Design and Theoretical Performance Analysis of Counter-Flow Indirect Evaporative Cooler with Modified Geometry

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Abstract— The more and more urgent requirement of energy saving in air-conditioning demands a careful consideration of all the cooling techniques. Evaporative cooling is one of the techniques used to lower the ambient air temperature according to the requirements. The technique includes the injection of moisture in the coming air, thus increasing its specific humidity. This technique can cool the air up to wet bulb temperature of the incoming air. This research paper focuses on Design and theoretical performance analysis of counter-flow indirect evaporative cooler with modified geometry. The use of trapezoidal plates in heat exchanger allows for area to volume ratio which increases the cooling capacity and effectiveness of the system. The performance testing was also carried out under various simulated conditions, which resulted in the variation of the dry and wet bulb effectiveness. As compared to other cooling systems it is more environment friendly while giving improved energy efficiency and maintain COP.

Keywords: Evaporative Cooling; Modified Geometry; Trapezoidal Plates; Cooling Capacity; Energy Efficiency; Environment Friendly

I. INTRODUCTION

Evaporative Cooler is a type of cooler that cools the air through evaporation of water. Evaporative cooling technique is different from other types of air conditioning systems which use Vapour Compression or Vapour Absorption cycles. In Evaporative cooling, the water will absorb a large amount of heat to evaporate. The dry air temperature can be dropped during this phase change of water to water vapour. This results in cooling of air using less energy than by refrigeration. The added advantage of Evaporative cooling is that in dry climatic conditions it cools the air along with moisture content for comfort of the occupants.

A plate Heat Exchanger makes uses of plates to transfer heat between the fluids used. The flow of fluids through the alternating plates results in heat transfer. [1] In plate type Heat exchanger the fluids are exposed to a larger surface area than other types as the fluids are spread over the plates giving them more surface area for heat transfer. This helps in faster transfer of heat and also increases the speed of temperature change. Various plate shapes are been used in order to get improved efficiency and a higher heat transfer rate per unit surface area. Some common types of plates are Square Plate, Rectangular Plate, Trapezoidal Plate, Circular Plate, Hexagonal Plate and Corrugated Plate. One of such type of plate is the Trapezoidal Plate, which provides more heat transfer rate per unit area. This research paper is about the Theoretical Performance Analysis of Indirect Evaporative cooler with Trapezoidal Plate type Heat Exchanger.

II. MATERIALS USED:

The materials used for the analysis of Trapezoidal Plates were selected based on the properties & functions of the component; its cost was also considered. The material selected for the trapezoidal plates is Aluminium due to its availability, less cost and low weight.

A. *Design Considerations:*

The following factors were considered for an optimal design:

1) Evaporative Cooling Type:

Evaporative cooling is of different types like Direct Evaporative Cooling, In-Direct Evaporative and Combined Direct & Indirect Evaporative Cooling. Indirect evaporative cooling is best suitable for this because it's compact than Combined Evaporative Cooling and doesn't require addition of moisture unlike Direct Evaporative Cooling.

2) Heat Exchanger Construction Type & Flow Arrangement:

In comparison to several types of heat exchangers and flow arrangements, a plate-type heat exchanger with counter flow arrangement best suited the necessary requirement of high thermal effectiveness and improved efficiency.

3) Heat Exchanger Plate:

Several types of plates are available which can be used in heat exchangers. Trapezoidal Plate was selected which gives slightly more Heat transfer rate per unit area. This helps to improve the efficiency and dry bulb and wet bulb effectiveness.

B. *Design Methodology:*

Designing of heat exchangers can be done in two ways. One is by determination of the heat exchanger dimensions for a specified heat transfer or second by tentatively specifying the dimension and then calculating the performance for comparison with specified performance. Here the Second method is used.

1) Heat Exchanger Input Data:

Fluid Used: Air
Temperature of Air at Inlet:
Temperature of Cold water at inlet:

2) Plate Geometry:

The Material used for Trapezoidal Plate is Aluminium. The dimensions of the basic geometry are given below:

SR NO.	GEOMETRY	DIMENSION in mm
01	Channel Length, L	400
02	Channel Height, z	4.2
03	Channel Total Width, W	193
04	Channel Thickness, δ	2.5
05	Channel Top Width, x	10
06	Channel Bottom Width, y	2
07	Number of Layers	5
08	Channel Gap	0.5

