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Research Article

SENSITIVITY ANALYSIS FOR COUNTER FLOW COOLING TOWER-PART I, EXIT COLD WATER TEMPERATURE

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ABSTRACT

Water cooling towers are sized and selected on the basis of economic considerations and constraints imposed by system components. The exit cold water temperature has direct impact on the economic of design and performance of process equipments. Therefore the accurate prediction of cooling towers performance and exit cool water temperature is of great importance. In this study sensitivity analysis is performed for the counter flow type cooling tower to identify the critical parameter to which cooling towers exit cold water is more sensitive.

Key Words: *Cooling Tower, Exit Cold Water Temperature, Sensitive Analysis, Wet Bulb Temperature*

INTRODUCTION

Now a day's large numbers of industrial applications are using cooling tower to remove the process heat especially in power generating, refrigeration and air conditioning, chemicals, petrochemicals and petroleum industries. Cooling towers are extensively being used, wherever water is used as a cooling medium or process fluid. In most industrial locations, cooled fresh water is scanty therefore, continuous reuse and re cooling of the limited fresh water with the help of cooling tower is more common and economical. Another strong motivation for the increased use of cooling towers is the environmental protection provided through the reduction of water withdrawals and minimizing of thermal discharge.

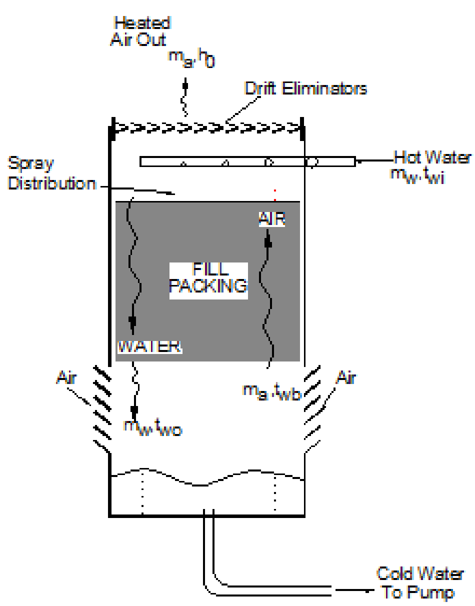

Figure 1

Figure 1: Schematic of a wet counter flow Cooling tower Khan *et al.*, (2003).

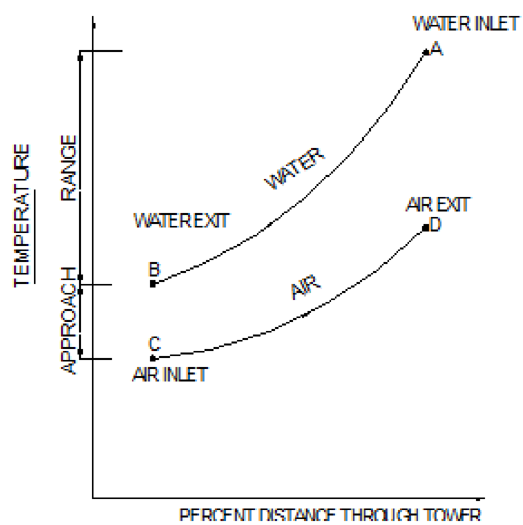

Figure 2

Figure 2: Temperature relationship between water and air in a counter flow cooling tower Mohiuddin and Kant (1996).

The most common type of cooling tower is wet cooling tower in which temperature of the re circulated water is reduced by bringing it into direct contact with unsaturated air. Figure 1 shows a schematic of a wet cooling tower which consist of large chambers, loosely filled with trays and deck of wooden board, asbestos sheet as slates or PVC material films called packing Khan *et al.,* (2003). These filling or packing provides sufficient area and time to get contact between air and water for energy transfer Mohiuddin and Kant (1996), Mohiuddin and Kant (1996). Figure 2 shows the temperature relationship between water and air as they pass through a counter flow-cooling tower. The difference between the water temperatures entering and leaving the tower is defined is the Range. The difference between the leaving water temperatures and entering air wet bulb temperature is known as Approach of the cooling tower.
In the power generation plants, the temperature of cooling water fixes the ultimate recovery of heat from the turbine and discharge pressure of the heat engines. In addition the cooling water temperature establishes the operating pressure of the condenser of distillation and evaporation operations. For these vital reasons exit cold water temperature from the cooling water play an important role in designing a cooling tower? Therefore the parameter that affects the exit cold water temperature the most is the paramount critical parameters for the cooling tower design. Thus a sensitive analysis has been performed for the counter flow cooling tower to identify the critical parameter to which cooling towers exit cold water is more sensitive.

