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To study and performance analysis of cooling tower

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Abstract

In this project the performance of cooling tower has been analyzed by varying inlet air parameters with different air inlet angles and by attaching a nozzle in air inlet. The cooling tower analyzed which is used specifically for small scale industries, forced draft counter-flow cooling tower with single module capacities from 10 to 100 cooling tons. 50 tons cooling capacity model has been taken as reference model. The analysis has been done by using computational fluid dynamics (CFD) ANSYS 14.5 software. The water cooling happens because of humidification of air. The heat lost by water is heat gained by air. Water recirculation is also important aspect in the cooling towers. The effectiveness of cooling tower depends on flow rates of air and water and water temperature. Minimization of heat loss is one of the important aspect of studies carried out by various investigators. The interfacial area between air and water is also crucial factor in cooling towers. Three types of pickings used in cooling towers are film, splash and film-grid pickings. Also it was observed that drift is one of the important losses in cooling towers. Various shapes of cooling towers are tried by various investigators to study effectiveness.

Keywords

Forced draft cooling tower, Air inlet parameter, Convergent nozzle, Cooling ton capacity, Counter flow cooling tower, Ansys 14.5, Solid works 2013, ICEM CFD 14.5, Effectiveness of cooling tower.

1.Introduction

Most air-conditioning systems and industrial processes generate heat that must be removed and dissipated. Water is commonly used as a heat transfer medium to remove heat from refrigerant condensers or industrial process heat exchangers. In the past, this was accomplished by drawing a continuous stream of water from a utility water supply or a natural body of water, heating it as it passed through the process, and then discharging the water directly to a sewer or returning it to the body of water. Water purchased from utilities for this purpose has now become prohibitively expensive because of increased water supply and disposal costs. Similarly, cooling water drawn from natural sources is relatively unavailable because the ecological disturbance caused by the increased temperature of discharge water has become unacceptable. Air-cooled heat exchangers cool water by rejecting heat directly to the atmosphere, but the first cost and fan energy consumption of these devices are high and the plan area required is relatively large. They can economically cool water to within approximately 20°F of the ambient dry-bulb temperature-too high for the cooling water requirements of most refrigeration systems and many industrial processes. Cooling towers overcome most of these problems and therefore are commonly used to dissipate heat from water-cooled refrigeration, air-conditioning, and industrial process systems. The water consumption rate of a cooling tower system is only about 5% of that of a once-through system, making it the least expensive system to operate with purchased water supplies. Additionally, the amount of heated water discharged (blow down) is very small, so the ecological effect is greatly reduced. Lastly, cooling towers can cool water to within 4 to 5°F of the ambient wet-bulb temperature, or about 35°F lower than can air-cooled systems of reasonable size. This lower temperature improves the efficiency of the overall system, thereby reducing energy use significantly and increasing process output.

The basic flow and for flow involving porous media was presented. It was revealed that the porosity introduced a high pressure drop inside the cooling tower. The pressure inside the cooling tower generally is lower that before the porous media was introduced. The results also revealed that if the heat transfer inside the porous media is to be improved, higher dynamic pressure inside the cooling tower is required which would result in higher fan power output. Their work includes the estimation of the number of transfer units for the cooling tower of interest and the effect of outside conditions such as air temperature and the inlet water temperature of the cooling tower[1-6]. The experimental results show the number of transfer unit is increasing by increasing the water to air flow ratio and decreases the approach They estimated that the reduction in the temperature of hot water takes place by approx 70% of evaporation and 30% of heat taken out by the air flowing in counter direction. The effectiveness of water and air is increased by increasing the water to air flow ratio. Increasing the range leads to an increase of many variables and parameters i.e. number of transfer units, water and air properties and heat load through the tower[7-9].

2.Working principle

In power plants, the hot water from condenser which is cooled in cooling tower, so that can be refused in condenser for condensation of steam. In a cooling tower water is made to trickle down drop by drop so that it comes in contact with the air moving in the opposite direction. As a result of this some water is evaporated and is taken away with air. In evaporation, the heat is taken away from the bulk of water, which is thus cooled.

