Theoretical Analysis of a Cooling Tower for Condensation of Fresh Water From Plume

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***Abstract:-* The lack of water resources all around the world give a view to us to conserve the water in a better manner. In thermal power plants, plume/ water vapour(Hot air with water vapour normally called as plume) released by evaporation in cooling towers which is left to atmosphere as a waste. This wasted water vapour is being collected and condensed to get fresh water by a condenser. This fresh water is used for several applications of that power plant itself. A few researches have been carried out for analysis of cooling tower to utilize the waste plume. In addition to the operational and physical parameters with appropriate material selection, a condenser has been designed to get fresh water from plume based on available typical data of existing counter flow wet cooling tower of thermal power plant. The stainless steel material was selected for condenser tubes in order to avoid corrosion . Fresh water collected by condensing the water vapour will be used for that power plant water supply needs and nearby villages.**

Keywords: Cooling tower, condenser, water vapour, fresh water.

1. INTRODUCTION

The demand for fresh water is continuously rising because of increasing population, climate change, urban growth, deforestation, intense agricultural practice, industrialization and overall life standard of human. Water is a basic resource and has a very crucial role in the development of economy. According to the current estimate the total volume of water on earth is 1400 million cubic km. but of this 97.3% is ocean water and 2% is locked in polar caps. So useable quantity of water is less than 1%. This survey makes us to understand the scarcity of fresh water and its importance. In order to overcome this problem a new economical way for production of fresh water at socially acceptable cost have to be established . In power plants large quantity of water is required for various operations in Chemical processing plants, Textile industries, dairy plants. And also there is a abundant amount of water vapour, which is released to the atmosphere as a waste.

Especially thermal power plants are releasing water vapour to the atmosphere as a waste. This wasted water vapour is being collected and condensed to get water for power plant needs. Then this water is being filtered for drinking purpose which can be supplied to nearby villages. (As per Steven R. Hanna's (1972) discussion that the water vapour released by a cooling tower is at the rate of about 4T/ hr/MW. Normally 840 MW capacity thermal power plant cooling tower releases approximately 933 kg/sec. of water vapour as waste). This water vapour released to atmosphere creates environmental problems like global warming and some scarcity of water. In order to find a solution for both the scarcity of water and environmental issues, this wasted water vapour from cooling tower is being collected and condensed for fresh water by using a new modified condenser.

2. LITERATURE SURVEY

Randall Koenig et al. (1978) examined the industrial effluents that they alter both the microphysical properties that regulate the rate of production of precipitation and the location and strengths of density and velocity perturbations that regulate the dynamical development of clouds.

Gan et al. (1999) investigated a numerical technique for evaluating the performance of a closed wet cooling tower for chilled ceiling system. Numerical simulation indicates that CFD can be used to predict the performance of a closed wet cooling tower, given that appropriate rate of heat generated from the heat exchanger.

Jameel ur. Rehman, Kahn et al. (2003) ,they used a detailed model of counter flow wet cooling tower in investigating the performance characteristics.

Wigley et al. (2005) presented the results of a numerical solution of the equations of moist plume rise and compared the trajectories of wet and dry cooling tower. It is noted that there is a greater rise and longer oscillation wavelength for the wet plume.

Affad and Saadeddine et al. (2006) discussed the effect of the relative humidity on an industrial plume behavior and concluded that the effect of relative humidity on plume composition (vapour mass) is notable, its effect on the plume rise, plume radius and plume temperature remain relatively slight.

Marmourch, orfi et al. (2008) presented the theoretical and experimental studies of a solar desalination system with humidification-dehumidification, correlated the variation of tower characteristics with liquid to gas mass flow rate ratio.

Sarker et al. (2008) conducted experiments on hybrid closed circuit cooling tower (HCCCT) having a rated capacity of 136kW. His results were supported to serve as basic design parameters for the HCCCT

Further, the same authors (2009) designed a new solar distiller and constructed a cooling tower to solve the condensation process problem. The results showed that the effect of the cooling tower with and without recuperation of steam and the effect of heating, humidification air before sending it to the condenser.

