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Design and Analysis of Cooling Tower

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ABSTRACT
Cooling Tower Is A Heat And Mass Transfer Device Commonly Used To Dissipate Heat From Devices Like Condensers In Power Plants, Compressors, Pumps In Industries. Cooling Tower Works On The Principle Of Evaporative Cooling In Which Water Is Cooled Down By The Impact Of High Velocity Flowing Air. It Offers An Effective Alternative At Locations Where There Is Cooling Water Scarcity And Where Hot Water Discharge Causes An Environmental Concern. The Effective Cooling Of Water Depends On Various Process Parameters Like Dry Bulb And Wet Bulb Temperature Of Air, Fill Material And Its Size, Inlet Air Flow Rate, Air Inlet Angles, Water Flow Rate And Temperature Etc. The Present Paper Is The Detailed Methodology Of Design Of Counter Flow Cooling Tower Based On The Input Process Parameters By Considering Different Types Of Possible Losses. The Designed Cooling Tower Is Then Modelled In Solidworks 2012 And Checked For Its Performance Through CFD Software. The Model Has Been Meshed And Analyzed In ANSYS 16.1 Software. The Air Inlet Angles Have Been Varied Along Horizontal And Vertical Direction And Temperature Contours Have Been Obtained. Based On Outlet Cold Water Temperature For Different Air Inlet Angles, The Effectiveness Of Cooling Tower Has Been Estimated And Compared.
Keywords-Air Inlet Angles, Counter Flow Cooling Tower, Effectiveness, ANSYS 16.1, Losses, Solidworks 2012

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I. INTRODUCTION

Cooling Tower Is A Direct Contact Type Heat Exchanger In Which Warm Water Gets Cooled Down By Mixing It With High Velocity Air. It Is Mostly Used In Power Plants, Process Industries To Carry Away The Heat From The Warm Cooling Water Coming From Condensers, Cooling Jackets Of Compressors, Pumps, IC Engines. Here Warm Water Is Pumped At The Top Of Cooling Tower And Sprayed Through Rows Of Nozzles. It Then Falls On Fill Material Packing Where Actual Heat Transfer Takes Place By The Phenomenon Of Evaporative Cooling Which Is Combination Of Latent Heat Removal Of Water From Itself And Sensible Cooling By Air. Finally The Cold Water Is Collected Into The Water Basin And Again Recirculated Through These Devices.

1.1. Types Of Cooling Tower

This Section Describes Two Main Types Of Cooling Towers

- Natural Draft Cooling Tower
- Mechanical Draft Cooling Tower

The Natural Draft Or Hyperbolic Cooling Towers Shown In Fig. 1 Are Big In Size As They Are Using Phenomenon Of Induction Of Draught Due To Difference In Densities Of Hot Air And Cold Air Generated By Difference In Temperatures. Hot Air Being Less Dense Moves Upwards And Cold Air Is Made To Enter Into The Tower Through Air Inlet At Bottom.

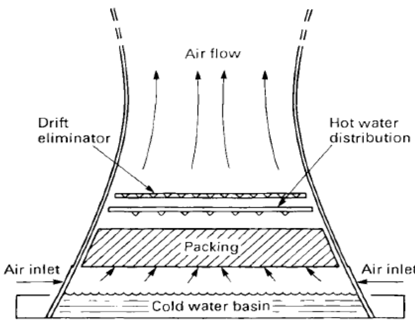

Fig.1. Natural Draught Cooling Tower

The Mechanical Draft Cooling Towers Shown In Fig.2 Uses Big Fans Which Either Draws The Air From Downwards (Induced Draft) Or Forces The Air Upwards (Forced Draft) Through The Circulated Water. The Water Enters From Top Of Cooling Tower And Made To Fall On Fill Surface Which Does Function Ofincreasing The Contact Area And Time Of Contact Of Water With Air. Many Types Of Fill Packing Like Splash Type, Film Type Are Used Which Plays An Important Role In Entire Performance Of Cooling Tower.

