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Experimental Study in a Spray Filled Tower for Flow Visualization and Drift Eliminators Characteristics

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Abstract: This study demonstrates the result of an experiment in a spray filled forced draft cooling tower. Air distribution at some specific points within the tower was investigated. The pressure drop and drift loss characteristics of cellular type drift eliminators and those made of wood and cement-asbestos were also experimentally investigated. The experiments were conducted with one, two and three stages of cellular type drift eliminators and that for wooden and cement-asbestos drift eliminators with two and three stages only with various orientation angle, θ of the eliminator plates. The results showed that the pressure drop and drift loss were strong functions of number of stages, n and air flow rate. In case of wooden and cement-asbestos drift eliminators, pressure drop and drift loss were strongly dependent on θ as well. For various flow rates of the air, the flow patterns inside the tower were found similar. The study establishes the superiority of the cellular type drift eliminators over the others.

Key words: Spray filled tower, flow visualization, drift eliminator, drift loss

INTRODUCTION

Experimental studies were carried out in a spray filled forced draft cooling tower designed and constructed for the purpose of investigation of different parameters of the cooling tower, flow visualization and the drift eliminator characteristics. Drift Eliminators (DE) form an integral part of a Cooling Tower (CT). Drift has been traditionally defined as mechanically entrained water droplets which are generated inside the tower and carried along with the air flowing through the tower exhausted to the environment[1]. As the air moves counter to or cross-wise to the flow of water, it will pick up much of the mist and droplets and carry them with the air stream out of the cooling tower. Drift eliminators basically refer to the baffles placed at the exit air end of a CT, in order to recover a good percentage of the water which otherwise would be lost to the atmosphere. This water loss apart from being a cost (cost of water plus that of pumping it), is also a hazard environmentally, leading sometimes to the fatal Legionnaires disease caused by the bacteria *Legionella* generally found in the CT water and living on the nutrients contained in it. In cold countries this drift settles down as fog in the nearby areas which is a nuisance specially if there are roads nearby.

The performance of a DE can be determined from the amount of water it lets go as a percentage of the circulating water rate. For the measurement of this drift, several methods have been suggested[2], but none of them is considered to be the reliable method for the complete range of droplet size distribution.

For drift eliminators it is found that as the complexity of the shape increases, the drift loss decreases, but at the cost of higher pressure drop, Δp across the DE. Very high Δp cannot be acceptable as it causes an additional financial burden in terms of increased cost of fan power. These opposing tendencies suggest that a compromise has to be reached between the cost of drift loss and that of the pressure drop[3,4].

Drift eliminators are normally designed to be efficient through a calculated range of air flow. Too great an air speed can result in excessive drift loss from the tower, while poorly designed DE will adversely affect the performance of the unit. Thus DE effectiveness is an essential aspect of CT design for many reasons, among them a few are[5]:

(i) Conservation of water.
(ii) Retention of chemicals used for the treatment of water in the sump.

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(iii) Prevention of staining by chemical additives e.g., chromates etc.
(iv) Avoiding fan blade corrosion in case of induced draft tower.
(v) Avoidance of violation of local area environmental protection regulations.

In the present investigations 3 types of DE were tested experimentally. Two of these are of the slat type made of Wood and Cement-asbestos. The third one is of the cellular type made of polypropylene. Drift eliminator stages, n from one to three were used and orientation angle from the horizontal, θ was varied from 30° to 75° for slat type.

MATERIALS AND METHODS

The experiments were carried out on a spray filled cooling tower in such a manner that the water which entered the tower was at the adiabatic saturation temperature of the entering air. This was achieved by continuously reintroducing the exit water to the tower immediately, without addition or removal of heat on the way[6]. In such a system, the temperature of the entire water falls to and remains at the adiabatic-saturation temperature. The air is cooled and humidified, following the process of adiabatic saturation. Depending upon the degree of contact, the air will approach more or less closely equilibrium with the liquid, or its adiabatic-saturation conditions. This presumes that the makeup water also enters at the adiabatic-saturation temperature, but for all practical purposes, the quantity of evaporation is so small relative to the total water circulation rate that minor deviations from the adiabatic saturation temperature for the makeup water can be ignored.

