Solar Energy Conversion Technology

Flat Plate Collectors

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- ✓ **Collector Efficiency Factor**
- ✓ **Collector Heat Removal Factor**

Collector Efficiency Factor

$$q_u = A_p S - q_l$$

$$q_l = U_l A_p \left(T_{pm} - T_a\right)$$

$$S = I_b r_b (\tau\alpha)_b + \{I_d r_d + (I_b + I_d) r_r\}(\tau\alpha)_d$$

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

$$q_u = F'\left[A_p S - U_l A_p \left(T_f - T_a\right)\right]$$

- ✓ Hottel-whillier-Bliss equation

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

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

- ✓ Collector efficiency factor is defined as the ratio of the actual useful heat collection rate to the useful heat collection rate which would occur if the collector absorber plate are at the temperature T_f.
- ✓ Its value ranges from 0.8 to 0.95.

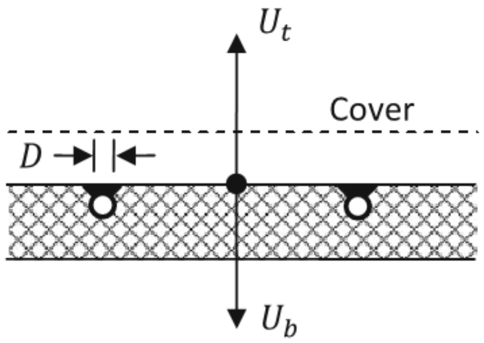
- ✓ Collector heat removal factor is defined as the ratio of the actual useful heat collection rate to the useful heat collection rate which would occur if the collector absorber plate are at the temperature T_{fi} everywhere.
- ✓ Its *value* rages from 0 to 1.

Collector Efficiency Factor

Combining eqn. (D) and (E)

$$\frac{1}{N}\left(\frac{dq_u}{dy}\right)=\frac{\left[S-U_l(T_f-T_a)\right]}{U_l\left[\frac{1}{U_l[(W-D_o)\phi+D_o]}+\frac{\delta_a}{k_aD_o}+\frac{1}{\pi D_i h_f}\right]}$$

(F)



Collector efficiency factor F'

$$F'=\frac{1}{WU_l\left[\frac{1}{U_l[(W-D_o)\phi+D_o]}+\frac{\delta_a}{k_aD_o}+\frac{1}{\pi D_i h_f}\right]}$$

Ratio of the actual useful gain rate per tube per unit length to the gain which would occur if the collector absorber plate were all the temperature T_f.

On substitution in eq.(F)

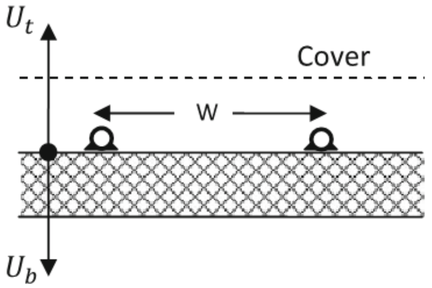
$$\frac{1}{N}\left(\frac{dq_u}{dy}\right)=WF'\left[S-U_l(T_f-T_a)\right]$$

$$q_u=F'\left[A_pS-U_lA_p\left(T_f-T_a\right)\right]$$

Collector Efficiency Factor for other configurations

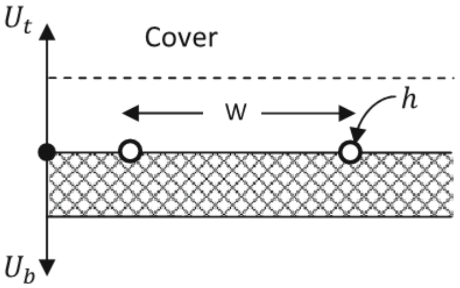
Tubes bonded above absorber plate

$$F' = \frac{1}{WU_l\left[\dfrac{1}{\left\{\dfrac{1}{U_l(W-D_o)\phi}+\dfrac{\delta_a}{k_a D_o}\right\}^{-1}+U_l D_o}+\dfrac{1}{\pi D_i h_f}\right]}$$



Tubes inline with absorber plate

$$F' = \frac{1}{WU_l\left[\dfrac{1}{U_l[(W-D_o)\phi+D_o]}+\dfrac{1}{\pi D_i h_f}\right]}$$



Summary: Collector efficiency factor

$$\dot{Q}_u = A_c F' \left[\dot{q}_{ab} - U_l \left(T_f - T_a \right) \right]$$

Instantaneous thermal efficiency,

$$\eta_i = \frac{\dot{Q}_u}{A_c I(t)} = F' \left[\frac{\dot{q}_{ab}}{I(t)} - \frac{U_l \left(T_f - T_a \right)}{I(t)} \right]$$

Or, $$\eta_i = F' \left[(\alpha\tau) - \frac{U_l \left(T_f - T_a \right)}{I(t)} \right]$$

- The collector efficiency factor, F’, is essentially a constant for any collector design and fluid-flow rate.
- F’ decreases with an increase in the centre-to-centre distance of the tube and increases with an increase in the material thickness and thermal conductivity.
- An increase of overall loss coefficient decreases F’, where as an increase in the fluid-to-tube heat transfer coefficient increases F’.