MATERIALS AND METHODS
Following procedure is adopted to determine the exit cold-water temperature form a counter flow cooling towers based on the Merkel and accurate models of cooling tower design Chitranjan (2004). The equation for NTU calculation can be written as following equation.

$$(NTU)_G = \left(\frac{h_d A_v V}{m_a}\right) = \int_{h_1}^{h_2} \frac{dh}{h_{sw} - h} \qquad (1)$$

$$(NTU)_L = \left(\frac{h_d A_v V}{m_w}\right) = C_w \int_{t_{w1}}^{t_{w2}} \frac{dt_w}{h_{sw} - h} \qquad (2)$$

The equation (1) is known as number of transfer unit (NTU) of Air path i.e. $(NTU)_G$ and equation (2) is known as number of transfer unit of liquid path i.e. $(NTU)_L$. With help of equation (1) we can write

$$\text{So} \qquad Z = \left(\frac{m_a}{h_d A_v A}\right) \int_{h_1}^{h_2} \frac{dh}{h_{sw} - h} \quad \text{Where } V = A*Z \qquad (3)$$

Here the term (m_a/ *hd Av A*) is known as height of transfer unit Kern and Donald (1997) i.e. $(HTU)_G$ therefore,

$$(HTU)_G = \frac{Z}{(NTU)_G} \qquad (4)$$

The integral involved in equation (1) and (2) could not be solved directly as the (h_{sw}–h) cannot be expressed simply in terms of an expression of temperature. Various methods being used to evaluate this integral viz: Graphical method Majumdar and Singhal (1983), use of Carey and Williamson charts Hill *et al.,* (1990), numerical integration using Simpson rule Arora (1997), Techebycheff method or by incremental step method ASHRAE Systems and Equipment Hand Book (2000). The cooling tower size can be calculated by equation (5) for the required value of exit cold water and inlet hot water temperature, given surrounding condition, packing types and material.

$$V = \left(\frac{m_w C_w}{h_d A_v}\right) \int_{t_{w1}}^{t_{w2}} \frac{dt_w}{h_{sw} - h} \qquad (5)$$

Initially for required inlet and outlet water temperature, NTU is calculated here by using series of incremental method. In this method, cooling tower is divided into small control volumes (*dv*). The calculation starts at the bottom of tower, where inlet air and water condition are known. Water to airflow ratio (m_w / m_a) is kept constant. Water temperature is increased by a small amount until the inlet water temperature is reached; corresponding air enthalpy is calculated by equation (6). In our calculations, small incremental value of temperature is taken 1^0C.

$$h_2 = h_1 + \frac{m_w}{m_a} C_w (t_{w1} - t_{w2}) \tag{6}$$

Air properties at water temperature t_w can be calculated by following empirical relations eq. (7-10).

$$P_s = \exp\left(16.41 - \frac{3891.4}{230 + t_w}\right) \tag{7}$$

$$w_s = 0.622\left(\frac{P_s}{101.32 - P_s}\right) \tag{8}$$

$$h_{gw} = 1.88 t_w + 2500 \tag{9}$$

$$h_{sw} = 1.005 t_w + h_{gw} w_s \tag{10}$$

NTU for a control volume (*dv*) can be obtained as

$$\Delta(NTU) = \frac{h_d A_v dv}{m_w} = C_w \left(\frac{dt_w}{(h_{sw} - h)}\right) \tag{11}$$

For complete tower volume NTU is the sum of NTU for small control volume. This calculated NTU is the required NTU of the cooling tower to cool the water from temperature (t_{w1}) to temperature (t_{w2}) for the given condition of surrounding air and packing material. For performing sensitivity analysis this calculated NTU is used to determine exit cold-water temperature with using the same equations but the calculations require iterations. The exit cold water temperature has been evaluated separately for % change in different operating parameters.

RESULTS AND DISCUSSION

Sensitivity analysis curve for the exit cold water temperature from the counter flow cooling tower is shown in Figure 3. The base values for the operating parameters are taken as NTU = 1.5, m_w= 100 kg/sec. m_a= 100 kg/sec. m_w/m_a = 1.00, t_{wbt}=25^{0}C, t_{w1}=40^{0}C and the atmospheric pressure P= 101.32 k Pa.

