Principles and Performance of Solar Energy Thermal Systems: *A Web Course by V.V.Satyamurty*

MODULE 13 Lecture No: 16

Heat Capacity Effects in Flat Plate Collectors

In this Module 13, Lecture No. 16 deals with

Lecture 16

13.1 INTRODUCTION

Eventhough most of the calculations on both short term and long term basis are performed on a steady state assumption, the solar energy systems seldom operate on steady state conditions. However, the justification comes from the argument that the performance calculated as steady state, represents a previopus time perion and when summed up over long term tends to lead to a low error. However, transient behavior is essential for certain situations, say to estimate the warm up period of the solar collector. Warm up period, may be defined as the time required from sunrise to the time collector heats up to the required operating temperature. As an example, if energy delivery is required at ≥ 60 ^{0}C, the absorber temperature may have to reach 82 ^{0}C. A certain amount of energy and hence time after sunrise is required to warm up the collector to 82 ^{0}C for the absorber and the associated temperatures for the glass covers etc. If this time period is higher than the time when the solar radiation reaches the critical radiation level, the period of operation of the collector is governed by the warm up period. The critical radiation may be ddefined as the minimum solar radiation required to supply energy at the desired temperature, T_{min} ; obtained as the value of I_T obtained by setting $Q_u = 0$. If we, designate this I_T as ‘ I_{Tc} ’, I_{Tc} is given by,

$$I_{Tc} = F_R U_L (T_{min} - T_a) / F_R(\tau\alpha)$$

13.2 UNSTEADY PERFORMANCE

In the analysis presented so far, the heat capacity effects have not been accounted for. However, the transient conditions can influence the collector performance particularly when the heat capacity is large or during warm up conditions. Also, it should be noted that, in reality, steady state conditions seldom exist, owing time dependent nature of solar radiation, ambient temperature and wind velocity.

13.3 HEAT CAPACITY EFFECTS

Even though the solar radiation is above the critical level of radiation, the collector cannot deliver energy at the desired temperature unless the absorber has reached the required temperature. This can happen when the absorbed energy prior to start up of the collector is insufficient to increase the temperature of the mass of all the elements of the collector to their equilibrium temperatures corresponding to the temperature of operation. This warm up period as well an account of response of solar collectors to varying input radiation can be understood by considering the heat capacity effects.

Consider a single cover collector. Let the absorber plate, water in the tubes and one half of the back insulation are all at the same temperature. Assume that the cover is at a single temperature. An energy balance on the collector absorber plate, water and back insulation yields,

$$(mC)_p \frac{dT_p}{d\tau} = A_c\left[S - U_{p-c}\left(T_p - T_c\right)\right] \tag{13.52}$$

An energy balance on the cover yields,

$$(mC)_c \frac{dTc_c}{d\tau} = A_c\left[U_{p-c}\left(T_p - T_c\right) - U_{c-a}\left(T_a - T_c\right)\right] \tag{13.53}$$

U_{p-c} and U_{c-a} are the loss coefficients from the plate to the cover and from cover to the ambient. Subscript p stands for the plate and c for the cover. Assuming that the ratio $\left(T_c - T_a\right)/\left(T_p - T_a\right)$ remains constant at its steady state value implies,

$$U_{c-a}\left(T_c - T_a\right) = U_L(T_p - T_a) \tag{13.54}$$

Differentiating Eq.(13.54) and assuming T_a to be constant, it follows,

$$\frac{dT_c}{d\tau} = \frac{U_L}{U_{c-a}} \frac{dT_p}{d\tau} \tag{13.55}$$

Adding Eqs.(13.52) and (13.53) and using Eq.(13.55),

$$\left[(mC)_p + \frac{U_L}{U_{c-a}}(mC)_c\right]\frac{dT_p}{d\tau} = A_c\left[S - U_L\left(T_p - T_a\right)\right] \tag{13.56}$$

where,

$$(mC)_e = (mC)_p + \sum_{i=1}^{n} a_i (mC)_{c,i} \tag{13.56 a}$$

Where a_i is the ratio of overall loss coefficient to the loss coefficient from the cover in question to the surrounding. If we assume S and T_a to be constant, solution to Eq.(13.56) is obtained as,

$$\frac{S - U_L\left(T_P - T_a\right)}{S - U_L\left(T_{P,initial} - T_a\right)} = e^{-\left(A_c U_L \tau / (mC)_e\right)} \tag{13.57}$$

$T_{p,initial}$ in Eq.(13.57) is the temperature of the plate at time $\tau = 0$. Though in reality S is not a constant, repeated use of Eq.(13.57) for small time intervals, taking the temperature at the end of the nth interval as the initial temperature for the $(n+1)^{th}$ interval yields reasonably accurate results.

13.4 SUMMARY

- The limitations of steady state analysis have been brought along with a transient analysis.
- Transient analysis becomes particularly important when the heat capacity of the collector is large and in determining the warm up period.
- The warm up period has a bearing on the operating period and the critical solar radiation.