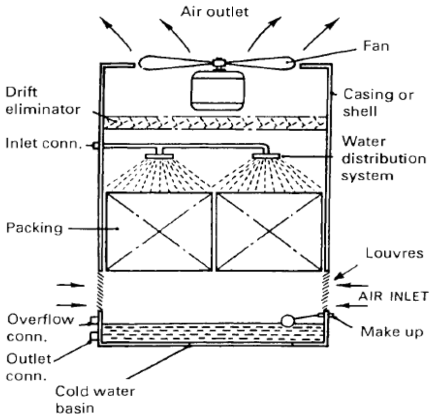

Fig.2. Mechanical Draught Cooling Tower

1.1.1. Types Of Mechanical Draft Cooling Tower

- Induced Or Forced Draft Counter Flow
- Induced Or Forced Draft Cross Flow

1.2. Components Of Cooling Tower

The Basic Components Of Cooling Towers Are Packing, Louvers, Water Inlet, Nozzles, Cooling Tower Basin, Fans, Drift Eliminators, The Frame And Casing.

1.3. Cooling Tower Terminology

Air Flow: Total Quantity Of Air Along With Water Vapour Flowing Through The Tower.

Recirculation: The Proportion Of Air From Outlet Which Reenters The Tower.

Heat Load (Or Cooling Load): Rate Of Heat Removal From The Water Flowing Through The Tower Expressed In KW.

Dry Bulb Temperature: Temperature Of Air Measured Under Atmospheric Conditions.

Wet Bulb Temperature: The Temperature In Degree Celsius To Which Air Can Be Cooled, Making It Adiabatic To Saturation By The Addition Of Water Vapour. In Practical Terms, The Wet Bulb Temperature Is The Temperature Indicated By A Thermometer, The Bulb Of Which Is Kept Moist By A Wick And Over Which Air Is Circulated.

Range dnA telnI neewteB ecnereffiD laciremuN ehT: retaW fO erutarepmeT teltuO.

Approach: The Difference In Temperature (Degree Celsius) Of The Cold Water Leaving The Tower And Wet Bulb Temperature Of Ambient Air.

Basin: The Area At The Bottom Of The Tower For Collecting Cold Water. Cross Flow Towers Have A Hot Water Distribution Basin At The Top And In Some Cases, A Water Basin Between The Top And Bottom Basin.

Cooling Tower Effectiveness (In Percentage): It Is The Ratio Of Range, To The Ideal Range, I.E., Difference Between Cooling Water Inlet Temperature And Ambient Wet Bulb Temperature, Or In Other Words It Is = Range / (Range + Approach).

Cycles Of Concentration (C.O.C): It Is The Ratio Of Dissolved Solids In Circulating Water To The Dissolved Solids In Makeup Water.

II. LITERATURE REVIEW

Ronak Shah, Trupti Rathor[1] Had Done Thermal Design Of Industrial Cooling Tower And Determined The Complete Performance Parameters With Given Inlet And Outlet Conditions And Considering Several Possible Losses. They Investigated That Cooling Tower Performance Increases With Increasing Air Flow Rate And Cooling Tower Characteristic Decreases With Increase In Water To Air Mass Ratio.

Pushpa B. S, Vasant Vaze, P. T. Nimbalkar[2] Have Evaluated Performance Of Cooling Tower In Thermal Power Plant By Varying Water Inlet Temperature, Air Inlet Temperature And Mass Flow Rate Of Water. They Found That Efficiency Of Cooling Tower Increases By Increasing Water Inlet Temp, Air Inlet Temperature And Decreases By Increasing Mass Flow Rate.

S. Parimala Murugaveni, P. Mohamed Shameer[3] In Their Research Have Analyzed A Forced Draft Cooling Tower By Varying Air Inlet Parameters And By Varying Air Inlet Angles In Horizontal And Vertical Direction And Both. The Cooling Tower Model Has Been Prepared In Solid Works 2013 And It Has Been Meshed Using ICEM CFD 14.5 Software And Meshed Models Have Been Analyzed Using FLUENT Software. On The Basis Of Temperature Contours Obtained, They Found That Outlet Temperature Of Water Increases As The Air Inlet Angle Increases Which Will Lead To Decrease In Effectiveness.

