International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:2, No:10, 2008

Performance Characteristics of a Closed Circuit Cooling Tower with Multi Path

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***Abstract*—**The experimental thermal performance of two heat exchangers in closed-wet cooling tower (CWCT) was investigated in this study. The test sections are heat exchangers which have multi path that is used as the entrance of cooling water and are consisting of bare-type copper tubes between 15.88mm and 19.05mm. The process fluids are the cooling water that flows from top part of heat exchanger to bottom side in the inner side of tube, and spray water that flows gravitational direction in the outer side of it. Air contacts its outer side of that as it counterflows. Heat and mass transfer coefficients and cooling capacity were calculated with variations of process fluids, multi path and different diameter tubes to figure out the performance of characteristics of CWCT.

The main results were summarized as follows: The results show this experiment is reliable with values of heat and mass transfer coefficients comparing to values of correlations. Heat and mass transfer coefficients and cooling capacity of two paths are higher than these with one path using 15.88 and 19.05mm tubes. Cooling capacity per unit volume with 15.88mm tube using one and two paths are higher than 19.05mm tube due to increase of surface area per unit volume.

***Keywords*—**Closed–Wet Cooling Tower, Cooling Capacity, Heat and Mass Transfer Coefficients.

I. Introduction

In recent days, a cooling tower is one of the efficient device that rejects generated heat from all most of industrial processes and air-conditioning & refrigeration systems. A cooling tower is frequently used to reject heat from those processes without consuming excessive quantities of water or thermally polluting a body of surface water. In general, a closed-wet cooling tower (CWCT) which maintain an indirect contact between the fluid and the atmosphere are used increasingly due to no cooling water pollution.

The first basic theory of cooling tower was proposed by Walker [1]. Some correlations of mass transfer coefficient between air and spray water interface and heat transfer coefficient between tube external surface and spray water film was presented by several authors [2-5]. Correlations of heat and mass transfer which was tested with tube banks consisting of 19.05 mm outside diameter in CWCT were proposed by Parker and Treybal[2]. The heat and mass transfer correlations of CWCT having 12 mm to 40 mm outside diameter were presented by Mizushina[3]. The heat and mass transfer correlations of CWCT having both smooth and finned tubes with 16 mm outside diameter were suggested by Nitsu[4]. Correlations for heat and mass transfer coefficients were obtained experimentally for a small-size indirect cooling tower having the tube bundle which has 228 staggered tubes of 10 mm outside diameter by Jorge Facao[5]. The cooling capacity and pressure drops as a function of air velocity and wet-bulb temperature of hybrid closed wet cooling tower were presented by M.M.Sarker[6]

A cooling water pump consumes 60 to 70 percent of total power consumption in CWCT. It is used to design to decrease the quantity of cooling water in order to reduce cooling water pump power. It is efficient to curtail an expenditure of tubes with reducing the quantity of cooling water. However, it is possible to lower cooling capacity with adapting this method to typical CWCT with one path because the velocity of process fluid in the tubes decreases. To increase velocity of process fluid in a tube is to block tube bundles to be multi path. Fig. 1 shows the concept of multi path. In the relevant literature, no results have been reported so far involving the CWCT with multi path.

In this paper, the objective of this experiment is to obtain basic data from experimental study on small-sized CWCT with multi path and a variation of diameter of tubes in a heat exchanger to analyze the performance of characteristics for designing a large-sized CWCT.

