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THERMAL PERFORMANCE OF FORCED DRAFT COUNTER FLOW WET COOLING TOWER WITH EXPANDED WIRE MESH PACKING

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Abstract- This paper presents an experimental investigation of the thermal performance of forced draft counter flow wet cooling tower with expanded wire mesh type packing. The packing used in this work is wire mesh with vertical [VOWMP] and horizontal [HOWMP] orientations. The packing is 1.25 m height and having a zigzag form. From the experiments it is concluded that the vertical orientation of the packing enhance the performance of the cooling tower.

Keywords: Cooling Tower, Packing, Wire Mesh, Characteristics.

I. INTRODUCTION

Cooling towers are widely used to remove heat from industrial processes and from refrigeration and air-conditioning systems. Simultaneous heat and mass transfer process in every section of the cooling tower gives rise to complicated design equation. Experimental investigations of cooling towers should lead to better design. In counter flow cooling tower, hot water is sprayed into an air stream. Heat and mass are transferred and the water enthalpy decrease while that air increases. In order to increase the cooling rate, there interface area between air and water is increased by packed and fluidized beds. There are three types of packings in use namely, film, splash and film-grid packings. In the experimental studies, film packings were used with different orientations. Cooling tower packing plays an important role in increasing the effective contact area between air and water to promote better heat and mass transfer.

The operation theory of cooling tower was suggested by Walker [1]; however, the generally accepted concepts of cooling tower performance were developed by Merkel [2]. A simplified Merkel theory has been used for the analysis of cooling tower performance. Simpson and Sherwood [3] studied the performance of forced draft cooling towers with a 1.05 m packing height consisted of wood slats. Baker and Shyrock [4] presented the ways to minimize the error due to the assumptions of Merkel theory. Sutherland [5] has done a more rigorous analysis of a cooling tower model that relaxed Merkel's restriction. Nithiarasu and Seetharamu [6] have studied the experimental investigation of the performance of counter flows in packed bed mechanical cooling and showed that the tower performance decrease with an increase in the L/G ratio.

Goshayshi and Missenden [7] studied experimentally the mass transfer and the pressure drop characteristics of many type of packings, including smooth and rough surface corrugated packing in the atmospheric cooling tower. Milosarljevic and Heikkila [8] carried out experimental measurements on two pilot scale cooling towers in order to analyze the performance of different cooling tower filling materials. Kloppers and Kroger [9] have studied the loss coefficients for wet cooling tower fills. They tested trickle, splash and film type fills in a counter flow wet cooling tower. Khan et al. [10] and Kloppers and Kroger [11] have proposed and discussed several other mathematical models which correlated heat and mass transfer processes occurring in wet cooling towers. The main objective of this study is to investigate the thermal performances of a forced draft counter flow wet cooling tower filled with expanded wire mesh packing with different orientation (HOWMP, VOWMP) The principle of its performance is as follows: the air enters by the bottom of the tower and arrives by the top of that while crossing several times the expanded mesh, whereas the water is introduced at the top of the tower and flows along the expanded mesh.

II. BASIC THEORY

Heat transfer rate in the cooling tower is represented by the difference between the enthalpy of moist air at bulk water temperature and the enthalpy of the moist air. Merkel equation describes the heat transfer characteristics of filler at the design condition. It needs several assumptions:
(i) effect of evaporation does not exist,
(ii) thermal and mass diffusion coefficients of air/water system are the same.

The analysis combines the sensible and latent heat transfer between air and water droplets in the tower. Total heat transfer rate per unit volume of filler (dV) from the interface to the air is the sum of sensible heat (dq_S) and latent heat (dq_L).

$$dq_S = U_G a dV\left(T^{"} - T\right) \quad (1)$$

$$dq_L = h_{fg} dm = h_{fg} K' a dV (W'' - W) \quad (2)$$

Energy conservation principle with the assumption principle with the assumption that the interface temperature is same as the air temperature derives equation (3).

$$L c_{pw} dt = K a dV (h' - h) \quad (3)$$

Integration of equation (3) results in equation (4).

$$NTU = KaV/L = \int_{t_2}^{t_1} c_{cw} dt/(h' - h) \quad (4)$$

Left hand side of the equation (4) is a dimensionless parameter called NTU (number of transfer unit) which is the characteristic value of the fill and represents the heat transfer capacity, that is a function of air and water temperature, size of the tower and shape of the fill. The temperature difference between the water entering and leaving the cooling tower is the range (R).The difference between the leaving water temperature and the entering air wet-bulb temperature is the approach (A) of the cooling tower. Cooling tower effectiveness is the ratio of range to the ideal range.