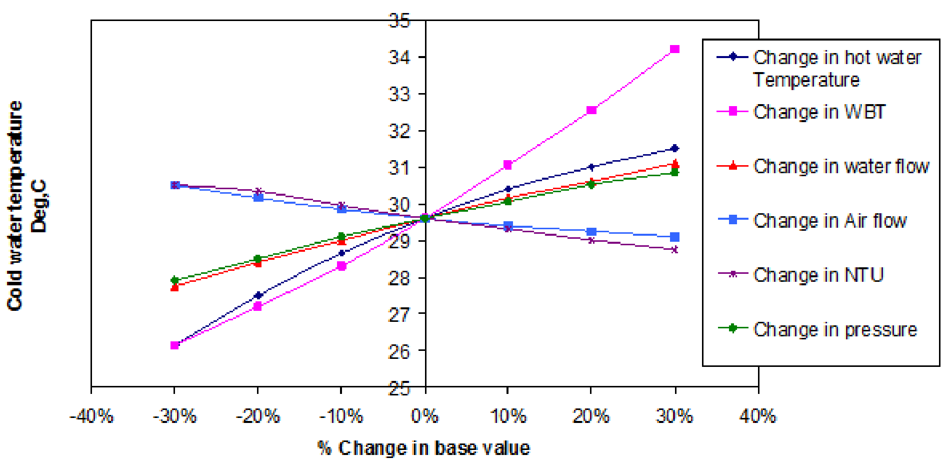

Figure 3: Sensitive analysis for Cold water temperature of Counter flow cooling tower

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The variation in the base values is done for -30% to +30%, the corresponding values of cold water temperature are given in Table 1. The percentage change in cold water temperature by changing base values of operating parameters are shown in Table 1. It is observed from Figure 3 and Table 1 that the cold water temperature is decreases by increase in m_a and NTU and it is increases by increase in t_{w1}, t_{wbt}, m_w and pressure values.

From Table 1 it is also observed that the exit cold water temperature is more sensitive to the change in wet bulb temperature (t_{wbt}) and the inlet hot water temperature (t_{w1}). Change in 60% from the base values of t_{wbt} and t_{w1} changes the cold water temperature (t_{w2}) by 27.19% and 18.06% respectively. From this table it is also observed that, by increasing operating parameters values exit cold water temperature increases with these operating parameters values except for the increase in Air flow (m_a) and NTU.

Table 1: Sensitivity Analysis for Exit Cold Water Temperature

S. No.	% Change in base value	Change in (t_{w1})		Change in (t_{wbt})		Change in mw	
		Hot water (t_{w1} in ^{0}C)	Cold water (t_{w2} in ^{0}C)	t_{wbt} in ^{0}C	Cold water (t_{w2} in ^{0}C)	m_w in kg/Sec	Cold water (t_{w2} in ^{0}C)
1	-30%	28	26.15	17.5	26.15	70	27.75
2	-20%	32	27.50	20.0	27.20	80	28.40
3	-10%	36	28.65	22.5	28.30	90	29.00
4	0	40	29.60	25.0	29.60	100	29.60
5	10%	44	30.40	27.5	31.05	110	30.15
6	20%	48	31.00	30.0	32.55	120	30.60
7	30%	52	31.50	32.5	34.20	130	31.10

Base values NTU=1.5, m_w=100 kg/sec, m_a=100 kg/sec, t_{wbt}=25^0 C, t_{w1}=40^0 C, P=101.32 kPa

S. No	% Change in base value	Change in m_a		Change in NTU		Change in Pressure	
		m_a kg/Sec	Cold water (t_{w2} in ^{0}C)	NTU	Cold water (t_{w2} in ^{0}C)	Pressure kPa	Cold water (t_{w2} in ^{0}C)
1	-30%	70	30.50	1.05	30.51	70.91	27.90
2	-20%	80	30.15	1.20	30.34	81.04	28.50
3	-10%	90	29.85	1.35	29.95	91.18	29.10
4	0	100	29.60	1.50	29.60	101.32	29.60
5	10%	110	29.40	1.65	29.32	111.45	30.05
6	20%	120	29.25	1.80	29.01	121.58	30.52
7	30%	130	29.10	2.05	28.75	131.71	30.85

CONCLUSION

With the performed sensitivity analysis it is found that Exit cold water temperature from the cooling tower is more sensitive to the wet bulb temperature and inlet hot water temperature but the effect of wet bulb temperature on cold water temperature is more compare to inlet hot water temperature. Therefore selection of location and range for which cooling tower is designed are also important for the performance of a cooling tower.

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