Summary: Collector heat removal factor

$$F_R = \frac{\dot{Q}_u}{A_c\left[\dot{q}_{ab} - U_l\left(T_{fi} - T_a\right)\right]} = \frac{\dot{m}_f C_{pf}\left(T_{fo} - T_{fi}\right)}{A_c\left[\dot{q}_{ab} - U_l\left(T_{fi} - T_a\right)\right]}$$

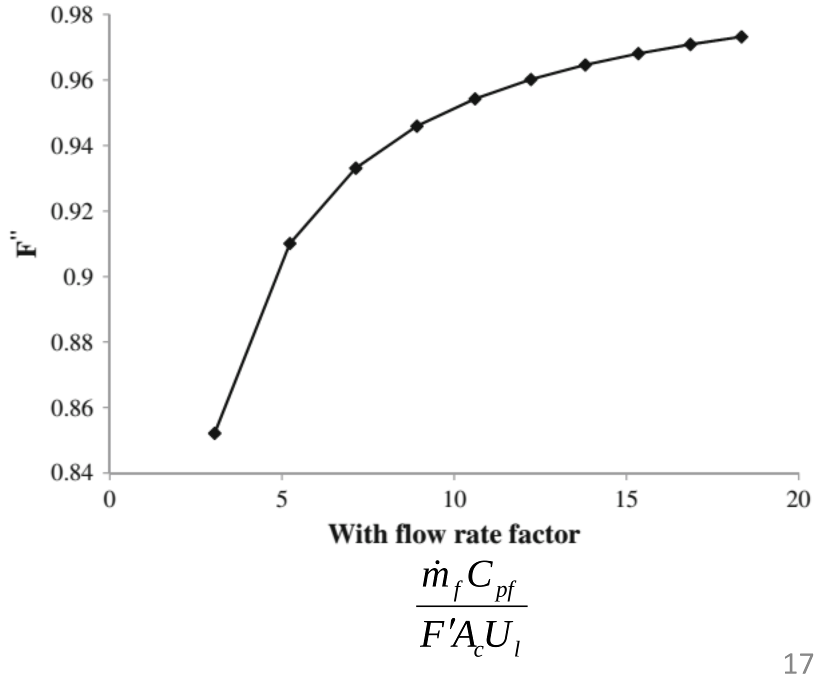
- Ratio of the rate of actual useful energy gain to the rate of useful energy gain if the entire collector were at the fluid-inlet temperature in a forced circulation mode.

$$F_R = \frac{\dot{m}_f C_{pf}}{A_c U_l}\left[1 - \exp\left\{-\frac{F' A_c U_l}{\dot{m}_f C_{pf}}\right\}\right]$$

Flat plate flow factor F''

$$F'' = \frac{F_R}{F'} = \frac{\dot{m}_f C_{pf}}{F' A_c U_l}\left[1 - \exp\left\{-\frac{F' A_c U_l}{\dot{m}_f C_{pf}}\right\}\right]$$

$$\dot{Q}_u = A_c F_R\left[\dot{q}_{ab} - U_l\left(T_{fi} - T_a\right)\right]$$



The insataneous thermal efficiency is given as (η_i)

$$\eta_i = \frac{\dot{Q}_u}{A_c I(t)} = \frac{\dot{q}_{ab}}{I(t)} = \frac{S - U_L(T_p - T_a)}{I(t)} = \alpha\tau - \frac{U_L(T_p - T_a)}{I(t)}$$

$$S = I(t) \times (\alpha\tau)_{av}$$

The overall collection of thermal efficiency is defined as the ratio of the useful gain to the incident solar energy over the same period of time.

$$\boxed{\eta_c = \frac{\int \dot{Q}_u \, dt}{A_c \int I(t) dt}}$$

Specification:

