INCREASING THE COOLING EFFECT OF A COOLING TOWER BY ADDING NOZZLES AT THE END OF EVERY PACKING

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***Abstract—**A replica model of PA Hilton H893 cooling tower was fabricated for experimentation. 2 types of decks were also fabricated, one with nozzles at the end of every packing and the other resembling the decks of a conventional H893 cooling tower. Experimental trials were done at a fixed air flow rate and water flow rate, to observe the effect due to addition of nozzles. In this paper, we shall see the procedure and result of the above-mentioned experiment. Further methods of increasing the cooling effect have also been discussed.*

Keywords—Air Flow Rate, Effectiveness, Heat Transfer, Nozzle Effect, Relative Percentage Increase

1. INTRODUCTION

Cooling towers are of several types. The main classifications are the dry types and the wet types. A dry cooling tower is one in which air along with some hot gases are cooled before being emitted into the atmosphere. A wet cooling tower is one in which liquids such as water, are cooled on a very large scale for reusing in industries. In this paper, we shall be dealing with a wet type cooling tower and hence further mentions of 'cooling tower' in this paper shall take the meaning of a wet type cooling tower. In such cooling towers the water (the liquid largely cooled in industries) is cooled by means of convection by using atmospheric air. The heat transfer process is explained in the further sections of this paper. Increasing the cooling effect of a cooling tower can be done in many ways, but the expenditure in terms of both capital and energy should be taken into consideration. In this paper, we shall see how installation of converging nozzles can bring a phenomenal increase in the cooling effect with very less capital investment and little energy requirement for the alteration. Heat transfer takes place through conduction, convection, radiation and evaporation out of which the heat transfer through evaporation is the most important phenomenon as it contributes the maximum. Evaporation is utilized to its fullest extent in cooling towers, which are designed to expose the maximum transient water surface to the maximum flow of air – for the longest period of time [1]. The air flow rate employed was 54.3g/s and the water flow rate employed was 80g/s. Converging Nozzles are mechanical devices that are used to increase the velocity of a fluid in the meanwhile decreasing its pressure energy. A drop in the pressure of the fluid will in turn drop its temperature. This is the phenomena based on which expansion devices such as throttle valves and turbines are used in air conditioning, refrigeration and cryogenics.

2. LITERATURE SURVEY

A study on the previous works carried out by various researches worldwide has provided guidelines for this research. Velimir et al [2] did an experimental study on heat and mass transfer in cooling towers in the year 2000. His work shows the variation of temperature along the vertical and horizontal distances of the cooling tower. During the same year, H. R. Goshayshi [3] et al investigated-on cooling tower packing in various arrangements. He found the mass transfer coefficient of different packings experimentally. He showed that the packing coefficient for mass transfer is dependent on pitch and distance of packings. Al-Waked et al [4] in the year 2007, worked on enhancing performance of wet cooling towers. He investigated the influence of wind break walls on the thermal performance of natural draft wet cooling towers (NDWCTs) under cross-wind through the three dimensional CFD modelling. Eventually, it was concluded that the NDWCTs performance could be enhanced by installing solid walls at the NDWCTs entry. In 2011 Matjaz et al [5] studied the influence of airflow inlet region modifications on the local efficiency of natural draft cooling tower operation. He showed experimentally that there is a small efficiency drop due to installation of drift eliminators in the cooling towers. Gaoming et al [6] observed the effects of discharge recirculation in cooling towers on energy efficiency and visible plume potential of chilling plants in the year 2012. The work done by Gaoming shows that discharge recirculation results in increased frequency of visible plume occurrence. Jing et al [7] performed experiments and analysed their results numerically to show that the performance of a cross flow closed wet cooling tower is better than parallel or counter flow patterns in the year 2013. Pooriya et al [8] in the year 2016 did an experimental study on improving operating conditions of wet cooling towers using various rib numbers of packing. His experiment shows the variation of efficiency with increase in packing density, inlet temperature of water, etc. In the same year, Mehdi Rahmati et al [9] studied the thermal performance of natural draft wet cooling towers under cross-wind conditions based on experimental data and regression analysis. The experimental data were employed to investigate the heat transfer performance of natural draft counter flow wet cooling towers under cross-wind and windless conditions.