09	Angle, θ	46.4°

Table 1: Basic Geometry

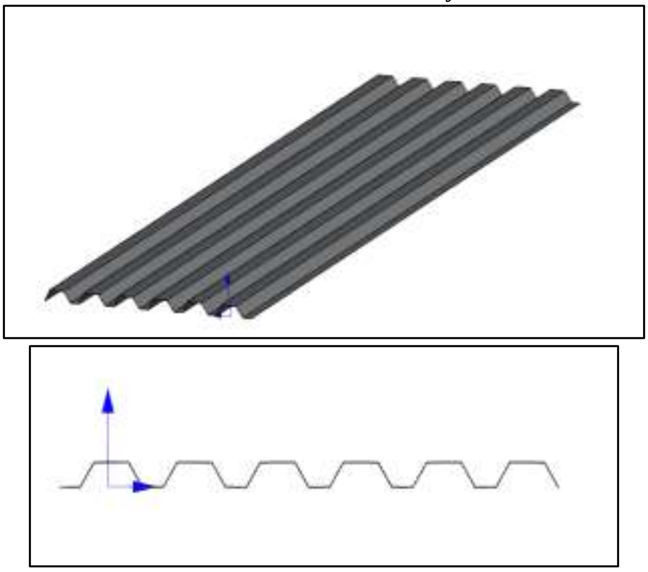

Fig. 1: Trapezoidal Plate Model

Figure 1 shows the Design of Trapezoidal Plates along with its sectional view.

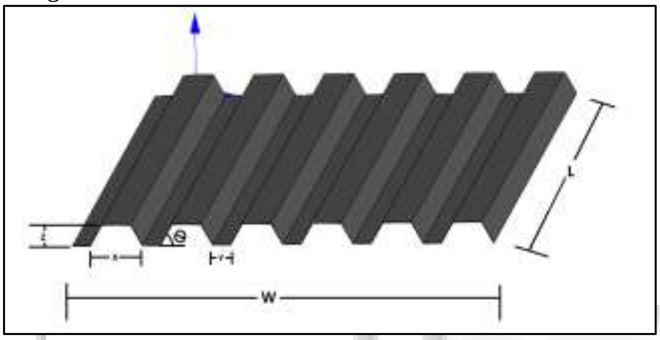

Fig. 2: Plate Geometry

Figure 2 represents all the various Geometrical Parameters of the Trapezoidal Plate.

C. Methodology and Parameters Adopted to Evaluate the Performance:

The following criteria are commonly used to evaluate the performance of an IEC system: i) Cooling Power; ii) Coefficient of Performance (COP); iii) Wet-Bulb Cooling Effectiveness; and iv) Dew-Point Cooling Effectiveness.

1) Cooling Power:

The Cooling Power can be written as:

$$Q_{cool} = C_P \cdot (Tdt_{dry,} - Tdt_{dry,ut}) \cdot (1 - \varphi) \cdot Q_{mass,dry,in} \quad (1)$$

2) Coefficient of Performance:

Coefficient of Performance (COP) is expressed as the ratio of the cooling capacity ($Qcool$) to the total power consumption (P) of the cooler system:

$$\boldsymbol{COP} = \frac{\boldsymbol{Qcool}}{\boldsymbol{Pfan + Ppump}} \quad (2)$$

Although actual power consumptions of the fans and pump are affected by numerous operational factors, the following theoretical formulas are often used to estimate their power needs. The power consumption of a fan can be expressed as follows:

$$\boldsymbol{P_{fan}} = \frac{\boldsymbol{\Delta Pr.v.s}}{\eta_f} \quad (3)$$

The power consumption of a pump is calculated based on the water circulation rate and water raising height, by using the following equation:

$$\boldsymbol{P_{pump}} = \frac{\boldsymbol{Q_{mass,water} . \Delta Pr_{water}}}{\boldsymbol{\rho_w} . \eta_p} \quad (4)$$

3) Wet-Bulb Cooling Effectiveness:

Wet-bulb cooing effectiveness (WBE) is defined as the ratio of the difference between the inlet and outlet product air temperatures to the wet-bulb depression i.e. the difference between the inlet air dry-bulb and wet-bulb temperatures, which is expressed as:

$$\varepsilon_{wetb} = \frac{\boldsymbol{Tdt_{dry,in} - Tdt_{dry,out}}}{\boldsymbol{Tdt_{dry,in} - Tdt_{dry,in\_wb}}} \quad (5)$$

4) Dew-Point Cooling Effectiveness:

Dew-point evaporative cooling systems can provide the product air at a temperature close to the dew point of the intake air; as such, the dew-point cooling effectiveness :

$$\boldsymbol{\varepsilon_{dp}} = \frac{\boldsymbol{Tdt_{dry,in} - Tdt_{dry,out}}}{\boldsymbol{Tdt_{dry,in} - Tdt_{dry,in\_db}}} \quad (6)$$

III. SIMULATION RESULTS & DISCUSSIONS:

The Simulations were done on the given Trapezoidal Plate to investigate the effect of Dry Bulb Temperature of Inlet Air on the cooling efficiencies ($\boldsymbol{\varepsilon_{wetb}}, \boldsymbol{\varepsilon_{dp}}$) and the Outlet Air Temperature of the product air. The Inlet Dry Bulb Temperature of air was varied from 25°C to 45°C and inlet air velocities were taken as 0.3 m/s, 0.55m/s, 0.70m/s and 0.75 m/s.

