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Comparison of Drift Eliminators Characteristics in Evaporative Condenser and Spray-Filled Tower

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Abstract *– This paper investigates the results of experimental studies conducted in an evaporative condenser with induced draft and in a spray filled forced draft cooling tower. The pressure drop and drift loss characteristics of cement-asbestos drift eliminators, concrete drift eliminators, wooden drift eliminators and cellular type drift eliminators were experimentally investigated. The experiments were conducted with one, two, and three stages of cellular type drift eliminators but for cement-asbestos, concrete and wooden drift eliminators only two and three stages were used with various orientation angles (*θ*) of the eliminator plates. The results showed that the drift loss for CTDE decreases with the increase of the number of stages and with decrease of flow rate whereas drift loss for CADE and CDE also decreases with decrease of orientation angle,* θ*.The pressure drop for CTDE is smaller than that for CADE and CDE in the practical range of* θ*. In this study, the superiority of the cellular type drift eliminators over the others has been divulged.*

Keywords **–** Drift eliminator, drift loss, evaporative condenser, spray-filled tower.

1. INTRODUCTION

Drift has been traditionally defined as entrained water droplets which are generated inside the cooling tower and carried by the air flowing through the tower exhaust to the environment [1]. The air moves counter to or cross-wise to the flow of water and carry much of the mist and droplets out of the cooling tower. Drift eliminators basically refer to the baffles placed after the spray system at the exit duct of a CT in order to recover the water of the flowing air which otherwise would be lost to the atmosphere. The 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. In cold countries, this drift settles down as fog in the nearby areas which is a nuisance especially to nearby roads.

The performance of a DE can be determined from the amount of water passing through the drift eliminator 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, if the complexity of the shape increases, the drift loss decreases, but higher pressure drop, Δp across the DE occurs. High pressure drop, Δp across the DE causes an additional financial burden due to 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 are [5]:

(i) Conservation of water,
(ii) Retention of chemicals used for the treatment of water in the sump,
(iii) Prevention of staining by chemical additives e.g., chromates etc.,
(iv) Avoidance of fan blade corrosion in case of induced draft tower, and
(v) Avoidance of violation of local area environmental protection regulations.

In order to determine the pressure drop and drift loss from cooling water equipment, experimental studies were carried out initially on an evaporative condenser (EC) to study various types of drift eliminators and a cellular type of packing. This unit of the EC was inside the laboratory. The spray filled forced draft cooling tower was designed and constructed outside the laboratory for the purpose of this experiment. Drift eliminators (DE) form an integral part of a cooling tower (CT).

In this present experimental investigation, four (4) types of DE were used. Among them, three DE are of slat type made of (a) wood, (b) cement-asbestos and (c) concrete, and the fourth one is of cellular type made of polypropylene. Slat type drift eliminator stages, n were used from one to three with the variation of orientation angle from the horizontal, θ from 15° to 90° for EC and from 30° to 75° for spray filled tower.

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2. THEORETICAL BACKGROUND AND FORMULATION

Studies on Spray-Filled Tower and Evaporative Condenser

A spray-filled tower is one which uses 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 depends 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 [6].

The present experiment was carried out to study the performance characteristics of a forced draft counter-flow spray filled cooling tower. The effectiveness of wooden, cement-asbestos and cellular type drift eliminators has also been investigated.

As no published data are available on drift loss and pressure drop across the drift eliminators, a preliminary study was taken up on an EC with induced draft [7]. The pressure drop and drift loss characteristics of cement asbestos drift eliminators (CADE), concrete drift eliminators (CDE) and cellular type drift eliminators (CTDE) were experimentally investigated. Normally, a fill or packing is not used in an EC, but a fill of cellular type was used in the present study in order to determine its characteristic. The geometry and the material of the packing are similar to that of CTDE.