The temperature and humidity changes, which lie entirely within the gas phase are shown schematically in Fig. 1. The enthalpy of the air is practically a function of its adiabatic saturation temperature, which remains constant throughout the operation. The enthalpy of the liquid at constant temperature is also constant, so that an operating 'line' in Fig. 1 would be merely a single point on the equilibrium curve. If mass transfer is used as a basis for design, then:

$$G\,dw = ka(w_{as} - w)\,dZ \tag{1}$$

$$\int_{w_1}^{w_2} \frac{dw}{(W_{as} - W)} = \frac{ka}{G}\int_0^Z dZ \tag{2}$$

and since w_{as} is constant,

$$\ln \frac{w_s - w_1}{w_s - w_2} = \frac{kaZ}{G} \tag{3}$$

Eq. (3) can be used directly, or it can be rearranged by solving for G and multiplying each side by $(w_2\text{-}w_1)$ or its equivalent,

$$G(w_2 - w_1) = \frac{kaZ\,[(w_{as} - w_t - (w_{as} - w_2)]}{\text{in}[(w_{as} - w_1)/(w_{as} - w_1)]}$$

$$= kaZ(\Delta w)_{av} \tag{4}$$

where, $(\Delta w)_{av}$ is the logarithmic average humidity-difference at the ends of the tower.

If heat transfer is used as the basis for design, one can write

$$Gc_h\,dt_a = ha(t_{as} - t_a)dZ \tag{5}$$

Similar treatment of this equation leads to

$$Gc_h(t_1 - t_2) = \frac{haZ\,[(t_1 - t_{as}) - (t_2 - t_{as})]}{\text{in}\,[(t_1 - T_{as})/(t_2 - t_{as})}$$

$$= haZ(\Delta t)_{av} \tag{6}$$

where, (h a) is the volumetric heat transfer coefficient of sensible heat transfer between the bulk of the air and the water surface.

Taking the saturation humidity as a quadratic function of temperature, for humidification process, Fahim *et al.*[7] obtain an analytical equation from which the change of water temperature in an adiabatic air-water contact tower can be calculated.

Estimation of the drift loss: Measurement of psychrometric data of the entering and leaving air can be used to calculate their specific humidities. A simple mass balance of the dry air and the moisture entering and leaving the main chamber yields:

$$\dot{m}_{a1} = \dot{m}_{a2} = \dot{m}_a \tag{7}$$

$$\dot{m}_{a1}w_1 - \dot{m}_e + \dot{m}_d = \dot{m}_{a2}w_2 + \dot{m}_d \tag{8}$$

i.e., $$\dot{m}_e = \dot{m}_a(w_2 - w_1) \tag{9}$$

The leaving air carries with it the drift also. In order to measure it, one possible method can be to make a fraction of the exit air flow through a sampling duct and ensure that the drift is completely evaporated by duct heaters installed inside the sampling duct. With the heaters switched on, the psychrometric data of the air from the sampling duct can be used to calculate its specific humidity[2]. This obviously will be a different psychrometric condition of the air. Mass balance then yields:

$$\dot{m}_{a1} w_1 + \dot{m}_e + \dot{m}_d = \dot{m}_{a3} w_3 \quad (10)$$

$$\text{or,} \quad \dot{m}_e + \dot{m}_d = \dot{m}_a (w_3 - w_1) \quad (11)$$

Eqs. (9) and (11) yield

$$\dot{m}_d = \dot{m}_a (w_3 - w_2) \quad (12)$$

where, $\dot{m}_{a1}$, $\dot{m}_{a2}$ = mass of dry air entering and leaving the CT;
$\dot{m}_d$, $\dot{m}_e$ = rates of drift and evaporation loss, respectively.

Studies on spray filled tower: A spray filled tower is one which is dependent solely upon spray nozzles for water break-up. Atomization of water requires higher pressure than in a packed tower. In small spray cooling towers, in contrast to packed ones, the water distribution across any section varies widely. The water distribution is dependent upon the type of spray used, water pressure-velocity, -temperature, air velocity and pressure, and the tower construction. In general, the pressures and velocities for any given rate of flow are fixed by the type of spray, while the air velocities and pressures for any given rate of flow are fixed by the tower design and partially by the characteristics of the water spray[8].

The present experiment was carried out to study the performance characteristics of a forced draft counterflow spray filled cooling tower, flow characteristics and the effectiveness of cellular type drift eliminators and also those made of wood and cement-asbestos.

Test rig: The cooling tower designed and constructed for this study consisted of a rectangular column approximately 4 m high having an inside plan area of 1.5x1.0 m. Active part of the tower was 1.3 m long (height between the center of the inlet air duct and the nozzles of the distribution system). It was made of angle iron frame and MS sheets. It housed the spray system and the drift eliminators. The air inlet for the tower was through a duct (300 mm high x 580 mm wide) located just above the top of the 800 mm deep water basin and was provided with air from a centrifugal blower installed on a concrete foundation.

The water distribution system consisted of a pump taking suction from the cooling tower basin and pumping the water to the main header of the distribution system. The quantity of make-up water was automatically controlled from a float in the tower basin. The water distribution system in the tower consisted of a 50 mm dia pipe as the main header with 25 mm pipe cross-arms each fitted with five nozzles of hole dia 3 mm. Schematic diagram for the spray filled tower and a photograph showing the inside view of the tower are shown in Fig. 2 and 3.

