

Study on the Effect of Blade Angle on the Performance of a Small Cooling Tower

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ABSTRACT

This paper presents the effect of blade angles on the packing characteristic curves of a small cooling tower on the site experimental data. The volumetric heat transfer coefficient (KaV/L) can be illustrated graphically and varied with the water to air flow ratio (L/G) for the blade angles of 59° , 67° , 75° , and 83° , respectively. The curves can be constructed by the experimental data from the cooling tower testing in accordance with the procedure of CTI standard. It was found that the characteristic curves can be represented in the form of $KaV/L = C(L/G)^n$ in the different range of L/G for each blade angle. Finally, it was found that the cooling tower can operate under all the given approaches (5°C , 6°C , 7°C and 8°C) at the blade angle of 67° by maintaining the cooling range of 5°C , wet bulb temperature of 26°C , and water flow rate of $3.9 \text{ m}^3/\text{h}$.

Key words: blade angles, performance of a small cooling tower

INTRODUCTION

During installation, the manufacturer must set up the proper blade angle for controlling the air flow through the tower as much as possible. The commercial cooling tower must provide the high heat transfer between the hot water and cold air by adjusting the proper blade angle during installation. Therefore, the manufacturer must determine the tower characteristic curves at various blade angles under the given wet bulb temperature, approach, hot water temperature, and water flow rate (Nicholas *et al.*, 1983).

For residential air conditioning duty, the small packaged cooling towers usually have the adjustable blade angles. Therefore, the purpose of this research is to study the effect of the blade angles on the performance of the counter flow

cooling tower with a small size (3 to 10 tons of refrigeration).

MATERIALS AND METHODS

The counter-flow cooling tower testing laboratory includes the circulated system of cooled water and hot water as shown in Figure 1. The counter-flow cooling tower system includes heater tank, cold water tank, balancing tank, cooling tower, cold water pump, hot water pump, control panel, and measuring devices.

1) The counter-flow cooling tower is the heat exchanger between the hot water and air, and the specifications are following as:

- The cooling tower size (using the corrugated packing) 5 tons of refrigeration

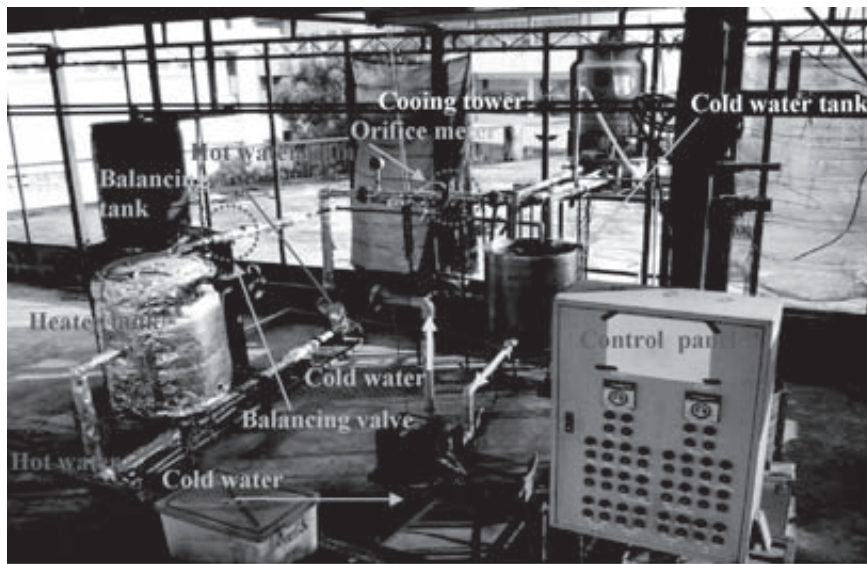


Figure 1 The apparatus of counter-flow cooling tower system for the experiment and testing.

