Solar Energy Conversion Technology

Flat Plate Collectors

Dr. Pankaj Kalita
Associate Professor
School of Energy Science and Engineering
Indian Institute of Technology, Guwahati

- Testing of LFPC
- Applications of LFPC

Testing of Flat Plate Collector

Three standard procedures for testing of a liquid collector suggested by ASHRAE

The essential requirements for all the procedure are

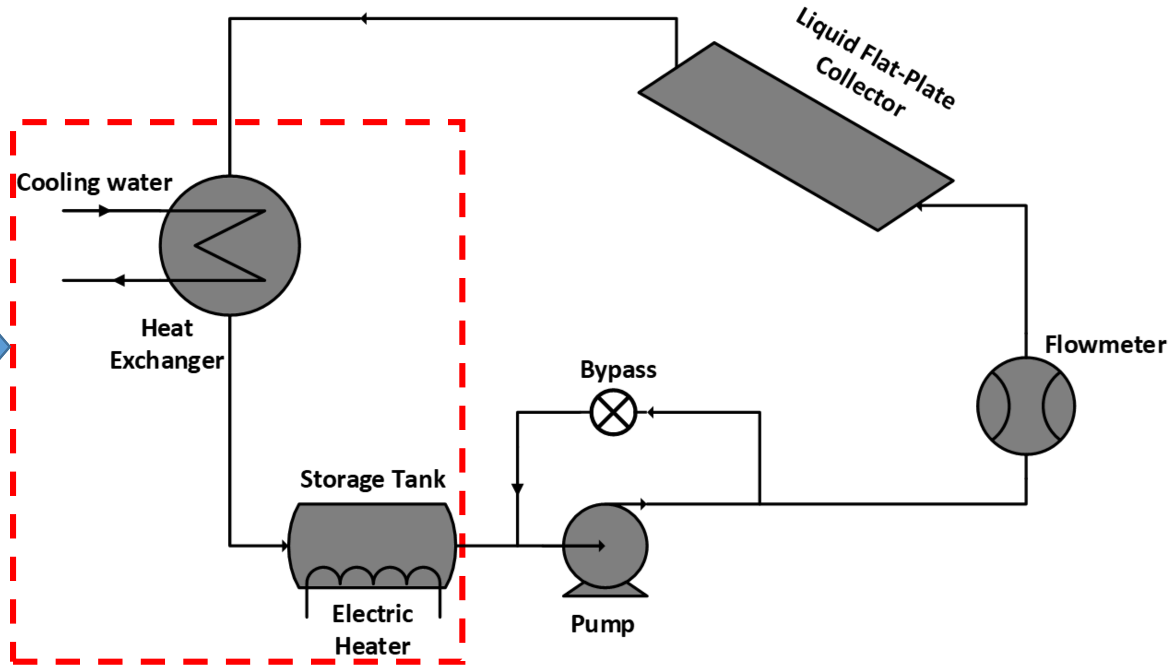
- ✓Arrangement for the inlet of fluid at constant temperature with flexibility to set different values of inlet temperatures.
- ✓Pyranometer to measure the solar radiation on the surface of the FPC.
- ✓Provisions for recording of mass flow rate and different temperatures.
- ✓Equipment for measuring pressure and pressure drop across the FPC.

Why standard testing?

Standardized testing and rating procedures provide an equitable basis for comparing the efficiency of different types of collectors and an essential basis for their selection for a given applications as well as their design improvement.

Testing of Solar Flat Plate Collector

The combination of the heat exchanger and the storage tank with an electric heater provides a means for adjusting and controlling the inlet fluid temperature to the collector to a desire value.



- ✓The testing standard specifies that the collector shall be tested under clear sky conditions to determine its efficiency characteristics.
- ✓On a given day, data is recorded under steady state conditions for fixed values of $\dot{m}$ and T_{fi} .

Measurements recorded in each data sets are:

- ✓ **Fluid flow rate**
- ✓ **Fluid inlet and outlet temperatures**
- ✓ **Solar radiation incident**
- ✓ **Ambient temperature**
- ✓ **Wind speed**

Testing of Solar Flat Plate Collector

- ✓ For fixed values of $\dot{m}$ and T_{fi} equal number of tests be conducted before and after solar noon i.e. at 1100, 1130, 1230 and 1300 h (LAT)
- ✓ Any bias due to transient effects is eliminated.
- ✓ Tests are to be performed at four inlet temperatures on different days, hence a total of 16 data sets are obtained.