Factors affecting cooling of water in a cooling tower are:-

- Temperature of air
- Humidity of air
- Temperature of hot air
- Size and height of tower
- Velocity of air entering tower
- Accessibility of air to all parts of tower
- Degree of uniformity in descending water
- Arrangements of plates in tower

Cooling towers may be classified according to the material of which these are made, i.e.,

- Timber
- Concrete (Ferro-concrete, multideck concrete hyperbolic)
- Steel duct type

Timber towers:-It is rarely used due to following disadvantages:-

- Due to exposure to sun, wind, water etc timber rots easily
- Short life
- High maintenance charges
- The design generally does not facilitate proper circulation of air
- Limited cooling capacity

Concrete towers:- It possess the following advantages:-

- Large capacity sometimes of the order of 5000 m^3/h
- Improved draught and air circulation
- Increased stability under air pressure
- Low maintenances

Steel duct type:- This type of cooling towers are rarely used in case of modern power plants owing to their small capacity.

The cooling towers require a draught of air for evaporation of water sprayed. The draught may be created by a chimney or the available natural air velocity (natural draught) or by fans (mechanical draught). The mechanical draught may be forced or induced depending on the placements of fans.

3.Reference cooling tower model

It plays a prominent role on cooling tower. Pioneer cooling towers are a forced draft counter-flow cooling tower with single module capacities from 10 to 100 cooling tons. These towers are a unique design that Delta Cooling Towers has been manufacturing since 1971 and have been very well received in both commercial and industrial applications.

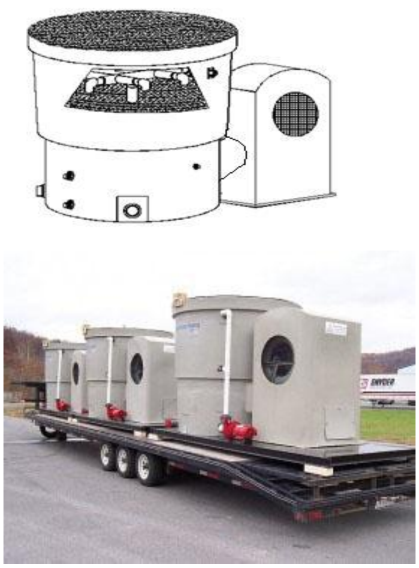


Figure 1 Reference model pioneer cooling tower

The towers are corrosion-proof, which is very prominent disjunction of Delta towers. Cooling towers are outdoor equipment, either on roofs or sides of buildings, and which are subjected to weather extremes continuously.

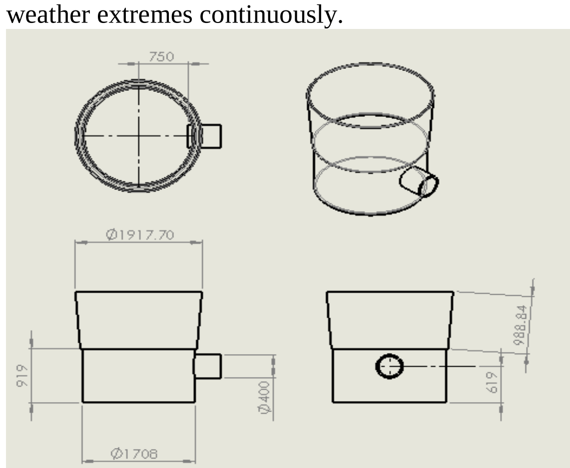


Figure 2 Cooling tower design specification

4.Modifications in cooling tower parameters

Cooling tower works on the Principle of water evaporation. Based on rate of evaporation, the hot water could be cooled more effectively. The rate of evaporation of hot water by,

- Increasing time of contact of air with hot water.
- Increasing air velocity.
- Increasing area of contact of air and hot water.

Table 1 Modifications in cooling tower parameters

Objectives	Methodologies
Increasing contact time of air with hot water	Changing the air inlet angle
Increasing air velocity	Implementing convergent type nozzle
Increasing area of contact of air and hot water	Nozzle implementation enhances swirl motion of air

4.1Air inlet pipe angles

- 0º degree
- 30º degree about horizontal axis
- 30º degree about vertical axis
- 30º degree about both horizontal and vertical axis

5.Solid works modeling

Based on the obtained specification from the reference cooling tower model, the cooling tower has been modeled using Solid works 2013 Modeling Software. In this project the performance of this cooling tower has been analyzed by changing the air inlet parameters, by varying air inlet angles as 0o, 30o horizontally, 30o vertically, 30o both horizontally and vertically. These varied air inlet angle models have been designed without changing any other parameters of reference model. Then these 4 models have been again modeled by assembling convergent nozzle at the air inlet. Totally 8 cooling tower models have been modeled and analyzed.