The eliminators were put just above the distribution system. Three different types of drift eliminators were used:

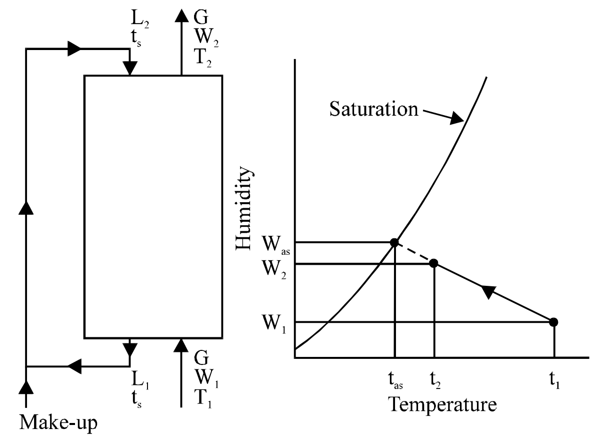

Fig. 1: Recirculating water, air humidification-cooling

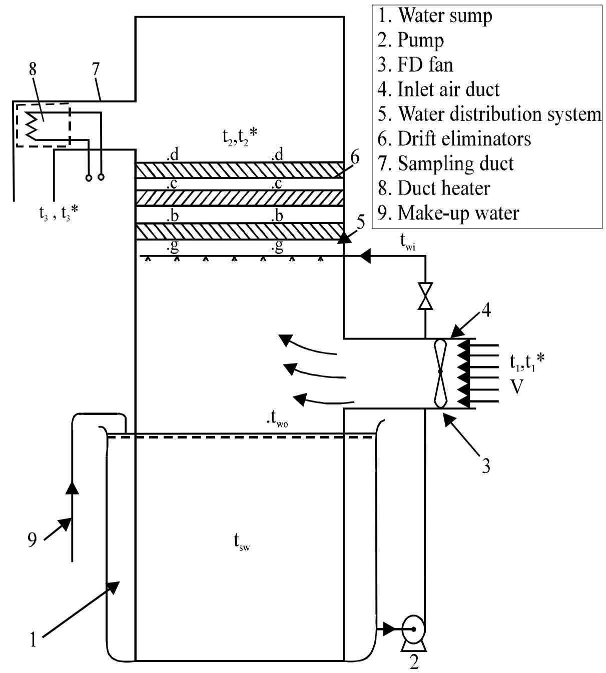

Fig. 2: Schematic diagram of the test tower

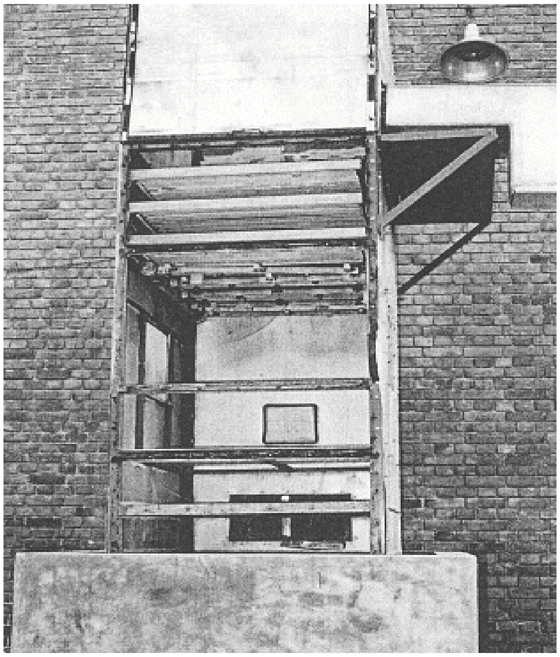

Fig. 3: Inside view of the test tower

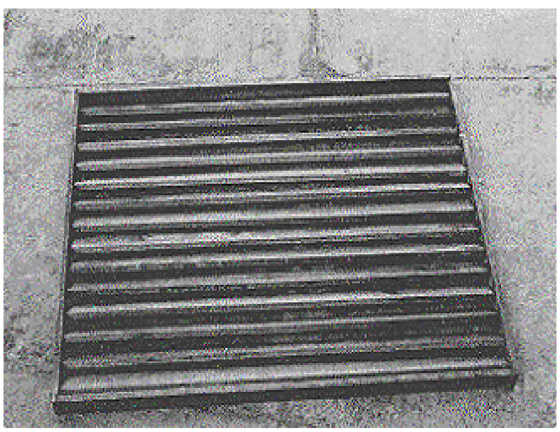

Fig. 4: Geometrical pattern of WDE

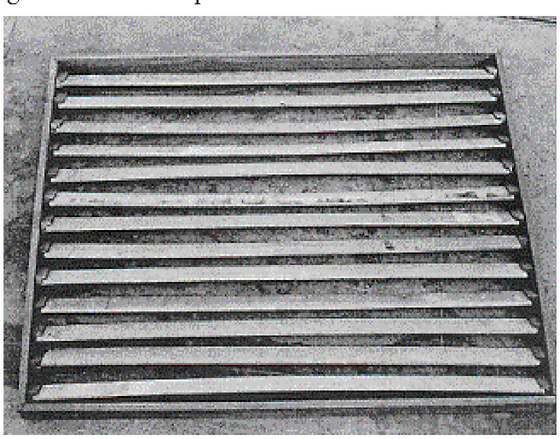

Fig. 5: Geometrical pattern of CADE

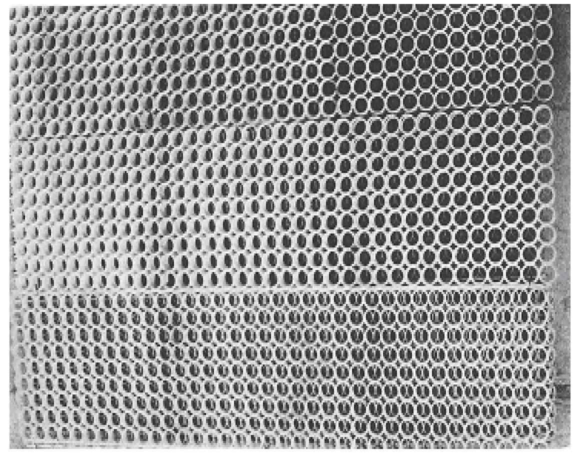

Fig. 6: Geometrical pattern of CTDE

(a) Wooden Drift Eliminators (WDE)
(b) Cement Asbestos Drift Eliminators (CADE) and
(c) Cellular Type Drift Eliminators (CTDE).

WDE, CADE and CTDE are shown in Fig. 4-6. Each stage of WDE and CADE consisted of two frames of 960x740x50 mm each. There were 28 strips in each stage of WDE. Dimension of each strip was 935x47x12 mm. The clearance between consecutive strips corresponding to $\theta = 0°$ for WDE was 4 mm. There were 26 strips in each stage of CADE. Dimension of each strip was 905x50x6 mm. The clearance between consecutive strips corresponding to $\theta = 0°$ for CADE was 5 mm. Each strip of the cellular type drift eliminator consisted of circles of 25 mm diameter and 15 mm in height, which were laid side by side. Three such strips made up a single stage of DE. The strips were arranged in a staggered fashion having an overall size of 1470x940x30 mm.

