Chapter Six

Solar Water Heaters

Solar Water Heaters (SWH) or Solar Hot Water Systems (SHWS) are one of the most successful thermal employment of solar energy. They proved to be feasible especially in providing hot water for domestic applications. They are commonly classified into two types:

a) Forced circulation systems.

b) Natural circulation systems (thermosyphon systems).

6.1 Forced circulation solar water heaters

In this type a pump is used to circulate the working fluid through the system. The typical solar heater consists of the following parts (Fig. 6.1):

a) Solar collector (usually flat–plate type)

b) Water storage tank.

c) Upriser (to carry the hot water from the collector to the tank).

d) Downcomer (to return the cold water from the tank to the collector).

e) Water pump (to circulate the fluid between the collector and the tank).

f) Thermal controller (to actuate the pump when the temperature difference between collector inlet and outlet exceeds certain limit.

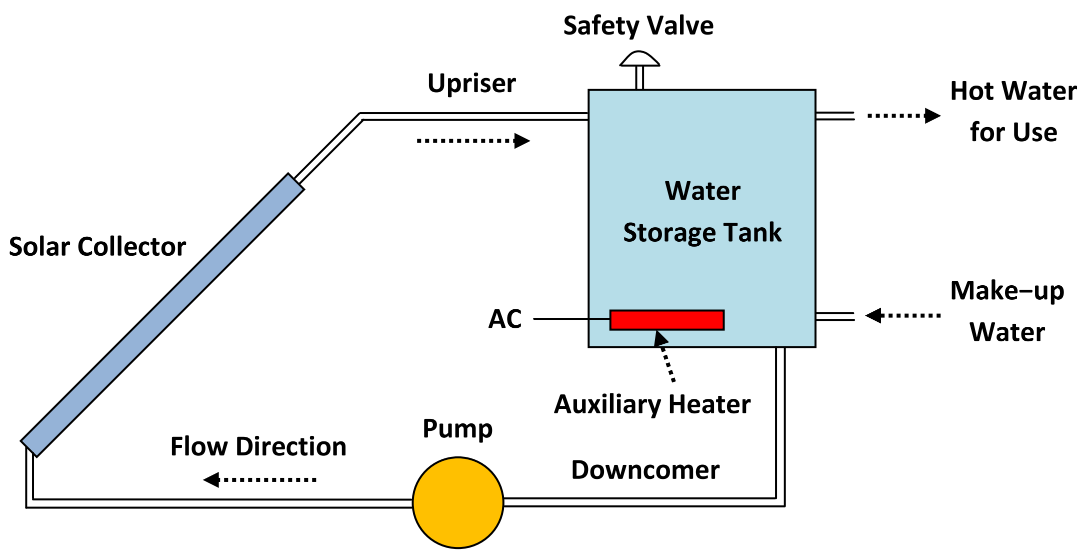

Fig. (6.1): Forced circulation solar water heater.

The water storage tank in forced circulation systems can be put anywhere regardless of the solar collector level since the pump will circulate the water at any condition. The pump is usually actuated when a certain temperature difference is reached between collector inlet and outlet. The freezing of water in the collector risers is a serious problem in cold weather nights. Anti–freeze solutions can be mixed with water inside risers which requires separating collector water from tank water via a heat exchanger.

6.2 Thermosyphon solar water heaters

These systems rely on natural convection to circulate the working fluid between the solar collector and storage tank without using a pump. The buoyancy forces generated by the density differences between the cold water at the bottom of the tank (high density) and the hot water at the top of the collector (low density), propels the circulation of the working fluid. It is therefore necessary to put the water storage tank at a position higher than the collector to ensure the continuity of circulation (Fig. 6.2).