Estimation of Drift Loss

The 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 is as follows:

$$\dot{m}_{a1} = \dot{m}_{a2} = \dot{m}_a \qquad (1)$$

$$\dot{m}_{a1} w_1 + \dot{m}_e + \dot{m}_d = \dot{m}_{a2} w_2 + \dot{m}_d \qquad (2)$$

$$\text{i.e., } \dot{m}_e = \dot{m}_a (w_2 - w_1) \qquad (3)$$

The leaving air also carries the drift. In order to measure it, one possible method is to allow a fraction of the exit air to 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:

$$\dot{m}_{a1} w_1 + \dot{m}_e + \dot{m}_d = \dot{m}_{a3} w_3 \qquad (4)$$

$$\text{or } \dot{m}_e + \dot{m}_d = \dot{m}_a (w_3 - w_1) \qquad (5)$$

Eqs. (3) and (5) yield:

$$\dot{m}_d = \dot{m}_a (w_3 - w_2) \qquad (6)$$

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

3. EXPERIMENTAL SET UP AND METHODOLOGY

Description of the Test Rig and DE for Spray-Filled Tower

The constructed cooling tower for this study consisted of a rectangular column approximately 4 m height having an inside area of 1.5 m × 1.0 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). The tower was made of angular iron frame and MS sheets which housed the spray system and the drift eliminators. The air enters the tower through a duct (300 mm high × 580 mm wide) located just above the top of the 800 mm deep water basin. A centrifugal blower installed on a concrete foundation provides the air.

The water is circulated from the basin of the cooling tower to the main header of the distribution system by a pump. The amount 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 diameter pipe as the main header with five 25 mm pipe cross-arms each fitted with five nozzles of hole diameter 3 mm. Schematic diagram and a photograph showing the inside view of the spray filled tower are shown in Figures 1 and 2.

The eliminators were placed above the distribution system. Three different types of drift eliminators were used as shown in Figures 3 to 5.

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

Each stage of WDE and CADE consisted of two frames of 960 mm × 740 mm × 50 mm each. In each stage of WDE there were 28 strips of dimension 935 mm × 47 mm × 12 mm. The clearance between consecutive strips corresponding to $\theta = 0°$ for WDE was 4 mm. There were 26 strips of dimension 905 mm × 50 mm × 6 mm in each stage of CADE. 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 was laid side by side. Three such strips make a single stage of DE. The strips were arranged in a staggered fashion having an overall size of 1470 mm × 940 mm × 30 mm.