$$\varepsilon = (t_{w1} - t_{w2})/(t_{w1} - t_{wb1}) \quad (5)$$

Liquid /Gas (L/G) ratio, of a cooling tower is the ratio between water and the air mass flow rate. Against the design values, seasonal variation requires adjustment and tuning of water and air flow rates to get the best cooling tower effectiveness. The heat removal from water must be equal to the heat absorbed by the surrounding air.

$$L(T_1 - T_2) = G(h_2 - h_1) \quad (6)$$

$$L/G = (h_2 - h_1)/(T_1 - T_2) \quad (7)$$

III. EXPERIMENTAL SETUP

Experimental water cooling tower model (Figure 1) comprises of tower of 0.3x0.3 cross sectional are and 1.5 m working height. Tower is fabricated out of M.S. sheet and angle frame and is provided with a Perspex sheet for visualization of tower operation.

Hot water spray arrangement is provided at the top of tower packing to distribute water over the packings. Just below the packing a wind box is fitted with holes on all sides for uniform entry of air in the tower. Bottom end of the tower goes in the water measuring tank used for water flow rate measurement. At the top end of the tower and in the wind box, psychrometers are fitted to measure entry and exit conditions of air in the tower.

A 3 HP centrifugal blower is used to supply are to the cooling tower. Air piping is provided with control valve and orifice meter for air flow variation and measurement respectively. Water line for cooling tower is connected through a rotameter for flow measurement and through water heating. By simultaneously varying water flow rate and heater input, various inlet water temperatures can be achieved. Water after passing through the tower packing is passed to a measuring tank for measuring outgoing water flow for measuring evaporation loss.

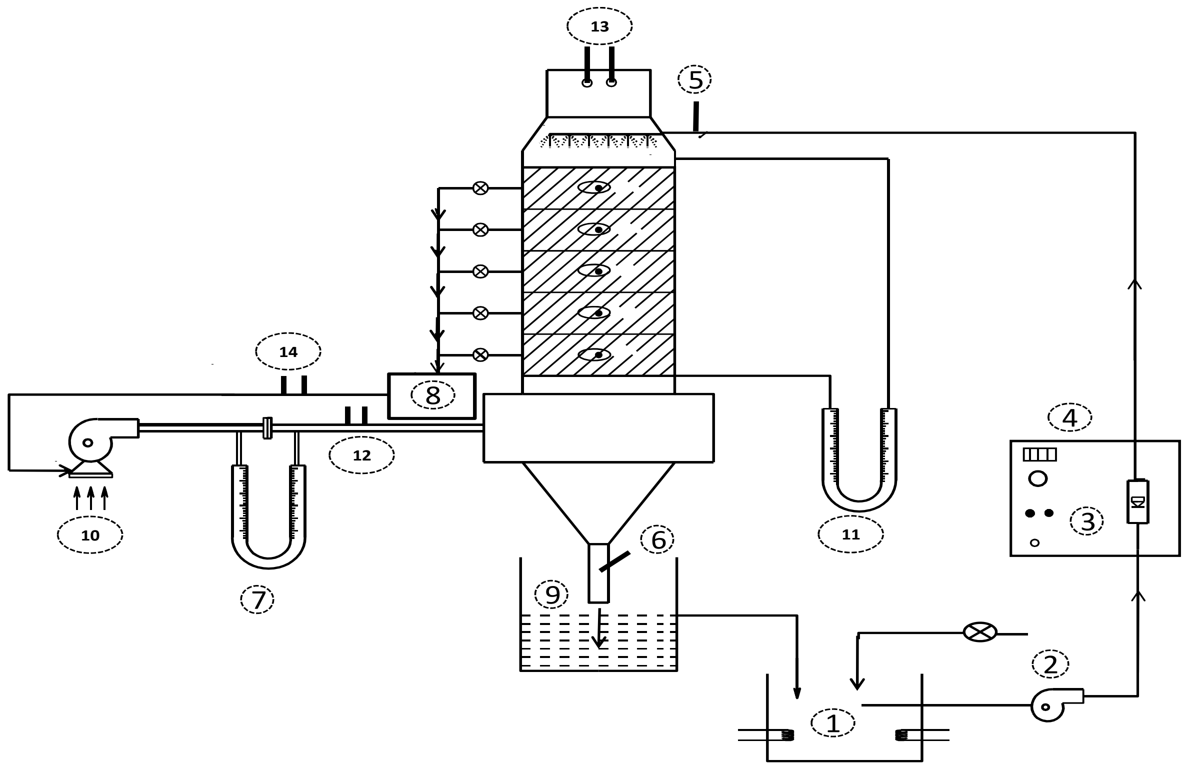

Figure 1. Experimental setup of forced draft cooling tower

1. Water heater, 2. Pump, 3. Flow meter, 4. Temp display and control unit, 5. Hot water thermometer, 6. Cold water thermometer, 7. U-Tube manometer - air flow, 8. Psychometric gun, 9. Receiving tank, 10. Forced draft fan, 11. U-Tube manometer-cooling tower, 12. Air inlet temperature. (T_{DB1} T_{WB1}), 13. Air outlet temperature (T_{DB2} T_{WB2}), 14. Psychometric gun temperature

