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EXPERIMENTAL STUDY OF FORCED DRAFT CROSS FLOW WET COOLING TOWER USING SPLASH TYPE FILL

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Abstract*- This paper deals with an experimental analysis of heat transfer phenomena between water and air by direct contact in a cross flow force draft cooling tower model. The tower is filled with splash type packing while sprayer nozzles are used to distribute the warm water. The packing is 10 inch high and consists of four stages having a distance of 2.5 inch between two stages. Each packing provides 11.5 inch × 1.75 inch cross sectional test area. This study investigates the effect of the air and water flow rates on the cooling capacity and effectiveness of the wet cooling tower as well as the evaporation loss of water into the air stream and the percent loss of water. The observations were made for six different air velocities and three different water flow rates by keeping the inlet water temperature constant. Performance factors like range, approach, effectiveness, cooling capacity, evaporation loss, percent loss is calculated from collected data. The results represent that effectiveness of cooling tower is higher for low water flow rate while the situation is reverse in case of cooling capacity. In contrast, all the parameters except approach increase with the increase of air velocity. As it is observed that cooling tower performance increases with the increase in air velocity, but at the same time evaporation loss and drift loss increases which causes need for extra make up water, so choosing a perfect air velocity which will give better effectiveness and less loss is important. Installing precise temperature control device at inlet to supply continuous hot water at constant temperature and using screen with ventilation in front of stages will be some paths to improve the performance of this cooling tower.*

Keywords: Wet cooling tower, Splash type fill, Direct contact, Effect of air velocity, Performance factors.

1. INTRODUCTION

A cooling tower is a heat exchanger which extracts waste heat to the atmosphere through the cooling of a water stream to a lower temperature. Cooling tower is an essential part of electric power generation plant like steam power plant and nuclear power plant as the part of circulating water system. Common applications for cooling towers are providing cooled water for refrigeration and air-conditioning systems, manufacturing processes, chemical plants and oil refineries etc.

The generic term "cooling tower" is used to describe both direct (open circuit) and indirect (closed circuit) heat rejection equipment. In an open circuit cooling tower, tow fluids, ambient air and warm water, are in direct contact with each other. The type of heat in this device is termed "evaporative" as it allows a small portion of the water being cooled to evaporate into a moving air stream to provide significant cooling to the rest of that water stream. The water to be cooled is commonly distributed over a packing material in the tower. The type of packing material used in the cooling tower has an important role in the tower as it provide a very large surface area for evaporative heat transfer to take place from hot water to ambient air. This causes the evaporation of a small portion of water, with a corresponding extraction of heat from the remaining water, while the air stream is humidified by picking up heat and moisture. The distributors such as sprayer nozzles also have significant effect on performance factors as they break the water stream into small particulates to increase the air-water interface area. Until now, several investigators have treated this subject through some experimental analysis of the heat and mass transfer phenomena in cooling towers as these equipments constitute an important energy conversion resource [1].

Kelly and Swenson studied the heat transfer and pressure drop characteristics of splash grid type cooling tower pickings. The authors correlated the tower characteristics with the water/air mass flow ratio and mentioned that the factors influencing the value of the tower characteristics were found to be the water-to-air ratio, the packed height, the deck geometry and, to a very small extent, the hot water temperature. They also mentioned that the tower characteristics at a given water-to-air ratio was found to be independent of wet bulb temperature and air loading, within the limits of air loading used in commercial cooling towers [2]. Barile et al. studied the performances of a turbulent bed cooling tower. They correlated the tower characteristics with the water/air mass flow ratio [3].