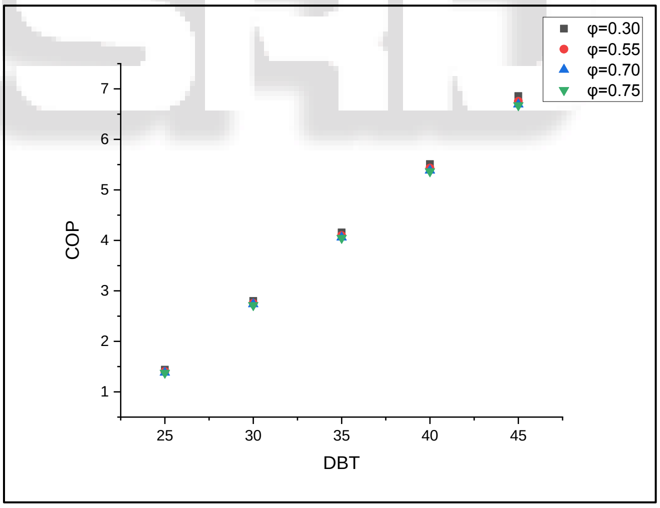

Fig. 3: DBT vs COP

Figure 3 shows the variation of Dry Bulb Temperature (°C) of Inlet Air with Coefficient of Performance (COP) and it can be observed that as the DBT increases along with its inlet velocity it causes the COP to increase as well , moreover the difference between COP remains negligible for almost all the velocities of 30% to 75%.

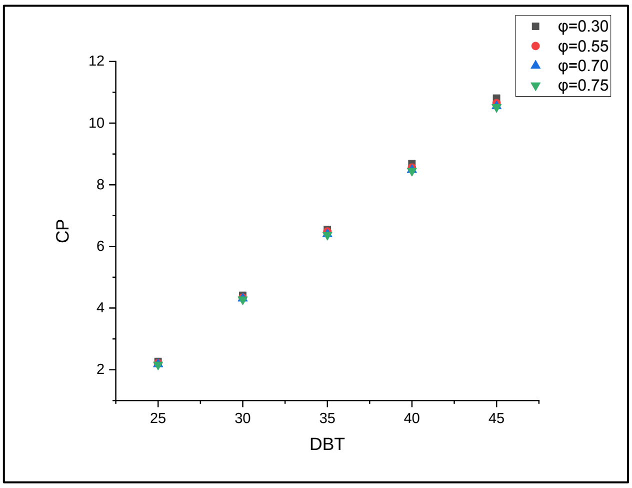

Fig. 4: DBT vs CP

Figure 4 shows the variation of Dry Bulb Temperature (°C) of Inlet Air with Cooling Power. As the DBT increases the CP also increases along with its inlet velocity and it is seen that the difference between CP remains negligible for almost all the velocities of 30% to 75%

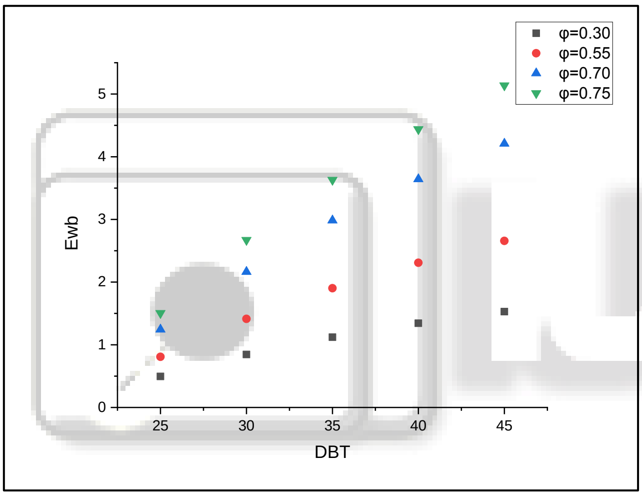

Fig. 5: DBT vs εwb

Figure 5 shows the variation of Dry Bulb Temperature (°C) of Inlet Air with Wet Bulb Effectiveness. It is observed as the DBT is increased it also results in increase of Wet Bulb Effectiveness as well as the difference between the εwb for the velocities of 30% to 75%.