- Water volume flow rate (\dot{V}_w) 65 L/min
- Air volume flow rate (\dot{V}_a) 55 m³/min
- Hot water temperature (HWT) 37 °C
- Cold water temperature (CWT) 32 °C
- Inlet wet bulb temperature (WBT) 27 °C
- Fan horsepower 0.20 hps

2) There are 3 units of water pumps, namely

2.1 Cold water pump is used to pump the water from cold water tank to heater tank and it has the discharge pressure of 22 m of water, pumping flow rate from 10 to 80 L/min, motor horsepower of 0.37 kW, motor speed of 2900 rpm, and water connection diameter of 25 mm.

2.2 Hot water pump is used to pump water from the heater tank to the cooling tower and it has the same specifications as the cold water pump.

2.3 Balancing pump is used to control the level of water in heater tank, cold water tank, and cooling tower. It has the discharge pressure of 35 m, pumping flow rate of 30 L/min, motor horsepower of 0.33 kW, motor speed of 2900 rpm, and water connection diameter of 25 mm.

3) There are 3 units of water tanks, namely

3.1 Heater tank is used to supply the hot water for testing of the cooling tower and it has the 7 units of heater. Each unit has capacity of 2 kW by using current at 9.09 A and 220 V.

3.2 Cold water tank is used to supply cold water to the heater tank by pump and it has volume of 240 liters.

3.3 Balancing tank is used to supply water for controlling water level in the heater tank, cold water tank, and cooling tower during testing and experiment. It has volume of 200 liters, height of 85 cm, and diameter of 55 cm.

4) Measuring Devices, consisted of:

4.1 The orifice meter is used to measure pressure drop across the orifice plate by different height of mercury with range from 0 to 300 mm of Hg and its dimension of 60mm × 440mm × 28mm.

The relationship between the different height of mercury, h_{Hg} (mm) and the water flow rate, \dot{V}_w (L/min) can be found from the experiment and written as:

$$\dot{V}_w = 7.5485\sqrt{h_{Hg}} \quad (1)$$

4.2 Anemometer is used to measure and record the air velocity by measuring the outlet air velocity (at the top of packing).

4.3 The digital instrument and recorder of temperature is used to measure water and air temperatures namely, wet bulb and dry bulb temperature, inlet and outlet water temperature of packing, and water film temperature.

4.4 The wet bulb and dry bulb thermometer on glass tube type, this instrument is used to measure wet bulb and dry bulb temperature of the inlet air (at the bottom of packing).

Methods

Tower characteristics and performance

Cooling tower characteristics are generally presented in the form of an empirical correlation. This correlation defines the relationship between the heat transfer coefficient, KaV/L and water-air flow ratio, L/G under the operating condition. Cooling tower data are most often plotted in the form of KaV/L versus L/G for the various wet bulb temperature (approach) and cooling range. These graphs have been published by the Cooling Tower Institute (Cooling Tower Institute, 1982).

Common practice is to neglect the effect of air velocity and develop the tower correlation in the form of a power law relation as (Mills, 1995):

$$\frac{KaV}{L} = C\left(\frac{L}{G}\right)^{-n} \quad (2)$$

A commercial cooling tower of 5 tons of refrigeration is used to perform the structural equipment of model, which can be operated and tested in accordance with CTI standard.

Cooling tower performance is specified in term of the cooling range, approach, wet bulb temperature and water flow rate. The rating of a tower is established by developing series of charts that related these variables (Hill *et al.*, 1990).

Calculation of KaV/L

The Tchebycheff method for numerically evaluating the integral $\int_a^b y dx$ uses values of y at predetermined values of x within interval a to b . It can be selected that the sum of these values of y multiplied by a constant times the interval $(b-a)$ gives the desired value of integral. In its four-point form, the values of y are taken at selected values of x of 0.102673, 0.40620, 0.59379, and 0.89732 of the interval $(b-a)$. For the determination of KaV/L , rounding off these values to the nearest tenth is entirely adequate. The approximate formula becomes (Cooling Tower Institute, 1982):

$$\int_a^b y dx = \frac{(b-a)}{4}(y_1 + y_2 + y_3 + y_4) \quad (3)$$

where y_1 = value of y at $x = a + 0.1(b-a)$,
 y_2 = value of y at $x = a + 0.4(b-a)$
 y_3 = value of y at $x = a + 0.6(b-a)$,
 y_5 = value of y at $x = a + 0.9(b-a)$

