondary fluid is reduced [16]. In this study, experimental analysis of solar water heaters in forced convection mode with a variation of different process parametershas been done.

II. EXPERIMENTAL SETUP

To increase further the thermal performance of solar collectors the interaction between the radiation and mass flow rate was employed in an experimental study on a solar water heater system to evaluate better results. The effect of the flow passage geometry on the heat convective coefficient between the air stream and the plate was particularly examined. Radiation and mass flow

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rateswerevaried and examined to optimize the thermal performance of the system. An experimental investigation was conducted on two matrices constituted by the randomly stacking level of Solar radiation level in which we considered High radiation level, Medium Radiation level and Low Radiation level, these parameters to identify the Radiation level in which Thermal efficiency is maximum and overall losses are minimum and another one is the Tilt angle of the flat plate collector is perpendicular to the Irradiation from the sun or Artificial Halogen setup then the Heat loss coefficient of the collector is the minimum and thermal efficiency of the sun is maximum.
Both objectives noticed the Experimental setup to perform many experiments at various parameters and conditions.

Other parameters with different characters and forms were used various conditions were tested, ambient temperature, wind flow speed, tilt angle, Solar radiation level, Inlet water temperature and outlet water temperature. In these cases, the test showed that the thermal performance of the solar water heater system was improved in comparison to those of plate collectors. The thermal performance of the flat plate collector has been evaluated theoretically and experimentally.

Where the copper tube of the collector was filled with water by the forced flow with the help of the pump from the analysis of the results it was observed that the collectors filled with recirculated water from the hot water storage tank and tube gavehigher efficiencies than the at plate collector. These materials were used for heat absorption and transfer the heat through the water to the hot water storage tank where it can be taken out for use. The test of performance on the solar water heater system with all parameters permitted to show the clear enhancement of thermal performance.Fig.1 experimental setup shows the overview of the system in which we can see the whole experimental setup.

Fig.1: Experimental setup of SWH

III. COMPONENTS OF THE SYSTEM

All information regarding the experimental setup comes from the experiment manual, The experimental system is efficient for the experiments performed taking various parameters for optimization results, and all data collected from the experimental setup is arranged in a specific table for reading and understanding purposes. At the time of experiments various instruments and devices were used, and they are necessary for the experiments while considering parameters for optimizations. Detailed information regarding solar water heater systemsis arranged in a tabulated form with their specifications and remarks.

Table 1: Overall Specifications of the System

Component	Specification	Remark
Water heating system (Collector and water tank)	Collector area: 0.716 m2 Tank Capacity: 50 L	Collector: Flat plate collector (To collect and transfer heat), A non-pressurized aluminum tank.
Halogen system	Halogen fixture's area: 0.72 m2 Number of halogen lamps: 21 Power: 150 W each Regulator: 5000 W	Halogen: To supply the required intensity on the collector. Regulator: To adjust the intensity at the desired level
Radiation meter	Range: 0 to 1999 W/m2 Power Supply: DC	To measure the radiation level on the collector
External water tanks	Capacity: 80 L	To supply cold water to the heating system
Water pump	Power supply: AC Power: 0.12 hp	To lift water up to the desired level. To facilitate the forced mode operation.
Water flow meter (for forced mode)	Sensor: Flow range: 0.5 to 25 LPM Working voltage: 4.5 to 24 VDC	Mini turbine wheel-based technology. To measure the water flow rate during the forced mode operation.
Anemometer	Air velocity: 0.42 to 45.0 m/sec Resolution: 0.1 m/sec Accuracy: (±2%+0.1 m/sec)	The anemometer can measure the air velocity and the ambient air temperature. The airflow sensor is a low-friction ball bearing. The temperallIre sensor is a precision thermistor
Thermometers	Class A sensor Range: - 200 to 650 °C Accuracy: ±0.15 + 0.002×(t) t in °C	Works out the principle of variation of resistance with temperature. To measure the inlet, outlet, plate and tank water temperature
fan	Range: 0 to 5 m/sec	Supply the wind

IV. METHODOLOGY

Fig.2 shows the methodology used in this work and the experiment performed according to instructions given in the experiment manuals.