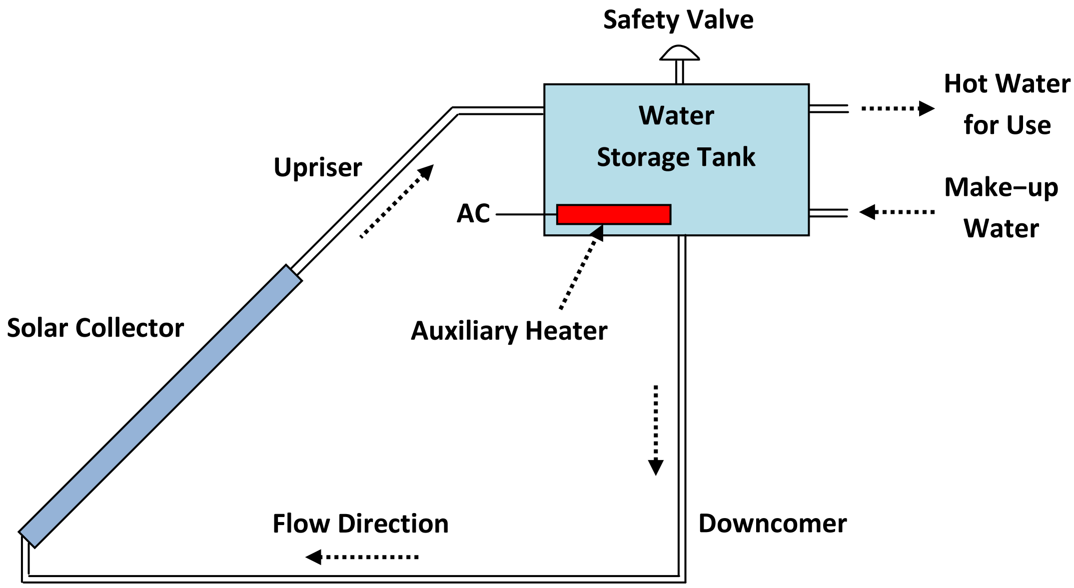

Fig. (6.2): Thermosyphon solar water heater.

6.3 Thermal analysis of solar water heaters

The aim of the thermal analysis of solar water heater is to estimate the tank water temperature at the end of daytime or after certain exposure time to solar radiation. The temperature of water depends on the solar collector area and the tank volume. As a rule of thumb, if a flat−plate solar collector of 1 m^2 area is connected to a storage tank of 50 L then the final tank water temperature at the end of daytime will be around 60 ^oC. However, the accurate estimation of tank temperature requires the incorporation of thermal models of all parts of the system in a process called (simulation). In the simulation of a solar system the real performance is imitated theoretically on computer to estimate the system performance for various imposing operation conditions (Irradiance, ambient temperature, working fluid flow rate and rate of hot water usage or water withdrawal from the tank). The following thermal models can be used in a simple simulation process:

a) Flat−plate solar collector

To evaluate the collector fluid outlet temperature T_{fo} equations 5.3, 5.41 and 5.42 can be used as follows:

$$T_{fo} = T_{fi} + \frac{Q_u}{\dot{m} c_{pf}} \qquad 5.3$$

Where: $$Q_u = A_c F_R [\tau\alpha I_T - U_L (T_{fi} - T_a)] \qquad 5.41$$

And: $$F_R = \frac{\dot{m} c_{pf}}{A_c U_L}\left(1 - e^{\frac{-A_c U_L F}{\dot{m} c_{pf}}}\right) \qquad 5.42$$

b) Upriser

The working fluid undergoes thermal losses to the environment when passes through the upriser. To estimate the working fluid temperate T_{uo} at the upriser outlet (before entering the tank) the following equation can be used:

$$T_{uo} = T_a + \left(T_{fo} - T_a\right) e^{\frac{-A_u U_u}{\dot{m} c_{pf}}} \qquad 6.1$$

Where U_u is the upriser heat loss coefficient and A_u is the outside surface area of the upriser.

c) Downcomer

The outlet fluid temperature of the downcomer T_{do} is the collector inlet temperature. It can be calculated similar to the upriser as follows:

$$T_{do} = T_{fi} = T_a + (T_{t2} - T_a) e^{\frac{-A_d U_d}{\dot{m} c_{pf}}} \qquad 6.2$$

Where T_{t2} is the tank water mean temperature after a period of operation time, U_d is the downcomer heat loss coefficient and A_d is the outside surface area of the downcomer.

