Solar Flat Plate Thermal Collector
OBJECTIVE:
Performance Study of Solar Flat Plate Thermal Collector Operation with Variation in Mass Flow Rate and Level of Radiation

INTRODUCTION:
Solar water heater is one of the simplest and basic technologies in the solar energy field. Collector is the heart of any solar water heating system. It absorbs and converts the solar energy into heat and then transfers that heat to a stream of water. There are different types of solar thermal collector. This experimental setup is using a flat plate collector.

Performance of Solar Thermal Water Heater has to be compared for the following cases:

CASE 1. Study the effect of mass flow rate on the Solar Thermal Water Heater (STWH) performance
1. Record the observations maintaining a time gap of 20 minutes among three different flow rate values and evaluate the parameters.
2. Following parameters to be plotted in graphs w.r.t. mass flow rate
   a. Efficiency, b. Outlet Temperature and c. Plate temperature
3. Obtain the optimum flow rate from graphs plotted in 2a and 2b.

CASE 2: Study the effect of varying level of radiation from Minimum to Maximum by
1. Maintaining a time gap of 20 minutes between each set of readings.
2. Ploting the efficiency vs radiation graph for different radiation levels.
THEORY:

A typical flat-plate collector consists of an absorber plate in an insulated box together with transparent cover sheet(s).

- **Work and properties of different components of a flat plate collector**
  - **Absorber plate:**
    It is a flat conducting plate to which the tubes, fins, or passages are attached. It may be a continuous or discrete plate. The plate is usually coated with a high absorptance and low emittance layer.
  - **Cover plate:**
    One or more sheet of glass or other radiation-transmitting material forms the cover plate. The cover plate serves two purposes, minimization of convective heat loss and blocking of IR radiation.
  - **Heat removal passages:**
    These are tubes, fins, or passages which conduct or direct the stream of water from the inlet to the outlet of the collector.
  - **Headers or manifolds:**
    These are the pipes to admit and discharge water that is meant to be heated.
  - **Insulation:**
    Insulations such as Rockwool or Glass wool are fitted in the back and sides of the collector to prevent heat loss from the collector.
  - **Casing:**
    The casing surrounds the aforementioned components and protects them from dust, moisture and any other material.

In the following Figure-1, schematic diagram of a typical flat-plate collector is shown with different parts at their proper locations.
Fig-1: Schematic diagram of a typical flat-plate collector

Table-1: Overall Specifications of the system

<table>
<thead>
<tr>
<th>Components</th>
<th>Specification</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water heating system (Collector and water tank)</td>
<td>Collector area: 0.716 m$^2$</td>
<td>Collector: Flat plate collector. To collect and transfer energy</td>
</tr>
<tr>
<td></td>
<td>Tank capacity: 50 L</td>
<td>Tank: non pressurized aluminum tank. To store water</td>
</tr>
<tr>
<td>Halogen system</td>
<td>Halogen fixture’s area: .0.72 m$^2$</td>
<td>Halogen: To supply the required intensity on the collector.</td>
</tr>
<tr>
<td></td>
<td>Number of halogen lamp: 21</td>
<td>Regulator: To adjust the intensity at the desired level</td>
</tr>
<tr>
<td></td>
<td>Power :150 W each</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Regulator: 5000 W</td>
<td></td>
</tr>
<tr>
<td>Radiation meter</td>
<td>Range: 0 to 1999 W/m$^2$</td>
<td>To measure the radiation level on the collector</td>
</tr>
<tr>
<td></td>
<td>Power supply: DC</td>
<td></td>
</tr>
<tr>
<td>External water tanks</td>
<td>80 L</td>
<td>To supply cold water to the heating system</td>
</tr>
<tr>
<td>Equipment</td>
<td>Specifications</td>
<td>Purpose</td>
</tr>
<tr>
<td>---------------------------</td>
<td>-----------------------------------------------------</td>
<td>-------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Water pump</td>
<td>Power supply: AC</td>
<td>To lift water up to the desired level.</td>
</tr>
<tr>
<td></td>
<td>Power: 0.5 hp</td>
<td>To facilitate the forced mode operation.</td>
</tr>
</tbody>
</table>
| Water flow meter (for forced mode) | Sensor:  
     Flow range: 0.5 to 25 LPM  
     Working voltage: 4.5 to 24 VDC  
     Max. Pressure: 17.5 bar  
     Working pressure: 0 to 10 bar  
     Max rated current: 8 mA  
     Withstand current: 15 mA  
     Working temp: up to 80°C  
     Storage temp: 25 to 65°C  
     Accuracy: 1 % fsd  
     Supply voltage: 230 V AC. | Mini turbine wheel based technology. To measure the water flow rate during the forced mode operation. |
| Stop watch                | With electronic On-Off switch and a Reset button    | To detect the time during natural flow rate measurement                 |
| Anemometer                | Air velocity:  
     Range: 0.4 to 45.0 m/sec  
     Resolution: 0.1 m/sec  
     Accuracy: (±2% + 0.1 m/sec)  
     Air Temperature:  
     Range: -14 to 60°C  
     Resolution: 0.1°C  
     Accuracy: 0.5°C  
     Power supply: DC 4*1.5 AAA size | The anemometer can measure the air velocity and the ambient air temperature. The air flow sensor is a conventional angled vane arms with low friction ball bearing. The temperature sensor is a precision thermistor. |
| Pressure Gauges           | Sensor:  
     Range: 0 to 6 bar  
     Accuracy: ±3 kPa  
     Output: 4 to 20 mA (±3)  
     Input: 4-20 mA DC  
     Power: 220 VAC | Semiconductor thin-film based technology. Works on the principle of generation of electrical signal due to exertion of pressure. To measure the inlet and outlet pressure. |
| Thermometers              | Sensor:  
     Class A sensor  
     Range: -200 to 650°C  
     Accuracy: ± 0.15 +0.002*(t)  
     Where t is absolute value of temperature in °C  
     Range -100 to 200°C  
     Supply Voltage: 230AC | Sensor is RTD based platinum probe. Works on the principle of variation of resistance with temperature. To measure the inlet, outlet, plate and tank water temperature. |
<table>
<thead>
<tr>
<th>Fan</th>
<th>Range : 0 to 5 m/sec</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Power supply: AC with regulators</td>
</tr>
<tr>
<td></td>
<td>To supply the wind at the desire speed</td>
</tr>
</tbody>
</table>