The water temperatures on the divided cross section of packing can be calculated in 4 positions. Each position can be determined from bottom to top of the packing as $T_2+0.1(T_1-T_2)$, $T_2+0.4(T_1-T_2)$, $T_2+0.6(T_1-T_2)$, and $T_2+0.9(T_1-T_2)$, respectively. So, the enthalpy difference at each position can be calculated and the value of KaV/L can be evaluated as

$$\frac{KaV}{L} = \frac{C_w(T_1 - T_2)}{4} \left[\frac{1}{\Delta h_1} + \frac{1}{\Delta h_2} + \frac{1}{\Delta h_3} + \frac{1}{\Delta h_4} \right] \quad (4)$$

where Δh_1 = saturated air and moist air enthalpy difference at $T_2+0.1(T_1-T_2)$
 Δh_2 = saturated air and moist air enthalpy difference at $T_2+0.4(T_1-T_2)$
 Δh_3 = saturated air and moist air enthalpy difference at $T_2+0.6(T_1-T_2)$
 Δh_4 = saturated air and moist air enthalpy difference at $T_2+0.9(T_1-T_2)$
 C_w = specific heat of water, T_1 = hot water temperature, T_2 = cold water temperature

The blade angle adjustment

The blade angles can be adjustable in four positions as shown in Figure 2. In each position of the blade angle, the performance of cooling tower can be tested by maintaining the speed of fan motor at 900 revolutions per minute

Procedure of experiment

The procedure of this research can be discussed as:

- 1) To fill water into a system (cold water tank, hot water tank, and balancing tank).
- 2) To set up the blade angle of 59° .
- 3) To set up the different height of mercury at 10 mm (the water volume flow rate of 23.87 L/min).
- 4) To start the heater and fan motor until the water temperature reaches 40°C and system reaches steady state.
- 5) To record the air volume flow rate, the outlet water temperature, the wet bulb temperature, and the dry bulb temperature.
- 6) To set up the new values of water flow rate by increasing the different height of 14, 18, 22,, 50 mm and repeat from the item (4) to (5) for each different height.
- 7) For the other blade angles (67° , 75° ,

and 83°), the experiment can be repeated as the item (3) to (6).

RESULTS AND DISCUSSIONS

The experiments are based on the setting of blade angles in cooling tower of 5 tons of refrigeration at the blade angle 59° , 67° , 75° , and 83° of respectively. For the testing of cooling tower, the hot water temperature remains constant at 40°C and the variation of circulating water flow rates are from 23.87 to 53.38 L/min and wet bulb temperatures varied from 25 to 27°C .

The characteristic curves for each blade angle in Figure 3 can be fit in the form of equation (2). The exponent, n and constant, C of the equation (2) for the various blade angles are shown in Table 1.

The cooling tower with 5 tons of refrigeration and the packing area of 3.463 ft^2 can be operated under the cooling range of 5°C , wet bulb temperature of 26°C , and water flow rate of $3.9\text{ m}^3/\text{h}$. The approach of 5°C , 6°C , 7°C and 8°C for cooling tower can be drawn in the same graph of the characteristic curves for each blade angle and the operating points can be represented as Table 2 to Table 5.