IV. EXPANDED WIRE MESH

In the experimental study, expanded wire mesh was used as tower packing material. This type of wire mesh is considered as unique for film packing. The forming of wire meshes is made such as each little aperture acts as directing vane on air, moving bulk of air alternately from one side to other. This action results in air travelling a distance of about 1.25 m total depth of packing. Flank angle and geometry into number of paths running are along the flank and finally through of the mesh on the next element below. Unlike solid film packings, wire mesh presents the minimum restriction to the passage of air.

The schematic arrangement of the HOWMP, VOWMP packings are shown in Figure 2(a) and Figure 2(b). Figures 3 and 4 show the enlarged and photographic view of the wire mesh packing. In one square inch area 32 diamond shapes are present. The thickness of the wire mesh is 1 mm and length and breadth of the diamond shape is 5 mm and 3 mm.

V. EXPERIMENTAL PROCEDURE AND OBSERVATION

Water is allowed to circulate through the cooling tower with the heaters on awaiting the temperature reaches a steady state value. Different water temperatures are achieved by adjusting the heater. After reaching steady state, the air forced through the tower by forced draft fan. The air flow rate is maintained at different level by adjusting the control vanes.

At the steady state, the outlet water temperature, the outlet and dry-wet bulb temperature of air at the inlet and exit and outlet water quantity were measured with the varying the operation parameters of Liquid flow rate (kg/h), air flow rate (kg/h) and water temperature at the inlet.

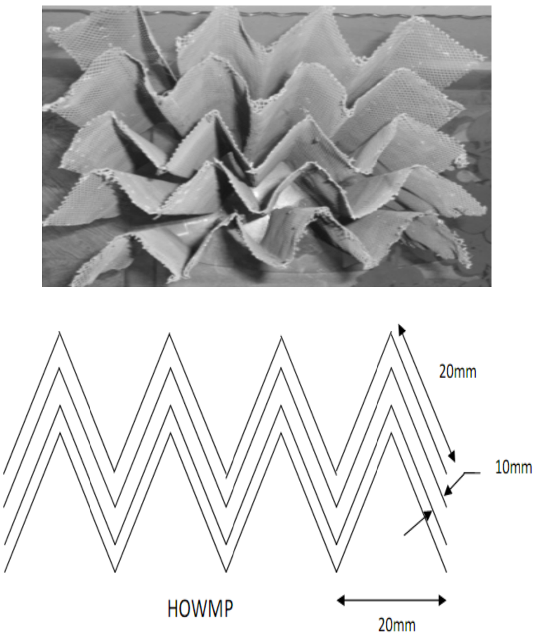

Figure 2(a). Schematic arrangements of HOWMP packing

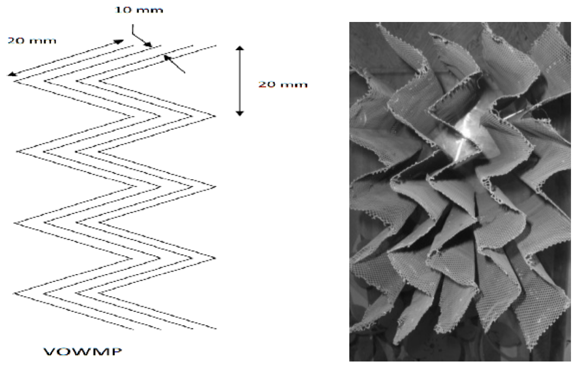

Figure 2(b). Schematic arrangements of VOWMP Packing

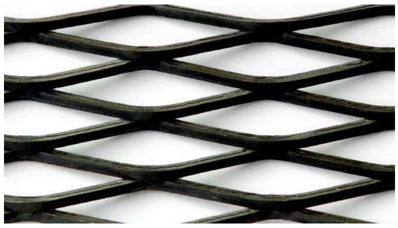

Figure 3. Enlarged photographic view of expanded wire mesh packing

VI. RESULTS AND DISCUSSION

In the literature review, Nithiarasu and Seetharamu [6] have studied the experimental cooling with inlet water temperature of 40 ˚C, 47 ˚C and 52 ˚C. In the industrial survive the cogeneration power plant and captive power plant are operated with the condenser outlet water temperature of 40 ˚C (winter) and 50 ˚C (summer). Based on the above reference we have selected the cooling water inlet temperature is 45 ˚C for the experimental operation.

