DEVELOPMENT OF A SPRAY DROUGHT COOLING TOWER

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ABSTRACT

A noval type direct contact cooling tower has been proposed in which the gas or air entering the tower is drawn by the ejector action of the sprays through which the feed water is admitted. The advantage offered by this type of tower is that it eliminates the usages of fan, thus saving the capital cost and power to drive it.

Entrainment of air by water was studied in a laboratory cooling tower and the result of the entire experiment indicate that the development of a spray drought tower is a feasible practice.

1. INTRODUCTION

The process of cooling water are among the oldest known. In use today are Mechanical drought tower and Natural drought cooling tower. The later is primarily suited for large installations, and the air flow is largely due to the difference in density between the cool inlet air and the warm exist air.

There are two types of Mechanical drought cooling tower, namely; the Forced drought and the Induced draft cooling tower, and are generally confined to small installations.

Among the important factors in evaluating Mechanical drought cooling tower economics is the power consumed by the fan which is necessary for the suction or induction of air in the tower.

This paper will propose a cooling tower in which air in the tower is drawn by an ejector action of the sprays through which water is admitted.

2. THE SPRAY DROUGHT COOLING TOWER ACTION

The spray drought cooling tower arrangement (fig.1) consisted of an assembly of nozzles spraying water upwards in a duct. The sprays caused the air in the surroundings to accelerate in the direction of the sprays. The sprays, on impacting on the disentrainer packing above the spray nozzle assembly lost their momentun and flow down the tower walls by gravity until it reached the water distributor trough located below the nozzle assembly. Water was then distributed over the main packing in which the larger fraction of mass transfer takes place. With regards to the flow of air and water in a spray drought cooling tower, two regions could therefore be distinguished;

1) Co. current flow: This is the region covered by the length of the sprays,
2) counter current: This occurs in the main packing.

2.1 Data of the Experimental Spray Cooling Draught Tower

Duct dimensions	460 x 240 x 2600 [mm]
Packing	Munters cooling tower fill
Main packing	460 x 240 x 280 [mm]
Disentrainer	3 layers, 460 x 240 x 60
Nozzle assembly	8 flat fan nozzles
Height of sprays	280 mm
Water flow rate (max)	1.45 $kg/m^2.s$

3. THEORETICAL TREATMENT OF MOMENTUM TRANSFER IN SPRAY DROUGHT COOLING TOWER

Many attempts by previous researchers who have studied the Entrainment of air by sprays have presented their results in terms of spray parameters which include; size and number of droplets, length of liquid sheet, spray angle and thickness of sprays. This approach ended up with very complicated equations which cannot readily be used in designing the spray cooling tower in which the flow of air is also restricted especially due to pressure drop across the packing.

As an alternative to the above approach it is proposed to apply the momentum balance for a given spray cooling tower arrangement as follows;

Rate of change of momentum of sprays = Rate of change of momentum of accelerating air + Rate of change of momentum of air to overcome resistances

3.1 Rate of change of Momentum of water sprays

An assumption is made that air initially at zero velocity is accelerated to a velocity V by sprays leaving the nozzle at velocity U.N. which is uniform across the nozzle cross sectional area. After interaction with air the water droplets would attain the velocity of air and the momentum of water consumed would be given by

$$Mw = Qw\rho w(U.N. - V)\eta \qquad (1)$$

Expressing U.N. in terms of flow rate, equation (1) becomes

$$Mw = \rho_w Qw \frac{(Qw - V)}{(N.Cd.An)}.\eta \qquad (2)$$

Where; N.Cd.An : Is the effective cross sectional area of the nozzle assembly.

η: Is the momentum transfer efficiency, and combines the effect of gravity and all other resistance which are not susceptible to a complete and exact mathematical analysis.

3.2 Rate of change of momentum of air

As air is accelerated from zero to a velocity V its momentum will increase according to;

$$Ma = G.At.V \tag{3}$$

$$= \rho_a.At.V^2 \tag{4}$$

3.3 Rate of change of momentum of air to overcome resistances

Contribution to this category is mainly due to pressure drop across the packings, its rate of change is given by

$$Mp = \Sigma \Delta P.At \tag{5}$$

Where the pressure drop of the air stream across the packing Δ can be expressed as a function of low rate of air.