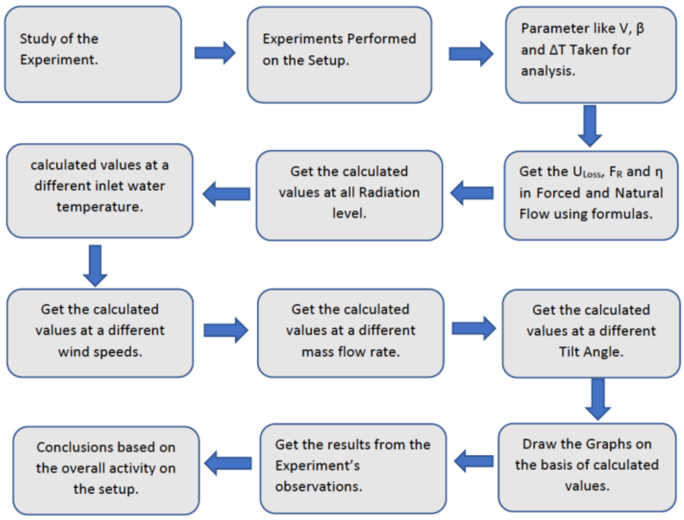

Fig.2: Flow diagram of the methodology

A proper installation of the set-up is carried out at the laboratory of the I.P. Department of Jabalpur Engineering

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College, Jabalpur. The arrangement is so made that maximum solar radiation remains available throughout the all-time at the time of Experiments. Careful instalments of measuring instruments at desired points are done for collecting data.

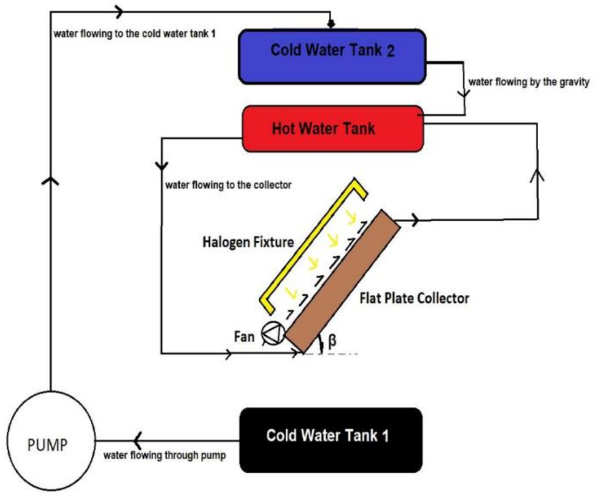

Fig.3: Flow Diagram of the Experimental setup

All the glass covers were cleaned properly from dust/dirt particles before /during the experimentation. Initially, cold-water tank 1 is filled with normal water then water transmits from the cold-water tank to cold water tank 2 with the help of a pump installed at the Bottom after that from cold-water tank 2 water is falling into the hot water tank with the help of gravity. All operations of water flowing from tank to tank or evenly to the collector are controlled by the valves one by one.

When the hot water tank is filled by the water we open other valves and close previously opened valves, now experiments going to start and water will flow from the hot water tank to the flat plate collector in forced flow mode, now switch on the halogen fixture, and regulate it to the certain radiation level according to the requirement of the experiment. Now the water gets warm by the radiation and gets back to the hot water tank for use. For initial parameters displayed on the Display measuring unit, we can record all values in the form of a table after a certain time interval when values are going to change due to an increase in temperature.Some major parameters and their formulas used in our analysis as a methodology to get optimised results: -

V. DATA DEDUCTION

1.Total Heat Loss Coefficients (U_L)

Basically, in the experiments, we aim to generate the maximum amount of heat from the source of generation and reduce the losses to maximize thermal performance.

Therefore, we calculate the total heat loss coefficient, we also evaluate the bottom heat loss coefficient, edge heat loss coefficient and top total heat loss coefficient. Optimization of the heat loss coefficient for the flat plate collector is important for the evaluation of its performance. If the values of a total heat loss coefficient are higher than losses are higher and efficiency is lower.

$$U_{total} = U_t + U_b + U_e \quad (1)$$

From the Klein (1975), the top heat loss using the flowing formula for the calculations

$$U_t = \left\{\frac{\frac{1}{N}}{\frac{C}{T_p}\left[\frac{T_p - T_a}{N+f}\right]^{0.33} + \frac{1}{h_a}}\right\} + \left\{\frac{\sigma(T_p+T_a)(T_p^2+T_a^2)}{(\varepsilon_{p+0.05N(1-\varepsilon_p)})^{-1} + \frac{2N+f-1}{\varepsilon_g} - N}\right\} \quad (2)$$