A collector is considered to be operating under steady conditions if the deviation of the experimental parameters is less than the following specified limits over a 15 minute period:

- Global radiation incident on collector plate: ± 50 W/m^2
- Ambient flow rate: ± 1 °C
- Fluid flow rate: ±1 %
- Fluid inlet temperature: ± 0.1 °C
- Temperature rise across collector: ± 0.1 °C

I_T should be greater than 700 W/m^2

Wind speed should be 2 to 5 m/s, fluid flow rate should be 0.02 kg per second per sq, meter of the gross collector area.

Testing of Solar Flat Plate Collector

$$\eta_i = \frac{q_u}{A_c I_T} = \frac{\dot{m} C_p (T_{fo} - T_{fi})}{A_c I_T}$$

Hottel-Whillier-Bliss equation

$$q_u = F_R A_P \left[S - U_l (T_{fi} - T_a) \right]$$

By dividing the expression by $A_c I_T$, we have

$$\frac{q_u}{A_c I_T} = \frac{F_R A_P \left[S - U_l (T_{fi} - T_a) \right]}{A_c I_T}$$

$$\Rightarrow \eta_i = F_R \left(\frac{A_p}{A_c} \right) \left[\frac{S}{I_T} - \frac{U_l (T_{fi} - T_a)}{I_T} \right]$$

$$S = I_T (\tau\alpha)_{av}$$

$$\therefore \eta_i = F_R \left(\frac{A_p}{A_c} \right) \left[(\tau\alpha)_{av} - \frac{U_l (T_{fi} - T_a)}{I_T} \right]$$

Intercept

Slope

$$\therefore \eta_i = F_R \left(\frac{A_p}{A_c} \right) (\tau\alpha)_{av} - F_R \left(\frac{A_p}{A_c} \right) \times \left[\frac{U_l (T_{fi} - T_a)}{I_T} \right]$$

$$\eta_i = 0.692 - 4.024 (T_{fi} - T_a) / I_T$$

Testing of Solar Flat Plate Collector

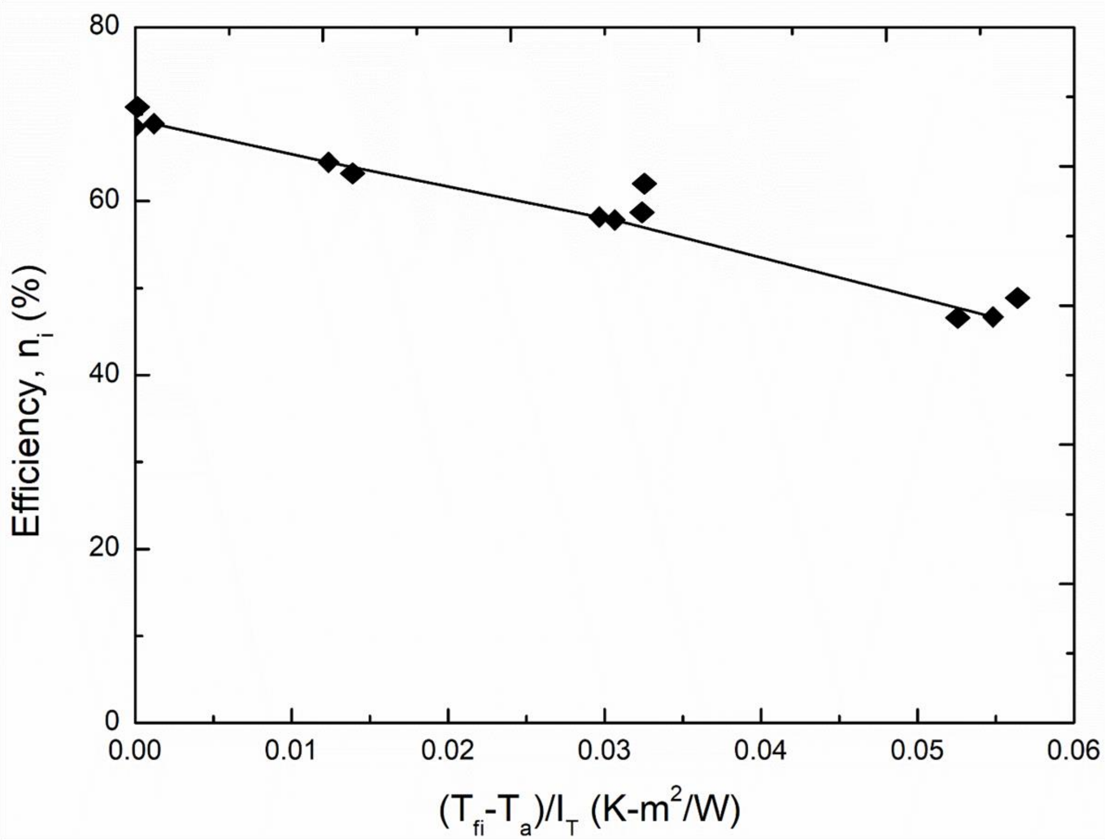
A straight line fitted to the data by the method of the least squares yields