Wue et.al (2009) discussed the heat and moisture transfer between water and air in a direct evaporative cooler. The predicted result show the direct evaporative cooler with high performance pad material may be well applied for air conditioning with reasonable choice for the inlet frontal velocity and pad thickness.

Xiang-liang et al. (2009) detailed the flow field in the hyperbolic natural draft wet cooling tower, which has great effects on the economy and security of power plant . Result found that the effect of circulated water temperature was evaluated to that of the water flux.

Kwangkook jeong et al. (2010) developed an analytical modeling of water condensation in condensing heat exchanger. The result showed that condensation efficiency is strongly affected by changing ratio of mass of cooling water to mass of gas inlet. The higher value of mass of cooling water to mass of gas inlet result in higher condensation efficiencies owing to higher thermal mass of cooling water side.

Matjaz Dvorsek-marko hocevar et al. (2011) discussed the influence of air flow inlet regional modifications on the local efficiency of natural draft cooling tower operation and results show a slight decrease of local efficiency at the circumference of the cooling tower, while in general decrease is small.

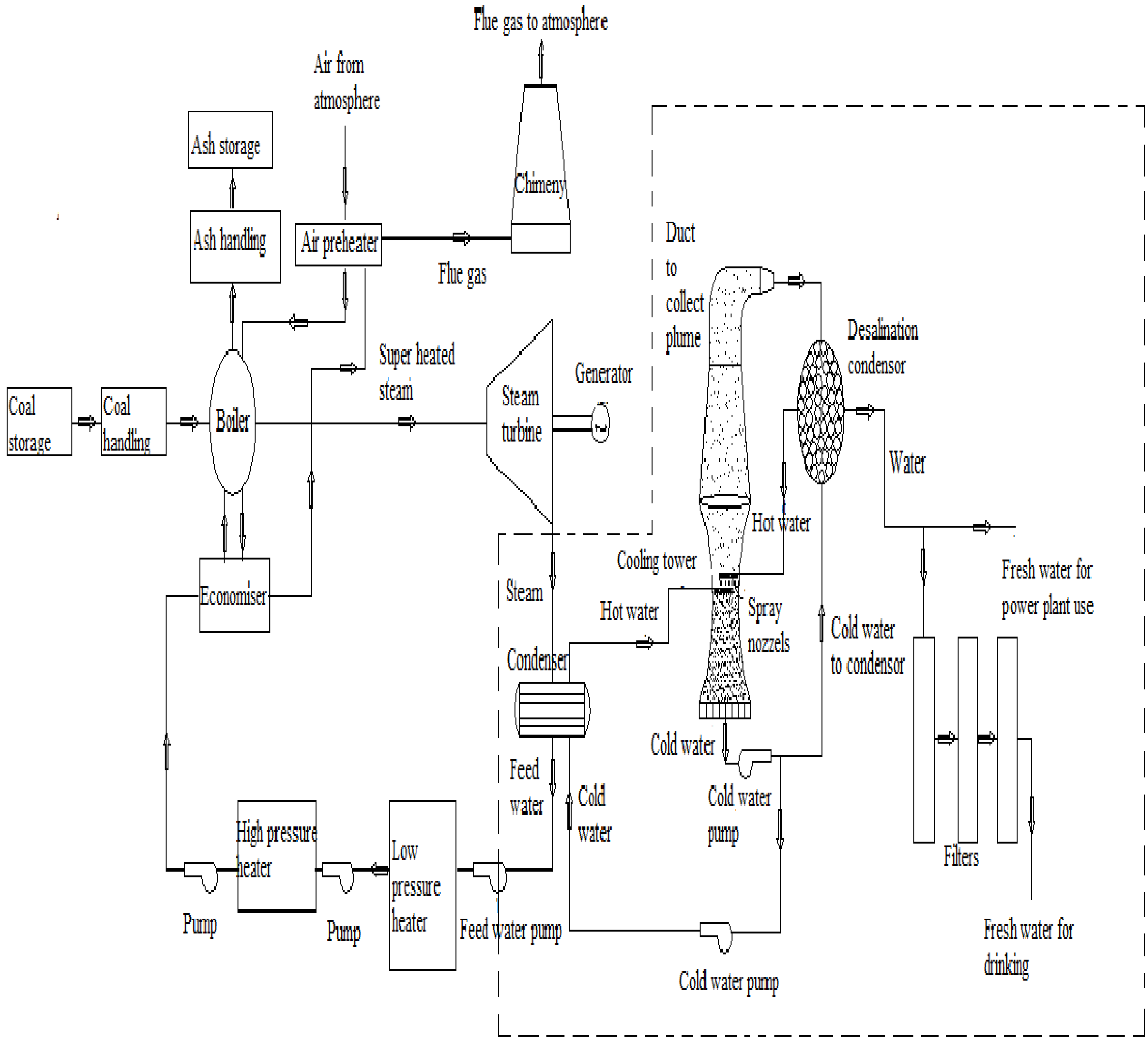

Fig 1. schematic diagram for cooling tower plume condensation for fresh water

Hamid Nabati et al. (2011) investigated on numerical modeling of water vapour condensation from a flue gas with high Co_2 content. The results showed the heat transfer co efficient decreases as a consequence of the increase in Co_2 mass fraction for constant wall temperature as a result of higher resistance to diffuse from the flue gas bulk to the boundary layer.

Ugwu, Hyginus Ubabuike et al. (2012) made a study to design of an efficient cooling tower for Alaoji power plant Aba, Nigeria. It was inferred that wet bulb temperature usually determined by the geographical location, should not exceed over 5% of the time in that area because the higher the wet bulb temperature, smaller the tower required to give a specified approach to the wet bulb temperature at a constant range and flow rate.

Rafal Marcin Laskowski et al.(2012) presented a mathematical model of a steam condenser in off design operation. The analysis of the relations showed that the water temperature at the outlet of the steam condenser depends on temperature at the inlet of both fluids, the heat capacity of cooling water, overall heat transfer coefficient and heat transfer surface area.

