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THE COOLING CAPACITY AND PRESSURE DROP IN A HYBRID CLOSED CIRCUIT COOLING TOWER

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ABSTRACT
Experimental study on the Hybrid Closed Circuit Cooling Tower has been done having a rated capacity of 30RT. Bare-type copper coil having an outer diameter of 15.88mm has been used in the 1.14m×2.36m×3.2m dimensional tower. Heat exchanger consists of 16 rows and 22 columns. The relevant temperatures and the velocities were selected based on the typical Korean weather for the year round operation. Cooling towers reported so far operate on plume-free mode during the mid-season and winter while ambient temperature remains below 12^{O}C. This study presents results related to the plume free operation while the ambient temperature is less or equal to 15^{O}C in dry mode. The cooling capacity of the tower is explained with respect to variable temperatures, cooling water inlet temperatures and G/W ratios. The capacity was found to be close to the rated one for the wet mode operation but rather low in dry mode

Keywords: Hybrid closed circuit cooling tower, Wet-bulb temperature, Cooling capacity.

1. INTRODUCTION
The use of cooling towers to reject heat, cool buildings and reduce the temperature of water circulated through various heat rejection equipments have increased considerably in recent days [1-3]. A closed circuit cooling tower maintains an indirect contact between the fluid and the atmosphere. Cooling towers respectively are called wet tower when evaporative cooling is used, dry tower when air blast cooling is utilized and wet-dry type which has the simultaneous characteristics of both dry and wet towers. Cooling effects in wet cooling towers are partially brought about by the evaporative condenser where a quota of the circulating water gets evaporated and partially by the sensible heat transfer [4]. A number of numerical simulation [5-7] and mathematical models of the cooling tower have been reported [8-10]. Experimental studies [11-12] have been carried out on the wet cooling tower but the experimental results on hybrid closed circuit cooling tower is lacking on the relevant literature.

The hybrid closed circuit cooling tower (HCCCT) is a closed circuit cooling tower which is capable of working both in wet mode and in dry mode. HCCCT works well in dry mode during the mid-season and winter as soon as ambient temperature is below 12-14^{O}C, no plume and no freezing and lower noise level. HCCCT operates smoothly in wet mode while the ambient temperature is above 12-14^{O}C, water consumption by HCCCT is lower and the process water can be cooled down to 4^{O}C above the wet bulb temperature and can be packed in light and compact bundle with optimized circuitry [13].

During the summer operation, no plume formation is expected due to the higher ambient temperature and higher dew-point temperature in Korea. In winter, only the cooled air from the bottom is used and plume-free state is predicted once more because the typical Korean winter ambient air contain lower moister. The cooling towers those are in use can operate without forming plume during the mid-season and winter only when ambient temperature is below 12^{O}C. The objective of this experimental study is to make HCCCT which would have the ability to operate in plume free mode until 15^{O}C in dry mode.

2. EXPERIMENTAL APPARATUS
Fig. 1 shows the schematic of the hybrid closed circuit cooling tower experimental apparatus and Fig. 2 gives the photograph of the section of 30 RT experimental apparatus. In the experiment, a prototype HCCCT is used where the coil section is located at the upper part, fans are installed at the lower part alongside of the water tank. In the coil section, coils, spray system, eliminator are sequentially organized and is kept in a casing. The copper coil having outer diameter of 15.88mm has been used in the heat exchanger in a staggered arrangement. The cooling water is supplied by pipes having 65 mm inlet diameters and the pipe is connected to the distribution head through 44 horizontal cooling coils.

Cooling water flows in downward direction from the top to the bottom, so lower pressure drop is expected across coil bank.