A sampling duct was installed above the drift eliminators. A 6 kW duct heater was put inside the sampling duct which was controlled by a Variac. The function of the duct heater was to evaporate the drift carried along with the air stream through the sampling duct.

The psychrometric data of the inlet and the exit air streams were measured using an electronic sensor which measured the Dry Bulb Temperature (DBT), Wet Bulb Temperature (WBT), relative humidity and absolute humidity. Velocity of the inlet air was measured using a vane anemometer at the inlet duct of the blower. But the air velocity at different points inside-the tower was measured using a velometer. The pressure drop across the drift eliminators was also measured by the velometer. The flow rate of water was measured by a digital water flow meter.

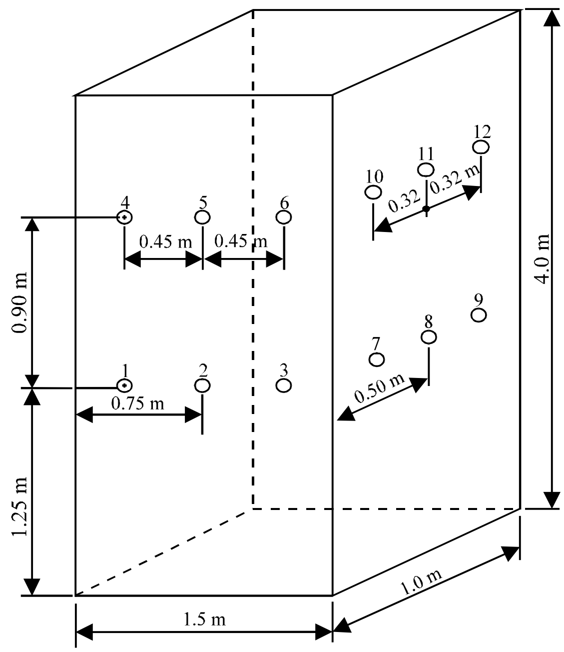

Fig. 7: Location of holes for velocity measurement

Experiments were carried out for three stages and two stages of WDE and CADE with varying orientation angles, θ = 30°, 45°, 60° and 75°. For CTDE, the experiment was carried out for three stages, two stages and single stage. The psychrometric data of the inlet and exit air streams were measured for different air discharge rates while the circulation rate of water was kept constant. The temperature and the humidity of the exit air through the sampling duct when the duct heater was switched on were also measured. For velocity distribution of air, the velocity of air was measured at (12x4) points inside the tower (Fig. 7) without spraying the water.