Where,

$C = 365.9 \times (1 - 0.00883\beta + 0.0001298\beta^2)$

$h_a = 5.7 + 3.8V$

$f = (1 + 0.04h_a - 0.0005ha^2) \times (1 + 0.091N)$

$$U_b = \frac{k_b}{x_b} \quad (3)$$

$$U_e = U_b\left(\frac{A_e}{A_c}\right) \quad (4)$$

Ub and Ue are the heat loass coefficient from the bottom and edge

2.Heat Removal Factor (F_R)

Heat removal is nothing but it is the ratio of the actual useful energy gain to the useful energy gain if the entire collector were at the fluid inlet temperature. The heat Removal Factor depends on factors like inlet water temperature, outlet water temperature and ambient temperature, area of the collector etc. The importance of heat removal factors remains with the efficiency of the system. The value of the heat removal factor is always higher when the system is highly efficient and losses are less. Heat removal factors formulate in the form of some basic equations For a straight fin with a rectangular profile, the fin efficiency is given as:

$$F_R = \frac{Actual\ useful\ energy\ gain}{Useful\ energy\ gain\ if\ the\ entire\ collector\ were\ at\ the\ fluid\ inlet\ temprature} \quad (5)$$

$$F_r = \frac{\dot{m}C_p(T_0 - T_i)}{A_c[I(\tau_0\alpha_0) - U_L(T_i - T_a)]} \quad (6)$$

3.Thermal Efficiency of the collector (η)

The efficiency of the system is the way to define the working of thesystem in a proper way, in which total input energy given to the systemis converted into Useful heat gain. The thermal efficiency of the systemis the ratio of the Useful heat gain to the Total input energy.Efficiency is the most important for a system. This factor can definethe system's output. For a flat plate collector based on a solar waterheater system, the efficiency is defined as the ratio of the useful energydelivered to the energy incident on the collector aperture.The value of the efficiency is dominated by parameters like the product ofthe glazing's transmittance and absorbing plate's absorptance, the intensity ofglobal radiation falling on the collector, water inlet temperature andambient air temperature.

$$\eta = F_r\left[(\tau_0\alpha_0) - \left\{\frac{U_L(T_i - T_a)}{I}\right\}\right] \quad (7)$$

Factor X

$$\text{FactorX} = \frac{(T_i - T_a)}{I} \quad (8)$$

The above formulas and their calculations-based parameters were taken at thetime of experiments, and performed at various times with accuracy.In the calculations some of the parameters are taken constant, we dealwith some of the parameters which are inlet water temperature, outlet watertemperature, ambient temperature, solar radiation, and wind flowspeed. We try our best to optimise our analysis for thecalculations. When calculating the combination of all parameters withtheir specified value, the results tend to the desired point.

VI.RESULTS

In this experimental analysis, three experimental analyses have been considered. The first case was performed at different mass flow rateswith a solar irradiance level of 400 w/m^2, the second case was performed at a different mass flow rate with a solar irradiance level of 600 w/m^2 and the third case was performed at a different mass flow rate with solar irradiance level of 800 w/m^2. The result of the variation of mass flow rate on efficiency and factor X at different solar irradiance levels has been discussed.

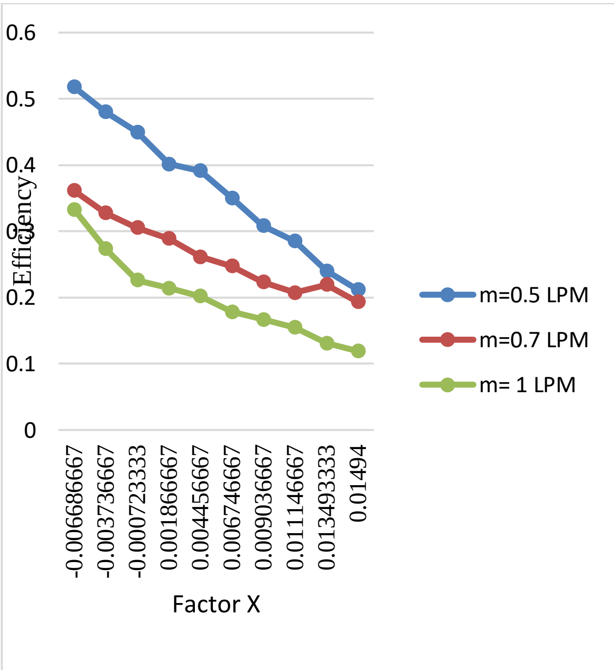

Fig.4: Variation of efficiency and factor X at different mass flow rates for solar irradiance 400 w/m^2

From Fig. 4, it is observed that efficiency decreases with an increase in mass flow rate. This suggests that the efficiency of the system depends on factor X, i.e. efficiency decreases with an increase in the value of factor X. Also, ata higher mass flow rate value, the collector may absorb more heat than it can effectively transfer to the working fluid (water). This can result in higher heat losses through conduction, convection, and radiation, reducing the overall efficiency.For case 1, max. efficiency is achieved at a mass flow rate of 0.5 LPM and a lower value of factor X is 0.517 to 0.211.