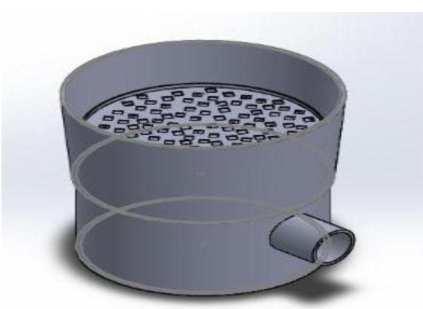


Figure 3 Isometric view of cooling tower model

5.1Varied air inlet angles without nozzle

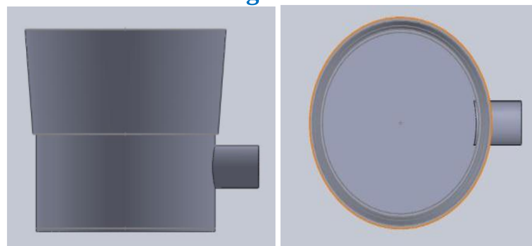


Figure 4 Air Inlet Pipe at 0º Cooling Tower Model

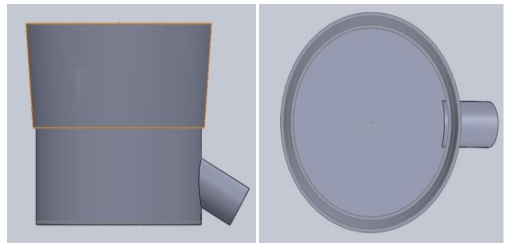


Figure 5 Air Inlet Pipe at 30º inclined horizontally cooling tower model

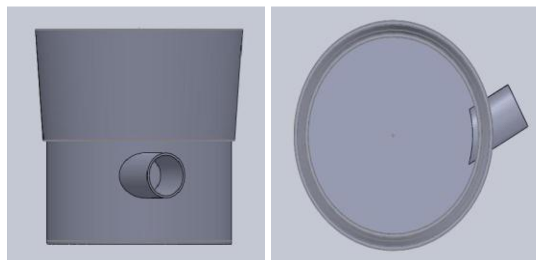


Figure 6 Air Inlet Pipe at 30º Inclined Vertically-Cooling Tower Model

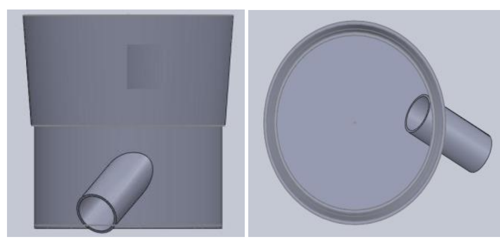


Figure 7 Air Inlet Pipe at 30º Inclined Horizontally and Vertically-Cooling Tower Model

5.2Convergent nozzle modeling

The convergent nozzle modeling which has been designed and implemented at the air inlet pipe in the cooling tower shell due to increase the air velocity and enhancing swirl motion of air in the shell, so that the air and water which is contact will be comparatively increased that enhance the rate of evaporation of hot water.

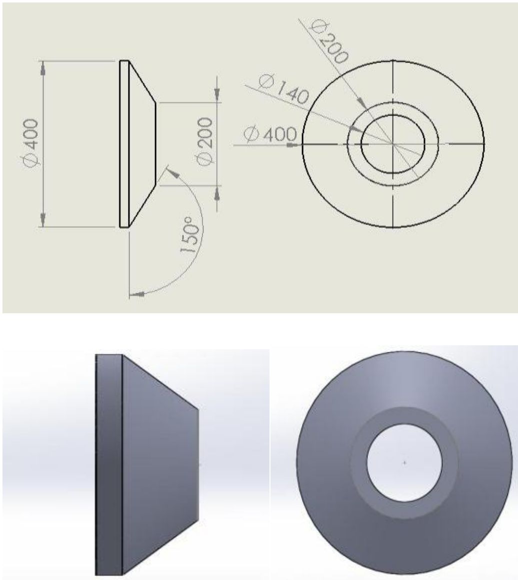


Figure 8 Convergent nozzle model

6.CFD Preprocessing

The cooling tower models have been imported as the geometries into IGES (Initial Graphics Exchange Specification) format. Then the models have been meshed using ICEM CFD software. For improved element quality, the Tetra mesher incorporates a powerful smoothing algorithm, as well as tools for local adaptive mesh refinement and coarsening.