Jun-De Li et al.(2013) presented simulation of water vapour condensation in the presence of non-condensable gas in vertical cylindrical condensers. The results shows clearly that the average axial velocity decreases rapidly as water vapour is condensed. It is expected that for lower Reynolds numbers of gas mixture at the inlet or long enough condenser tube with high mass flow rate of coolant, the axial velocity of gas mixture at the interface can be higher than the average axial velocity of the gas mixture.

Vikram Haldkar et al.(2013) analyzed the parametric analysis of surface condenser for thermal power plant . The result showed that the power plant efficiency is reduced by deviation due to cooling water inlet temperature deviation due to water flow rate and deviation due to condenser pressure.

Giangfranco Caruso et al. (2014) analysed heat and mass transfer analogy applied to condensation in the presence of non-condensable gases inside inclined tubes. Results showed that under laminar condition (Re<2000) adopted colburn analogy is not applicable. For inclination of 45^0 the results showed that wide difference with respect to analogy especially at low inlet gas concentration because of inadequacy of chato's model at this inclination and to larger experimental uncertainties in the diffusion of temperature profile.

3. PRINCIPLE OF OPERATION

Fig.1 shows the schematic diagram of the system. The system consists of cooling tower, condenser for desalination, condenser for thermal power plant, filters, fresh water pump, duct etc.

The steam produced from boiler of thermal power plant is expanded in a steam turbine for energy conversion from thermal to mechanical. This expanded steam is condensed in the thermal power plant condenser. There is a phase change from steam to water. This water is pumped by a feed water pump to use as a feed water in the boiler.

The warm water from condenser is sprayed on the top of the cooling tower as a fine drops. The ambient air is passed from bottom of the cooling tower. When the air from atmosphere passes through the wetted surface, there will be both sensible and latent heat transfer occurs. For heat transfer there is a difference in temperature is essential if there is a difference in the partial pressure of water vapour in the air and water there will be a mass transfer. This mass transfer causes a thermal energy transfer because if some water is evaporated from the water layer, the latent heat of vaporized water will be supplied to the air.

The plume from top of the Cooling Tower is collected through duct and is sent to the condenser, where it is condensed to get fresh water. For condensation the water is taken from river (in addition to the water collected from the coldwater basin of cooling tower) to the condenser and the warm water from the condenser is sent back to the Cooling Tower .