**Table-2: Detail Specification of the collector**

<table>
<thead>
<tr>
<th>Overall data</th>
<th>Overall collector dimension</th>
<th>Mm</th>
<th>915X810 X95</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight of the collector</td>
<td>Kg</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Aperture Area</td>
<td>m²</td>
<td>0.63</td>
<td></td>
</tr>
</tbody>
</table>

**Glazing**

<table>
<thead>
<tr>
<th>Glazing type and number</th>
<th>Type of glass</th>
<th>Toughened Glass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glazing thickness</td>
<td>mm</td>
<td>3</td>
</tr>
<tr>
<td>Glazing transmission</td>
<td>%</td>
<td>85</td>
</tr>
<tr>
<td>Glazing Emissivity</td>
<td>%</td>
<td>88</td>
</tr>
</tbody>
</table>

**Absorption plate**

<table>
<thead>
<tr>
<th>Absorber material</th>
<th>Copper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absorber plate thickness</td>
<td>mm</td>
</tr>
<tr>
<td>Absorber plate dimension</td>
<td>mm</td>
</tr>
<tr>
<td>Emissivity of surface</td>
<td>%</td>
</tr>
<tr>
<td>Absorption of surface</td>
<td>%</td>
</tr>
</tbody>
</table>

**Risers & headers**

| Number of risers | 6 |
| Riser dimension | mm | 800 |
| Headers dimension | mm | 882 |
| Test pressure | kpa | 400 |
| Maximum working pressure | kpa | 250 |

**Insulation**

<table>
<thead>
<tr>
<th>Insulation material</th>
<th>Rockwool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation density</td>
<td>Kg/m³</td>
</tr>
<tr>
<td>Insulation thickness-base</td>
<td>mm</td>
</tr>
<tr>
<td>Insulation thickness-side</td>
<td>mm</td>
</tr>
<tr>
<td>Conductivity</td>
<td>W/mK</td>
</tr>
</tbody>
</table>

**Casing**

| Frame type | Aluminum Box |
| Frame colour | Black |
| Casing thickness | mm | 1.4 |

**Insulated tank**

| Tank type | Non pressurized, Horizontal |
| Tank materials | SS – 304 |
| Tank insulation | PUF |
| Tested pressure | kPa | 294.11 |
| Tank size | 815 X400 |

**Overall Efficiency**

|Ƞ | % | 80 % |
Important parameters of a flat plate collector based solar water heating system:

The performance of a solar water heating system depends upon different design and atmospheric parameters. The meaning and importance of some of the most dominating parameters are described below.