$$\boxed{\eta_i = 0.692 - 4.024\left(T_{fi} - T_a\right)/I_T}$$

For a given collector, $\dfrac{A_p}{A_c} = 0.909$

$$F_R\left(\tau\alpha\right)_{av} = 0.692/0.909 = 0.761$$

$$F_R U_l = 4.024/0.909 = 4.427\ \text{W/m}^2\text{-K}$$



Efficiency curve for a commercial FPC- single cover, selective copper absorber plate

$$A_c = 2.270\ \text{m}^2; \dot{m} = 0.0456\ \text{kg/s}$$

Testing of Solar Flat Plate Collector

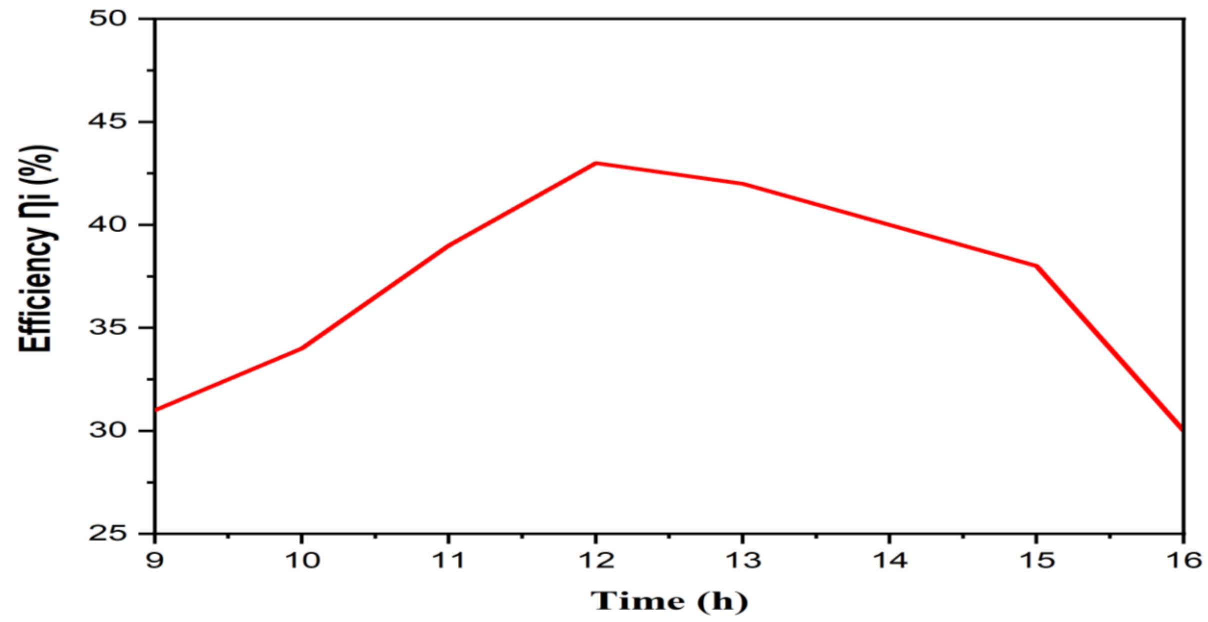
- For liquid flat plate collectors, changes in mass flow rate do not appreciably affect the performance because of the relatively high value of the liquid side heat transfer coefficient h_f.

