Chapter Seven

Concentrating Collectors

7.1 Introduction

Concentrating collectors are used to achieve temperatures higher than those obtained from flat−plate collectors. Many designs have been set forth for concentrating collectors. Concentrators can be reflectors or refractors, can be cylindrical or surfaces of revolution, and can be continuous or segmented. Receivers can be convex, flat, or concave and can be covered or uncovered. Some concentrating collectors require tracking at which is the device is made to follow the movement of sun in the sky.

The solar concentrating collector is generally made of two main part:

a) The concentrator (reflector): which is the optical system that directs the solar radiation onto the receiver surface.

b) The receiver: which receives the reflected solar radiation from the concentrator and converts it to useful heat gain. The receiver includes the **absorber**, its associated covers and the insulation. The absorber is usually covered with glass and the gap between the absorber and glass is sometimes evacuated to minimize thermal losses to environment.

The solar concentrating collectors have two advantages over the flat−plate solar collectors:

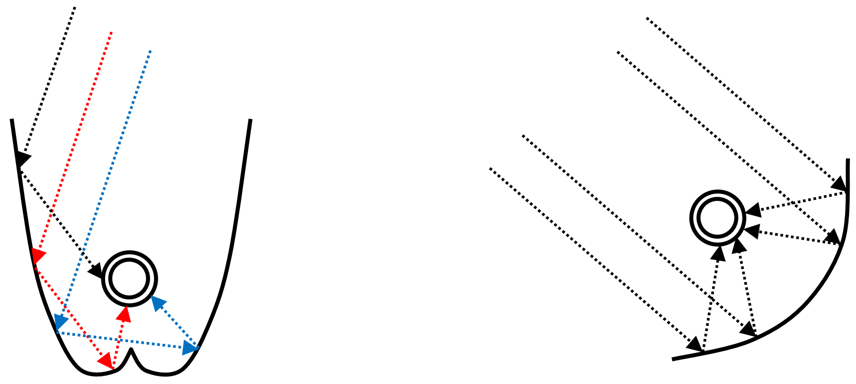
a) They can produce higher temperatures than in flat−plate collector because the solar flux is concentrated on a small receiving area.

b) The thermal losses from the absorber is significantly decreased due to the decreased absorber area.

According to tracking requirements, concentrating collectors can be classified into two main groups:

Nonimaging concentrating collectors: in this category the collector is designed to reflect all the incident solar radiation on the absorber within certain range of incidence angles without the need for any tracking. The incident solar radiation may undergo several reflections before reaching the receiver (Fig. 7.1).

Imaging linear and point concentrating collectors: in this category the collector must track the movement of the sun so that the reflected radiation is focused on a small receiving are with one reflection process. This category produce higher temperatures than in the nonimaging type.



(a) (b)

Fig. (7.1): Two types of concentrating collectors: (a) Non–imaging. (b) Imaging.

7.2 Acceptance Angle (θ_a)

It is the angle through which the solar radiation entering the concentrating collector can eventually reach the absorber even after several reflections.