El-Dessouky [4] studied the thermal and hydraulic performances of a three-phase fluidized bed cooling tower. He used spongy rubber balls 12.7mm in diameter and with a density of 375 kg/m3 as a packing, and developed a correlation between the tower characteristics, hot water inlet temperature, static bed height, and the water/air mass flux ratio. Bedekar et al. [5] studied experimentally the performance of a counter flow packed bed mechanical cooling tower, using a film type packing. Their results were presented in terms of tower characteristics, water outlet temperature and efficiency as functions of the water to air flow rate ratio, L/G. They concluded that the tower performance decrease with an increase in the L/G ratio, however they did not suggest any correlation in their work [5]. Goshayshi and Missenden [6] also studied experimentally the mass transfer and the pressure drop characteristics of many types of corrugated packing, including smooth and rough surface corrugated packing in atmospheric cooling towers. Their experiments were conducted in a 0.15 m × 0.15 m counter flow sectional test area with 1.60 m packing height. From their experimental data, a correlation between the packing mass transfer coefficient and the pressure loss was proposed. Recently, Kloppers and Kröger [8] studied the loss coefficient for wet cooling tower fills. They tested trickle, splash and film type fills in a counter flow wet cooling tower with a cross-sectional test area of 2.25 m^2. They proposed a new form of empirical equation that correlates fill loss coefficient as a function of the air and water mass flow rates [8]. In another paper, Kloppers and Kröger [9] studied experimentally the transfer characteristics of wet cooling tower fills. They reported that the transfer characteristic correlations for wet cooling tower fills are functions of the air and water mass flow rates, the inlet water temperature and fill height but not of the air dry bulb and wet bulb temperatures [9]. There exist several other mathematical models which can correlate simultaneous heat and mass transfer phenomena occurring within direct contact cooling towers, such as the models presented in Braun [12], Braun et al. [13], Benton and Waldrop [14], Hawlader and liu [15], Khan et al. [16], Kloppers and Kröger [l7] and more recently, Qureshi and Zubair [18].

The aim of this paper is to carry out an experimental investigation through a previously constructed then modified direct contact evaporative cooling tower to observe the effects of air and water flow rates on cooling tower characteristics. Reza Shakeri et al. [19] used this type of packing in an evaporative cooling system to study its thermal performances.

2. EXPERIMENTAL SETUP AND PROCEDURE

Figure 1 illustrates the experimental setup used in this investigation. It consists mainly of a packed cooling tower which represents the main device used in this test, a cold water basin, a water reservoir which contains an electric heater, a water pump, a rotameter, a water distributor, a fan. Auxiliary items are also used such as thermostat, temperatures and pressures measuring devices, system for the regulation of the water flow rates into the water distributor etc. the cooling tower has dimensions 18 inch × 18 inch × 17 inch, and fabricated from fiber glass. It is filled with splash type packings having a cross sectional test area of 11.5 inch × 15 inch, a height of 12.5 inch and consists of four stages. The tower also holds a fan vertically for air flow into it. A plastic water reservoir was used which has capacity to reserve 50 liters of water. In this experiment, a gravity water distributor made of steel was used that has dimensions 16 inch × 12 inch × 2 inch. Fine droplets of water that sweeps into splash fill are introduced through this distributor. The considered measurements which were taken consist of the temperatures (dry and wet) of the air at the entry and exit of the tower as well as the inlet and outlet water temperatures.

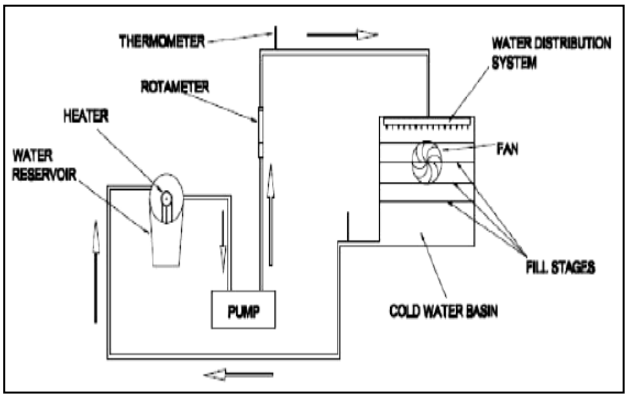

Fig. 1: Schematic diagram of the laboratory scale cooling tower

The experimental procedure is as follows:

1. At first water was heated in the reservoir using the heater.
2. When the temperature of water in the reservoir reached the desired temperature then the fan and pump were started.
3. The water flow rate was adjusted at 7.5 lit/min by gate valve and the rotameter reading was taken.
4. When the inlet and outlet water temperature came to a steady position, the temperature readings were taken by mercury thermometer.
5. At the same time the relative humidity of air at inlet and outlet was measured by hygrometer.
6. Inlet air wet bulb temperature was also taken by thermometer simultaneously.
7. The velocity of air was measured at fill inlet by digital anemometer.
8. Then keeping inlet water temperature and flow rate of water constant, the air velocity was changed to measure the other parameters for current condition.
9. The total procedure again followed for water flow rate of 5.0 lit/min and 3.0 lit/min respectively.