**Overall Heat loss coefficient ($U_L$):**

All the heat that is generated by the collector does not resulted into useful energy. Some of the heat gets losses to the surroundings. The amount of heat losses depends upon the convective, conductive and radiation heat loss coefficients.

Estimation of heat loss coefficient of the flat plate collector is important for its performance evaluation. A higher value of heat loss coefficient indicates the lower heat resistance and hence the lower efficiency.

Among all heat loss parameters the top loss contributes the most. The top heat loss coefficient is a function of various parameters which includes the temperature of the absorbing plate, ambient temperature, wind speed, emissivity of the absorbing and the cover glass plate, tilt angle etc.

**Heat Removal Factor ($F_R$):**

Heat removal factor represents the ratio of the actual useful energy gain to the useful energy gain if the entire collector were at the fluid inlet temperature. It depends upon the factors like inlet and outlet water temperature, the ambient temperature, area of the collector etc. The importance of heat removal factors remains with the efficiency of the system. For a highly efficient system a higher value of heat removal factor is must.

**Efficiency ($\eta$):**

Efficiency is the most important factor for a system. This factor determines the system’s output. For a flat plate collector based solar water heater system the efficiency is defined as the ratio of the useful energy delivered to the energy incident on the collector aperture. The value of efficiency is dominated by parameters like product of glazing’s transmittance and absorbing plate’s absorptance, intensity of global radiation falling on the collector, water inlet temperature and ambient air temperature.

**Collector Time constant:**

Collector time constant is required to evaluate the transient behavior of a collector. It is define as the time required rising the outlet temperature by 0.632 of the total temperature increase from $T_{f_0} - T_a$ at time zero to $T_f - T_a$ at time infinity i.e. time at which the outlet temperature attains a stagnant value. It can be calculated from the curve between R and time as shown below. The time interval for which R value is 0.632, is the time constant of the give collector.
In terms of temperatures R is defined as,

\[ R = \frac{T_{fo}(t) - T_{fo}(0)}{T_{fo}(\alpha) - T_{fo}(0)} \]

Where,

- \( T_{fo}(t) \): Outlet water temperature at any time \( t \)
- \( T_{fo}(0) \): Outlet water temperature at time zero
- \( T_{fo}(\alpha) \): Outlet water temperature at infinite time (maximum temperature)

Shape of the graph between \( R \) and time is as shown below.

**Basic Equations to calculate different parameters:**

**A. Heat Loss coefficient (UL)**

\( U_L \) is the overall heat transfer coefficient from the absorber plate to the ambient air. It is a complicated function of the collector construction and its operating conditions.

In simple terms it can be expressed as,

\[ U_L = U_t + U_b + U_e \] (1)

According to Klein (1975), the top loss coefficient can be calculated by using the following formula

\[
U_t = \left( \frac{C}{T_p + T_o} \right)^{0.55} \left( \frac{1}{h_a} \right) + \frac{1}{T_p + T_o} \frac{1}{N + f} \left[ \frac{1}{h_a} + \frac{1}{\sigma (T_p + T_o)} \left( T_p + T_o \right) \left( T_p^2 + T_o^2 \right) \left( \varepsilon_p + 0.05N(1 - \varepsilon_p) \right) \right]^{-1} \left( \frac{1}{h_g} + \frac{1}{\varepsilon_g} \frac{1}{N} \right)
\] (2)

Where,

- \( C = 365.9 \times (1 - 0.00883a + 0.0001298 \times \beta^2) \)
- \( f = (1 + 0.04 h_a - 0.0005 h_a^2) \times (1 + 0.091N) \)
- \( h_a = 5.7 + 3.8v \)
The heat loss from the bottom of the collector is first conducted through the insulation and then by a combined convection and infrared radiation transfer to the surrounding ambient air. However the radiation term can be neglected as the temperature of the bottom part of the casing is very low. Moreover the conduction resistance of the insulation behind the collector plate governs the heat loss from the collector plate through the back of the collector casing. The heat loss from the back of the plate rarely exceeds 10% of the upward loss. So if we neglect the convective term there will not be much effect in the final result. Thus to calculate the bottom loss coefficients we can use the following formula

\[ U_b = \frac{k_b}{x_b} \]  

Typical value of the back surface heat loss coefficient ranges between 0.3 to 0.6 W/m²K.