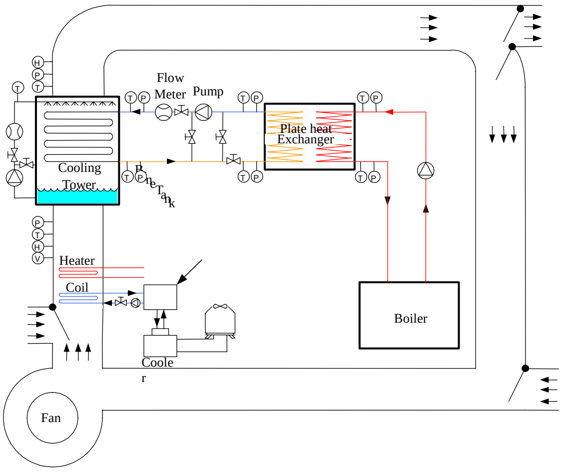

Fig 1. Schematic of the experimental apparatus

The spray system consists of the header which is made of copper tube, the spray distributing pipe and a spray nozzle having big caliber so that blocking/fouling can be prevented and thus the spray water is uniformly distributed at the upper part of the coils.

3. EXPERIMENTAL METHODS

The important sequences of the experiment are as follows:

After the all the relevant conditions normalized, the system were let to work for a specific time and then the data were collected and measured to minimize the experimental errors and optimize the accuracy of the outputs. A fixed air flow rate is maintained by using fan and 15HP type inverter, the discharged air from the outlet of the cooling tower which is highly humid and has high temperature, passes though the return duct and mixes with the ambient air and thereby, the dry-bulb temperature and the wet-bulb temperature are controlled. The proper air constraint is maintained by applying 10 RT type heater and the cooling coil at the inlet of the HCCCT. The surplus discharged air is released to the outside of the tower.

Fig 2. Photograph of experimental apparatus

Cooling water flows in the internal part of the coil of the HCCCT. The cooling water after coming out through the outlet of the HCCCT is sent to the plate type heat exchanger. At the other side of the plate heat exchanger, the heated water having temperature of 80^0C is supplied from the 150 Mcal/h type boiler. While passing though the plate heat exchanger, the cooling water gains heat and get stabilized to a certain temperature and is recirculated to the HCCCT. To control the temperature more accurately, a bypass pipe is installed at the cooling water pipe and the heated water supplying pipe. Then the temperature of the desired level could be maintained through controlling the supply of the flow rate of the cooling water and the heated water to the plate heat exchanger.

The experiment was run changing the air flow rate. The pressure loss of the air was measured when the fan functioning get stabilized and pressure difference was recorded applying manometer. The humidity sensor is used to measure the humidity and both humidity and temperature at 5 points both at the air inlet and outlet were measured at every 5 second and the averages of these values were applied.

4. RESULTS AND DISCUSSION

Under the standard experimental condition given in Table 1, the experiment was repeated over and over again changing the wet-bulb temperature of inlet air as well as the air-water ratio. Only the valid data, selected from the stabilized state has been used for the analysis. To calculate the heat balance, following couple of equations are utilized

$$Qr_1 = W \bullet (T_{Wi} - T_{Wo}) \tag{1}$$

$$Qr_2 = (G + L) \bullet h_{a,i} - G \bullet h_{a,i} \tag{2}$$

Here, Eq. (1) gives the exchanged heat capacity of the cooling water and Eq. (2) represent the exchanged heat capacity of air brought about by the enthalpy difference between the inlet and outlet of the air. The results have been shown in Fig. 3 where the heat balance data those fall within $\pm 15\%$ were used. Heat balance of the apparatus could be claimed to be satisfactory.

Table 1: Experimental Condition

Cooling water	Volume Flow Rate	[m^3/h]	24
	Inlet Temperature	[^{O}C]	37
Spray Water	Volume Flow Rate	[m^3/h]	33
Air	Velocity	[m/s]	3.1
	Wet-bulb Temperature	[^{O}C]	27