Manoj Kumar Chopra, Rahul Kumar[4] In Their Research Carried Out The CFD Analysis On A Counter Flow Cooling Tower Reference Model. The Model Has Been Prepared In Creo And Meshed And Analyzed Through ANSYS 12.1. The Analysis Is Carried Out By Simultaneous Varying Of Three Parameter Inlet Water Flow Rate, Inlet Air Rate And Fills Porosity And Applied Taguchi Method To Carry Out The Optimization. They Investigated That Cooling Tower Gives Best Performance At Lower Mass Flow Rate Of Water, High Mass Flow Rate Of Air And Fill Porosity Of 50%.

III. DESIGN OF COOLING TOWER

Table 1. Technical Specifications

Volume Of Circulating Water (V)	320 $\frac{m^3}{hr}$
Inlet Temperature Of Water (T_1)	30°C
Outlet Temperature Of Water (T_2)	25°C
Wet Bulb Temperature (WBT)	22°C
Inlet Temperature Of Air (T_{a1})	25°C
Outlet Temperature Of Air (T_{a2})	28°C
Design Relative Humidity (∅)	80%
Allowable Evaporating Losses	1.44%

Table 2. Data From Psychometric Chart And Steam Table

Enthalpy Of Air At Inlet Temperature (H_{a1})	65 $\frac{kJ}{kg}$
Enthalpy Of Air At Outlet Temperature (H_{a2})	75 $\frac{kJ}{kg}$
Specific Humidity Of Air At Inlet Temperature (W_1)	0.016 $\frac{kg}{kgofdryair}$
Specific Humidity Of Air At Outlet Temperature (W_2)	0.019 $\frac{kg}{kgofdryair}$
Specific Volume Of Air At Inlet Temperature (V_{s1})	0.8605 $\frac{m^3}{kg}$
Specific Volume Of Air At Outlet Temperature (V_{s2})	0.88 $\frac{m^3}{kg}$
Enthalpy of water at outlet temperature (H_{s1})	125.8 $\frac{kJ}{kg}$
Enthalpy of water at inlet temperature (H_{s2})	104.9 $\frac{kJ}{kg}$

3.1. Thermal Design Calculations

Cooling Tower Approach (CTA)

CTA = T_2– WBT
=25 – 22
CTA = 3°C

Cooling Tower Range (CTR)

CTR = T_1– T_2
= 30 - 25
CTR = 5°C

Mass Of Water Circulated In Cooling Tower

M_{w1}= Volume Of Circulating Water X Mass Density Of Water,
= 320 X 1000
M_{w1}= 320000 Kg/Hr

Heat Loss By Water (HL)

HL= M_{w1}X C_{pw}X (T_1– T_2)
= 320000 X 4.186 X (30 - 25)
HL= 6699200 Kj /Hr

Volume Of Air Required (V)

V= (HL X V_{s1}) / [(H_{a2}– H_{a1}) - (W_2– W_1) X C_{pw}Xt_2]
= (6699200 X 0.865) / [(76-65) – (0.019 – 0.016) X 4.186 X 25]
V= 663887.582 M^3 / Hr

Mass Of Air Required (M_a)

Ma= Volume Of Air Required / Specific Volume Of Air At Inlet Temperature
= V / V_{s1}
= 663887.582/0.8605
Ma= 795729.62 Kg/Hr

Quantity Of Make-Up Water ($M_{make-Up}$)

$M_{make-Up}$ = (V X (W_2-W_1)) / V_{s2}
= (663887.582 X (0.0186 – 0.0162)) / 0.88
Taking Evaporative Loss In Consideration,
$M_{make-Up}$ = 1814.73 X [1 + (1.44 / 100)]
= 1840.86 Kg/Hr
$M_{make-Up}$= 30.68 Kg/Min

Effectiveness Of Cooling Tower (€)

$€ = \frac{range}{range + approach}$
= 5/8 = 0.625
€= 62.5 %

3.1.1. Estimation Of Different Types Of Losses In Cooling Tower

Drift Losses (DL)

Taking Drift Losses As0.20% Of Circulating Water,
DL = 0.20 X M_{w1}/ 100
= 0.20 X 320000 / 100
DL = 640 Kg /Hr

Windage Losses (WL)

Taking Windage Losses As 0.5% Of Circulating Water,
WL = 0.005 X M_{w1}
= 0.005 X 320000
WL = 1600 Kg /Hr

Evaporation Losses (EL)