3.4 Momentum transfer equation

Combining the above individual contributions, equations 2, 4 and 5 then the overall momentum transfer equation becomes

$$\eta.\rho_w.Qw.\frac{(Qw-V)}{NCd\,An} = \rho_w.At.V^2 + \Sigma \Delta P.At \tag{6}$$

3.5 Enthalpy Temperature Diagram

3.5.1 Counter current flow

With reference to fig.2 taking the liquid and air Enthalpy balance, then for counter current flow we have;

$$L.C_l.(\theta_{L2} - \theta_{L1}) = G.(H_{G2} - H_{G1})$$

Rearranging

$$\frac{\theta_{L2} - \theta_{L1}}{H_{G2} - H_{G1}} = L.\frac{G_l}{G} \tag{7}$$

The right term gives the slope of the operating line in the Enthalpy temperature diagram, which is POSITIVE in this case.

3.5.2 Co. current flow

Likewise with reference to fig. 3 the Enthalpy balance in the Co. current flow becomes

$$-L.C_{l}.(\theta_{l2}-\theta_{l1})=G.(H_{G2}-H_{G1})$$

Rearranging

$$\frac{(\theta_{l2}-\theta_{l1})}{(H_{G2}-H_{G1})}=-L.\frac{C_{l}}{G} \tag{8}$$

Equation 8 is similar to equation 7 with a negative sign introduced so as to make both LHS and RHS of the equation positive since for co. current flow $\theta_{l2}<\theta_{l1})$when$(H_{G2}>H_{G1})$ or vice versa.

It follows therefore that the operating line for co. current flow has a NEGATIVE gradient given by $(-l.C_{l/G})$.

In the Co. current portion of the tower (ref. fig. 1) it can be assumed that;

(i) Enthalpy of air H_{G0} surrounding a jet of water at nozzle exit (where the temperature of water is θ_{l0} is the same as the Enthalpy of air just after leaving the main packing.

$$H_{G2}=H_{G0} \tag{9}$$

(ii) Neglecting cooling of water occuring within a spray chamber then,

$$\theta_{l3}=\theta_{l2} \tag{10}$$

3.5.3 Complete Enthalpy Temperature Diagram

It follows from the above arguments that, depending on whether water is being cooled or heated up by air, the operating lines for Counter current and Co. current flows when superimposed on the same Enthalpy temperature diagram shall result in either fig. 4 or 5 respectively.

4. THE EXPERIMENT

The spray drought cooling tower (fig. 1) was used to cool hot water by air. Hot water at selected temperatures was pumped from a water tank into the spray drought cooling tower and cooled down due to direct contact with the induced air. Cooled water returning from the tower was collected in a second water tank. Water temperature in both hot and cold tank before and after circulation and the amount that has been cooled were determined. At each liquid rate, air flow rate and its Dry and Wet bulb temperatures, water supply pressure, and pressure drops across the packings were recorded. Such measurements were necessary for mass and energy balance calculations.

The experiment was repeated starting with difference temperatures of the feed water and at different liquid rates.

5. SUMMARY OF RESULTS

The results concerning the momentum transfer due to sprays are as presented in figure 6 while those relating the liquid to gas ratio to liquid rate are as presented in figure 7.

Figures 7 shows that for a given set of nozzles arranged in a spray drought cooling tower, there exist a relationship between the liquid rate and the amount of air being entrained. This relationship however, is dependent on the tower dimensions and specifications. Generally at higher liquid flow rate the liquid to gas ratio becomes smaller (i.e. The air flow rate tends to increase sharply for a small increase in liquid flow rate).

Figure 6 also suggests that the Spray drought cooling tower should be operated at higher air flow rate (which results from higher liquid rates) as under such conditions we convert the momentum of the spray into useful work down of entraining the air before it is overcome by the effect of gravity.