In a similar way, the heat transfer coefficient for the heat loss from the collector edges can be obtained by using the following formula

\[ U_e = U_b \frac{A_e}{A_C} \]  

**B. F factors of a flat plate collector (F, F’, FR, F”)**

1. Fin efficiency (F)

For a straight fin with rectangular profile the fin efficiency is given as

\[ F = \tanh \left( \frac{m(W-\delta)}{2} \right) \]  

Where,

\[ m = \frac{U_l}{k \delta} \]

2. Collector efficiency factor (F’)

\[ F' = \frac{\text{Actual useful heat collection rate}}{\text{Useful heat collection rate when the collector absorbing plate is at the local fluid temperature}} \]

Mathematically,

\[ F' = \frac{\frac{1}{U_L}}{W \left[ \frac{1}{U_L} \right] \left[ \frac{1}{C_f \pi \delta h_f} \right] \left[ \frac{1}{C_f \pi \delta h_f} \right]} \]

3. Heat Removal factor (F_R)

\[ F_R = \frac{\text{Actual useful energy gain}}{\text{Useful energy gain if the entire collector were at the fluid inlet temperature}} \]

Mathematically,

\[ F_R = \frac{\frac{\dot{m}C_p}{A_c U_L}}{1 - \exp \left( - \frac{U_L F' A_c}{\dot{m}C_p} \right)} \]
Another formula for FR,

\[ F_R = \frac{m c_p (T_f - T_i)}{A_c \left[ (r F + T_f) - U_c (T_f - T_a) \right]} \]  \hspace{1cm} (8)

4. Flow Factor (F"

It is the ratio of the heat removal factor (F_R) and the collector efficiency factor (F/) Mathematically,

\[ F" = \frac{m c_p}{A_c U_c F} \left[ 1 - \exp \left( - \frac{U_c F}{m c_p} \right) \right] \]  \hspace{1cm} (9)

The parameter \( \frac{m c_p}{A_c U_c F} \) is called the collector capacitance rate. It is a dimensionless

C. Collector Plate Temperature (T_P)

At any point of time the collector plate temperature is given as

\[ T_P = T_i + \frac{Q_u}{A_c F_R U_c} (1 - F_R) \]  \hspace{1cm} (10)

Where, the useful heat gain \( Q_u \) is given as:

\[ Q_u = A_c F_R [I_c (r F + T_f) - U_c (T_f - T_a)] \]  \hspace{1cm} (11)

D. Thermal Efficiency of the collector (\( \eta \))

It is the ratio of the Useful heat gain to the Total input energy

Mathematically,

\[ \eta = k_\theta F_R \left[ (r F + T_f) - U_c (T_f - T_a) \right] \]  \hspace{1cm} (12)

E. Thermal Efficiency of the collector when angle of incident is not 90° (\( \eta_\theta \))

The equation number (12) for the thermal efficiency is applicable for a normal incident angle situation. In a situation where angle of incident is not 90° we will have to add a new parameter in the equation number (12). The new parameter is known as incident angle modifier (k_\theta). The necessity of (k_\theta) is arises due to change in (r F) product.

For a flat plate collector (k_\theta) is given as
For a single glaze collector we can use a single order equation with,

\[ k_\theta = 1 - b_0 \left( \frac{1}{\cos \theta} - 1 \right) \]  

(13)

Thus for a collector where angle of incident is not 90°, the efficiency can be calculated by using the following equation,

\[ \eta_\theta = k_\theta F_g \left[ (\tau_0 a_0) - \frac{u_c (T_r - T_a)}{I_t} \right] \]  

(15)

**Experimental set-up:**
The system has been designed to perform experiments in both Thermosyphonic and Forced modes of flow.

**Schematic diagram of the experimental setup:**
Description of different components:

1. Radiation meter: To measure the radiation level that is received by the collector a radiation meter is supplied with the system. It is a sensing based device. It can measure the radiation level in the range of 0 to 1999 w/m².

2. Thermometer

Five thermometers are connected to the system. The Sensors are RTD based platinum probe and work on the principle of variation of resistance with temperature. The probes are class A RTD and can measure the temperature in the range of -200°C to 650°C.

3. Pressure Gauge

Two pressure gauges are there in the setup. They work on the principle of generation of electrical signal by semiconductor device due to exertion of pressure. The pressure gauges can measure the pressure in the range of 101.3 to 650 kpa.

4. Water flow meter

To measure the water flow rate a panel mount flow meter with a mini turbine flow sensor is connected near the collector inlet. It is a programmable meter. It can measure the flow rate in the range of 0.5 to 25LPM. The temperature limit of the meter is up to 80°C.