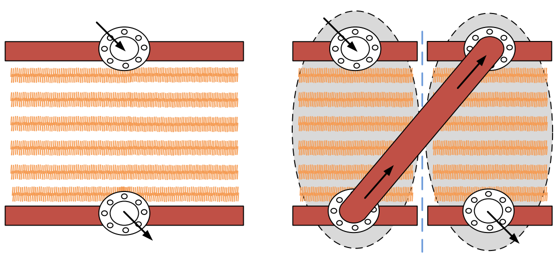

Fig. 1 Concept of Multi Path

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II. Experimental Apparatus and Method

The schematic diagram and photograph of experimental apparatus used in this study is showed in Fig. 2. The prototype of CWCT is used where the heat exchanger is located at the upper part and fans are installed at the lower part of the water tank. The plain circular tubes are used both a diameter of 15.88 mm with ten rows and ten columns in the dimensional tower of 0.6 m ×0.318m×0.336m and a diameter of 19.05 mm with eight rows and twelve columns in the dimensional tower of 0.6m ×0.304m×0.525m and in a staggered arrangement. The cooling water is supplied by pipes which are connected to the distribution head through horizontal cooling tubes. The spray water is constantly distributed at the upper part of the heat exchanger and circulates in CWCT by pump. The water tank section consists of a spray water and ambient air forcing fans. Ambient air was controlled to designated state by an air-heater and humidifier while passing through the air duct. Therefore,

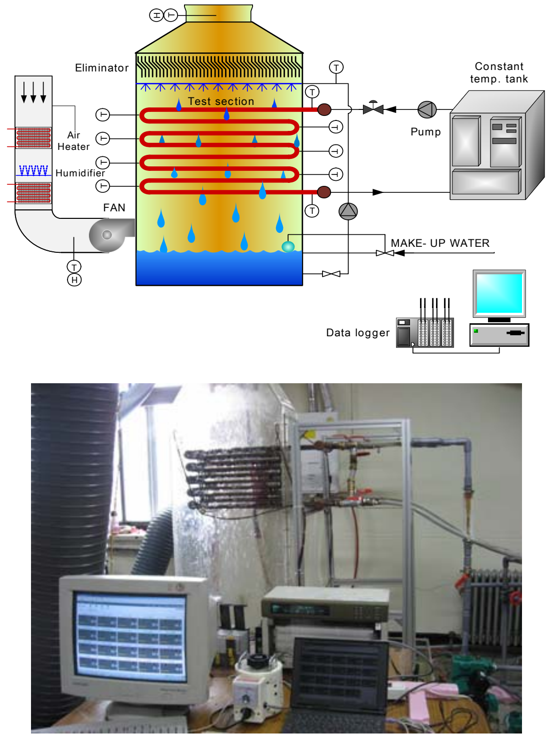

Fig. 2 Schematic diagram and photograph of the experimental apparatus

TABLE I
Specification of Heat Exchanger and Experimental Conditions

Tube diameter	15.88	19.05	[mm]
Transversal pitch	31.8	38.1	[mm]
Row pitch	39	46	[mm]
Dimension	W0.6·L0.318·H0.336	W0.6·L0.304·H0.525	[m]
Cooling water	Flow rate	600-3120	[kg/h]
	Inlet temperature	32-50	[°C]
Spray water	Flow rate	720-2160	[kg/h]
Air	Velocity	1.0-3.5	[m/s]
	Inlet wet-bulb temperature	22-29	[°C]

wet-bulb temperature can be controlled with adjusting dry-bulb temperature and relative humidity.

Cooling water flows in the inside of the tubes in CWCT. The cooling water after coming out through the outlet of the heat exchanger is sent to the constant temperature tank. The cooling water gains heat and gets stabilized to a certain temperature while passing though the constant temperature tank. Then, it recirculates in CWCT.

The experiment was conducted with variations of the cooling water flow rate, cooling water inlet temperature, spray water flow rate, wet-bulb temperature and inlet air velocity.

Table I shows the experimental conditions and the tower geometry.