Taking Evaporation Losses As 1% Of Circulating Water Per 10°F Of Cooling Range.
EL= (0.01 X M_{w1}X Range)/10
= 0.001 X 320000 X (86 - 77)
EL= 2880 Kg /Hr

Blow Down Losses (BL)

Number Of Cycles Required Is Given By,
Cycles Of Concentration (C.O.C) = XC / XM
XC = Concentration Of Solids In Circulating Water,
XM = Concentration Of Solids In Make-Up Water
Water Balance Equation For Cooling Tower Is,
M = WL + EL + DL
= 1600 + 2880 + 640
M = 5120 Kg /Hr
XC / XM = M / (M - EL)
= 5120 / (5120 - 2880)
C.O.C. = 2.2857
So, Blow Down Loss (BL)
BL= EL / (C.O.C - 1)
= 2880 / (2.2857 - 1)
BL= 2240.02 Kg /Hr

3.2. Structural Design Calculations

3.2.1. Cooling Tower Characteristics

Outlet Air Temperature (Assumed) = 27.5℃ = 28 ℃

Relative Humidity = Ø = 80%

H_{sa}= Enthalpy Of Saturated Air At Water Temperature.

H_a = Enthalpy Of Moist Air At That Temperature And Humidity

Table 3. Calculation For $(H_{sa} – H_a)^{-1}$

T ℃	H_{as} (KJ/Kg)	H_a (Kj/Kg)	$H_{sa} – H_a$	$(H_{sa} – H_a)^{-1}$
25	76.5	65.5	11	0.0909
26	81	69.5	11.5	0.08696
27	85	73	12	0.08333
28	90	77.5	12.5	0.08
29	95	80	15	0.0667
30	99.5	85	14.5	0.06897

Cooling Tower Characteristic Equation Can Be Given As,

$(\frac{K_a \text{ X } \bar{V}}{\bar{L}})_{Calc} = R \text{ X } (1 / (H_{sa} – H_a))_{Avg}$

Where,

K= Mass Transfer Coefficient $(\frac{Kg}{hr.m^2})$

A = Constant Area (M^2)

V = Active Cooling Volume (M^3)

$\bar{L}$ = Loading Factor (Kg_{water} / Sec-M^2_{water})

$(H_{sa} – H_a)^{-1}_{avg}$ = 0.07948

$(\frac{K_a \text{ X } \bar{V}}{\bar{L}})_{Calc}$ = 5 X 0.07948

$(\frac{K_a \text{ X } \bar{V}}{\bar{L}})_{Calc}$= 0.3974 $\frac{Kg_{air}}{Kg_{water}}$

3.2.2. Determination Of Loading Factor ($\bar{L}$)

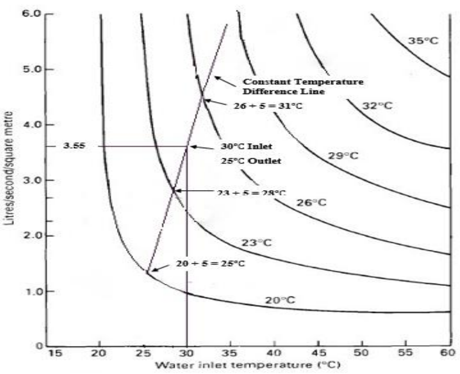

Fig.3. Loading Factor Vs Water Inlet Temperature

From Graph,

$\bar{L}$ = 3.55 Litres / Seconds / M^2

3.2.3. Determination Of Tower Dimension

$Z = (\frac{K_a \text{ X } \bar{V}}{\bar{L}})_{Calc} \text{ X } \frac{\bar{L}}{K_a}$

Where,

Z = Height Of Tower (M)

B = Base Area (M^2)

V_f= Fill Volume (M^3)

Considering,

K_aAs 100 Pound Air/Hr X Ft_{fill}^{-3}(Standard}

K_a = 0.47 Kg_{air} / Sec-M^3

$\bar{L}$ = 3.55 Litres / Sec-M^2

= 3.55 X 10^{-3} M^3_{water} / Sec – M^2_b

$\bar{L}$ = 3.55 Kg_{water} / Sec-M^2_{water}

So,

Z = (0.3974 X 3.55) / 0.47

Z = 3 M …..(Fill Height)