4.DESIGN DETAILS OF CONDENSER

The material of the condenser tubes has been selected as SS316 for its anti-corrosion properties. Then annular fins for condenser tubes have been selected for increasing the surface area and enhance the heat transfer rate.

The following equations were used to design the condenser

Heat rejected in the condenser

$$Q = m \times h_{fg} \qquad (1)$$

Water flow rate

$$m_w = \frac{Q}{C_p\,(T_{w2} - T_{w1})} \qquad (2)$$

Velocity of water through tubes

$$u_w = \frac{m_w}{A} \qquad (3)$$

$$Reynolds\ number\ (R_e) = \frac{D_i\, u_w\, \rho}{\mu} \qquad (4)$$

$$Prandl\ Number\ (P_r) = \frac{C\ \mu}{k} \tag{5}$$

$$Nusselt\ Number (N_u) = \frac{h_i\ D_i}{k} \tag{6}$$

Water side co-efficient

$$Water\ side\ coefficient\ (h_i) = \frac{N_U\ K}{D_i} \tag{7}$$

Average co-efficient of Heat Transfer for vapour Condensing on the Outside of horizontal tubes

$$h_0 = 0.725 \left[\frac{k_f^3\ \ \rho_f^2\ \ g\ \ h_{fg}}{N\ \ D_0\ \ \mu_f\ \ \Delta T}\right]^{0.25} \tag{8}$$

Efficiency of fin

$$\eta_f = L \times \sqrt{\frac{2h}{kt}} \tag{9}$$

External surface area (A_t)

$$A_t = \frac{Q}{U_t \times (\Delta T)_m} \tag{10}$$

Over all heat transfer co-efficient based on total extended surface side area A_t

$$\frac{1}{U_t} = \frac{1}{h_0}\left(\frac{A_t}{\eta_f A_f + A_b}\right) + \frac{1}{h_{ff}}\ \frac{A_t}{A_i} + \frac{1}{h_i}\left(\frac{A_t}{A_i}\right) \tag{11}$$

Log - Mean Temperature Difference

$$(\Delta T)_m = \frac{(t_c - t_i) - (t_c - t_0)}{ln\left[\frac{t_c - t_i}{t_c - t_0}\right]} \tag{12}$$

Length of the tubes

$$L = \frac{A_0}{\pi\ D_0} \tag{13}$$

Table.1 Details of condenser

Sl.No	Description	Details
1	Inner diameter of the tube	0.002875 m
2	Outer diameter of the tube	0.003175 m
3	Length of each tube	10 m
4	Number of tubes	4,50,000 nos.
5	Total length of condenser tube	45,00,000 m
6	Diameter of fin	0.052 m
7	Fins per inch	7fins/0.0254 m
8	Height of the fin	0.001 m
9	Thickness of the fin	0.0001 m

Table.2 Details of designed thermal Power Plant cooling tower

Sl no	Description	Details
1	Total no. of cooling towers/840 MW power plant	30
2	Water vapour released /cooling tower	31.1 kg/sec
3	Total length of condenser tube /cooling tower	1,50,000 m
4	No of tubes /cooling tower	15000 nos.

5. METHODOLOGY

When there is a direct contact between water and air, the concept of enthalpy potential is a very useful on quantifying the sensible and latent heat transfer. The total heat transfer is directly proportional to the difference between the enthalpy of saturated air at the water temperature and the enthalpy of air at the point of contact with water.

$$Q = K \times S \times (h_w - h_a) \tag{14}$$

The heat transfer rate from water side is

$$Q = C_w \times L \times R \qquad (15)$$

The heat transfer rate from air side is

$$Q = G \times (h_{a2} - h_{a1}) \qquad (16)$$

$$NTU = \frac{KaV}{L} = C_w \int_{Tw_1}^{Tw_2} \frac{dt_w}{(h_w - h_a)} \qquad (17)$$

$$\frac{KaV}{L} = Tower\ Characteristics$$

Tower characteristics can also be referred to as the number of transfer units (NTU) of the system.