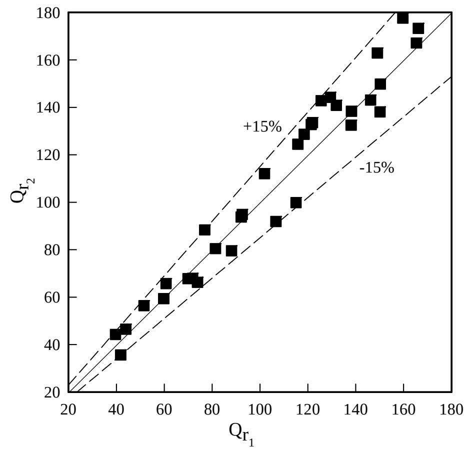

Fig 3. Heat balance of the experimental apparatus

4.1 Results Based on the Wet Mode Operation

4.1.1 Effect of WBT on Temperature Range and the Cooling Capacity

Fig.4 shows the difference of the inlet and the outlet temperatures of the cooling water with respect to the variable wet-bulb temperature (WBT) of the HCCCT. From this figure it is clear that the outlet temperature of the cooling water increases with the increase of the wet-bulb temperature and that at a WBT of 20^{O}C, the outlet temperature is about 7^{O}C cooler than the inlet temperature. This is mainly because, when the WBT at the inlet increases, then the temperature difference of the cooling water and the air at the respective inlets decreases. Therefore, the vaporization of the spray water outside of the pipe decreases so that the falling of the temperature of the cooling water flowing inside the tube deceases. The drastic decline of the temperature range could be noted while the WBT is greater than or equal to 26^{O}C. The performance of the HCCCT is shown in Fig. 5. The cooling performance of the HCCCT can defined as the product of the cooling water flow rate and the temperature difference between the inlet and the outlet of the HCCCT, multiplied by the specific heat of the cooling water. Since, the cooling water flow rate is defined in the standard design condition and the specific heat is constant, so the trend of the performance of the HCCCT looks identical to that of the temperature difference range plot given earlier. At design condition, i.e. at the WBT of 27^{O}C at the inlet of the HCCCT, the cooling performance found from Fig. 5 is 112,000kcal/h whereas the rated capacity is 117,000kcal/h, so, the experimental performance is seen to be about 4.5% lower than the expected capacity and the difference could be claim not be that big.

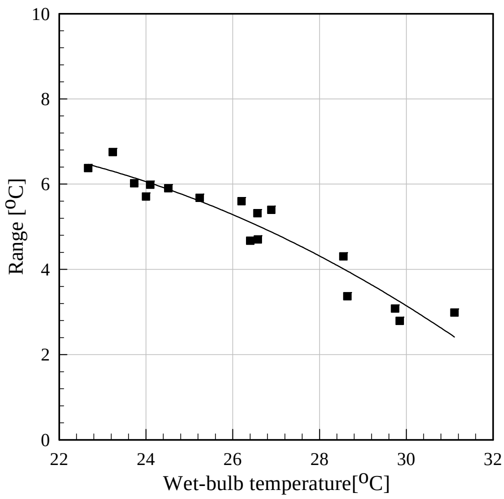

Fig 4. Temperature range w.r.t. WBT

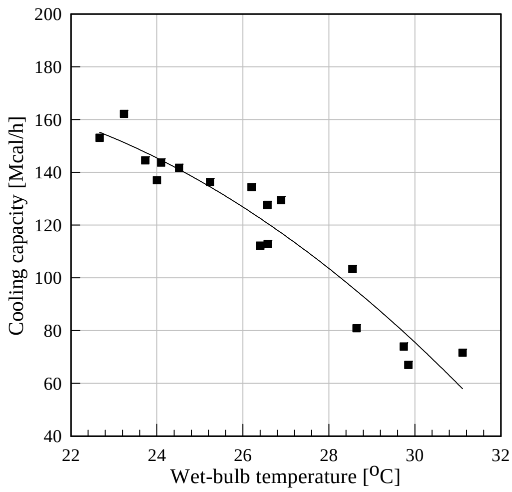

Fig 5. Cooling capacity w.r.t. WBT

4.1.2 Characteristics by Ratio of Air to Cooling Water Volume Flow Rate

Fig. 6 and Fig. 7 respectively show the temperature range and the cooling capacity with respect to the air flow rate to the cooling water volume flow rate. Cooling capacity found from the ratio for the design condition is 116 Mcal/h which agrees well with the rated cooling capacity.