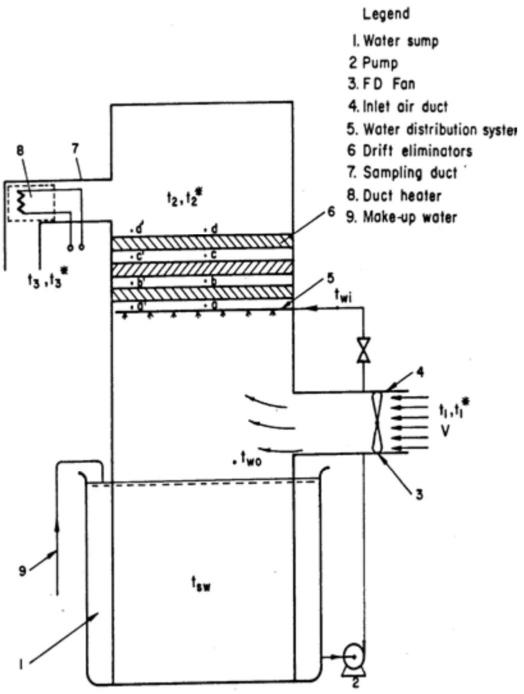

Fig. 1: Schematic Diagram of the Spray-Filled Tower

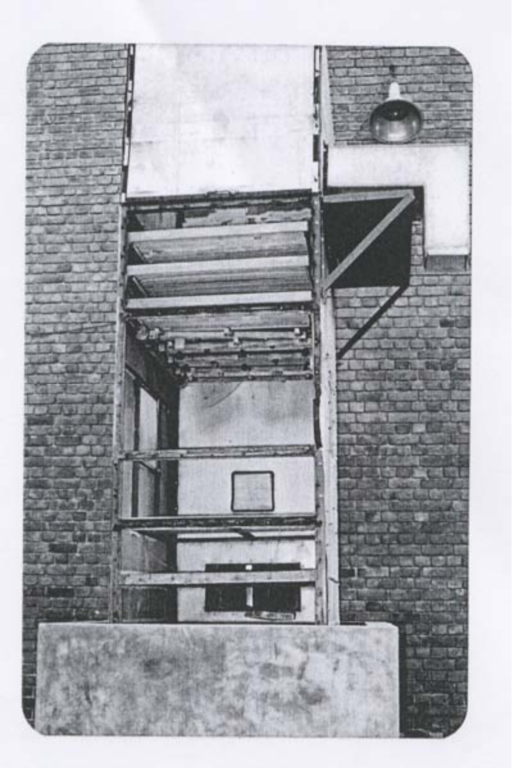

Fig. 2. Inside View of the Spray Filled Tower

Fig. 3. Geometrical Pattern of WDE

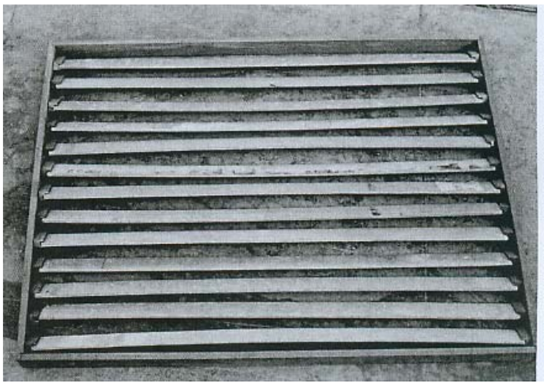

Fig. 4. Geometrical Pattern of CADE

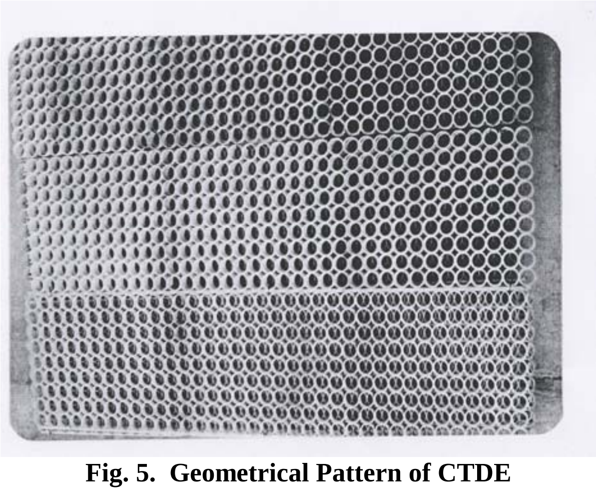

Fig. 5. Geometrical Pattern of CTDE

Description of the Test Rig and DE for Evaporative Condenser

The complete test rig consisted of an EC with a cellular packing using an induced draft (ID) fan. The EC formed one of the components of a vapor compression refrigeration system of 1.5 ton capacity using R-22 as a refrigerant. The main components of the test rig are shown in Figure 6.

Main Chamber consists of a rectangular box (1.00m × 0.90m × 1.40), a DE chamber (1.00m × 0.52m × 0.52m) having a top portion tapered and heater box (0.45m × 0.45m × 0.45m). The heater box houses six finned electric duct heaters of 1 kW capacity each on the top of the DE chamber. The bottom portion of the main chamber is used as a water sump.

In this study, three types of DE were tested experimentally. Two of these were slat type made of cement asbestos and concrete and the third one was of the cellular type made of polypropylene. The geometric pattern of CADE and CTDE is shown in Figures 4 and 5.

