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Research Article

SENSITIVITY ANALYSIS FOR COUNTER FLOW COOLING TOWER-PART II, COOLING TOWER EFFECTIVENESS

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ABSTRACT
This paper deals with the part-2 of the sensitivity analysis of a counter flow cooling tower. The effect of change in various operating parameters on the effectiveness of a counter flow cooling tower has been investigated in the present study. It has been observed with this sensitive analysis that the effectiveness of a counter flow cooling tower is more sensitive to the change in water flow rate and the change in surrounding pressure.

Key Words: *Cooling Tower, Tower Effectiveness, Sensitive Analysis, Wet Bulb Temperature*

INTRODUCTION
Use of cooling tower is inevitable in various industrial applications, where evaporative cooling principle is used to cool process water. The cooling is achieved partly by the evaporation of a fraction of the circulating water and partly by the transfer of sensible heat Watt (1996). The wet cooling towers generally have packing that provides sufficient area and time to get contact between air and water for energy transfer. The physical situation with in a cooling tower is very complex, films and droplets of water in air are constantly changing its configuration. There is no mathematical model available, which is capable of simulating every detail of the simultaneous heat and mass transfer processes occurring within the cooling tower. Therefore, some simplified assumptions were made for the analysis. There are various mathematical models available for both mechanical and natural draft cooling tower to calculate tower performance and designing. Each model makes use of different set of assumptions and thus the results of calculation for heat and mass transfer coefficient from each model are also different. This may result in different condition of the cold water and tower performance at deign and off design condition.
The present investigation is the extension of part-1 of this study, where sensitivity analysis was performed to evaluate the effect of change in various operating parameters on the exit cold water temperature from a cooling tower. However, this investigation (Part-2) deals with the effect of change in various operating parameters on the cooling tower effectiveness. The accurate model suggested by Chitranjan (2004) has also been used to determine the cooling tower exit water temperature similar as used in the part-1 of this study.

MATERIALS AND METHODS
The method for determining the exit cold-water temperature form a counter flow cooling towers remains the same as discussed in part-1 of this study. Initially Equation (1) was used to determine the required tower NTU for the base (designed) condition of a cooling tower.

$$\Delta(NTU) = \frac{h_d A_v dv}{m_w} = C_w\left(\frac{dt_w}{(h_{sw} - h)}\right) \qquad (1)$$

The determination of exit cold water temperature form a counter flow cooling tower for different set of operating condition required iteration process and were calculated for the required tower NTU. The exit cold water temperature and the corresponding operating parameters were used to determine the cooling tower effectiveness with the help of following Equation (2). The Effectiveness of a cooling tower can be define as the ratio of actual change of water temperature in cooling tower to the maximum possible change of water temperature inside the cooling tower Jaber and Webb (2000)-ASHARE and Equipment (1989).

$$\xi = \frac{t_{w1} - t_{w2}}{t_{w1} - t_{wbt1}} \quad (2)$$

$$= \frac{\text{Water temperature at inlet - Water temperature at outlet}}{\text{Water temperature at inlet – Air wet bulb temperature}}$$

It can also be written as

$$\xi = \frac{t_{w1} - t_{w2}}{\left[\left(t_{w1} - t_{w2}\right) + \left(t_{w2} - t_{wbt1}\right)\right]} \quad (3)$$

$$= \frac{\text{Range}}{\text{Range + Approach}}$$

The base value of different operating parameters for cooling tower design were as follows
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.

Table 1: Sensitivity Analysis for counter flow cooling tower

S. No.	% Change in base value	Change in hot water temperature		Change in wet bulb temperature		Change in mw	
		Hot water (t_{w1} in ^{0}C)	Effectiveness (ε)	t_{wbt} in ^{0}C	Effectiveness (ε)	m_w in kg/Sec	Effectiveness (ε)
1	-30%	28	0.616	17.5	0.615	70	0.810
2	-20%	32	0.642	20.0	0.640	80	0.770
3	-10%	36	0.668	22.5	0.668	90	0.733
4	0	40	0.693	25.0	0.693	100	0.693
5	10%	44	0.715	27.5	0.720	110	0.652
6	20%	48	0.739	30.0	0.745	120	0.624
7	30%	52	0.760	32.5	0.773	130	0.591

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	Effectiveness (ε)	NTU	Effectiveness (ε)	Pressure kPa	Effectiveness (ε)
1	-30%	70	0.633	1.05	0.652	70.91	0.806
2	-20%	80	0.656	1.20	0.639	81.04	0.766
3	-10%	90	0.676	1.35	0.672	91.18	0.726
4	0	100	0.693	1.50	0.693	101.32	0.693
5	10%	110	0.705	1.65	0.713	111.45	0.663
6	20%	120	0.716	1.80	0.733	121.58	0.633
7	30%	130	0.722	2.05	0.749	131.71	0.612

For performing sensitivity analysis the base values of an operating parameter changed by -30 to + 30 percentages while the remaining parameters were kept invariable. The change in tower effectiveness was

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determined with the change in different operating parameters to evaluate the operating parameters that affects the tower performance the most.