III. Data Reduction

Heat transfers from a hot process fluid inside tubes to spray water and to air through a water film. Heat transfer is in latent and sensible forms when heat transfers from spray water to air. The rate of heat lost by cooling water is given by,

$$Q_w = m_w c_{Pw} dt_w = U_o (t_w - t_s) dA \quad (1)$$

The rate of heat gain by air is,

$$Q_a = m_a di_a = k(i' - i_a) dA \quad (2)$$

The mass transfer coefficient can be obtained using mass balance

$$m_a (x_{a,2} - x_{a,1}) = kA dx_{LM} \quad (3)$$

dx_{LM} is the logarithmic mean humidity difference, defined as

$$dx_{LM} = \frac{x_{a,2} - x_{a,1}}{\ln \dfrac{x'_3 - x_{a,1}}{x'_3 - x_{a,2}}} \quad (4)$$

U_o is the overall heat transfer coefficient based on the outer area of the tube. To calculate U_o , the following equation was used

$$\frac{1}{U_o} = \frac{1}{h_i}\left(\frac{D_o}{D_i}\right) + \frac{D_o}{2\lambda}\ln\left(\frac{D_o}{D_i}\right) + \frac{1}{h_o} \quad (5)$$

IV. Results and Discussion

Fig. 3 shows the heat balance between cooling water and air side of the experimental apparatus. Only the valid data which were selected from the stabilized state was used for the analysis. To calculate the heat balance, equations (1) and (2) are used. The heat balance data have fallen within ±20% were used. The heat balance of the apparatus could be claimed to be satisfactory.

Fig. 4 shows the mass transfer coefficients k as a function of air velocity in CWCT using 15.88mm tube. The mass transfer coefficients k are compared to the values of the correlations

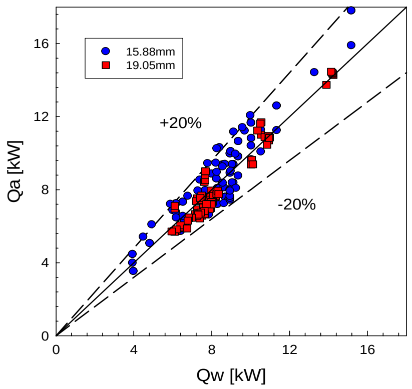

Fig. 3 Heat balance between cooling water and air side

by Parker and Treybal[1], Mizushina[2]and Nitsu[3]. It is shown that mass transfer coefficients in CWCT using one path are similar to the correlation of Mizushina[2]. It is observed that mass transfer coefficients k which are calculated in CWCT having one path and two paths increase with the increase of the air velocity. This is mainly because the measured temperature of spray water in the surface of tubes in the outlet of CWCT using two path are higher than the other and then it caused to increase the absolute humidity at the outlet of CWCT using two paths. Mass transfer coefficients k using two paths are approximately 18% higher than those having one path at standard experimental condition, air velocity is 3m/s.

Fig. 5 shows heat transfer coefficients h_o as a function of spray water flow rate which are calculated in CWCT using one and two paths, and these values are similar to the correlation by Nitsu[3]. It indicates that heat transfer coefficients h_o are increasing as increasing spray water. Heat transfer coefficients h_o in CWCT using two paths are higher than those using one path. Heat transfer coefficients h_o using two paths are approximately 17% higher than those having one path at standard experimental condition, spray water flow rate is 18 ℓ/min.

Fig. 6 shows the mass transfer coefficients k as a function of air velocity in CWCT using 19.05mm tubes. In case of the CWCT using one path, mass transfer coefficients k are similar to the correlation of Mizushina[2]. This means that there is a high reliability of the experimental apparatus. It is observed that mass transfer coefficients which are calculated in CWCT having one path and two paths increased with the increase of the air velocity. Mass transfer coefficients having two paths are approximately 43% and 17% higher than those having one path when air velocity are 1m/s and 3.5m/s respectively.