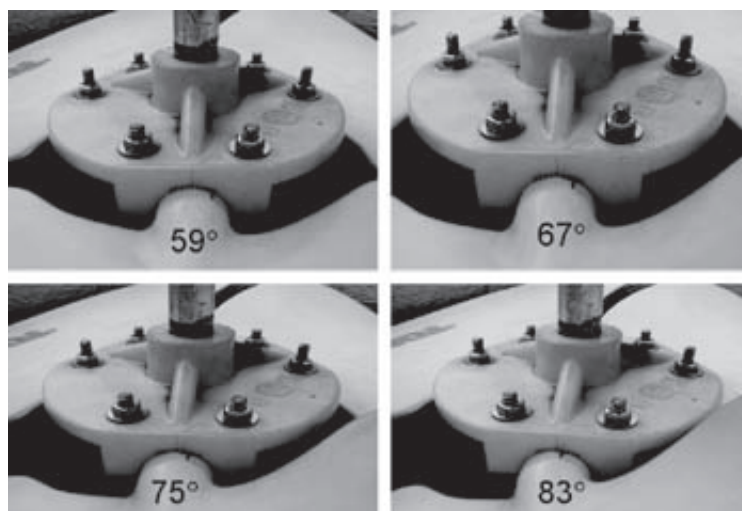


Figure 2 Adjustment of blade angles at 59° , 67° , 75° and 83° .

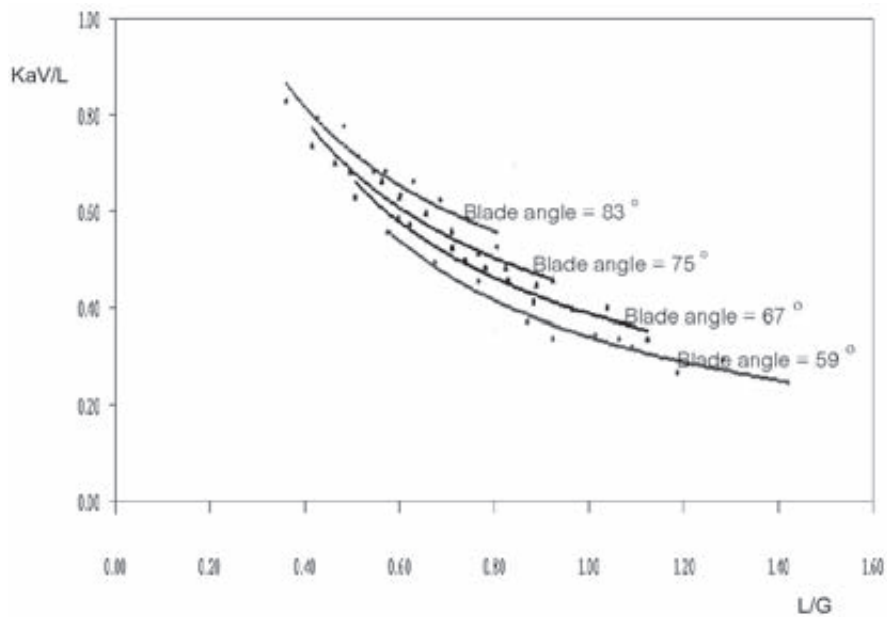


Figure 3 The volumetric heat transfer coefficient at blade angles of 59°, 67°, 75° and 83°.

Table 1 The exponent, n and constant, C of the equation (2) for the various blade angles.

Blade angle	n	C	the range of L/G
59°	0.8955	0.3403	0.576 to 1.420
67°	0.7781	0.3879	0.507 to 1.125
75°	0.6505	0.4350	0.415 to 0.924
83°	0.5482	0.4935	0.360 to 0.807

Table 2 The operating point (L/G , KaV/L) under the approach of 5°C, 6°C, 7°C and 8°C, range of 5°C, and wet bulb temperature of 26°C for blade angle of 59°.

WBT(°C)	CWT(°C)	HWT(°C)	L/G	KaV/L	GPM	CFM
26	31	36		Out off range of L/G		
26	32	37	0.596	0.541	17.16	3432.2
26	33	38	0.694	0.472	17.16	2949.4
26	34	39	0.799	0.416	17.16	2563.7

Table 3 The operating point (L/G , KaV/L) under the approach of 5°C, 6°C, 7°C and 8°C, range of 5°C, and wet bulb temperature of 26°C for blade angle of 67°.