The performance of a cooling tower depends on the range of cooling, approach and the L/G ratio. At given operating conditions, the outlet water temperatures measure tower capabilities. Figure 5 shows the outlet water temperature variation with L/G ratio for different water flow rates. The rate of increase in water temperature is quite small at low L/G ratios. As the L/G ratio increases, a sudden increase in the slopes of the curves is observed. This change occurs at low L/G ratios when the water flow rate is small; it is delayed with an increase in flow rate. It is clear from Figure 5 that cooling water output temperature is lower in VOWMP compared with HOWMP. In VOWMP the water fell into droplets and split into fine size compared with HOWMP.

For the best performance, the water should be cooled to the entering air wet bulb temperature. In practice, this is possible either when the water flow tends to zero or the packing height to infinity. The outlet water temperature variation is a function of L/G ratio and different inlet air wet bulb temperatures; it is shown in Figure 6. A decrease in air wet bulb temperature reduces the out let water temperature. In VOWMP the different between cooling water outlet and air wed bulb temperature is maintained at the band width of 5 ˚C to 6 ˚C compared with HOWMP at 7 ˚C to 9 ˚C. Sink temperature of cooling water is low and better heat transfer occurred in VOWMP.

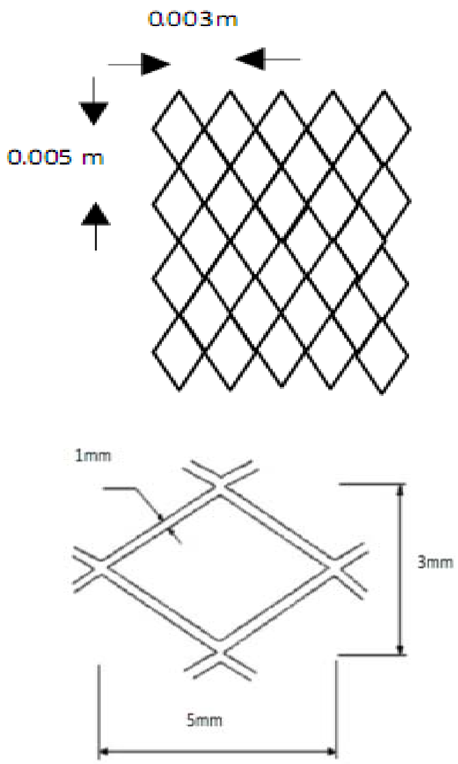

Figure 4. Wire mesh dimension in one square inch area (top) and single mesh dimension (bottom)

Figure 7 shows tower characteristics variations with the L/G ratio for different water flow rate. Cooling tower characteristics is very close for both orientations up to 0.7L/G ratio. Over the 0.7L/G the performance of cooling tower was affected and cooling tower characteristics was drooped down drastically results in a decrease in performance with an increase in L/G ratio. The efficiency is plotted against the L/G ratio in Figure 8. It is seen that, due to the higher available potential lower water flow rate results in higher efficiencies. If the water flow rate is increased, the efficiency of water cooling decreased for both orientations.