Fig. 7 shows heat transfer coefficient h_o as a function of spray water flow rate in CWCT using 19.05mm tubes. Heat transfer coefficients which are calculated in CWCT using one path are similar to correlation by Nitsu[3]. In addition, heat

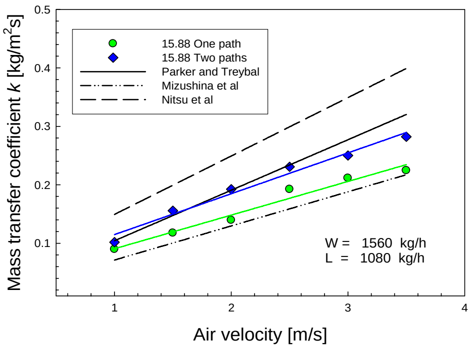

Fig. 4 Mass transfer coefficient k as a function of air velocity in 15.88mm tube

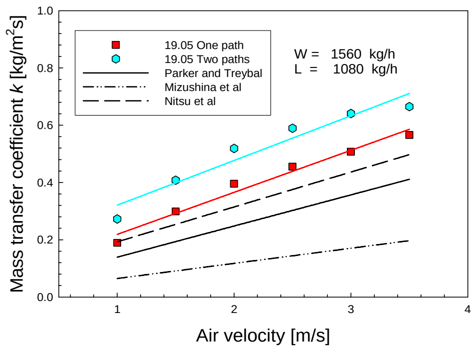

Fig. 6 Mass transfer coefficient k as a function of air velocity in 19.05mm tube

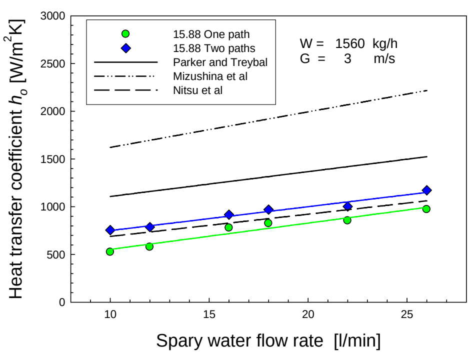

Fig. 5 Heat transfer coefficient h_o as a function of spray water flow rate in 15.88mm tube

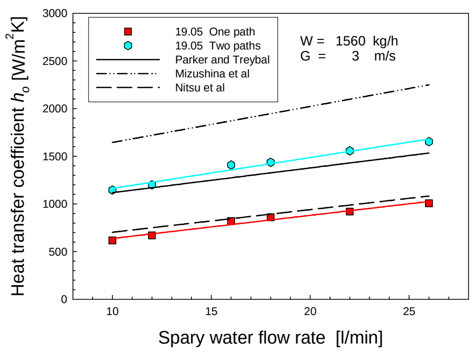

Fig. 7 Heat transfer coefficient h_o as a function of spray water flow rate in 19.05mm tube

transfer coefficients using two paths are similar to the correlation by Parker and Treybal[1]. It indicates that heat transfer coefficients are increasing as increasing spray water flow rate. Heat transfer coefficients in CWCT using two paths are higher than those using one path in this figure.

Fig. 8 shows mass transfer coefficients *k* per unit volume as a function of air velocity in CWCT using 15.88 and 19.05mm tubes with one path and two paths. Mass transfer coefficients *k* per unit volume in CWCT using 19.05mm tube are higher than those using 15.88mm tube. This is because the height of heat exchanger of using 19.05mm tube are longer than its of using 15.88mm tubes so, higher absolute humidity at the outlet of CWCT using 19.05mm tube was generated comparing to CWCT using 15.88mm tube.

Fig. 9 shows heat transfer coefficient h_o per unit volume as a function of spray water flow rate in CWCT using 15.88 and 19.05mm tubes with one path and two paths. In this figure, heat transfer coefficients per unit volume which are calculated in CWCT with 15.88mm and 19.05mm tubes increase with the increase of the spray water flow rate. In contrast to the trend of mass transfer coefficient, heat transfer coefficients h_o per unit volume in CWCT using 15.88mm tube are higher than those using 19.05mm tube.