WBT(°C)	CWT(°C)	HWT(°C)	L/G	KaV/L	GPM	CFM
26	31	36	0.530	0.636	17.16	3858.2
26	32	37	0.643	0.547	17.16	3182.8
26	33	38	0.763	0.479	17.16	2684.6
26	34	39	0.763	0.479	17.16	2296.0

Table 4 The operating point (*L/G*, *KaV/L*) under the approach of 5°C, 6°C, 7°C and 8°C, range of 5°C, and wet bulb temperature of 26°C for blade angle of 75°.

WBT(°C)	CWT(°C)	HWT(°C)	L/G	KaV/L	GPM	CFM
26	31	36	0.553	0.640	17.16	3698.7
26	32	37	0.691	0.553	17.16	2963.2
26	33	38	0.841	0.487	17.16	2440.8
26	34	39		Out off range of L/G		

Table 5 The operating point (*L/G*, *KaV/L*) under the approach of 5°C, 6°C, 7°C and 8°C, range of 5°C, and wet bulb temperature of 26°C for blade angle of 83°.

WBT(°C)	CWT(°C)	HWT(°C)	L/G	KaV/L	GPM	CFM
26	31	36	0.607	0.649	17.16	3371.4
26	32	37	0.780	0.566	17.16	2627.4
26	33	38		Out off range of L/G		
26	34	39		Out off range of L/G		

For the adjustment of blade angle at 67°, the cooling tower can operate in all approaches (5°C, 6°C, 7°C and 8°C) by maintaining the cooling range of 5°C, wet bulb temperature of 26°C, and water flow rate of 3.9 m³/h.

Under the constant demand of *WBT* = 26°C, *CWT* = 32°C, *HWT* = 37°C, it was found

that *L/G*, *KaV/L* and *CFM* are dependent upon the blade angles of fan as shown in Figure 4. The air quantities decreased with blade angles by maintaining the water flow rate of 17.16 GPM. So, the ratio of *L/G* and *KaV/L* increased with blade angle.

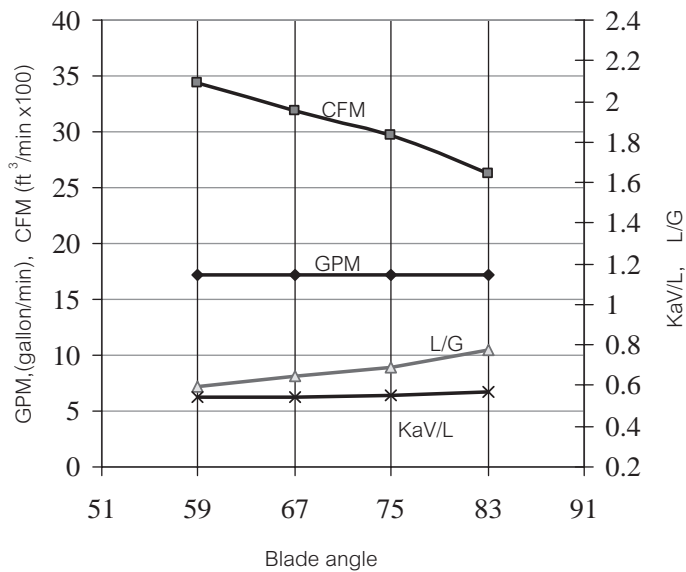


Figure 4 The effect of blade angle on *KaV/L*, *L/G*, and *CFM* for *HWT* = 37°C, *CWT* = 32°C and *WBT* = 26°C.

CONCLUSIONS

This research studied the effect of blade angles on the packing characteristic curves of a small cooling tower. The curves can be constructed by the experimental data from the cooling tower testing in accordance with the procedure of CTI standard. As the lack of performance curves at the various blade angles, the fan blades may not be adjusted properly by manufacturers during installation. In each blade angle, it is important to find the operating points between the characteristic curves and approach curves and these points must not be out-of range of L/G for each characteristic curve. It was found that the cooling tower can operate in all approaches (5°C , 6°C , 7°C and 8°C), the cooling range of 5°C , wet bulb temperature of 26°C , and water flow rate of $3.9 \text{ m}^3/\text{h}$ by the adjustment of blade angle at 67° .

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