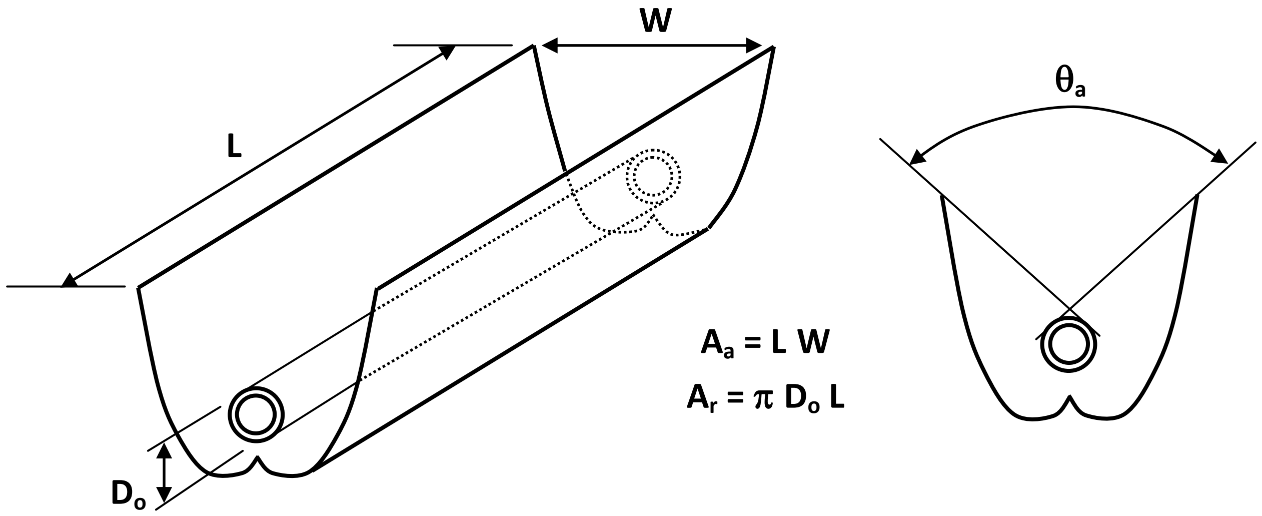


Fig. (7.2): Schematic view of a solar concentrator with aperture and receiver areas and the acceptance angle.

7.3 Concentration Ratio (C)

It is defined as the ratio of the aperture area A_a to the receiver area A_r Fig. (7.2):

$$C = \frac{A_a}{A_r} \qquad 7.1$$

7.4 Thermal Analysis of Concentrating Collectors

Thermal analysis of concentrating collectors are in general similar to flat plate collectors. The main difference between them is that the receiving area in concentrating collectors is larger than thermal losses area. The useful heat gain in the concentrating collector (Q_u) can be found as follows:

$$Q_u = \rho\tau\alpha I_T A_a - A_r U_L\left(T_{pm} - T_a\right)$$

$$Q_u = A_a\left[\rho\tau\alpha I_T - \frac{A_r}{A_a} U_L\left(T_{pm} - T_a\right)\right]$$

$$Q_u = A_a\left[\rho\tau\alpha I_T - \frac{U_L}{C}\left(T_{pm} - T_a\right)\right] \qquad 7.2$$

Equation 7.2 can be written in terms of heat removal factor F_R and working fluid inlet temperature T_{fi} as follows:

$$Q_u = A_a F_R\left[\rho\tau\alpha I_T - \frac{U_L}{C}\left(T_{fi} - T_a\right)\right] \qquad 7.3$$

Where ρ are the reflectance coefficient of the reflecting surface and $\tau\alpha$ is the transmittance−absorptance product of the absorber.

The heat removal factor F_R has the same form of that of flat plate collectors:

$$F_R = \frac{\dot{m} c_{pf}}{A_r U_L}\left(1 - e^{\frac{-A_r U_L F}{\dot{m} c_{pf}}}\right) \qquad 7.4$$

An expression for the collector efficiency factor (F) can be derived from its definition as the ratio of thermal resistance between the absorber and the atmosphere to thermal resistance between the working fluid and the atmosphere:

$$F = \frac{\frac{1}{A_r U_L}}{\frac{1}{A_r U_L} + R_f} \qquad 7.5$$

Where R_f represents thermal resistance between the working fluid and the absorber pipe wall:

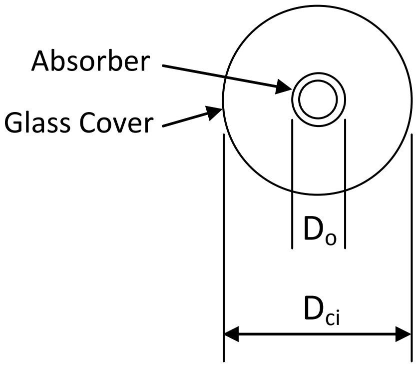
$$R_f = \frac{1}{h_{fi} \pi D_i L} + \frac{ln\left(\frac{D_o}{D_i}\right)}{2\pi k L} \tag{7.6}$$