Fig. 10 shows cooling capacity per unit (heat exchanger) volume as a function of wet-bulb temperature. Two heat exchangers do not have same volumetric size so, it is expressed that cooling capacity which was divided by the volume of each heat exchanger in this figure. It is observed that cooling capacity per unit volume in CWCT decrease with the increase of the wet-bulb temperature. This is mainly because the temperature difference between inlet cooling water and air is getting so decreasing that the evaporation of spray water and range evaporation of spray water and range decreases when wet-bulb temperature at the inlet of CWCT increases. Cooling capacity per unit volume in CWCT using 15.88mm tubes with two paths have highest values in CWCT among four variations. Cooling capacity per unit volume with 15.88mm tube using two paths are approximately 27.5% and 41.01% higher than those having 19.05mm tube using two paths when inlet wet-bulb temperature of CWCT are 24℃ and 28℃ respectively.

Fig. 11 shows cooling capacity per unit volume as a function of inlet cooling water temperature. Cooling capacity per unit volume in CWCT using 15.88mm tubes with two paths also have highest values the same as Fig. 10. This is because this result is shown that due to increase of surface area per unit volume using 15.88mm tubes even though mass transfer coefficient *k* and heat transfer coefficients h_o per unit volume in CWCT using 15.88mm tubes with one and two paths have lower or similar to values of CWCT using 19.05mm tubes. Cooling capacity per unit volume with 15.88mm tube using two

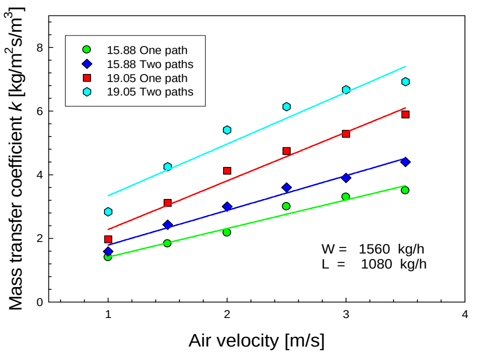

Fig. 8 Mass transfer coefficient *k* per unit volume as a function of air velocity in 15.88 and 19.05mm tubes

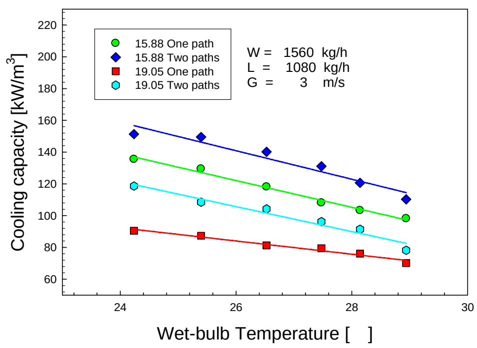

Fig. 10 Cooling capacity per unit volume as a function of wet-bulb temperature in 15.88 and 19.05mm tubes

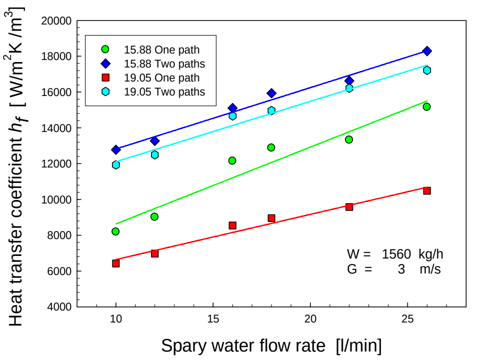

Fig. 9 Heat transfer coefficient h_o per unit volume as a function of spray water flow rate in 15.88 and 19.05 mm tubes

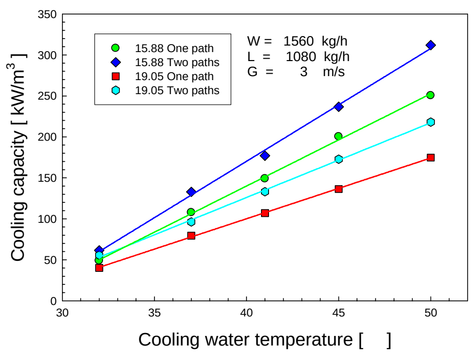

Fig. 11 Cooling capacity per unit volume as a function of cooling water temperature in 15.88 and 19.05mm tubes