d) Water storage tank

The working fluid enters the storage tank at a temperature T_{uo} and mixes with the tank water that is initially at T_{t1} . The resulting tank temperature T_{t2} after the system operates for a period of time Δt depends on the tank volume, ambient temperature and the water withdrawal rate from the tank. The following energy balance can be written for a fully mixed water storage tank:

$$\begin{pmatrix} Change\ of\ Tank \\ Internal\ Energy \\ in\ Joules \end{pmatrix} = \begin{pmatrix} Input\ Energy \\ from\ Upriser \end{pmatrix} + \begin{pmatrix} Input\ Energy \\ from\ the\ AC \\ Heater \end{pmatrix} - \begin{pmatrix} Thermal \\ Losses\ to \\ Environment \end{pmatrix} - \begin{pmatrix} Thermal\ Losses \\ due\ to\ Water \\ Withdrawal \end{pmatrix}$$

$$M_t c_{pt} (T_{t2} - T_{t1}) = \Delta t \left[Q_{up} + Q_{AC} - Q_{loss} - Q_w \right] \qquad 6.3$$

Where: $$Q_{up} = \dot{m} c_{pf} (T_{uo} - T_{t1}) \qquad 6.4$$

$$Q_{loss} = A_t U_{ta} (T_{t1} - T_a) \qquad 6.5$$

$$Q_w = \dot{m}_w c_{pw} (T_{t1} - T_w) \qquad 6.6$$

And, M_t is the tank water mass, Δt is the time period, U_{ta} is the tank heat loss coefficient, A_t is the outside surface area of the tank, $\dot{m}_w$ is the water withdrawal rate for usage and T_w is the temperature of the make−up water.

Equation 6.3 can be rearranged to evaluate the new tank temperature T_{t2}:

$$T_{t2} = T_{t1} + \frac{\Delta t \left[Q_{up} + Q_{AC} - Q_{loss} - Q_w \right]}{M_t c_{pt}} \qquad 6.7$$

Ex. 6.1 A solar water heater has a tank containing 100 kg of water initially at 20 °C. Water from a flat plate solar collector enters the tank at 40 °C at a rate of 0.03 kg/s. If the tank is equipped with auxiliary heater of 2000 W power, then find the tank temperature after one hour of operation with and without actuating the auxiliary heater. Neglect any losses from the tank whether to the environment or by the water withdrawal and take the value of specific heat of the working fluid and tank to be 4180 J/(kg °C). What would be the tank temperature after the same period if water is withdrawn during the second 15 minutes of the hour at a rate of 0.05 kg/s with a make−up water of 10 °C and the electric heater is turned on.

Sol. Rate of heat gain from the upriser:

$$Q_{up} = \dot{m}c_{pf}(T_{uo} - T_{t1}) = 0.03 \times 4180 \times (40 - 20) = 2508\,W$$

Final tank temp. after 1 hr without withdrawal (only solar):

$$T_{t2} = T_{t1} + \frac{\Delta t \times Q_{up}}{M_t c_{pt}} = 20 + \frac{3600 \times 2508}{100 \times 4180} = 41.6\ °\text{C}$$

Final tank temp. after 1 hr without withdrawal (solar and AC):

$$T_{t2} = T_{t1} + \frac{\Delta t\left[Q_{up} + Q_{AC}\right]}{M_t c_{pt}} = 20 + \frac{3600[2508 + 2000]}{100 \times 4180} = 58.82\ °\text{C}$$

Final tank temp. after the first 15 min without withdrawal (solar and AC):

$$T_{t2} = T_{t1} + \frac{\Delta t\left[Q_{up} + Q_{AC}\right]}{M_t c_{pt}} = 20 + \frac{900[2508 + 2000]}{100 \times 4180} = 29.7\ °\text{C}$$

Rate of heat losses due to water withdrawal from the tank:

$$Q_w = \dot{m}_w c_{pw}(T_{t1} - T_w) = 0.05 \times 4180 \times (29.7 - 10) = 4117.3\,W$$

Final tank temp. after the second 15 min. with withdrawal (solar and AC):

$$T_{t2} = T_{t1} + \frac{\Delta t\left[Q_{up} + Q_{AC} - Q_w\right]}{M_t c_{pt}} = 29.7 + \frac{900[2508 + 2000 - 4117.3]}{100 \times 4180} = 30.54\ °\text{C}$$

Final tank temp. after 1 hr with withdrawal in the second 15 min. (solar and AC):

$$T_{t2} = T_{t1} + \frac{\Delta t\left[Q_{up} + Q_{AC}\right]}{M_t c_{pt}} = 30.54 + \frac{1800[2508 + 2000]}{100 \times 4180} = 49.95\ °\text{C}$$