6.6. Mixture of Steam and Dry Air in the Condenser.

Dalton's law of partial pressures stated that "the absolute pressure inside condenser is the sum of partial pressures of steam and air inside it". The partial pressure of steam shall be equal to the saturation pressure corresponding to entering steam temperature. This partial pressure of steam could be predicted from steam table. Mathematically, absolute pressure in condenser (P_c), as per Dalton's law;

$$Condenser\ pressure = Steam\ pressure + Air\ Leakage\ pressure$$

$$P_C = P_S + P_a$$

Where: P_C: is the condenser pressure.
P_S: partial pressure of steam.
P_a: partial pressure of air leakage in the condenser.

Moreover, the absolute pressure inside the condenser is:

$$Absolute\ pressure = Atmospheric(Barometric)\ presure + (gauge\ pressure)$$

i.e.,

$$P_{Condense(absolute)} = P_{Barometric} - P_{Vacuum}$$

Where for vacuum the gauge, pressure has a negative sign as illustrated in figure (6.2). It's useful to know the standard barometric head is 750 mmHg or 1.0 bar, to convert the pressure units.

Example (6.1) The following observations were recorded during a condenser test; Vacuum reading=700 mmHg, Barometric reading=760 mmHg, Condensate temperature=34^oC. Find;

a. Partial pressure of air.
b. Mass of air per $m^3$of condenser volume.

Solution: Given;

$P_{vacuum} = 700\ mmHg, P_{Barometric} = 760\ mmHg, T_{condenser} = 34°C$

$$Absolute\ pressure(condenser\ pressure)$$
$$= Atmospheric(Barometric)\ presure + (gauge\ pressure)$$

$P_c = P_{Barometer} - P_{Vacuum} = 760 - 700 = 60\ mmHg$

$P_c = 60 \times 0.00133 = 0.0798\ bar \qquad (where\ 1\ mmHg = 0.00133\ bar)$

From steam tables

$@T = 34°C \rightarrow \quad P_{steam} = 0.0532\ bar$

$P_c = P_S + P_a$

a. Partial pressure of air is;

$P_a = P_c - P_S = 0.0798 - 0.0532 = 0.0266\ bar$

b. Mass of air per m^3 of the condenser volume can be calculated as follows:

$P_a.v = m_a R_a T \rightarrow m_a = \frac{P_a.v}{R_a T}$

$m_a = \frac{0.0266\times10^5\times1}{287\times(34+273)} = 0.03\ kg\ of\ air\ per\ m^3$

6.7. Mass Flow Rate of Cooling Water.

The mass flow rate of the cooling water required to condensate the steam exhausted from the turbine can be predicted by using the energy balance for the heat through the steam condenser.

$Energy\ lost\ by\ wet\ steam = Energy\ gained\ by\ cooling\ water$

$m_s^o \times (h - h_f) = m_w^o \times C_{pw} \times (T_{water,out} - T_{water,in})$

In addition, is can be stated that the heat (energy) transferred from steam to cooling water passing across the walls of pipes of the steam condenser (heat exchanger), as follows:

$Q = U \times A_{Surface} \times LMTD$

Thus, $Q_{lost} = Q_{gained} = Q$

Where;

m_s^o : mass flow rate of steam across the condenser in kg/s.

h : enthalpy (heat) of steam entering the condenser in kj/kg.

h_f : enthalpy (heat) of condensate leaving the condenser in kj/kg.

m_w^o : mass flow rate of cooling water in the condenser in kg/s.

C_{pw} : specific heat of water in kj/kg.K.

$T_{water,in}$: inlet temperature of cooling water in K.

$T_{water,out}$: outlet temperature of cooling water in K.

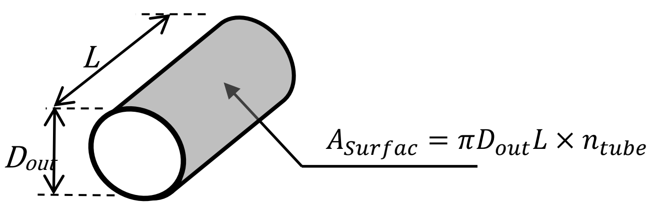
U: universal heat transfer coefficient in W/m^2.K.

$A_{Surface}$: surface area at which heat transferred from steam to cooling water in m^2, see figure (6.7).

$LMTD$: logarithmic mean temperature difference in K.

$LMTD = \frac{\Delta T_1 - \Delta T_2}{\ln\frac{\Delta T_1}{\Delta T_2}}$ see figure (6.8).

ΔT_1 : red line and ΔT_2 : blue line in figure (6.8)



Surface area for tube.

Figure (6.7): Surface area at which heat transferred from hot steam to cooling water flows inside tubs.

Figure (6.8) shows the temperature profile in a steam condenser. It can be noticed that the temperature of the steam entering the condenser does not change. Where's the wet steam entering the condenser converted to liquid water at the same temperature, there is a phase change only. For the direct contact steam condenser there is no surface area at which the heat transferred across it, where the two fluids is mixed directly.

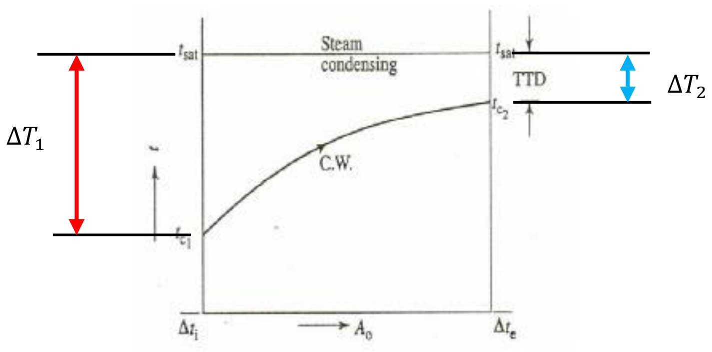


Figure (6.8): Temperature Profile in a Surface Steam Condenser.