3. HEAT TRANSFER PHENOMENA IN THE COOLING TOWER

Heat transfer phenomena of wet cooling tower is measured in terms of it approach, how close temperature of cooling water comes to wet bulb temperature of the ambient air, when water is cooled through the desired range. The cooling tower range and approach are defined as [21].

Cooling range = $T_{wi} - T_{wo}$ (1)

Approach = $T_{wo} - T_{wb}$ (2)

Cooling tower thermal efficiency or effectiveness can be calculated as

$$\eta_{ct} = (T_{wi} - T_{wo}) / (T_{wo} - T_{wb}) \quad (3)$$

Cooling capacity of the tower can be derived from the following equation

Cooling capacity = Water mass flow rate × specific heat of water × range (4)

Evaporation loss can be found by the equation

Moisture added = $m_a(\omega_2 - \omega_1)$ (5)

The loss of water due to evaporative cooling can be calculated as

$$\textbf{Percent loss} = \frac{\textit{Evaporation Loss (kg/hr)}}{\textit{Inlet Water (kg/hr)}} \times 100\% \quad (6)$$

There are several factors which affect the performance of cross flow wet cooling tower. Some of these effects are discuss below

3.1 Effect of Inlet Water Temperature

The effect of inlet water temperature on the evolution of dry bulb air temperature and absolute humidity as evidence the increase of inlet water temperature enhance the rate of increase of dry bulb air temperature inside the cooling temperature. Similar observations can be made for the effect of inlet water temperature on the variation of air humidity ratio inside the cooling tower. The highest overall reduction of water temperature can be observed for high values of inlet water temperature. For low and moderate inlet temperature, the sensible heat exchange potential becomes negative close to the top of the cooling tower.

3.2 Effect of Air Velocity

The air velocity has a great effect on the performance of wet cooling tower. It varies the effectiveness varying with respect to range, approach. The air velocity also affects the cooling capacity and outlet relative humidity.

3.3 Effect of Fill Media

In a cooling tower, hot water is distributed above fill media which flows down and is cooled due to evaporation with intermixing air. Heat exchange between air and water is influenced by surface area of heat exchanger, time of heat exchange (interaction) and turbulence in water effecting thoroughness of intermixing. Fill media in cooling tower is responsible to achieve the desired cooling capacity.

3.4 Effect of Heat Load

The heat load imposed on a cooling tower is determined by the process being served. The degree of cooling required is controlled by the desired operating temperature level of the process. In most cases, a low operating temperature is desirable to increase process efficiency or to improve the quality or quantity of the product. In some applications, however, high operating temperatures are desirable. The size and cost of the cooling tower is proportional to the heat load. If heat load calculations are low undersized equipment will be purchased. If the calculated load is high, oversize and more costly, equipment will result.

4. EXPERIMENTAL RESULTS

Allowing the system to the steady state conditions necessary data were collected as described in the procedure. Consequently, the performance factors calculated from collected data were indicated as shown in figure 2-7.

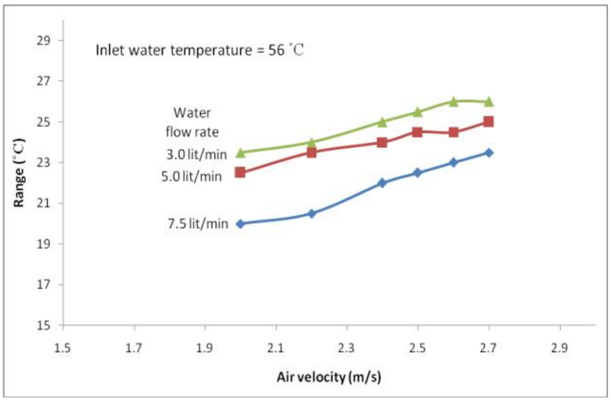

Fig.2: Cooling tower range vs. air velocity for different values of water flow rates at an inlet temperature of 56˚ C.