	Vertical collector SRV 2.3	Horizontal collector SRH 2.3
Dimensions & weight		
Orientation	Vertical (Portrait)	Horizontal (Landscape)
Height / Width / Depth (mm)	2035 / 1233 / 80	1233 / 2035 / 80
Overall collector area (mm)	2.51	2.51
Aperture area (m2)	2.35	2.35
Absorber area (m2)	2.32	2.32
Weight (empty) (kg)	38	38
Capacity (solar fluid) (l)	1.85	2.16
Performance		
Solar glass transmission (%)	91	91
Solar radiation absorption (%)	95	95
Solar radiation emission (%)	5	5
Efficiency η o (%)	79.0	80.1
Efficiency coefficient a1 (W/M^2K)	2.41	3.32
Efficiency coefficient a2 (W/M^2K^2)	0.049	0.023
Max operating pressure (bar)	10	10
Stagnation temperature (‹C)	210	210
Certification	CE 0036 & Solar Keymark	CE 0036 & Solar Keymark
Materials & construction		
Absorber Sheet	Aluminium	Aluminium
Absorber plate coating	Sunselect (selective)	Sunselect (selective)
Absorber tube	Copper	Copper
Absorber tube joints	Laser welded	Laser welded
Frame Aluminium	Extruded sides / sheet rear	Extruded sides / sheet rear
Glazing	Safety glass (low iron), 3.2mm	Safety glass (low iron), 3.2mm
Rear insulation	40mm	40mm
Solar fluid	Water / propylene glycol	Water / propylene glycol
Flow / return connections	DN 16 (G3/4")	DN 16 (G3/4")

Combination of FPCs

Parallel connection

- ✓ The upper and lower headers of each FPC are connected to increase the volume of water to be heated.
- ✓ The mass flow rate per FPC is the total mass flow rate divided by number of FPCs.
- ✓ The outlet-water temperature is the same at the outlet of each FPC.
- ✓ FPC modules can operate in natural as well as forced mode.

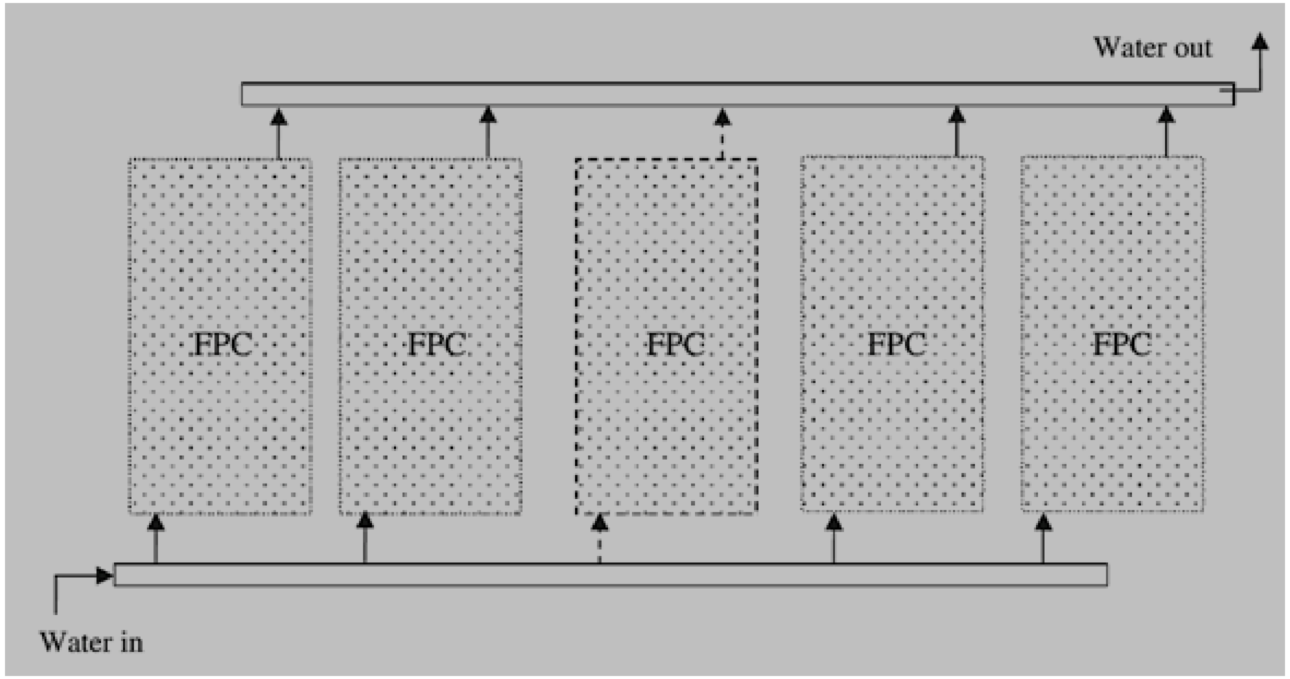
Series connection

- ✓ The outlet of one row of FPCs (the first module) is connected with the inlet to a second row of FPCs (second module) and so on.
- ✓ The mass-flow rates are the same for all rows.
- ✓ The outlet temperature depends on the number of rows of FPCs connected in series.
- ✓ Such series-connected FPC modules can only operate in forced mode.