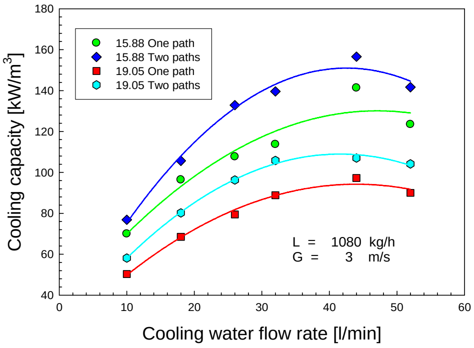

Fig. 12 Cooling capacity per unit volume as a function of cooling water flow rate in 15.88 and 19.05mm tubes

paths are approximately 10.5% and 43.06% higher than those having 19.05mm tube using two paths when inlet cooling water temperature are 32℃ and 50℃ respectively.

Fig. 12 shows cooling capacity per unit volume as a function of inlet cooling water flow rate. It is observed that cooling capacity in CWCT are getting increasing and the final point of cooling capacity have lower values comparing to previous points in common with the increase of cooling water flow rate. Cooling capacity per unit volume in CWCT using 15.88mm tubes with two paths also have highest values the same as previous two figures.

V. Conclusion

The performance characteristics of the closed-wet cooling tower with multi path and different tubes have been investigated experimentally having a rated capacity of 2RT. Mass transfer coefficients for variable air velocity of CWCT having two paths are respectively about 18% and 26% higher than those having one path using 15.88 mm and 19.05 mm using one and two paths with 15.88mm tube are 3.9℃ and 4.7 ℃ tubes at the standard condition. Heat and mass transfer coefficients of CWCT using one path was found to conform respectively and range of CWCT using two paths is higher approximately 20% than range in CWCT using one path. In addition, ranges of the CWCT using one and two paths with well to the already reported results for almost all cases considered. At the standard design condition, ranges of CWCT 19.05mm tubes are 4.2℃ and 5.1℃ respectively and range of CWCT using two paths is higher approximately 21% than range in CWCT using one path. The cooling capacity per unit volume of the CWCT using 15.88 mm tubes with two paths has the highest values. Hence, we can claim that it is efficient way to use smaller diameter tube in heat exchanger in order to increase surface area per unit volume. The result obtained from this study is supposed to provide basic relevant data which could be referred for the optimum design of the CWCT with multi path.

Acknowledgment

This work was partially supported by NURI Project in 2008.

References

[1] Walker WH, Lewis WK, McAdams WH, Gilliland ER. 1923. Principles of chemical engineering. 3rd. ed. McGraw-Hill Inc.
[2] Parker, R.O., and R. E. Treybal. 1961. The heat, mass transfer Characteristics of Evaporative coolers. Chemical Engineering Progress Symposium Series. pp57-32. pp138-149.
[3] T. Mizushina, R ito, H. Miyashita, 1968. Characteristics and methods of thermal design of evaporative cooler. International Chemical Engineering. Vol 8. No 3. pp532-538.
[4] Nitsu, Y., K. Naito, and T. Anzai. 1969. Studies of the Characteristics and Design Procedure of Evaporative Coolers, Journal of the society of Heating, Air-Conditioning. Sanitary Engineers of Japan. Vol. 41. No 12. and Vol 43. No 7
[5] Jorge Facao and Armando Oliveira. 2004. Heat and mass transfer correlations for the design of small indirect contact cooling towers. Applied Thermal Engineering. Vol 24. issues 14-15. pp1969-1978.
[6] M. M. A. Sarker, E. Kim, C. G. Moon, J.I.Yoon. 2008. Performance characteristics of the hybrid closed circuit cooling tower. Energy and Building. Vol 40. No 8. pp1529-1535.