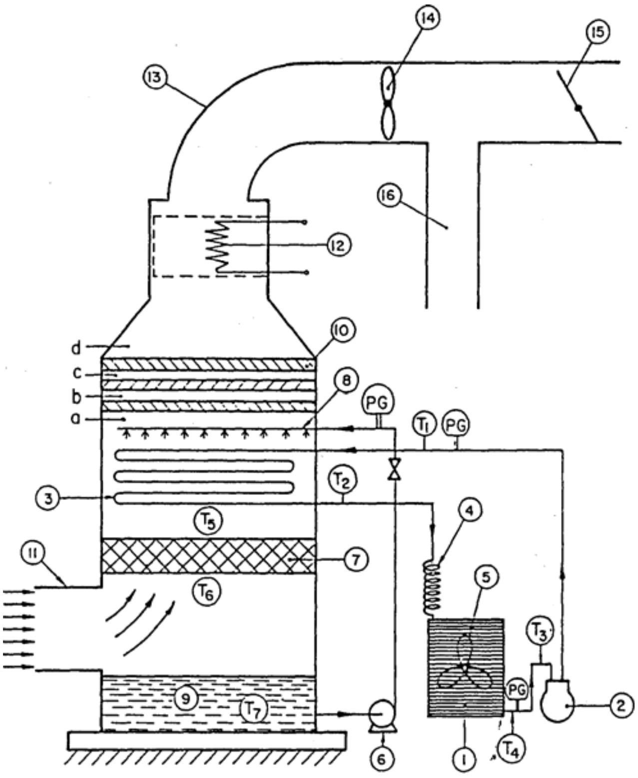

Fig. 6. Schematic Diagram of the Test Rig for Evaporative Condenser

1. Evaporator, 2. Compressor, 3. Condenser, 4. Capillary Tube, 5. Fan, 6. Pump, 7. Packing, 8. Spray System, 9. Sump, 10. Drift Eliminators, 11. Inlet Air Duct, 12. Heater, 13. Main Duct, 14. ID Fan, 15. Damper, 16. Sample Duct.

Instrumentation

A main duct was connected at the top of heater box of the inlet of an ID fan. A 6 kW duct heater was installed above the DE of the tower. The function of the duct heater was to evaporate the drift carried by the air stream through the main duct. The discharge duct was connected at the outlet of an ID fan to carry the air out of the room. A sampling duct was installed in the discharge duct before the damper.

The psychrometric data such as dry bulb temperature (DBT), wet bulb temperature (WBT), relative humidity and absolute humidity of the inlet and the outlet air streams were measured using an electronic sensor. Inlet air velocity was measured using a vane anemometer at the inlet duct of the blower. The pressure drop across the drift eliminators was measured by a velometer. Water flow rate was measured by a digital water flow meter.

Experimental Procedure

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. In spray filled tower the experiments were carried out for three stages and two stages of WDE and CADE with varying orientation angles, $\theta = 30°, 45°, 60°$ and 75°. For CTDE, three stages, two stages and single stage were used. 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.

In evaporative condenser, the angle of inclination with the horizontal, θ was varied from 15° to 90° for CADE and CDE and one to three stages were used for all the three types of DE. The Dry Bulb Temperature (DBT) and Wet Bulb Temperature (WBT) were measured for the air entering and leaving the EC with and without duct heater. The damper of the main discharge duct was kept closed during recording of the data. Psychrometric data with ID fan using one, two and three stages of CADE and CDE with varying θ were recorded. Similar data for CTDE were also recorded for varying flow rates of the air through the unit. The airflow rate was changed by changing the supply voltage to the fan.

4. RESULTS AND DISCUSSIONS

The results of this experiment are discussed in the following section.

Spray Filled Tower

In this section pressure loss and drift loss have been discussed in details.

i. 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 (Figure 2). The orientation angle of the drift eliminator plates θ was varied from 30° to 75° for WDE and CADE and at the same time 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 is shown in the Figures 7 through 10 for WDE and CADE.