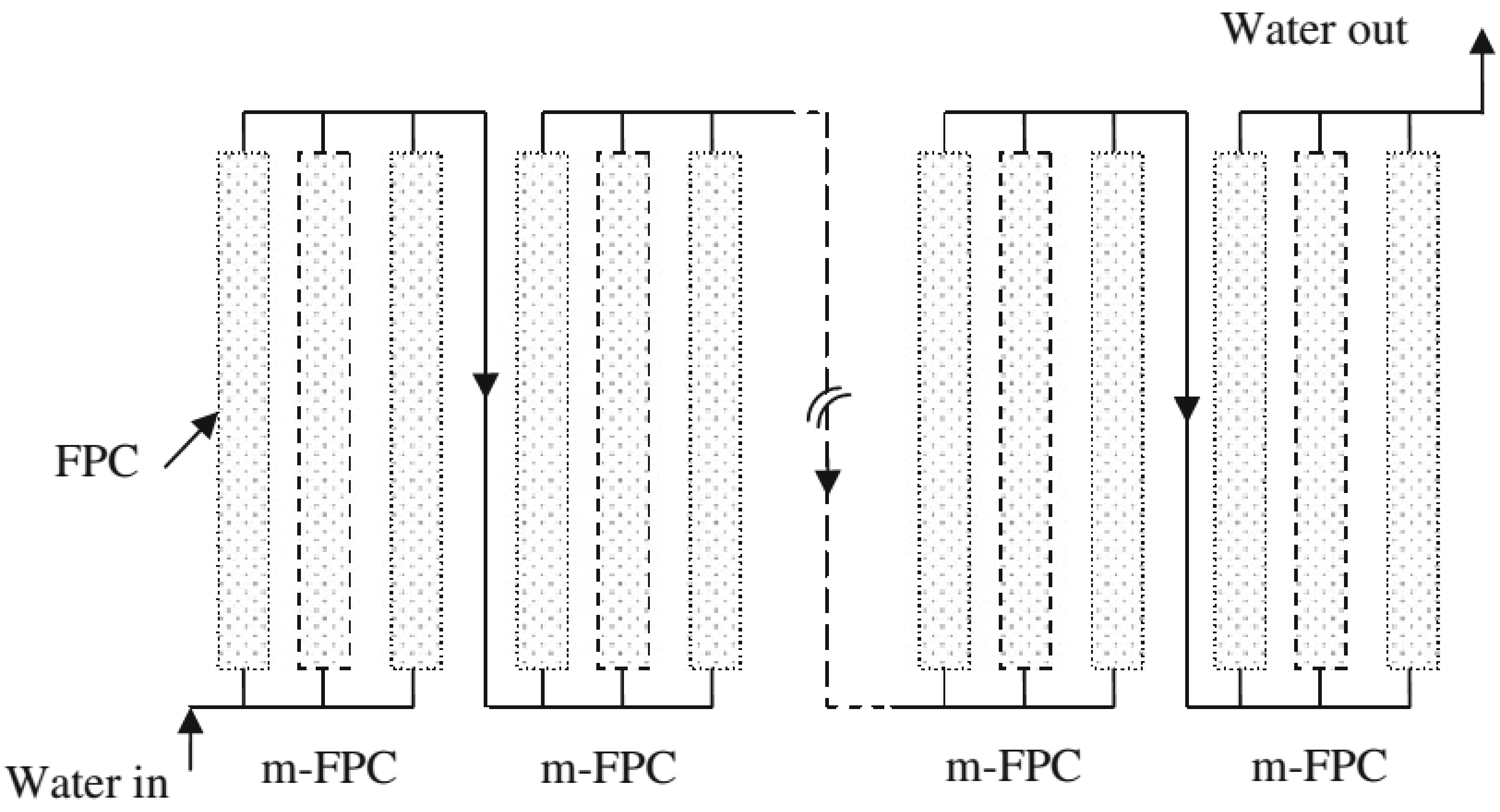
Mixed-connection combination

- ✓ The first FPCs are connected in parallel for a given capacity of hot water to make one row (one module), and such modules formed are connected in series to increase the temperature per the requirement. This is generally referred to as “arrays.”
- ✓ FPCs’ arrays will only operate in forced mode.

Flat-plate collectors connected in parallel makes one module



Mixed connection combination



Summary

- Energy Balance of an Absorber Plate
- Thermal Resistance Network
- Temperature Profile of an FPC
- Analysis of Collector Efficiency Factor
- Analysis of Collector Heat Removal Factor
- Instantaneous efficiency
- Series and Parallel Connection of Collectors