- For this reason, although the efficiency curve of a collector is determined for a particular value of mass flow rate, it can also be used for predicting the behavior of the collector for other flow rates which differ a little from the value used during testing.

Performance over a day

Variation of Instantaneous efficiency of a collector over a day (keeping following parameters are constant)

- ✓ Water flow rate
- ✓ Water inlet temperature
- ✓ Ambient temperature
- ✓ Wind speed



Performance of a FPC over a whole day

IST(h)	0900	1000	1100	1200	1300	1400	1500	1600
I_b(W/m^2)	390	547	665	725	715	615	476	337
I_d(W/m^2)	192	210	230	730	233	239	221	185
I_T(W/m^2)	536.3	712.7	852.9	914.7	908.2	814.7	657.9	482.4
T_{pm}(K)	340.8	345.8	349.5	351.2	351.0	348.5	344.3	339.5
U_T(W/m^2-K)	3.99	4.05	4.10	4.12	4.12	4.09	4.03	3.96
q_a(W)	377.1	619.2	805.6	888.3	879.2	755.4	548.8	313.0
T_{fo}(K)	337.8	340.8	343.1	344.1	344.1	342.5	340.0	337.1
η_i(%)	31.6	39.0	42.4	43.6	43.6	41.7	37.5	29.1

Data: Solar Energy Principles of Thermal Collection and Storage,2008, by S P. Sukhatme and J N Nayak, 3rd Edition, TataMcGraw Hill Education Privet Limited, New Delhi

Ex.1 A water heating flat plate collector is fitted with two glass covers and a non-selective absorber plate of dimensions 1× 2 m. The collector is tested by the standard procedure and the following data is obtained.

T_{fi}	T_{fo}	T_a	I_T
(°C)	(°C)	(°C)	W/m^2
84.95	93.98	23.0	885
79.97	89.83	22.4	879
75.63	85.51	22.1	862
69.54	79.24	21.6	841
68.19	77.36	21.3	827
50.05	61.19	20.4	819
43.37	54.06	20.4	792
38.17	49.79	19.3	770
33.92	45.44	19.0	761

Given $(\tau\alpha)_{av}=0.74; \dot{m}=1.10$ kg/minutes $C_P=4.18$ kJ/kg^{o}C; $A_c/A_P=1.2$

(a) Calculate the values of η_i and plot these against the parameters $(T_{fi}-T_a)/I_T$ draw a best fit straight line and determine the values of U_l and F_R

(b)How does the value of F_R change if the value of mass flow rate is reduced to 1.3 kg/minutes? Assume that the value of F' does not change significantly because of increase of mass flow rate ($\dot{m}$)

Ex.2 A liquid flat plate collector has the following characteristic parameters

$$\boxed{F_R(\tau\alpha)_{av} = 0.68; F_R U_l = 6.1 \text{ W/m}^2\text{-K}}$$

It is operating under the following conditions:

- Solar flux incident on the collector plane: 900 W/m^2
- Water flow rate : 0.015 kg/s-m^2 of the absorber area
- Ambient temperature : 20 ^{o}C
- Inlet water temperature:40 ^{o}C

i. Calculate the mean absorber plate temperature of the collector, if the collector efficiency factor is 0.90.

ii. If the circulating pump fails what is the maximum temperature attained by the plate.