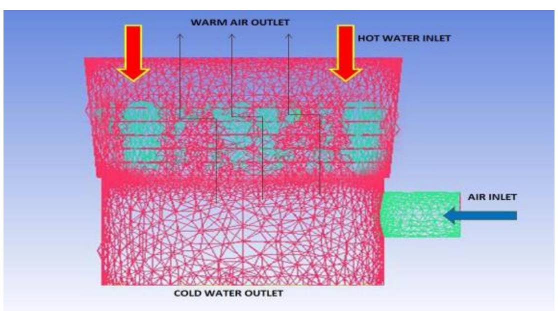


Figure 9 Meshed model of cooling tower with 0º air inlet pipe

6.1Mesh Details

Total no of elements = 188943
Total no of nodes = 31060

Surface Mesh
No of shells = 9100

Volume Mesh
No of cells = 171887

6.2Boundary conditions applied

- Air inlet diameter, D_A = 0.18 m
- Water inlet diameter, D_W = 1.66 m
- Mass flow rate of water, m_W = 0.055 kg/s
- Mass flow rate of air, m_A = 0.0404 kg/s
- Water inlet temperature, T_1= 330 K
- Air inlet WB temperature, T_{WB}= 300 K

7.Analyzed cooling tower models

The imported models are solved by applying boundary conditions, the solution is initialized and the temperature contours have been obtained after the solution convergence criteria get reached up to its minimum value. The analyzed cooling tower models are displayed below.

7.1Air inlet pipe at 0º without nozzle

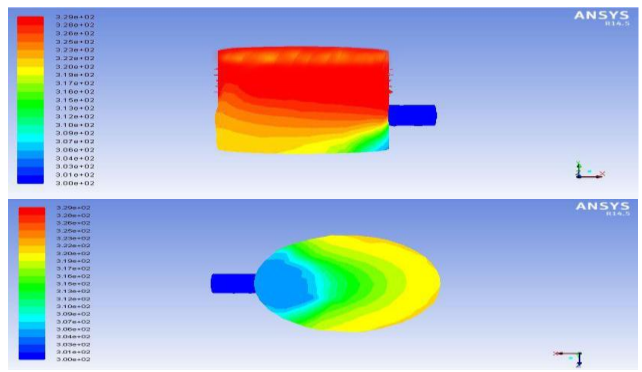


Figure 10 Temperature contours for cooling tower air inlet pipe at 0º

Air Inlet Temperature	300 K
Water Inlet Temperature	330K
Water Outlet Temperature	305K

7.2 Air Inlet Pipe at 30º Inclined Horizontally without Nozzle

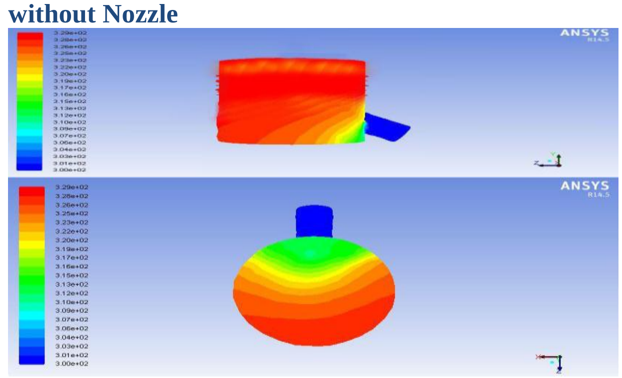


Figure 11 Temperature contours for cooling tower air inlet pipe at 30º inclined horizontally

Air Inlet Temperature	300K
Water Inlet Temperature	330K
Water Outlet Temperature	312K