RESULTS AND DISCUSSION

As described earlier, the pressure drop and drift loss across the drift eliminators were determined from the experimental study.

Pressure drop: The pressure drop, Δp across the drift eliminators was determined by recording the static pressures at points a, a'; b, b'; c, c' and d, d' depending upon the number of stages used (Fig. 2) for θ varying between 30° to 75° for WDE and CADE. For each value of θ, the supply voltage was varied in order to change the fan speed or the air flow rate. The pressure drop versus velocity for different values of θ are shown in Fig. 8-11 for WDE and CADE.

From these curves it is inferred that as θ decreases, Δp increases due to a reduction in the available flow area.

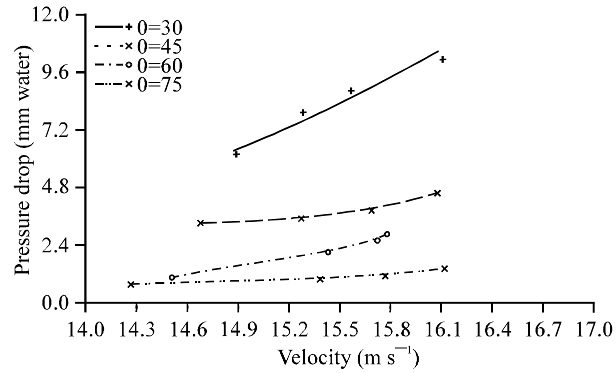

Fig. 8: Pressure drop vs. air velocity for 3 stages WDE

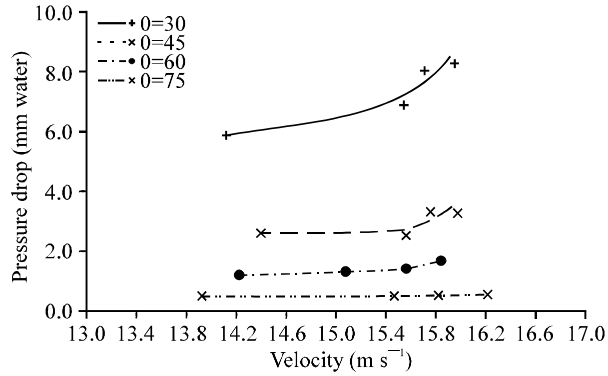

Fig. 9: Pressure drop vs. velocity for 2 stages CADE

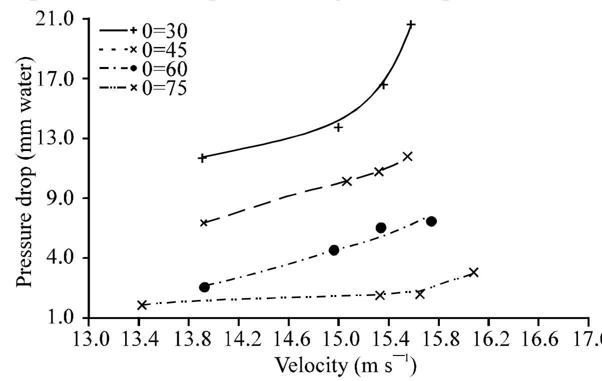

Fig. 10: Pressure drop vs. air velocity for 3 stages CADE

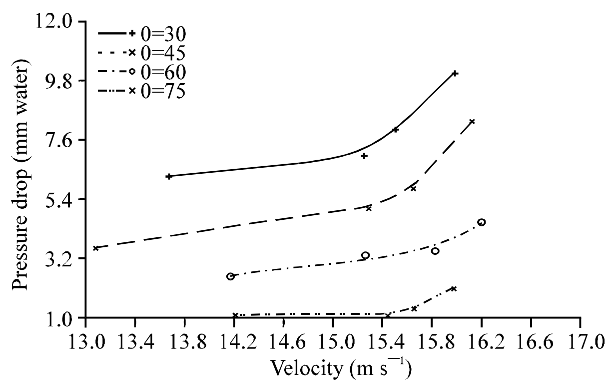

Fig. 11: Pressure drop vs. air velocity for 2 stages CADE

With an increase in fan speed, the fan discharge and therefore the flow velocity increases resulting in a larger pressure drop. As n increases, Δp increases due to a larger resistance to the flow. It can be seen from these figures that Δp for WDE varies between 0.4 and 10.0 mm of water whereas the same for CADE varies between 1.0 and 20.5 mm of water.

For CTDE the pressure drop versus velocity of the inlet air is shown in Fig. 12. The pressure drop increases with an increase in the number of stages. Also, as the velocity increases there is an increase in the pressure drop. Figure 12 shows Δp for these DE is fairly small, the maximum value for 3 stages being only 1.0 mm of water, which obviously establishes its superiority over other types of drift eliminators.