RESULTS AND DISCUSSION

The sensitivity analysis curve for the cooling tower effectiveness is shown in Figure 1.

The variation in the base values is done for -30% to +30% and the corresponding values of tower effectiveness are given in Table 1. The percentage change in tower effectiveness by change in base values of the operating parameters are shown in Table 2.

It is observed from Figure 1 and Table 1 that by increasing the values of t_{w1}, t_{wbt}, m_a and NTU the tower effectiveness increases. Nonetheless by increasing m_w and atmospheric pressure the tower effectiveness decreases. From table 2 it is observed that effectiveness of counter flow cooling tower is more sensitive to the water flow rate and the surrounding pressure, change in 60% of the base value of these parameters changes the tower effectiveness by 31.52% and 28.18% respectively. Whereas in the part -1 of this study it was has been observed that the exit cold water temperature is more sensitive to the 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. Thus the critical parameters that affects the cooling tower effectiveness the most is not the same as the critical parameters that affect the cooling tower exit cold water temperature the most. From these Figure and Tables it is also observed that, by increasing operating parameters the tower effectiveness increases except by increase in the water flow (m_w) and the surrounding pressure.

Table 2: Percentage Change in tower effectiveness with Change in base value of operating Parameters

S.No	% Change in Base Value	Change in t_{w1}	Change in t_{wbt}	Change in m_w	Change in m_a	Change in NTU	Change in P
1	-30	-11.11	-11.20	16.88	-8.65	-8.80	16.30
2	-20	-7.36	-7.64	11.11	-5.34	-7.79	10.53
3	-10	-3.60	-3.60	5.77	-2.45	-3.03	4.85
4	10	3.17	3.89	-5.91	1.73	2.88	-4.32
5	20	6.63	7.50	-9.95	3.31	5.77	-8.65
6	30	9.96	11.54	-14.71	4.18	8.08	-11.68

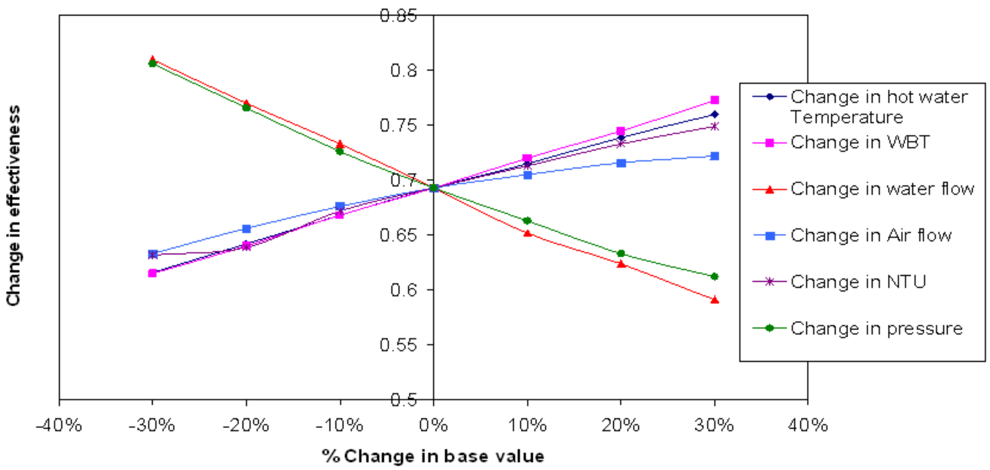

Figure 1: Sensitive analysis for counter flow cooling tower effectiveness

CONCLUSIONS

With the sensitivity analysis it is found that the cooling tower effectiveness is more sensitive to water flow rate. Therefore, water flow rate must be maintained at the specified design value. The change in water flow rate from its specified design value affects the cooling tower effectiveness the most as compare to the other operating parameters. Tower effectiveness is also sensitive to the atmospheric pressure but to a lesser extent than the water flow rate. Hence, position of cooling tower is also an important parameter in determining cooling tower performance, as by changing the height from the earth surrounding pressure varies and consequently the tower effectiveness changes.

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