7.3Air Inlet Pipe 30º inclined vertically without nozzle

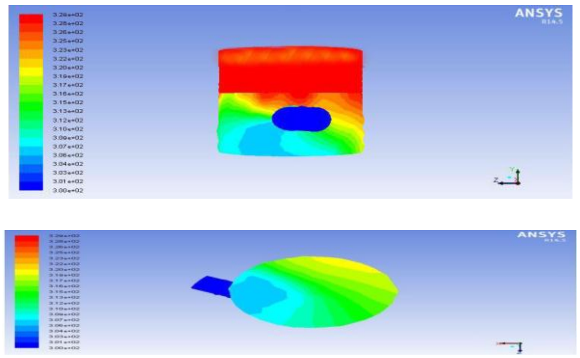


Figure 12 Temperature contours for cooling tower air inlet pipe at 30º inclined horizontally

Air Inlet Temperature	300K
Water Inlet Temperature	330K
Water Outlet Temperature	308K

7.4 Air Inlet Pipe at 0º with Nozzle

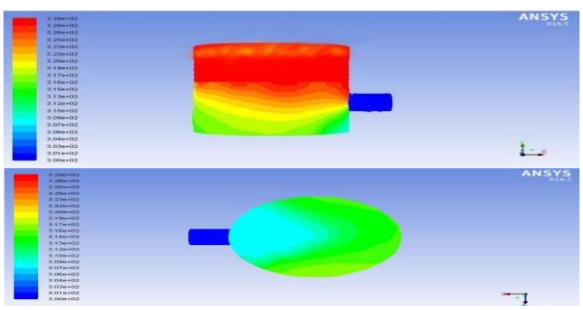
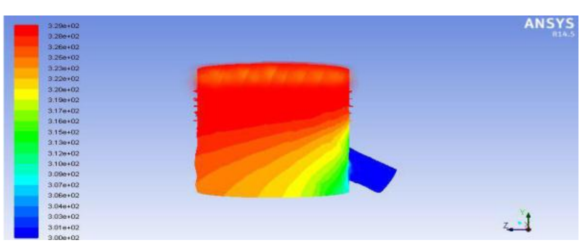


Figure 13 Temperature Contours for Cooling Tower Air Inlet Pipe at 0º with Nozzle

7.5 Air Inlet Pipe at 30º Inclined Horizontally with Nozzle



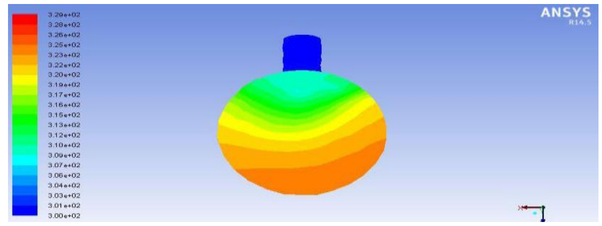


Figure 14 Temperature Contours for Cooling Tower Air Inlet Pipe at 30º Inclined Horizontally with Nozzle

Air Inlet Temperature	300K
Water Inlet Temperature	330K
Water Outlet Temperature	310K

7.6 Air Inlet Pipe at 30º Inclined Vertically with Nozzle:-

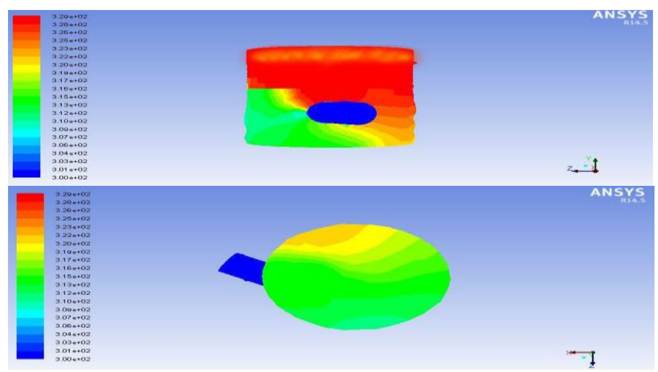


Figure 15 Temperature contours for cooling tower - air inlet pipe at 30º inclined vertically with nozzle

8.Cooling tower analysis calculation

Formulae:-

Range:- CT Range (K) = $T_1 - T_2$

Approach:-CT Approach (K) = $T_2 - T_{WB}$

Effectiveness:- CT Effectiveness (%) = [Range / (Range + Approach)] x 100

Evaporation loss:- Evaporation loss (E.L) (m^3/hr) = 0.00085 * 1.8 * QW * ($T_1 - T_2$)

Percentage evaporation loss:- Percentage evaporation loss (%) = (E.L / QW) * 100

Where,

T_1 - Hot water inlet temp (K)

T_2 - Cold water outlet temp (K)