Performance of cooling tower is often expressed in terms of range and approach.

$$Range(R) = T_{w1} - T_{w2} \qquad (18)$$

$$Approach(A) = T_{w2} - T_{wb1} \qquad (19)$$

The effectiveness of counter flow cooling tower.

$$Effectiveness = \frac{1 - e^{NTU(R-1)}}{1 - R.e^{NTU(R-1)}} \qquad (20)$$

6. RESULT AND DISCUSSION

The mass transfer co-efficient (Ka) - kg/m^{3}s was found and the factors that influence the mass transfer co-efficient also affect the heat transfer co-efficient.

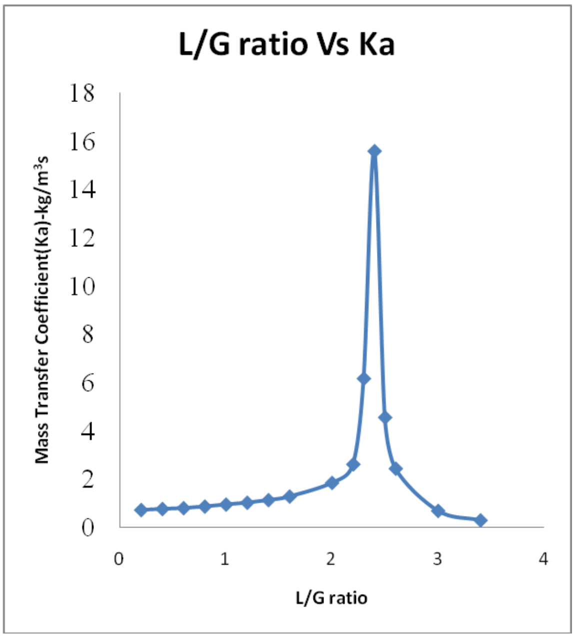

Fig.2.Variation of Mass Transfer Coefficient with L/G ratio

the mass transfer co efficient increased with the increases of the L/G ratio. However, it can be observed that there is some degree of difficulty in the mass transfer when a high L/G ratio was employed.

The mass transfer co-efficient increased up to L/G=2.4 and then drastically decreased. At L/G is <2.4, the contact area is larger between air and water and so retention time is long. Within this L/G<2.4, the better heat transfer rate is achieved. When L/G>2.4, the mass transfer rate is reduced. So the mass transfer coefficient is decreased drastically. This is because of reduction in air flow rate.

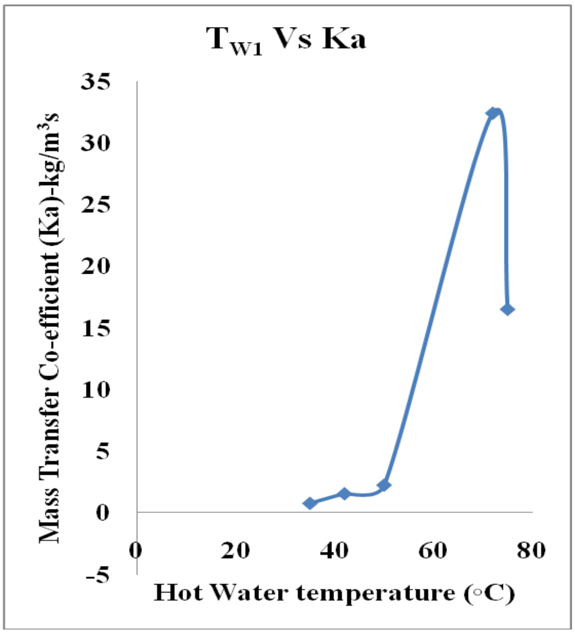

Fig.3 Variation of Mass Transfer Coefficient with Hot water temperature (^{0} C) (T_{W1})

Fig.3 shows the variation of mass transfer co-efficient with inlet hot water. The mass transfer coefficient is increased when hot water temperature increases from 50^0 C to 72^0 C as shown in fig 3. But when the hot water temperature is exceeds 72^0 C the mass transfer coefficient is decreased. This is because the driving force increases with the increase of inlet water temperature and a better heat and mass transfer occurs. But by increasing inlet water temperature continuously, the outlet water temperature will also increase. So that above 72^0 C the heat transfer rate will be decreased, the water evaporation rate is increased.