Figure 8 shows the operating lines which were obtained in the spray Entrainment cooling tower based on overall performance of the tower rather than performance of the separate regions (co. current and counter current) which would otherwise require to draw operating lines as in fig. 4. Practically it was not easy to measure separately the temperature and Enthalpy values for air and water in co. current region.

Nevertheless these operating lines show an increase in the cooling range $(\theta_{Lo} - \theta_{Lo}1)$ as the temperature of the feed water θ_{Lo} is increased. It is important to note however that for a given set of inlet conditions of air Enthalpy and water temperature, the cooling range is dependent on the slope of the operating line, as such an increase in the flow rate of liquid may cause an appreciable difference in the cooling range only if the liquid to gas ratio has changed significantly.

6. CONCLUSION

Throughout the experiments, only one nozzle assembly was used with limited range of the operating conditions. More experimental results would be necessary to explain the effects of various contributing factors towards the overall performance of the tower. Such factors would include the number and size of the nozzle assemblies, the tower cross sectional area and the relative tower dimensions, the height of the sprays and many more. Possibly with a lot more data it could be possible to formulate general equations which could apply to a tower of any dimension. However, with this few representative data one can conclude that the operating principle of the spray drought cooling tower is a feasible practice, and it is hoped that the foregoing review will generate some interest to reseachers in the same field to put in more thought.

Symbol	SI Units	
An	M	Cross sectional area of nozzle
At	M	Cross sectional area of tower
Cd	–	Coefficient of discharge
G'	$Kg/s.m^2$	Mass flow rate of dry air per unit area
H	J/Kg	Enthalpy per unit mass of air
L	$Kg/s.m^2$	Mass rate of flow of liquid
Ma	N	Rate of change of momentum of air
Mw	N	Rate of range of momentum of water
Mp	N	Rate of change of momentum of air to overcome resistances
N	–	Number of nozzles
δP	N/m^2	Pressure drop
Qw	m^3/s	Volumetric flow rate of water
U.N.	m/s	Velocity of spray at nozzle exit
ρa	Kg/m^3	Density of air
ρw	Kg/m^3	Density of water
η	–	Momentum transfer efficiency
θ_G	°C	Temperature of air
θ_L	°C	Temperature of water

Subscripts

G	Gas or (air)
L	Liquid (or water)
W	Water
1	Main packing OR Condition at bottom of tower
2	Disentrainer packing OR Condition at top of tower

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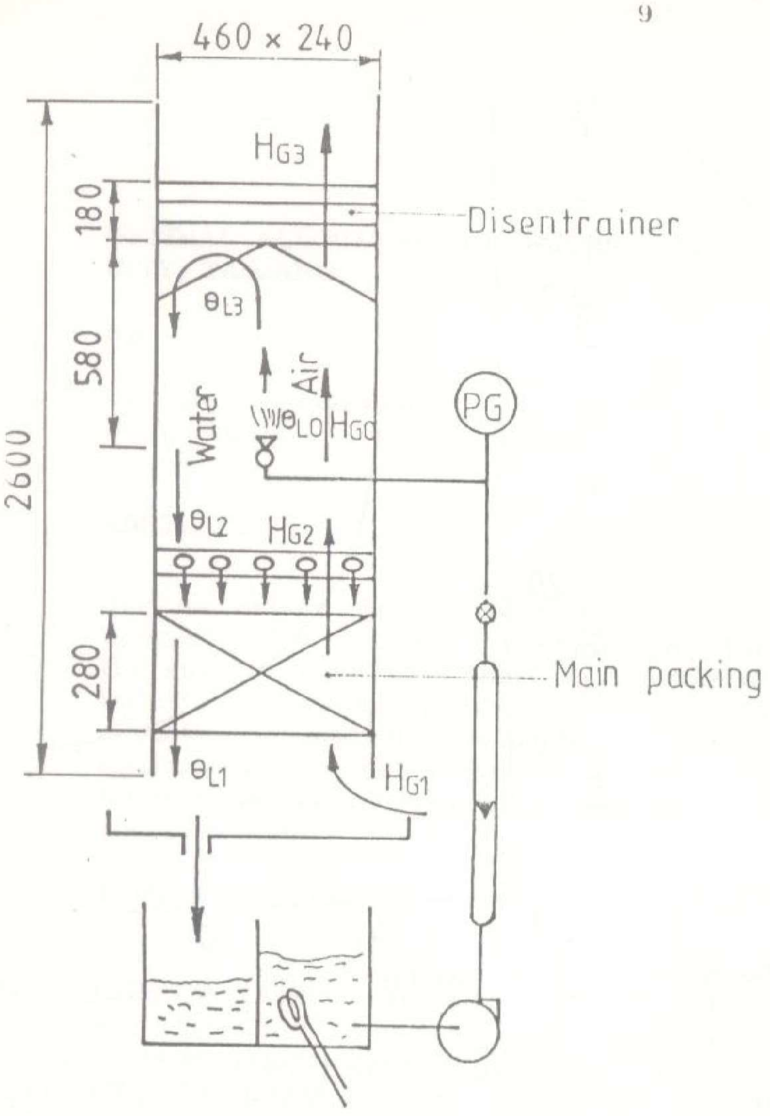