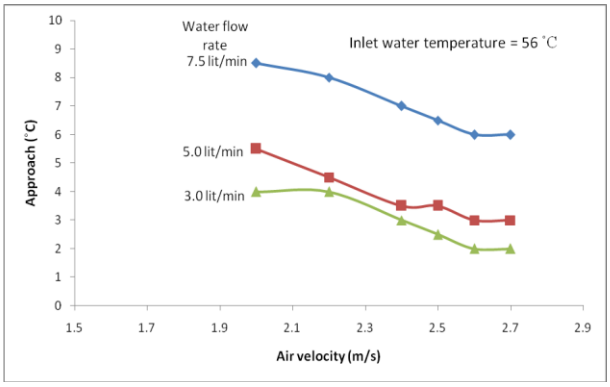

Fig. 3: Cooling tower approach vs. air velocity for different values of water flow rates at an inlet temperature of 56˚ C.

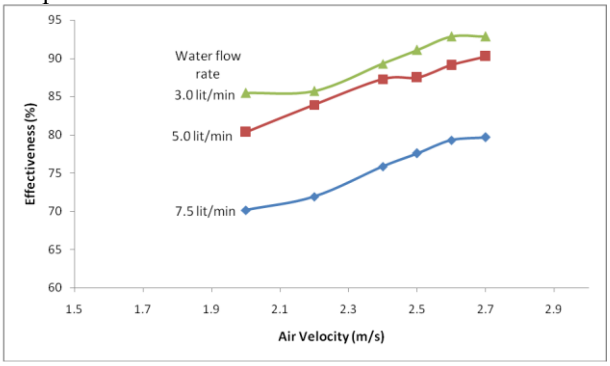

Fig 4: Cooling tower effectiveness vs. air velocity for different values of water flow rates.

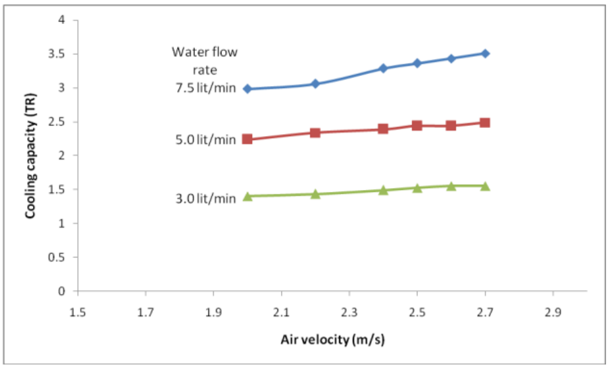

Fig. 5: Cooling capacity vs. air velocity for different values of water flow rates.

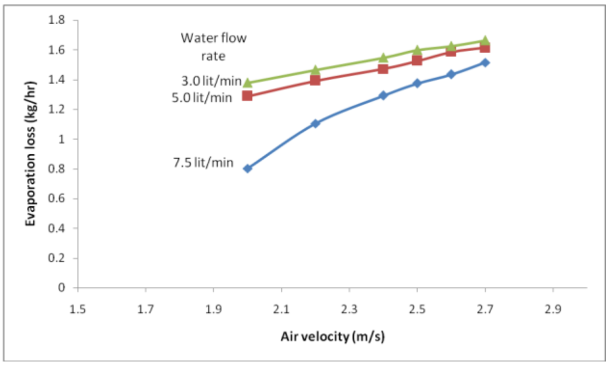

Fig. 6: Effect of air velocity on cooling tower evaporation loss.

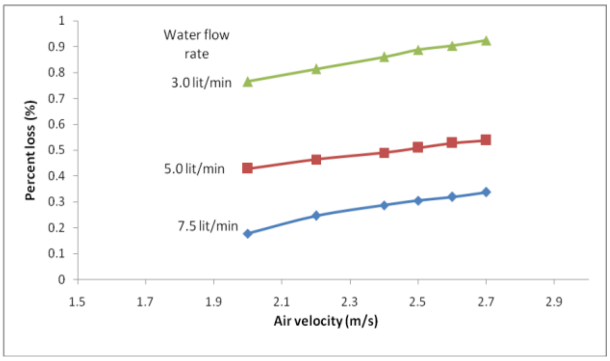

Fig. 7: Percent loss of water vs. air velocity for different values of water flow rates.