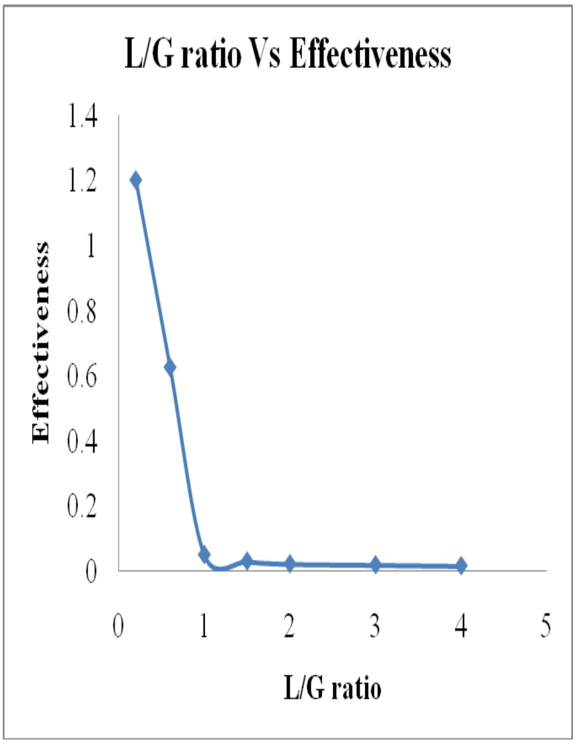

Fig 4. Variation of Effectiveness with L/G ratio

Fig 4 shows that the effectiveness is high when the L/G ratio is low. With increasing of L/G ratio the effectiveness was decreased drastically. In lower value of L/G ratio, Larger the quantity of air was in contact with less quantity of water. But when L/G ratio is high the quantity of water and air will be reverse. So the effectiveness of cooling tower is achieved in low L/G ratio only.

7. CONCLUSION

The condenser has been designed for fresh water by condensing the water vapour from counter flow wet cooling tower. The material of the condenser was selected as stainless steel for anti corrosion properties and finned tubes were selected for enhancing the heat transfer. The fresh water from desalination condenser can be used for power plant water needs as well as near by villages. The water collected from condenser is to be also tested for W.H.O standards for drinking water.

Nomenclature

Q = Heat rejected in the condenser (kJ)
m_w = Mass flow rate of water (kg/s)
u_w = Velocity of water in tubes (m/s)
ρ = Density of water (kg/m^3)
Re = Reynolds number
Pr = Prandle number
N_u = Nusselt number
K_f = Thermal conductivity of water (W/mk)
h_i = Water side co – efficient (W/m^{2}k)
h_o = Condenser film co – efficient of heat transfer (W/m^{2}k)
$1/h_{ff}$ = Fouling factor (m^{2}k/W)
A_i = Inside tube surface area (m$^{2)}$
A_f = Fin surface area (m$^{2)}$
A_b = Bare tube surface area (m$^{2)}$
A_t = Total tube surface area (m$^{2)}$
A_o = Outside area of the tube (m$^{2)}$
L = Total length of the condenser tube
K = overall enthalpy transfer coefficient
S = heat transfer surface m$^{2.}$
a = area of transfer surface per unit of tower volume. (1/m),
V = effective tower volume(m^3).
h_w = enthalpy of air-water vapor mixture at the bulk water temperature (KJ/kg)
h_a = enthalpy of air-water vapor mixture at the wet bulb temperature (KJ/Kg)
C_w = Specific heat of water (KJ/kgk)
L = Water flow rate (kg/s)
G = Air flow rate (kg/s)
R = Range (k)
NTU= Number of Transfer Unit
T_w = Temperature (^{0} C)
T_{wb1} = Wet bulb temperature (^{0} C)
C_p = Specific heat capacity at constant pressure (KJ/kgk)
h_{fg} = Latent heat of evaporation (KJ/kg)

Abbreviations

LMTD = Log Mean Temperature Difference
Cond = Condenser

Greek letters

μ_f = Dynamic viscosity of liquid (kg/ms)
ρ_f = Density of vapour (kg/m^3)

Subscripts

w = water
f = fluid
i = internal
O = outer
b = bare
t = total
c = condense
c_w = Cold water

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