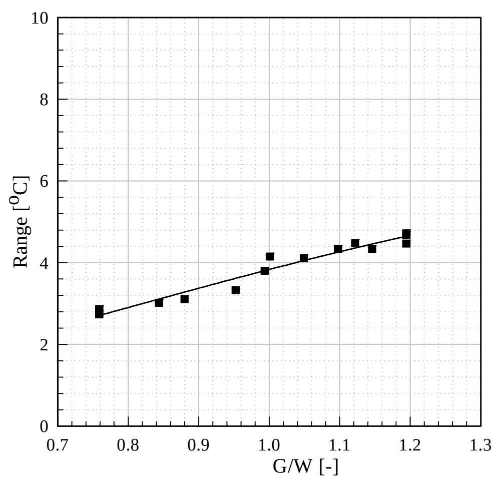

Fig 6. Temperature range w.r.t. air to cooling water flow rate.

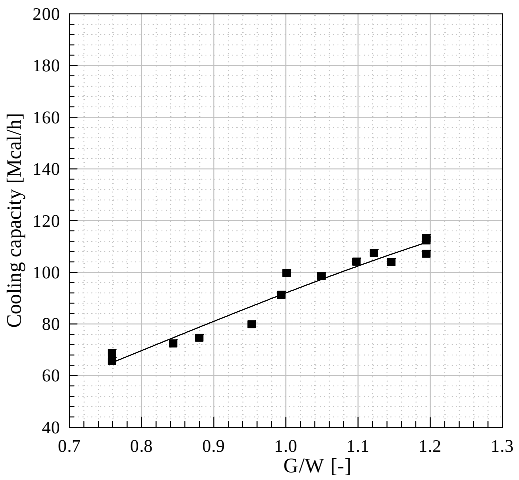

Fig 7. Cooling capacity w.r.t. air to cooling water flow rate.

4.1.3 Pressure Drop with Respect to Air Velocity

Pressure drop with respect to a variable air velocity has been shown in Fig. 8. Pressure drop increases almost exponentially with the increase of the air velocity. The increasing rate has been escalated due to the spray water in the wet mode operation. At the design condition, the pressure drop can be seen to be around 4 mmAq.

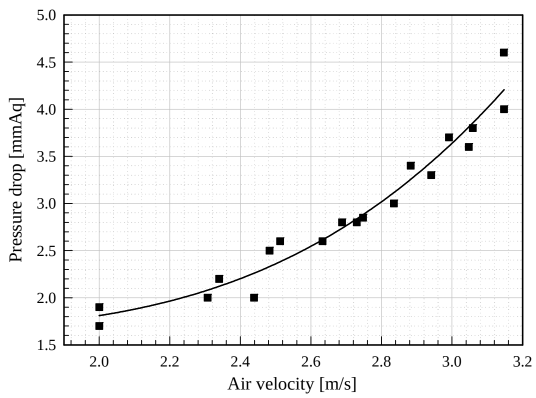

Fig 8. Pressure drop with respect to air velocity in wet mode

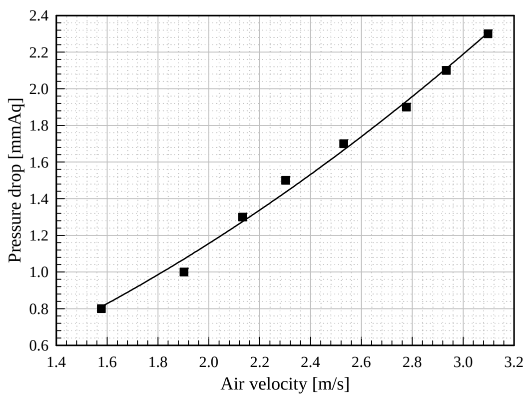

Fig 9. Pressure drop with respect to air velocity in dry mode.

4.2 Results Based On the Dry Mode Operation

4.2.1 Pressure Drop with Respect to Air Velocity

Fig. 9 shows the pressure drop with respect to air velocity in dry mode operation. It's evident that the pressure drop increases almost linearly with the increasing air velocity. At the standard design condition, the pressure drop was around 2.3 mmAq.