5. Pump:

We are using an AC pump to fill up the collector tank as well as to circulate the water through the collector at some regulated speed. A continuous regulator is there to maintain the flow rate.

6. Anemometer

An anemometer is supplied with the system. This can be used to measure the air velocity and the ambient air temperature. 

The air flow sensor is a conventional angled vane arms with low friction ball bearing while the temperature sensor is a precision thermistor. The anemometer can measure the wind velocity in the range of 0.4 to 45.0 m/s while the temperature range is -10 to 60°C.

7. Fan:

One AC fan is integrated with the system to generate the artificial wind speed. To set the wind speed as per requirement a regulator is there in the main control unit.

8. Valve: Different valves are there to direct the water flow as per requirement.

Assumptions:

To perform different experiments with this set-up a number of assumptions need to be made. These assumptions are not against the basic physical principles but simplify the problems up to a great extent.

1. The collector is in a steady state.

2. The headers cover only a small area of the collector and can be neglected.
3. Heaters provide uniform flow to the riser tubes.
4. Flow through the back insulation is one dimensional.
5. Temperature gradients around tubes are neglected.
6. Properties of materials are independent of temperature.
7. No energy is absorbed by the cover.
8. Heat flow through the cover is one dimensional.
9. Temperature drop through the cover is negligible.
10. Covers are opaque to infrared radiation.
11. Same ambient temperature exists at the front and back of the collector.
12. Dust effects on the cover are negligible (if otherwise mention).
13. There is no shading of the absorber plate (if otherwise mention).

**CASE 1**

**Objective:** Evaluation of $U_t$, $F_r$, $\eta$ and drawing of different curves in forced mode of flow with different flow rate.

**Note:** The minimum flow rate that can be measured by the flow meter is 0.5 LPM. So user should set the flow rate above 0.5 LPM.

<table>
<thead>
<tr>
<th>Sl No</th>
<th>Valve no</th>
<th>Connection</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Cold water tank 1 to pump</td>
<td>To fill cold water tank 2</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Pump to cold water tank 2</td>
<td>To fill cold water tank 2</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>Cold water tank to Hot water tank</td>
<td>To fill hot water tank</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>Hot water tank to collector (Natural mode)</td>
<td>Natural mode of operation</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>Cold water tank to hot water tank</td>
<td>To drain hot water tank</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>Hot water tank to pump (forced mode)</td>
<td>Forced mode of operation (to supply water to pump)</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>Pump to collector (forced mode)</td>
<td>To regulate flow in forced mode</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>Pump to hot water tank</td>
<td>To regulate flow in forced mode</td>
</tr>
</tbody>
</table>
Methodology:

1. Fill the cold water tank 2.
2. Close all valves except valve no. 3 and 4.
3. Once water overflows the hot water tank close all valves except valve no.6 and 7.
4. Switch ON the pump and set the regulator at the middle position.
5. See the flow rate on the flow meter screen (forced mode).
6. To get the required flow rate first open the valve No. 8 completely and then adjust the valve No. 7.
7. Wait for some time to get a stable flow rate reading.
8. Once flow rate is set note all the readings.
9. Switch ON the wind generating fan and set the speed at the desire level.
10. To know the wind speed and ambient air temperature use same methodology as in experiment No 1.
11. Switch ON the halogen system and set the radiation at the desire level.
12. To know the radiation level use same methodology as in experiment No 1.
13. Note all the readings after every 5 minutes.
14. Keep the pump ON throughout the experiment.

Observations:

- Tilt angle of collector ($\beta$) ______ deg
- Wind speed (v): ______ m/sec
- Radiation level (I): ______ W/m$^2$

Table - 1: Values of different parameters in forced mode of flow with flow rate

<table>
<thead>
<tr>
<th>Sl No</th>
<th>Time ($t_{min}$)</th>
<th>Ambient temperature ($T_\text{a}^\circ C$)</th>
<th>Inlet Water temperature ($T_\text{f}^\circ C$)</th>
<th>Plate temperature ($T_\text{p}^\circ C$)</th>
<th>Outlet water temperature ($T_\text{f}^\circ C$)</th>
<th>Water temperature in the storage tank ($T_\text{s}^\circ C$)</th>
<th>Water mass flow rate ($\dot{m}$, kg/sec)</th>
<th>Inlet water pressure ($p_\text{in},$ kPa)</th>
<th>Outlet water pressure ($p_\text{out},$ kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Similar observations must be tabulated for other values of flow rate.

Calculations:

Calculate $U_1$, $F_R$ and $\eta$ for each cases
Calculate flow factor ($F^//_R$) for each cases.