These curves show that as θ decreases, Δp increases due to a reduction in the available flow area. If the fan speed is increased, the flow rate is also increased resulting in a larger pressure drop. If the number of stages n is increased, pressure drop, Δp also increases due to 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 increases with an increase in the number of stages as shown in Figure 11. The pressure drop also increases with the increase of air velocity. The pressure drop Δp for CTDE is very small which only 1.0 mm of water for 3 stages. This small pressure loss obviously establishes its superiority over other types of drift eliminators.

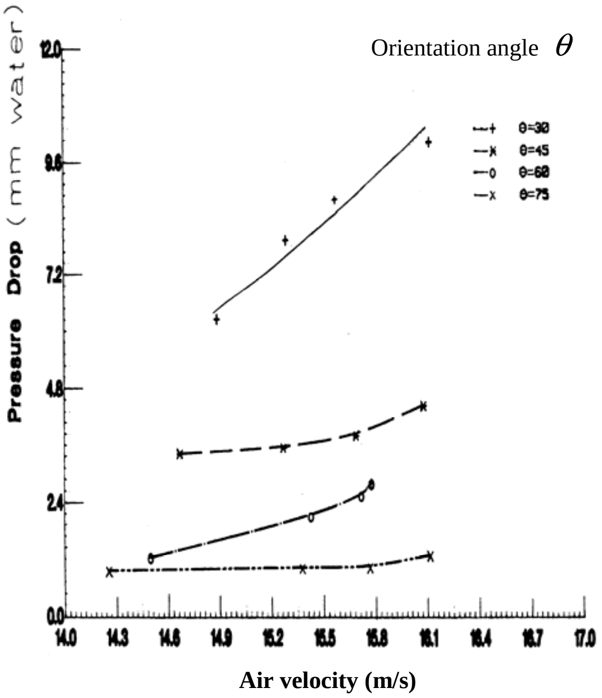

Fig. 7. Pressure Drop vs. Air Velocity with different orientation angle for 3 Stage WDE

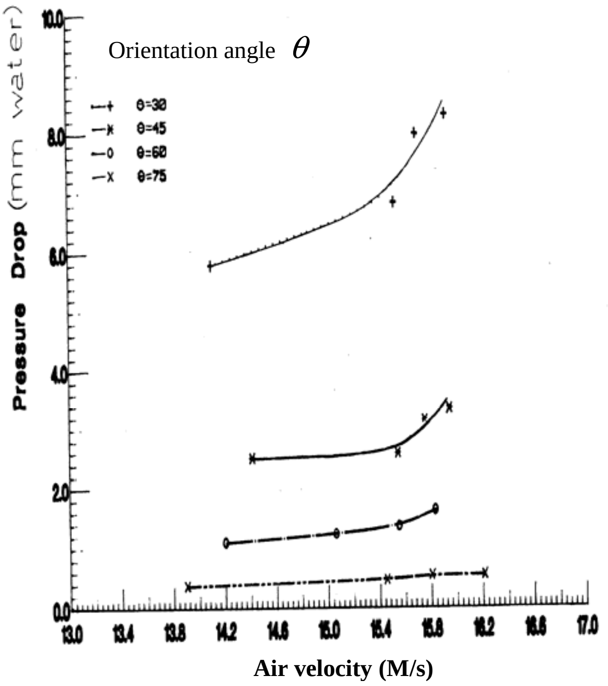

Fig. 8. Pressure Drop vs. Air Velocity with different orientation angle for 2 Stage WDE