In addition, influences of cross-wind velocity, inlet water temperature and water flow rate on the water temperature difference and cooling efficiency were found out. Furthermore, to have a more applicable study, regression analysis of the experimental data was utilized for the sake of developing general mathematical equations. Finally, two common parameters including root mean square error and correlation coefficient were considered to examine accuracy of the fit between experimental data and regression outputs.

3. HEAT TRANSFER PROCESS

Consider the surface of a warm droplet of water to be in contact with an air stream as shown in Fig.1.

The cooling process in a cooling tower takes place mostly through the evaporation process as explained below. Cooling takes place as molecules of water diffuse from the surface into the surrounding air. The stream of air in contact with the water molecule is assumed to be completely saturated. So, the moisture available (the evaporated water) in this saturated air diffuse into the stream ahead of it whose vapor pressure is comparatively lower. These molecules of water (moisture of the saturated air) get replaced by the layer of molecules currently present at the surface of the water (liquid) and the energy needed for this is taken from the rest of the liquid. By this way the water gets cooled down continuously. It is very important to circulate unsaturated air through the cooling tower for effective cooling to take place.

4. NOZZLE EFFECT

The velocity increase in a nozzle is due to conservation of mass. Mass conservation means that the mass flow rate in the tube, 'm', must be constant at any position along the nozzle.
This can also be expressed as
m=ρV=constant
where ρ is the density of the fluid and V is the volumetric flow rate. If the fluid is incompressible or nearly incompressible, then the volumetric rate is constant.

The volumetric flow rate can be expressed as
V= vA = constant V
where v is the flow velocity and A is the cross-sectional area of the nozzle. From this you can see that if the area decreases, the velocity must necessarily increase and the velocity is inversely proportional to the area of the nozzle (ignoring surface tension effects that can cause the velocity to max out when the opening gets too small).
Here pressure can be seen as the mechanical potential energy and velocity can depict the mechanical kinetic energy. So, as velocity increases, pressure would decrease. And this decrease in pressure would be accompanied by a drop-in temperature.

5. EXPERIMENTAL SETUP

Fig. 2 shows the line diagram of the experimental setup of a laboratory scale cooling tower.