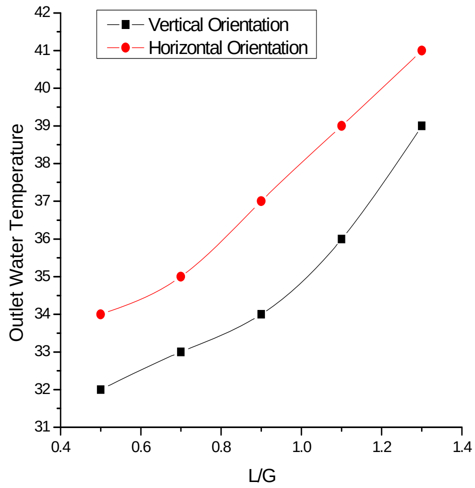

Figure 5. Outlet water temperature Vs L/G at 45 ˚C inlet water temperature

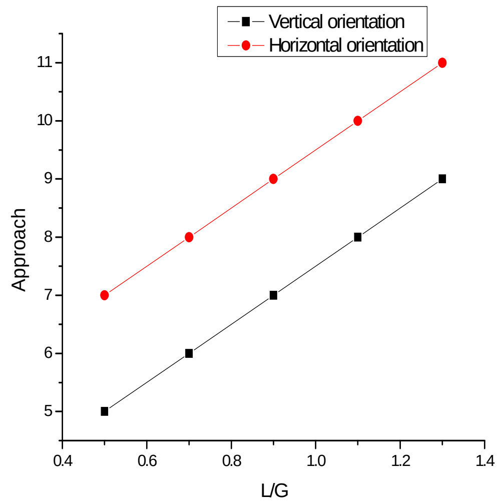

Figure 6. Approach Vs L/G at 45 ˚C inlet water temperature

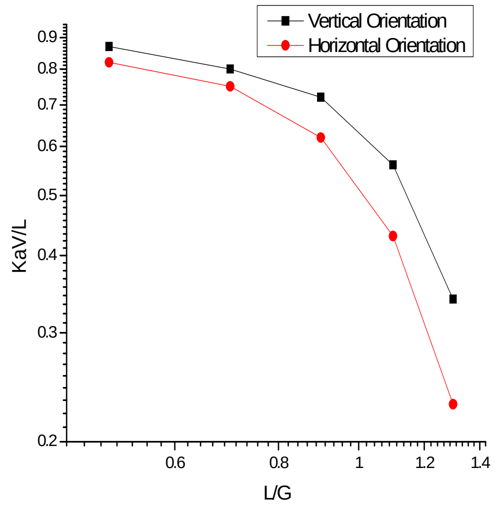

Figure 7. Tower characteristics Vs L/G at 45 ˚C inlet water temperature

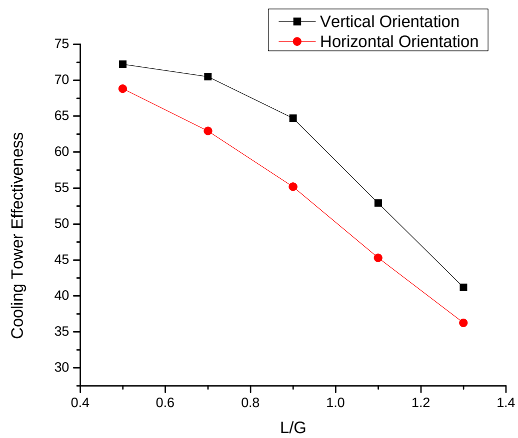

Figure. 8. Effectiveness Vs L/G at 45 ˚C inlet water temperature

VII. CONCLUSIONS

Performance of the cooling tower was analysed with expanded wire mesh packing with two different orientations. From the experimental results, the VOWMP is having better performance than HOWMP. It is due water passing over the flank angle of the wire mesh fills and fine water droplets formed in the VOWMP.

In VOWMP the water droplets are split into fine size compared with HOWMP. The air to water contact is more in VOWMP, so better heat transfer has been occurred and the cooling water outlet temperature is reduced compared with HOWMP. From the experimental study the efficiency of the cooling tower and cooling tower characteristics are higher in VOWMP due to higher contact area of water to air. Up to 0.8 L/G ratio because of better contact area between air to water the drop in performance of the cooling tower is less. Above 0.8 L/G ratio, the cooling tower performance was decreased drastically due to large quantity of water and lesser quantity of air. For that reason the contact area between air to water is in improper ratio. The L/G ratio up to 0.8, the VOWMP performance is good and over 0.8L/G the performance is dropdown. The present study can be extended with different pitch of the mesh and different size of the diamonds shape.

NOMENCLATURES

a Area of water interface per unit volume (m^2/m^3)
C_p Specific heat (kJ/kg.˚C)
L Mass flow rate of water (kg/s)
G Mass flow rate of air (kg/s)
H Enthalpy (kJ/kg)
M Mass (kg)
K_a Combined heat and mass transfer coefficient ($kJ/m^2.s$)
A_v Surface area of water droplet per unit volume of the tower (m^2/m^3)
K Overall mass transfer coefficient ($kg/s.m^2$)
Q Heat transfer rate (kJ/s)
U Overall heat transfer coefficient ($kJ/m^2.s.˚C$)
V Cooling tower volume (m^3)
T Water temperature (˚C)
W Absolute humidity

SUPERSCRIPTS AND SUBSCRIPTS

' Air bulk water temperature
'' Interface between water and air
A Air
S Sensible heat
L Latent heat
W Water
Wb Wet bulb temperature
1, 2 Inlet and outlet of cooling tower

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BIOGRAPHIES

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