Fig. 1 Spray Drought Cooling Tower

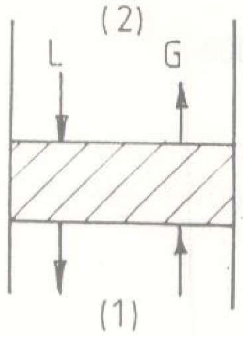

Fig. 2 Counter Current Flow

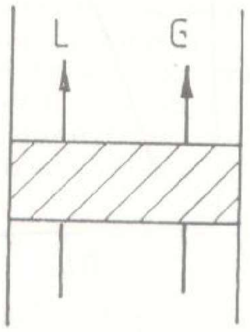

Fig. 3 Co Current Flow

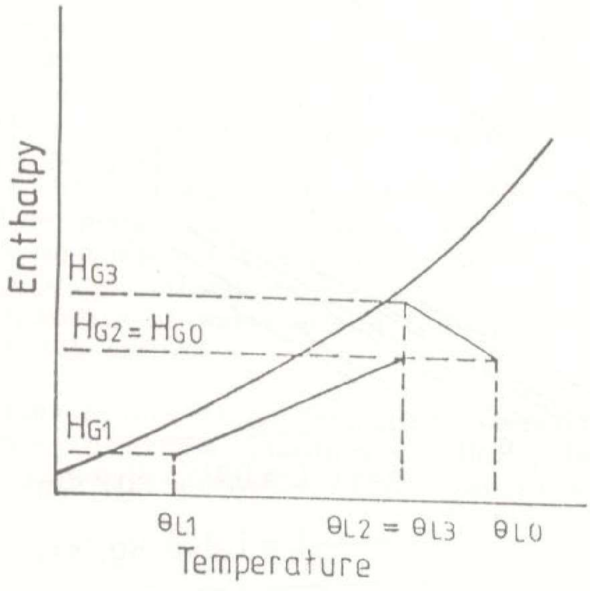