T_{WB}- Air Wet bulb temp (K)

QW - Water Circulation rate (m^3/hr)

Case 1: Air inlet pipe at 0º

T_1= 330 K , T_{WB}= 300 K , Q_W= 0.198 m^3/h , T_2= 305 K

CT Range (K) = $T_1 - T_2$ = (330 – 305) = **25 K**
CT Approach (K) = $T_2 - T_{WB}$ = (305 – 300) = **5 K**
CT Effectiveness (%) = [Range / (Range + Approach)] x 100 = [25/25+5] *100
= **83.33%**
Evaporation loss (E.L) (m^3/hr)
= 0.00085 * 1.8 * QW * ($T_1 - T_2$)

Models	Water inlet temp	Air inlet temp	Water outlet temp	Range	approach
Units	K	K	K	K	K
I	330	300	305	25	5
II	330	300	312	18	12
III	330	300	308	22	8
IV	330	300	309	21	9
V	330	300	310	20	10
VI	330	300	314	16	14

= 0.00085 * 1.8 * 0.198*25
= **$7.5735 * 10^{-3} m^3/hr$**

Percentage evaporation loss (%) = (E.L / QW) * 100
= ($7.5735 * 10^{-3}$/0.198) * 100
= **3.825%**

9.Results and discussion

Air Inlet Pipe at 0º without Nozzle
Air Inlet Pipe at 30º Inclined Horizontally without Nozzle
Air Inlet Pipe at 30º Inclined Vertically without Nozzle
Air Inlet Pipe at 0º with Nozzle
Air Inlet Pipe at 30º Inclined Horizontally with Nozzle
Air Inlet Pipe at 30º Inclined Vertically with Nozzle

9.1Calculation and tabulation

Models	Effectiveness	Evaporation loss	Percentage evaporation loss
Units	%	m^3/hr	%
I	83.33	$7.5735 * 10^{-3}$	3.825
II	60.00	$5.4529 * 10^{-3}$	2.754
III	73.33	$6.6648 * 10^{-3}$	3.366
IV	70	$6.3617 * 10^{-3}$	3.213
V	66.67	$6.0588 * 10^{-3}$	3.06
VI	53.33	$4.8470 * 10^{-3}$	2.448

By using the above formulae, the performance parameters of all cooling tower models have been found out and tabulated and graphed as follows,

9.2Performance Graph

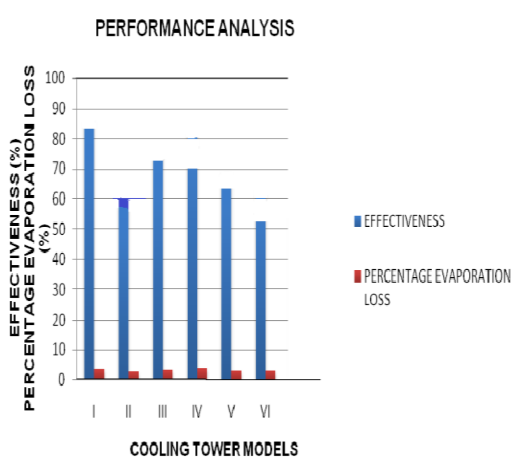


Figure 16 Performance graph comparing all 6 cooling tower models

9.3Discussion

From the results of analyzed 6 models of cooling tower, the reference cooling tower model 1 has effectiveness of about **83.33%**, meanwhile the modified cooling tower model 2 and 3 with air inlet pipe inclined at 30º about both horizontal and vertical axis have derived an improved effectiveness of about **60 and 73.33%** respectively. Hence the evaporation rate characteristic between air and water have been varied for cooling tower models due to the change in contact surface of air and water which have been caused by varying air inlet angles. The cooling tower model 4 has effectiveness of about **70%**, meanwhile the modified cooling tower model 5 and 6 with air inlet pipe inclined at 30º about both horizontal and vertical axis have derived an improved effectiveness of about **66.67** and **53.33%** respectively.

10.Conclusion

On comparing the effectiveness values of 6 cooling tower models, the cooling tower with air inlet pipe at 0º and the cooling tower with air inlet pipe inclined at 30º about both horizontal and vertical axis have nearly same effectiveness but there are some variations. Hence both models could be validated experimentally and implemented for forced draft cooling towers specifically for small scale industries.

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