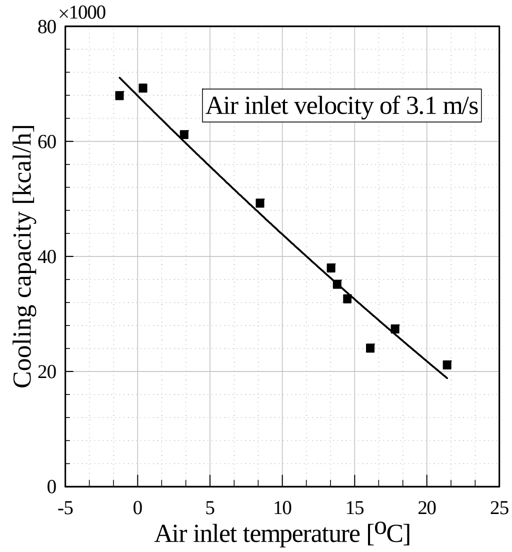

Fig 10. Cooling capacity w.r.t. air inlet temperature

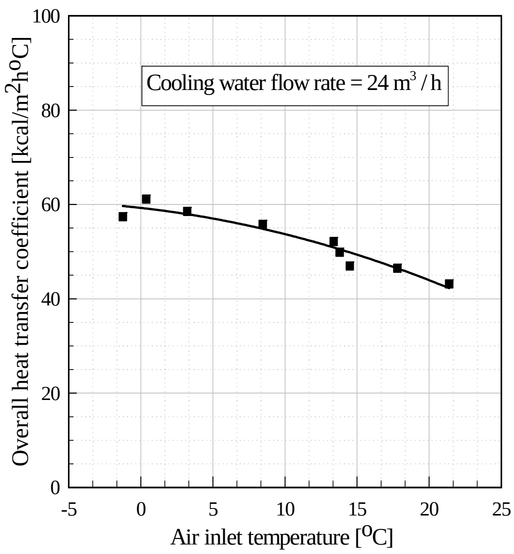

Fig 11. Overall heat transfer coefficient by air inlet temperature

4.2.2 Characteristics with Respect to Air Inlet Temperature

Cooling capacity and overall heat transfer coefficient with respect to a variable air inlet temperature are respectively shown in Fig. 10 and Fig. 11. Cooling capacity decreases almost linearly with the increase of the air inlet temperature and vice versa. The cooling capacity is seen to be rather poor due to the fact that no spray water was used during winter operation. Overall heat transfer coefficient also decreases with the increase of the air inlet temperature.

5. CONCLUDING REMARKS

The performance characteristics of the hybrid closed circuit cooling tower were investigated experimentally having a rated capacity of 30RT. The wet-bulb temperature at the experimental condition was 27^{O}C and the cooling capacity at this WBT was 112,000 kcal/h, which is about 4.5 % lower than the rated capacity. The capacity with respect to air to the cooling water volume flow rate was 116kcal/h which agreed well with the rated capacity. All these results were obtained for the wet mode operation of the HCCCT. The pressure drops in wet mode operation were seen to increases almost exponentially with the increase of the air velocity and the pressure drop was about 4 mmAq for the wet mode. Performance characteristics have also been investigated for the dry mode operation. At an air inlet temperature of 10^{O}C, the cooling capacity was about 43 kcal/h which is around 36% of the rated capacity. At the design condition, the pressure drop for the dry mode was around 2.3 mmAq. These lower capacities are due to the absence of the spray water. It may be mentioned that this apparently lower performance is cost-effective due to the lower power consumption. The result obtained from this study is supposed to provide basic relevant data which could be referred for the optimum design of the hybrid closed circuit cooling towers.

6. REFERENCES

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7. NOMENCLATURE

Symbol	Meaning	Unit
G	Flow rate of air	(kg/h)
h	Enthalpy	(kcal/kg.dry air)
L	Portion of spray water lost due to evaporation	(kg/h)
Q	Cooling capacity	(Kcal/h)
W	Cooling water flow rate	(kg/hr)

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