Drift loss: The drift loss was calculated as a percentage of the circulating water flow rate. For WDE and CADE, the angle of inclination with horizontal, θ was varied from 30° to 75°. For any given set of data, the drift eliminators were set at a particular angle. The number of stages used were two or three at a time. For each angle of orientation, the fan speed and in turn the air flow rate was varied by varying the supply voltage.

The variations of drift loss versus inlet air velocity are shown in Fig. 13 and 14 for 3 stage and 2 stage WDE, respectively. As can be seen, the trend of these curves is similar. With an increasing angle of orientation, the drift loss increases, but it decreases with an increase in the number of stages, n of the drift eliminators due to increased Δp across the DE. Besides, as n increases the exit air stream carrying the drift droplets makes a large number of turns and thus the droplets undergo a more effective inertial separation.

For CTDE also the drift loss is plotted versus the velocity of the inlet air for one, two and three stages of the drift eliminators. The typical curves are shown in Fig. 15. The drift loss decreases as n increases, due to a larger Δp across the drift eliminator stages and also because of relatively more effective inertial separation. The drift loss also decreases with a decrease in the flow velocity or the flow rate of air. It is obvious from Fig. 13-15 that the drift loss for CTDE is smaller than that for WDE.

Air distribution: Velocity of air was measured through 12 holes made on the two sides of the tower at a height of 1.25 and 2.15 m from it's bottom. At 1.25 m, three holes on each side were made. On the wider side of the tower (length = 1.5 m) one hole was made in the center and two 0.45 m away from the center. On the other side of the tower (width = 1.0 m), one hole was made in the center and the two 0.32 m away from the center. Similar six holes were