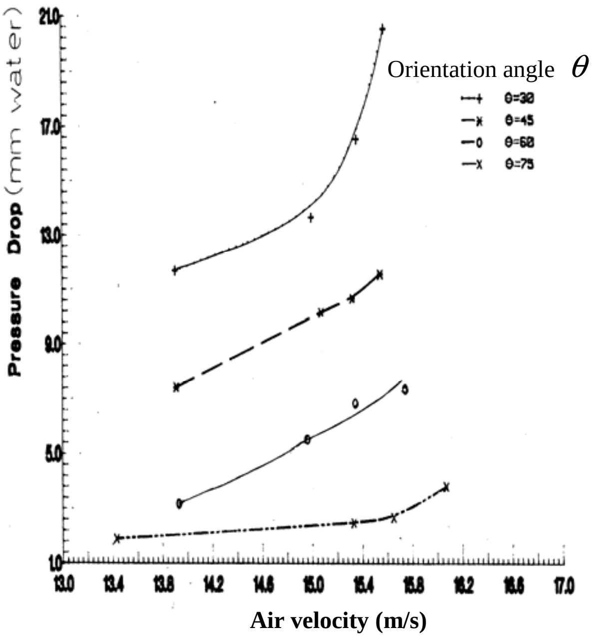

Fig. 9. Pressure Drop vs. Air Velocity with different orientation angle for 3 Stage CADE

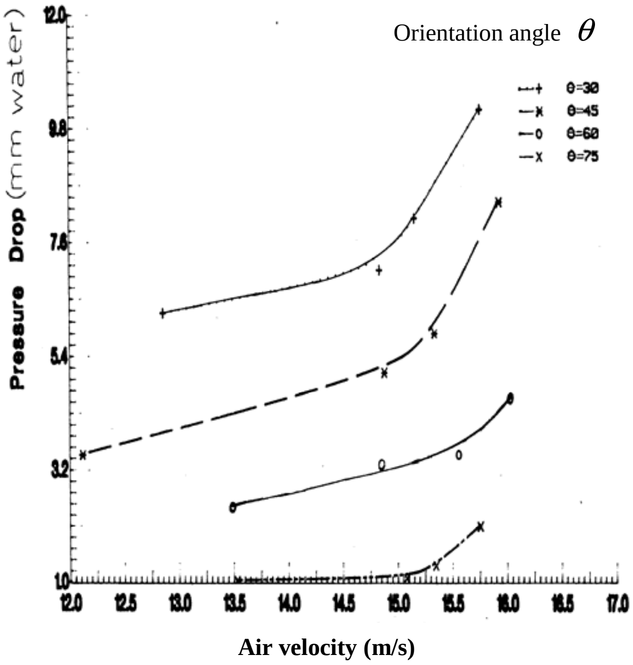

Fig. 10. Pressure Drop vs. Air Velocity with different orientation angle for 2 Stage CADE

ii. Drift Loss

The rate of drift and evaporation loss has been calculated using equations (3) and (4) respectively. 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 was 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 Figures 12 and 13 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, the drift loss versus the velocity of the inlet air for one, two and three stages of the drift eliminators is also plotted. A typical curve is shown in Figure 14. 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 Figures 12 to 14 that the drift loss for CTDE is smaller than that for WDE.