Fig. 4 Cooling Water by Air

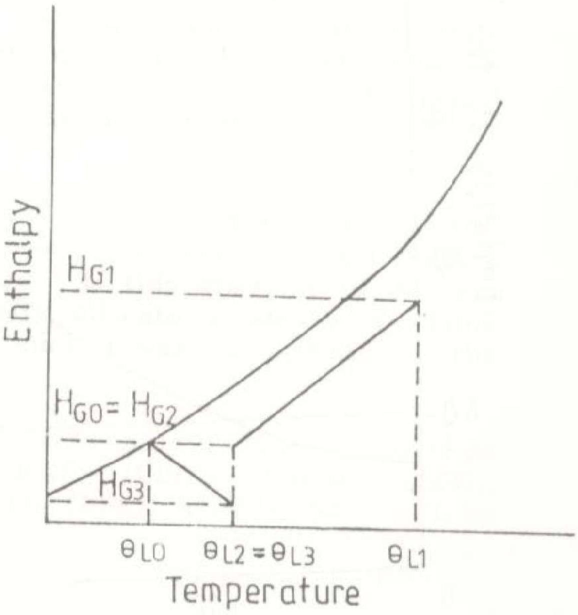

Fig. 5 Heating Water by Air

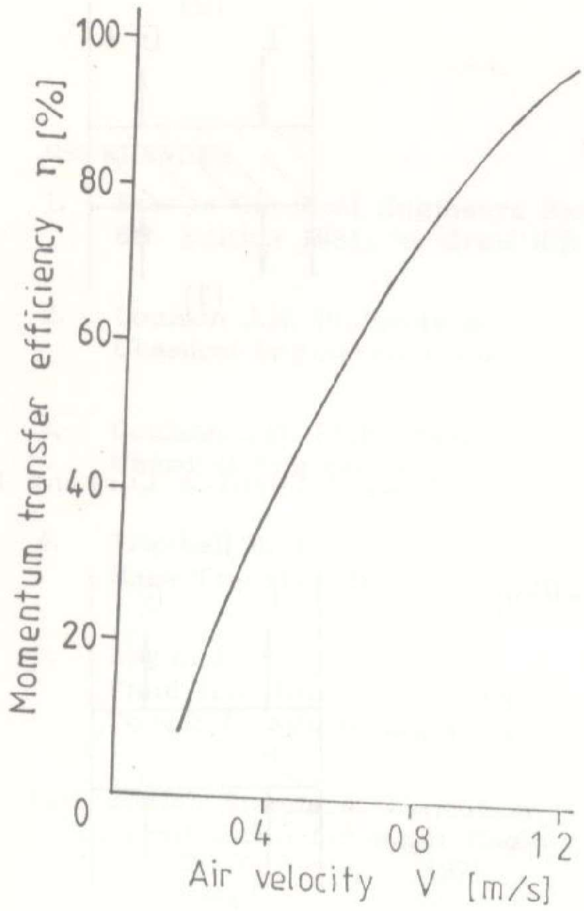

Fig. 6 Momentum Transfer
vs Air Velocity