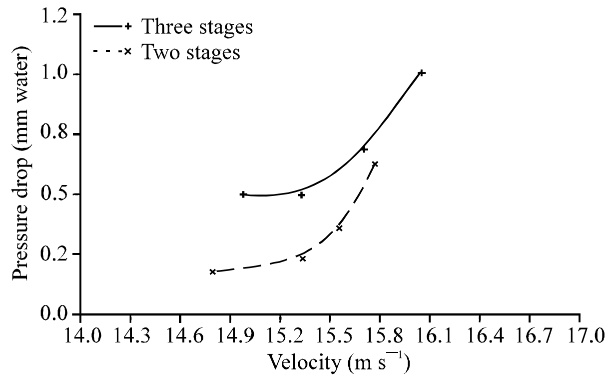

Fig. 12: Pressure drop vs. air velocity for CTDE

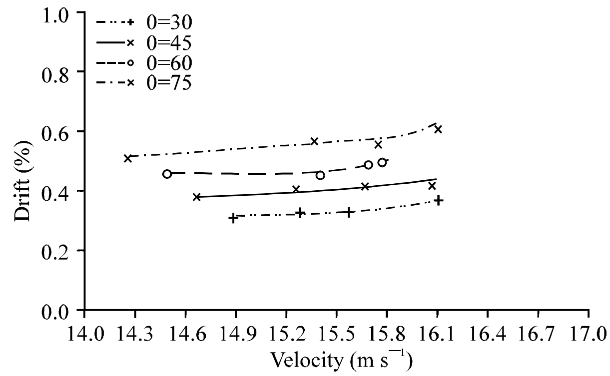

Fig. 13: Drift loss vs. air velocity for 3 stages WDE

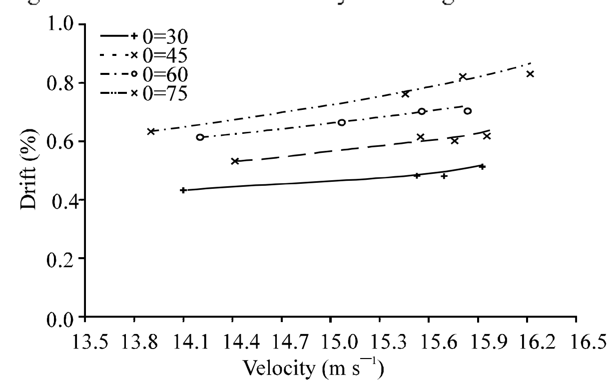

Fig. 14: Drift loss vs. air velocity for CTDE

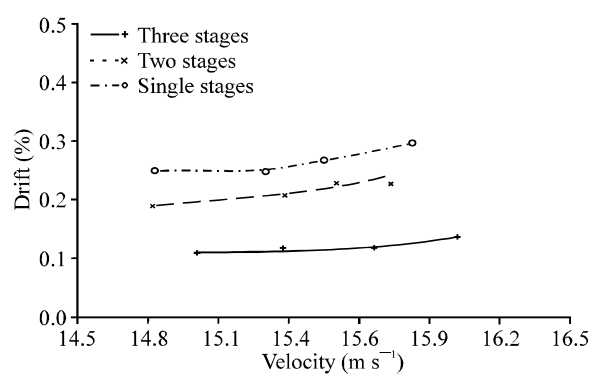

Fig. 15: Drift loss vs. air velocity for CTDE

made at 2.15 m height of the tower on the two sides as shown in Fig. 7. Velocity were measured at four points through each hole at distances of 915, 610, 305 and 25 mm from the tower wall. Air velocity inside the tower was measured corresponding to different values of inlet air flow rates (or flow velocity) which was varied by varying the supply voltage to the blower. Velocity versus distance are plotted in Fig. 16-23. The flow pattern of air inside the tower is depicted in the Fig. 16-23. It can be seen that for