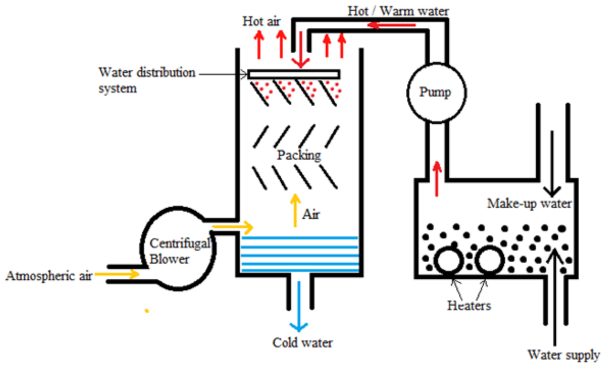

Fig.2- Experimental setup

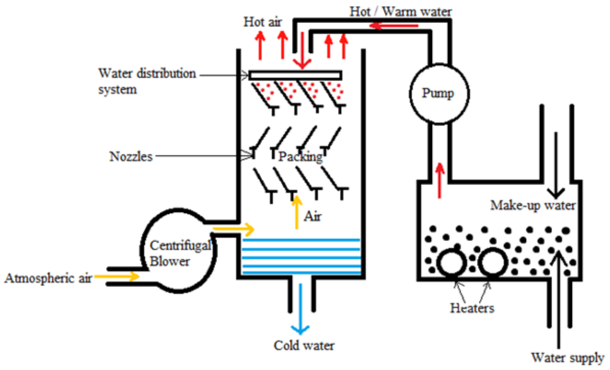

Fig.3- Experimental setup with nozzles

A. *Fabrication*

The outer casing or the column was made by using fibre glass. Then the packagings were cut out from the same material, painted and then coated with saw dust. Nozzles were made of nylon and attached to a PVC mounting on the packagings. They were then attached in inclined angles (30° to the vertical), to the column with the help of L- Clamps. 8 decks of packaging were attached to the column in a zig zag manner. A metal sheet was bent to form crests and troughs and holes were drilled. Small sized holes for water to flow through at the troughs and larger sized holes at the crests for air to pass through were drilled. The water inlet pipe was then fixed at the top of the water distribution system and holes were drilled in the pipe for uniform water distribution. A foam sheet at the top and bottom of the column were placed to act as particle arrestor and water filter. At the bottom, a tank is provided to collect the cold water and the water is taken out and given to the heating tank. The heating tank consists of the heater and submersible pump. The water is then sent to the inlet of the column. A make-up tank is fitted on top of the load tank to ensure constant water flow rate. The make-up tank and the load tank are connected through a float valve. A DC Wheelchair motor with specifications of 24V x 4A was used for the fan that was fitted at the top of column to provide circulation of air, replicating an induced draft cooling tower.

B. *Experimental Procedure and Working*

Initially water was heated in the load tank and pumped up to the water distribution system. As the water flows down through the column along the packings the fan at the top sucks the air up the column. The hot water comes in contact with the comparatively cold and unsaturated atmospheric air and starts exchanging its heat with the air. The water turns cold gradually and at the bottom cold water can be collected. The heaters are switched off and the water is sent back to the load tank and pumped up. The hot air escapes into the atmosphere from the top. A thermometer is placed in the load tank to measure the temperature of the water. Some of the water gets evaporated during this cycle and hence the make -up water from the make-up tank enters the load tank through the float valve. This helps in maintaining the constant head of water. The cycle repeats itself till the apparatus is turned off and the water gets cooler and cooler. The maximum drop in temperature can be till when the water achieves the temperature of atmospheric air.

Experimental trials of 2 minutes each were conducted in 2 phases.

Phase - 1: Initially experimental trials were done on the fabricated replica of conventional cooling tower under the conditions 80g/s water flow rate and 54.3g/s air flow rate.

Inlet temperature of air was 306.2 K

The inlet temperature of water was 314.4 K

And the Outlet temperature of water after cooling attained was 310.5 K

Phase - 2: Experimental trials were then performed by inserting a deck of packaging with nozzles at their ends under the same conditions.

Inlet temperature of air was 306.6 K

The inlet temperature of water was 316 K

And the Outlet temperature of water was 310.5 K

6. FORMULA AND OBSERVATION TABLE

Effectiveness. This is the ratio between the range and the ideal range (in percentage), i.e., difference between cooling water inlet temperature and ambient wet bulb temperature, or in other words it is = Range / (Range + Approach). The higher this ratio, the higher is the performance.

The formula is given by: Effectiveness (%) = 100 x [Cooling tower water inlet temperature (˚C) – Cooling tower water outlet temperature (˚C)] / [Cooling tower water inlet temperature (˚C) – Wet bulb temperature (˚C)]. [10]

	Without Nozzles	**With Nozzles**
Initial Temperature of Water	314.4 K	316 K
Final Temperature	310.5 K	310.5 K
Temperature of Atmospheric air	306.2 K	306.6 K
Effectiveness	0.475	0.585

7. RESULT

The effectiveness of the cooling tower has increased after introducing a deck of packing with nozzles at their ends.

Effectiveness (Phase - 1) = 0.475

Effectiveness (Phase - 2) = 0.585

Relative % increase in cooling effectiveness because of nozzles = 100*(0.585-0.475)/0.585 % = 18.8%

Hence introducing nozzles at the end of every deck would increase the cooling effect much more without any doubt. Installing nozzles to cooling tower would not need a huge capital and would be a permanent solution to increase the cooling effect with very less maintenance needed. And also, there wouldn't be any extra energy or power needed after the installation.

Other techniques to increase the cooling effect would include:

- Increasing the packing Density.
- Changing the inclination of the packings.
- Increasing air flow rate.
- Using a cooling turbine to expand the air.
- Using throttle valves at the entry of water into the cooling tower.
- Increasing the height of the column.

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