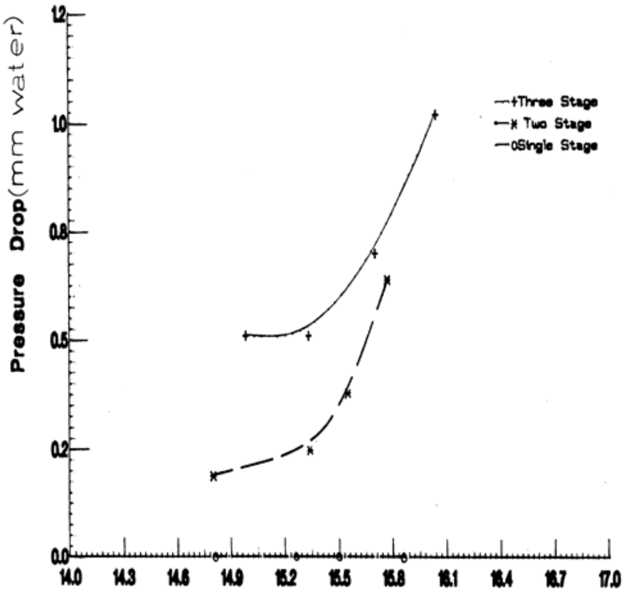

Fig. 11. Pressure Drop vs. Air Velocity with different stages for CTDE

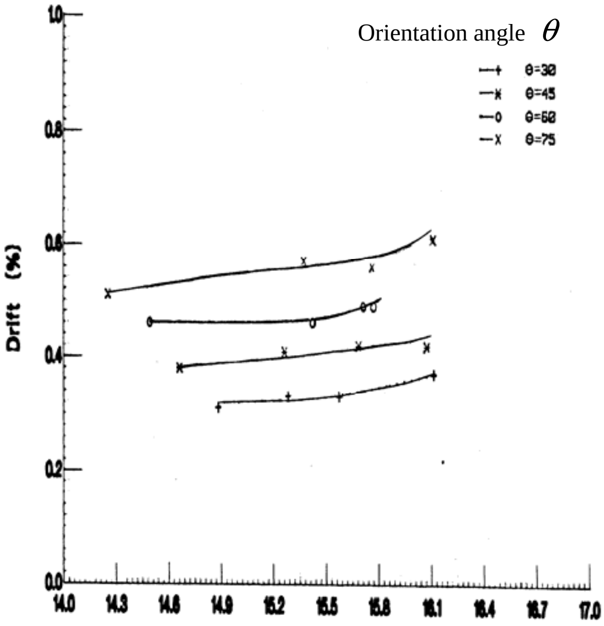

Fig. 12. Drift Loss vs. Air Velocity with different orientation angle for 3 Stage WDE

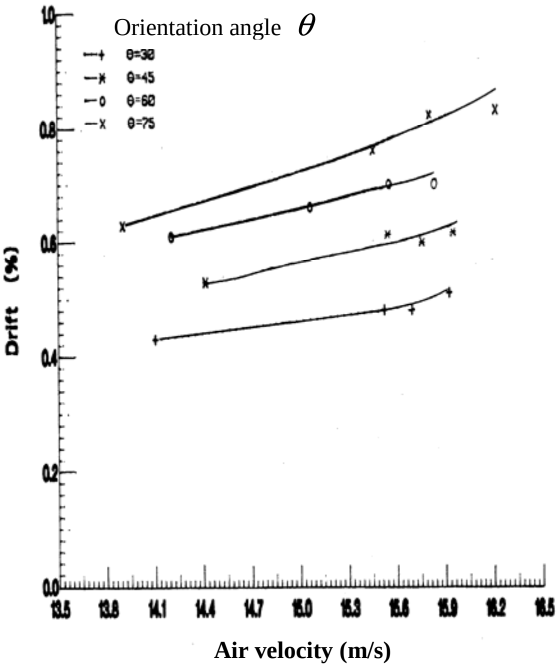

Fig. 13. Drift Loss vs. Air Velocity with different orientation angle for 2 Stage WDE