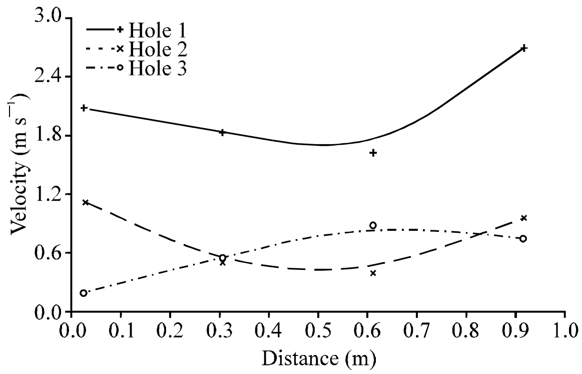

Fig. 16: Variation of air velocity with distance

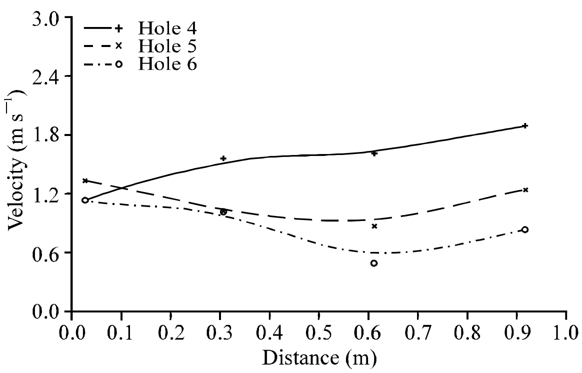

Fig. 17: Variation of air velocity with distance

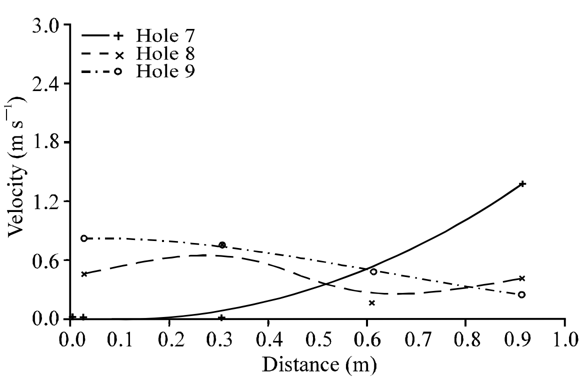

Fig. 18: Variation of air velocity with distance

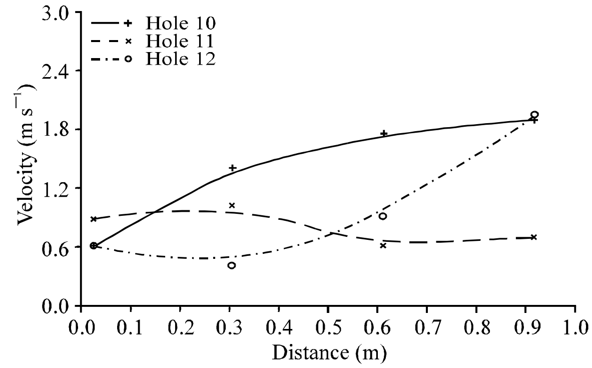

Fig. 19: Variation of air velocity with distance

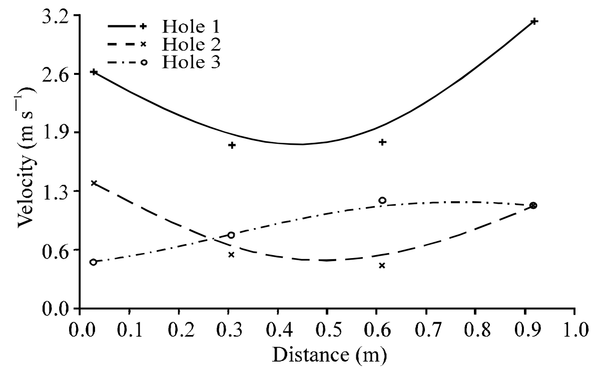

Fig. 20: Variation of air velocity with distance

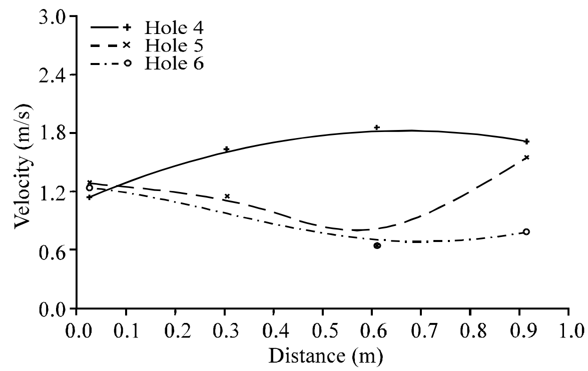

Fig. 21: Variation of air velocity with distance

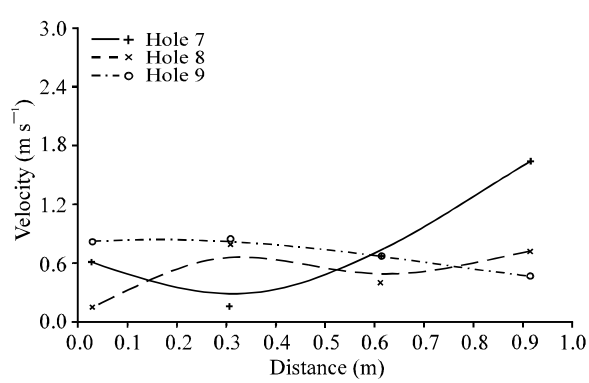

Fig. 22: Variation of air velocity with distance

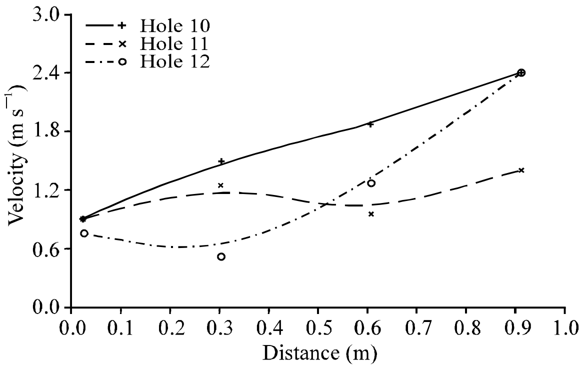

Fig. 23: Variation of air velocity with distance

various flow rates of the air (or the inlet air velocities), the flow patterns inside the tower are similar. Figure 16-23 show the patterns for inlet velocities of 14.2 and 15.6 m s^{-1}.

CONCLUSIONS

Based upon the experimentation, it is concluded that:

- The drift loss for CTDE decreases with increasing number of stages and decreasing flow rate whereas that for WDE and CADE it also decreases with the decrease in the orientation angle of the DE plates.
- The pressure drop through the DE increases with increasing n and flow rate. For WDE and CADE, it also increases with decreasing θ.
- For a given flow rate and n, the pressure drop for CTDE is smaller in comparison to that for WDE and CADE in the practical range of θ.
- It can be seen that for various flow rates of the air (or the inlet air velocities), the flow patterns inside the tower are similar.

The pressure Δp for CADE is the highest among the three and for CTDE it is the lowest. This establishes, the superiority of CTDE.

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NOMENCLATURE

a	Surface area of water droplets per unit volume of tower (m^2/m^3)
c_h	Specific heat of moist air (kJ/kg °C)
G	Air loading (kg/h. m^2)
h	Convective heat transfer coefficient (kw/ m^2 °C)
k	Mass transfer coefficient (kg/h. m^2 (kg_w/kg_{da}))
L	Water loading (kg/h. m^2)
$\dot{m}$	Mass flow rate (kg/h)
$\dot{m}_a$	Mass flow rate of dry air (kg/h)
$\dot{m}_d$, $\dot{m}_e$	Rate of drift and evaporation losses respectively (kg/h)
n	Number of drift eliminator stages
t	Temperature (°C)
t_1	Dry bulb temperature of entering air (°C)
w	Specific humidity (kg_w/kg_{da})
w_1, w_2	Specific humidities of entering and leaving air respectively (kg_w/kg_{da})
w_3	Specific humidity of leaving air with duct heater switched on (kg_w/kg_{da})
w_{as}	Specific humidity at adiabatic saturation (kg_w/kg_{da})
Z	Active height of the tower (m)
Δp	Pressure drop (mm of water)
Δt	Temperature difference (°C)
$(\Delta w)_{av}$	Logarithmic average humidity difference (kg_w/kg_{da})
θ	Orientation angle of the drift eliminator plates

Subscripts:

a	Dry air
as	Adiabatic saturation
av	Average
s	Water surface condition (at the interface)
1	Air inlet condition
2	Air exit condition