5. DISCUSSION

From graphical representation it is found that air velocity has a significant impact on the performance of wet cooling tower. With the gradual increase of velocity of air, more air comes into contact with hot water and takes heat from water with a greater rate. So the range of the cooling tower increases with the increase of air velocity. In case of approach, it is observed that the approach decreases with the raise in air velocity. As the approach is the difference between water outlet temperature and ambient wet bulb temperature, it depends on the weather condition. So the decrease of approach is not uniform which can be seen in figure 3. It is also demonstrated that range and approach varies significantly with the variation of water flow rate (Figure 2 and figure 3). Theoretically range needs to be high and approach has to be low. From results it is found that the water flow rate 3.0 Lit/min meets the criteria. Effectiveness of the cooling tower is a calculative term mainly depends on range and approach. That's why its variation is related with the change of range and approach. From the demonstration it is observed that effectiveness of cooling tower increases with the increase in air velocity. Effectiveness is also higher for lower water flow rate. It should be noted here that, the effectiveness found for the current setup by experimental analysis is quite high. High effectiveness is good but a practical system can not give such kind of high effectiveness. This is may be due to discontinuous flow of hot water. If hot water at 56˚C can be supplied continuously the effectiveness of cooling tower will not be that high. Another important term for cooling tower performance evaluation is evaporation loss. Evaporation loss increases with the increase of air velocity. When the air velocity increases the volume flow rate of air also increases which takes away more water vapor. As a result evaporation loss increases. More makeup water is needed for increased evaporation loss. Therefore we have to choose an intermediate air velocity where cooling efficiency is good and evaporation loss is less. As evaporation loss raise in lower flow rate we should also mull over the water flow rate. The percent loss changes significantly in case of water flow rate change rather than air velocity change. It is evident from the experiment that the range has been increased from the previous experiment. Effectiveness increased to 71.93% (present) from 42.5% (previous) for water flow rate 7.5 Lit/min and air velocity 2.2 m/s. the cooling capacity of the tower also influenced by the air velocity. Cooling capacity increased slowly with the increase in air velocity. The cooling capacity of current setup increased to 3.062 TR from 1.194 TR of previous setup for water flow rate 7.5 Lit/min and air velocity 2.2 m/s.

6. CONCLUSION

In recent years almost every industries and power plant recycle water by using circulating water system. Cooling is one of the most essential parts of circulating water system. Hot water coming from the process is cooled in cooling tower. So the efficiency of cooling tower should be of high concern. But efficiency (effectiveness) of cooling tower depends upon many factors such as inlet water temperature, air velocity, and inlet air temperature, fill area, fill spacing, flow rate of water etc. In this experiment the main objective was the enhancement of efficiency by installing a better water distribution system and re-arranging splash type fill and to find out the effect of air velocity on cooling tower performance. The experiments were carried out in a wet cooling tower having cross flow of air. It is observed that cooling tower performance increased with the increase in air velocity, but at the same time evaporation loss and drift loss increased which causes need for extra make up water. So it is important to choose a perfect air velocity which will give better effectiveness and less loss. In future, performance evaluation can be done by considering following recommendations:

- The drift loss of water can be minimized by installing a screen with ventilation in front of fill stages.

- Fill stages can be increased and fill spacing can be changed.
- A better speed regulator of air velocity can be installed for higher speed.
- To supply hot water at constant inlet temperature continuously, the heating system should be changed.
- Height of cooling tower can be increased and more fans can be added.

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8. NOMENCLATURE

Symbol	Meaning	Unit
T_{wi}	Inlet water temperature	(˚C)
T_{wo}	Outlet water temperature	(˚C)
T_{wb}	Ambient wet bulb temperature	(˚C)
η_{ct}	Cooling tower effectiveness	(%)
m_a	Mass flow rate of air	Kg/s
m_w	Mass flow rate of water	Kg/h