Results:

Draw the following graphs:

a. Efficiency v/s Mass flow rate
b. Outlet temperature v/s Mass flow rate

c. Optimum flow rate

d. Flow factor v/s Collector capacitance rate

e. Plate temperature v/s Mass flow rate

f. Heat loss v/s Flow factor
CASE 2

Objective: Evaluation of $U_t$, $F_r$, $\beta$ in forced mode of flow at different radiation level

2.1 Maximum Radiation Level

Methodology:

1. Fill up the cold water tank 2 with water at the desire temperature
2. Close all valves excepts valve No. 3 and 4
3. Once water overflows the hot water tank close all valves except valve No.6 and 7
4. Switch ON the pump and set the regulator at the middle position
5. See the flow rate on the flow meter screen (forced mode)
6. To get the required flow rate adjust the valve No. 7 and 8
7. Wait for some time to get a stable flow rate reading
8. Once flow rate is set note all the readings
9. Switch ON the halogen system and set the Regulator for Radiation at the desire level
10. Note all the readings after every 5 minutes
11. Keep the pump ON throughout the experiment
12. To know the radiation level, wind speed and ambient air temperature use same methodology as in experiment No 1.

Observation:

- Tilt angle of collector ($\beta$)__________ deg
- Wind speed (v):_____________ m/sec
- Water mass flow rate : _____________________($\dot{m}$, kg/sec)

Table -2: Values of different parameters in forced mode of flow with different irradiation levels

<table>
<thead>
<tr>
<th>Sl No.</th>
<th>Time (tmin)</th>
<th>Ambient temperature ($T_{a}^{0}C$)</th>
<th>Inlet Water temperature ($T_{t}^{0}C$)</th>
<th>Plate temperature ($T_{p}^{0}C$)</th>
<th>Outlet water temperature ($T_{f}^{0}C$)</th>
<th>Water temperature in the storage tank ($T_{s}^{0}C$)</th>
<th>Radiation level (W/m$^2$)</th>
<th>Inlet water pressure ($p_{i}$, kPa)</th>
<th>Outlet water pressure ($p_{o}$, kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Similar observations must be tabulated for other radiation levels.

Calculation:

1. Calculate $U_t$, $F_r$ and $\eta$ for each cases as in Case.1
2. Result: Draw the efficiency graph for different radiation level

DISCUSSION:

1. With increase in flow rate, how the temperature of the hot water tank should change and why?
2. What are the other parameters which will affect the performance of the Solar Thermal Water Heater (STWH) and how?
Nomenclatures:

- $A_c$: Area of the collector (m$^2$)
- $A_e$: Area of the edge (m$^2$)
- $b$: Bond conductance
- $C_p$: Heat capacity of water (kJ/(kg °C))
- $D$: Outer diameter of the risers (mm)
- $h$: Heat transfer coefficient between the water and the riser wall
- $I$: Radiation falling on the collectors per unit area (W/m$^2$)
- $k_b$, $k_e$: Conductivity of the back and edge insulation (W/mK)
- $k$: Conductivity of the fin (W/mK)
- $L$: Collector’s length (mm)
- $m$: Water mass flow rate (kg/sec)
- $N$: Number of glass cover
- $T_a$: Ambient temperature (°C)
- $T_p$: Plate temperature (°C)
- $U_t$, $U_b$, $U_e$: Top, bottom and edge heat loss coefficient respectively.
- $v$: Wind velocity (m/sec)
- $w$: Distance between two risers (mm)
- $x_b$, $x_e$: Back and Edge insulation thickness (mm)
- $\tau$: Transmissivity of the glass cover
- $\alpha$: Absorptivity of the absorbing plate
- $\epsilon_p$: Emissivity of the absorbing plate
- $\epsilon_g$: Emissivity of the glass cover
- $\sigma$: Stephan Boltzmann constant (W/m$^2$ K$^4$)
- $\delta$: Thickness of the fin (mm)
- $\theta$: angle of incident (Deg)

Constant values:

- $A_c = 0.74115$ m$^2$
- $A_e = 0.32775$ m$^2$
- $k_b = 0.04$ W/m.k
- $N = 1$
- $C_p = 4180$ J/kg°C
- $X_b = 0.05$ m
- $X_e = 0.025$ m
- $\tau = 0.85$
- $\alpha = 0.96$
- $\epsilon_p = 0.12$
- $\epsilon_g = 0.88$
- $\sigma = 5.67 \times 10^{-8}$ W/m$^2$ K$^4$