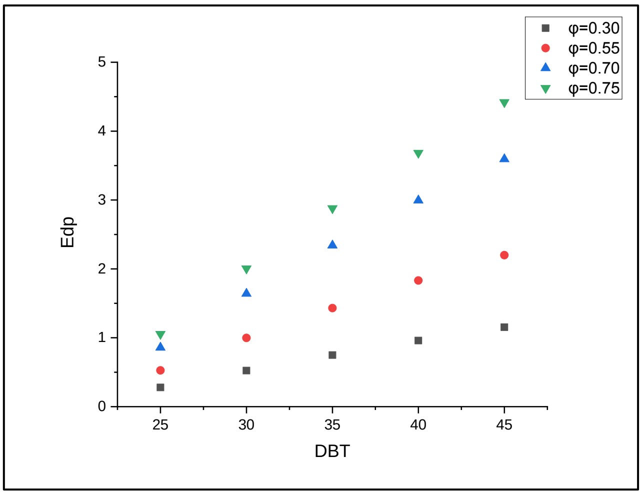

Fig. 6: DBT vs Edp

Figure 6 shows the variation of Dry Bulb Temperature (°c) of Inlet Air with Dew Point Cooling Effectiveness. It is observed that with the increase of DBT of Air, its velocity leads to improve the Dew Point Cooling Effectiveness of air.

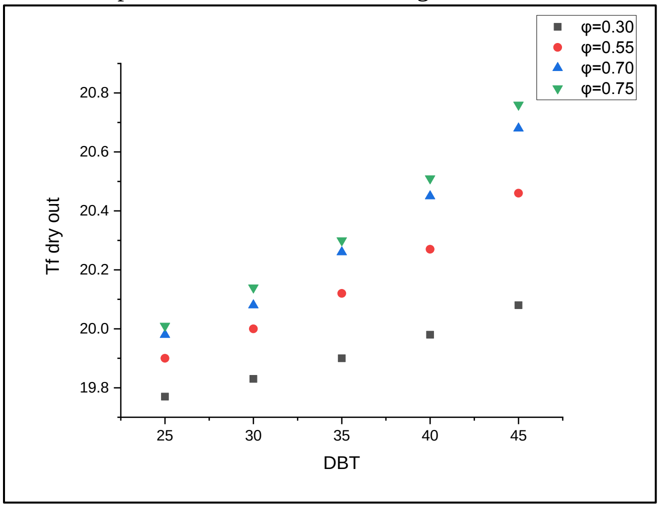

Fig. 7: DBT vs Tf dry out

Figure 7 shows the variation of Dry Bulb Temperature (°C) of Inlet Air with Dry Bulb Temperature of Outlet air. It is seen that with the increase in Dry Bulb Temperature of Air it increases the Dry Bulb Temperature of Outlet air.

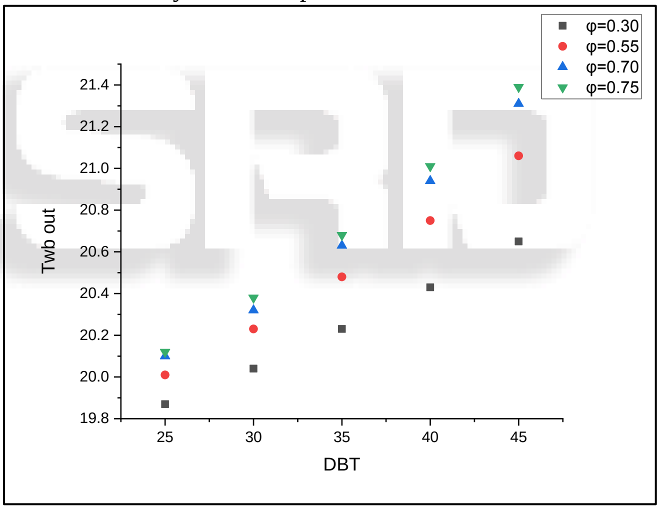

Fig. 8: DBT vs Twb out

Figure 8 shows the variation of Dry Bulb Temperature (°C) of Inlet Air with the Wet Bulb Temperature of Outlet air. It is seen that the Wet Bulb Temperature of Outlet Air increases with the increase in the Dry Bulb Temperature of Inlet Air.

IV. CONCLUSION:

The study shows that the use of Trapezoidal Plates instead of conventional Square Plates in Heat Exchanger leads to improved Cooling Power and also enhances Cooling Effectiveness. The use of Trapezoidal plates gives –

1) Increased Surfaced Area
2) Improved Cooling Power
3) Increased Efficiency and Cooling Effectiveness
4) The given arrangement provides larger surface area of plate for cooling than other type of plates

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