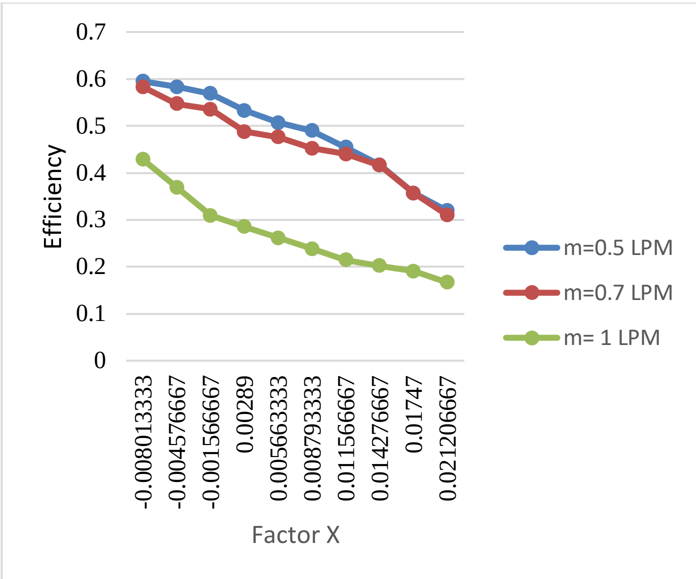

Fig.5: Variation of efficiency and factor X at different mass flow rates for solar irradiance 600 w/m^2

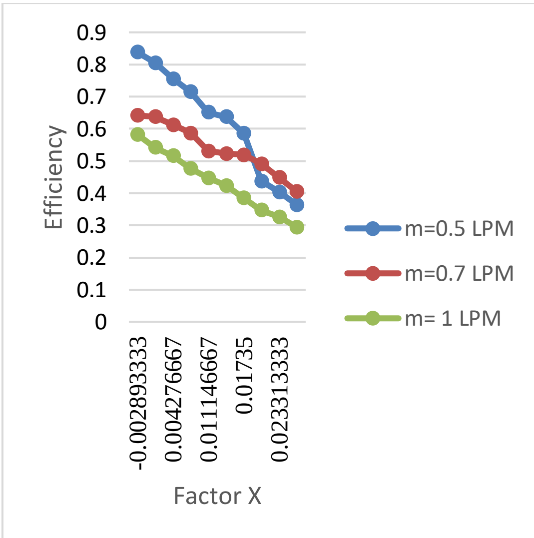

Fig.6: Variation of efficiency and factor X at different mass flow rates for solar irradiance 800 w/m^2

From fig. 5 and 6, it is observed that efficiency decreases with an increase in mass flow rate. This suggests that the efficiency of the system depends on factor X, i.e. efficiency decreases with an increase in the value of factor X. Also, with an increased mass flow rate, the collector plate temperature can rise significantly. If the temperature of the collector plate becomes too high, it can lead to higher thermal losses due to increased heat transfer to the surroundings. For case 2, max. efficiency is achieved at a mass flow rate of 0.7 LPM with the lower value of factor X is 0.594 to 0.319. For case 3, max. efficiency is achieved at a mass flow rate of 0.5 LPM and a lower value of factor X is 0.837 to 0.363.

VII. CONCLUSION

In this research work, experimental analysis has been carried out at different levels of solar mass flow rate.It is conducted that:

- Efficiency decreases with an increase in mass flow rate in all considered cases.
- At higher solar irradiance levels, there may be a tendency for thermal stratification within the collector. This means that there can be a significant temperature difference between the top and bottom of the collector, leading to reduced overall efficiency.
- For case 1 at 400 w/m^2, max. efficiency is achieved at a mass flow rate of 0.5 LPM and factor X is 51.7% to 21.1%.
- For case 2 at 600 w/m^2, max. efficiency is achieved at a mass flow rate of 0.5 LPM with factor X is 59.4% to 31.9%.
- For case 3 at 800 w/m^2, max. efficiency is achieved at a mass flow rate of 0.5 LPM and factor X is 83.7% to 36.3%.

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