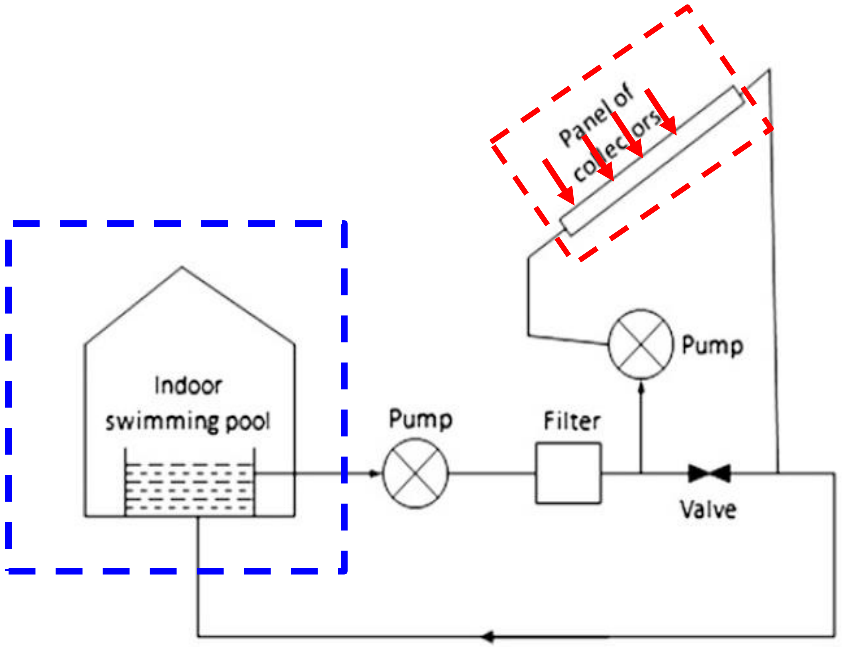
✓ Hottel-whillier-Bliss equation

$$\boxed{q_u = A_p S - U_l A_p \left(T_{pm} - T_a\right)}$$

$$\boxed{q_u = F_R A_p \left[S - U_l \left(T_{fi} - T_a\right)\right]}$$

$$\boxed{F_R = \frac{\dot{m}C_p}{U_l A_p}\left[1 - \exp\left(-\frac{F' U_l A_p}{\dot{m}C_p}\right)\right]}$$

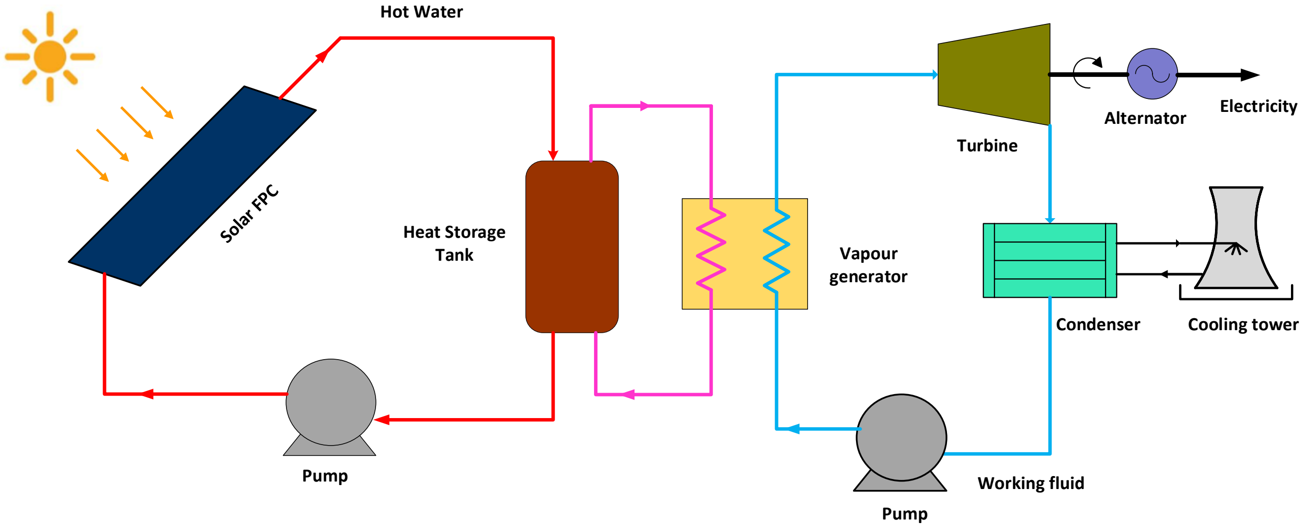
Applications of LFPC



Active indoor swimming pool

- ❑ Indoor Swimming pool
- ❑ Water heating
- ❑ Milk pasteurization
- ❑ Power generation (low temp)
- ❑ Drying
- ❑ Solar water heater for biogas
- ❑ Slurry drying

- The hot water at a temperature around 100 °C is stored in the thermal storage tank.
- The low boiling point working fluid vaporizes at vapour generators at about 90 °C and leaves the condenser at about 35 °C after expanding in the turbine.
- The working fluids used:R-11,R-113, R-114, methyl chloride etc.



Summary

- **Testing of LFPC**
- **Applications of LFPC**