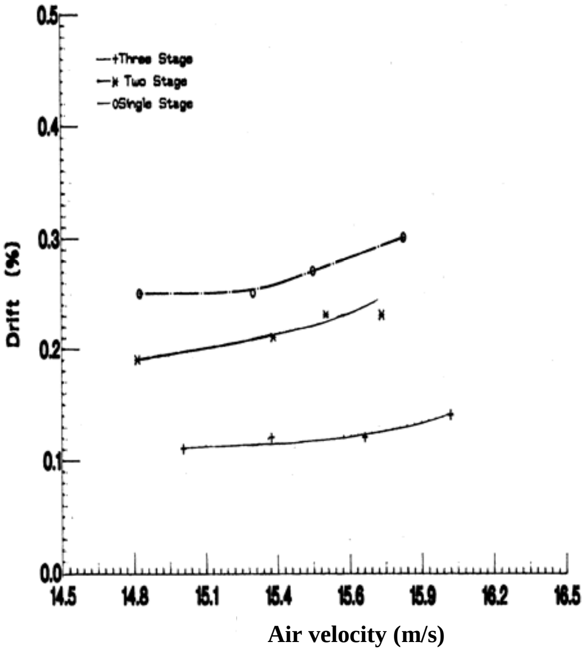

Fig. 14. Drift Loss vs. Air Velocity with different orientation angle for CTDE

Evaporative Condenser

Same data on three types of DE including that on the cellular packing were collected during the study. The results for CADE and CDE show a decrease in drift loss with decreasing θ and increasing number of stages *n* of the DE (similar pattern as that of Figures 9 and 10). This is basically due to the fact as n increases or θ decreases, the static pressure drop across the DE stages increases. This in turn leaves a smaller fraction of the fan static pressure available for causing the flow, which results in a relatively small volumetric discharge. Thus the amount of water droplets carried along with the exit stream decreases. Besides, as *n* increases, the exit air stream carrying the drift droplets makes a larger number of turns and thus the droplets undergo a more effective inertial separation.

For CTDE, the drift loss decreases as *n* increases (Figure 14), due to a larger pressure drop across the DE stages and also because of relatively more effective inertial separation. Drift loss also decreases with a decrease in the flow rate of air.

The pressure drop, Δp due to the variation of θ between 15° to 90° was recorded for CADE and CDE. Experimental data indicate that pressure drop Δp increases as θ decreases because of the reduction of flow area. If the fan speed is increased, the flow rate is also increased but results in large pressure drop. As the number of stages *n* is increased, pressure drop Δp is also increased this is because of the resistance to the flow. The pressure drop at an inclination angle 45° - 60° is much smaller for the CADE compared to that for CDE.

From the above discussion, it is evident that as θ is increased, pressure drop decreases and drift loss increases. These opposing trends result in the intersection of the drift and pressure drop characteristics for CADE and CDE indicating a value of θ which may be considered as the optimum angle of orientation of the DE plate. This can be determined on the basis of a realistic cost analysis of the make-up water (due to drift loss) and the increased fan power (due to the increased pressure drop). Additional data are required to draw any meaningful conclusions.

For CTDE, as the number of stages *n* increases, pressure drop Δp also increases. This happens because of the larger resistance to flow. The pressure drop also increases with the increase of flow rate but the value is smaller than that of the CADE and CDE (range of inclination angle $\theta = 45° - 60°$) for the same *n* and flow rate through the EC.

5. CONCLUSIONS

The following conclusion can be made from this study:

1. The drift loss for CTDE decreases with increasing number of stages and decreasing flow rate whereas that for CADE and CDE it also decreases with the decrease in the orientation angle of the DE plates.
2. The pressure drop through the DE increases with increasing *n* and flow rate. For CADE and CDE, it also increases with decreasing θ.
3. For a given flow rate and *n*, the pressure drop for CTDE is smaller compared to that for CADE and CDE in the practical range of θ.

The test results on evaporative condenser also showed similar findings for WDE, CADE and CTDE. The pressure drop for CADE is the highest among the three and lowest for CTDE which establishes the superiority of CTDE.

NOMENCLATURE

a	Surface area of water droplets per unit volume of tower (m^2/m^3)
G	Air loading (kg/h. m^2)
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
PG	Pressure gauge
T	Thermocouple
T_{sw}	Sump water temperature
T_{wi}	Inlet water temperature to spray nozzle
T_{wo}	Outlet temperature of water to sump
V	Air velocity (m/s)
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})
Δp	Pressure drop (mm of water)
θ	Orientation angle of the drift eliminator plates

ABBREVIATIONS

CADE	Cement Asbestos Drift Eliminators
CDE	Concrete Drift Eliminators
CT	Cooling Tower
CTDE	Cellular Type Drift Eliminators
DBT	Dry Bulb Temperature
DE	Drift Eliminators
FD	Forced Draft
ID	Induced Draft
WBT	Wet Bulb Temperature
WDE	Wooden Drift Eliminators

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