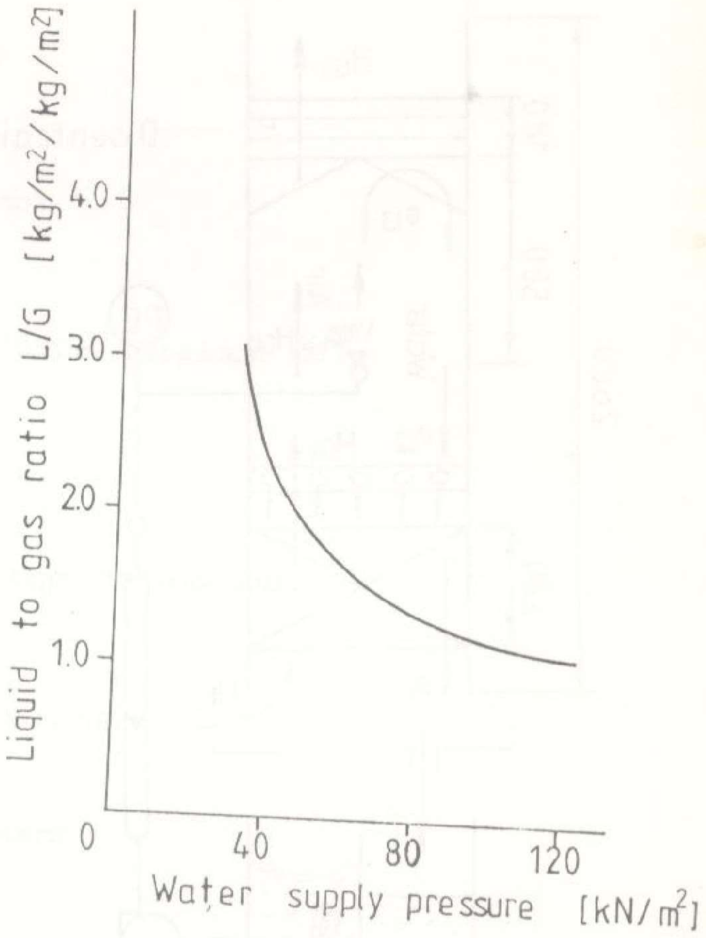

Fig. 7 Liquid to Gas Ratio
vs Water Supply Pressure

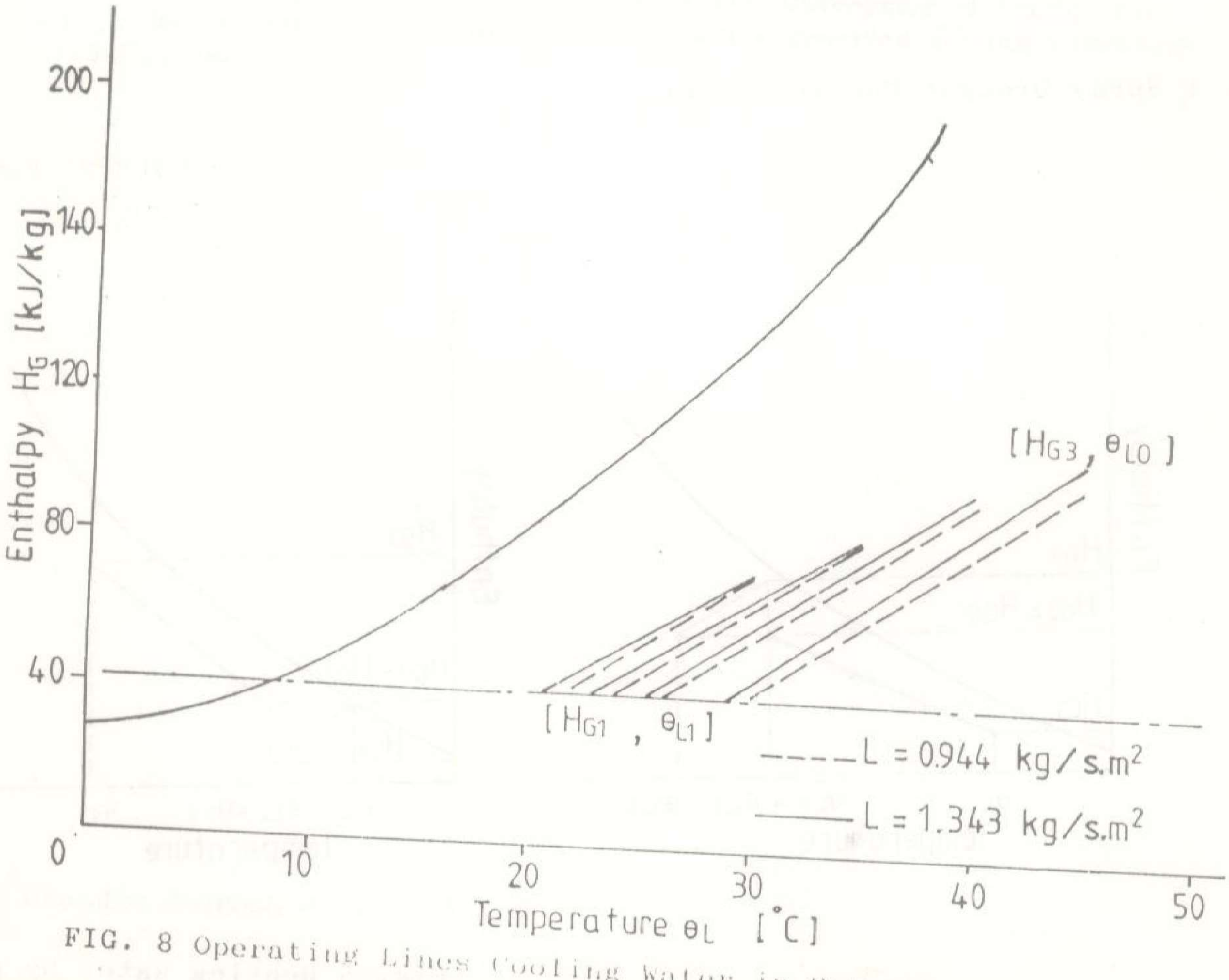

FIG. 8 Operating Lines Cooling Water in Spray Drought Tower