Where L is the absorber pipe length and h_{fi} is the convection heat transfer coefficient inside the pipe. Substituting eq. 7.6 in eq. 7.5 and rearranging:

$$F = \frac{\frac{1}{U_L}}{\frac{1}{U_L} + \frac{D_o}{h_{fi} D_i} + \frac{D_o ln\left(\frac{D_o}{D_i}\right)}{2k}} \tag{7.7}$$

The overall heat loss coefficient U_L can be found by the same procedure followed in the flat plate solar collector taking into account that the convection losses from the absorber can be neglected if the space surrounding the absorber is evacuated. Accordingly the losses are only due to radiation:

$$q_{pr} = \frac{A_r \sigma \left(T_{pm}^4 - T_c^4\right)}{\frac{1}{\epsilon_p} + \frac{D_o}{D_{ci}}\left(\frac{1}{\epsilon_c} - 1\right)}$$



$$q_{pr} = \left(T_{pm} - T_c\right)\left[\frac{A_r \sigma \left(T_{pm} + T_c\right)\left(T_{pm}^2 + T_c^2\right)}{\frac{1}{\epsilon_p} + \frac{D_o}{D_i}\left(\frac{1}{\epsilon_c} - 1\right)}\right]$$

$$q_{pr} = \frac{\left(T_{pm} - T_c\right)}{R_{pc}} \tag{7.8}$$

Where R_{pc} is the thermal resistance between the absorber and the glass cover:

$$R_{pc} = \frac{\frac{1}{\epsilon_p} + \frac{D_o}{D_i}\left(\frac{1}{\epsilon_c} - 1\right)}{A_r \sigma \left(T_{pm} + T_c\right)\left(T_{pm}^2 + T_c^2\right)} \tag{7.9}$$

The radiation thermal losses from the glass cover to the environment is:

$$q_{cr} = \epsilon_c A_c \sigma (T_c^4 - T_s^4)$$

And the convection thermal losses from the glass cover to environment is:

$$q_{cc} = A_c h_w (T_c - T_a)$$

So the total loss is the sum of radiation and convection losses:

$$q_{ct} = q_{cc} + q_{cr}$$

$$q_{ct} = A_c h_w (T_c - T_a) + \epsilon_c A_c \sigma (T_c^4 - T_s^4)$$

$$q_{ct} = (T_c - T_a)\left[A_c h_w + \frac{\epsilon_c A_c \sigma (T_c^4 - T_s^4)}{(T_c - T_a)}\right]$$

$$q_{ct} = \frac{(T_c - T_a)}{R_{ca}} \qquad 7.10$$

Where R_2 is the thermal resistance from the glass cover to the environment:

$$R_{ca} = \frac{1}{A_c h_w + \frac{\epsilon_c A_c \sigma (T_c^4 - T_s^4)}{(T_c - T_a)}} \qquad 7.11$$

When the collector reaches thermal equilibrium:

$$q_{ct} = q_{pr} = q_t \qquad 7.12$$

From eq. 7.10 and 7.12 :

$$T_c = q_t R_{ca} + T_a \qquad 7.13$$

Substitute T_c from eq. 7.13 in eq. 7.8 and using eq. 7.12:

$$q_t = \frac{T_{pm} - T_a}{R_{pc} + R_{ca}} = A_r U_L (T_{pm} - T_a) \qquad 7.14$$

Combining eqs. 7.13 and 7.14 to evaluate the new cover temperature $T_{c,new}$:

$$T_{c,new} = A_r U_L (T_{pm} - T_a) R_{ca} + T_a \qquad 7.15$$

Accordingly the overall heat loss coefficient of the concentrating collector is:

$$U_L = \frac{1}{A_r (R_{pc} + R_{ca})} \qquad 7.16$$