Now,

Volume Of Fill = Base X Z

$$B = \frac{L}{\bar{L}} = \frac{88.89}{3.55} \frac{\frac{Kg\ water}{sec}}{\frac{Kg\ water}{sec - m^2}}$$

B = 25.05 M^2

Square Shape Tower Dimensions Are {5m X 5m}$_{Approx}$

fill Volume = 25.050 X 3

V_f= 75.15 M^3

IV. ANALYSIS OF COOLING TOWER

4.1. Modelling Of Cooling Tower

Based On The Obtained Specifications (Size And Dimensions), The Cooling Tower Model Has Been Prepared In Solidworks 2012 3D Modelling Software.

Here The Same Cooling Tower Has Been Assembled In 3 Ways By Varying The Air Inlet Pipe Angles As 0°, 30° About Both Horizontal And Vertical Axis Without Changing Any Other Parameter Of Model. Total 3 Cooling Tower Models Have Been Modelled As Shown In Figures Below,

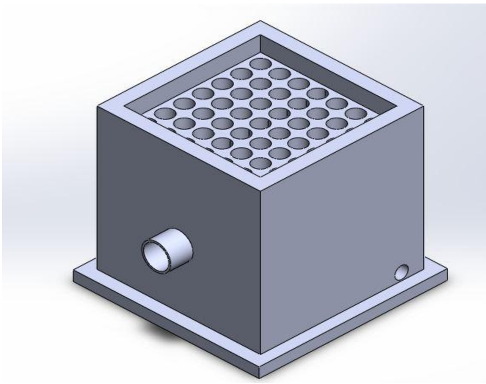

Fig.4. Isometric View Of Cooling Tower Model

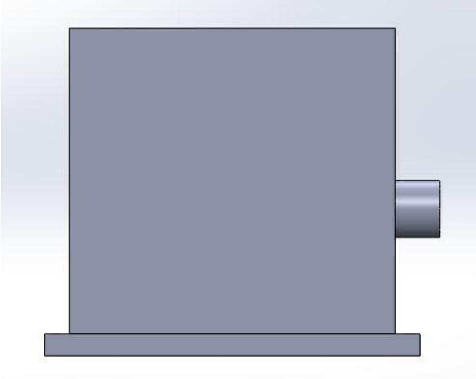

Fig.5. Air Inlet Pipe At 0°- Cooing Tower Model

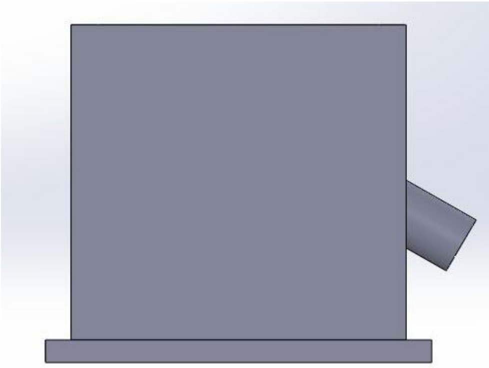

Fig.6. Air Inlet Pipe At 30° Inclined Horizontally- Cooing Tower Model

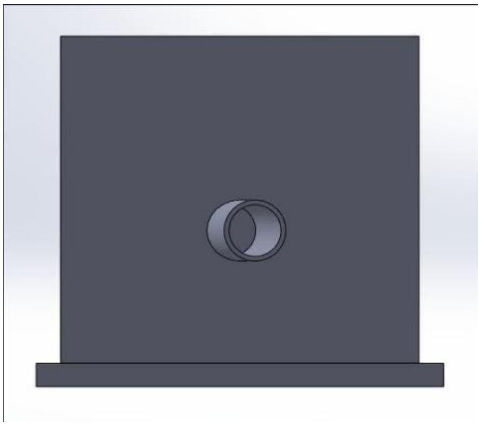

Fig.7. Air Inlet Pipe At 30° Inclined Vertically - Cooing Tower Model

4.2. CFD pre-Processing

The Cooling Tower Models Have Been Imported As The Geometries Into IGES (Initial Graphics Exchange Specification) Format. Then These Models Are Meshed And CFD Analysis Is Carried Out Using ANSYS 16.1 By Applying The Appropriate Boundary Conditions.

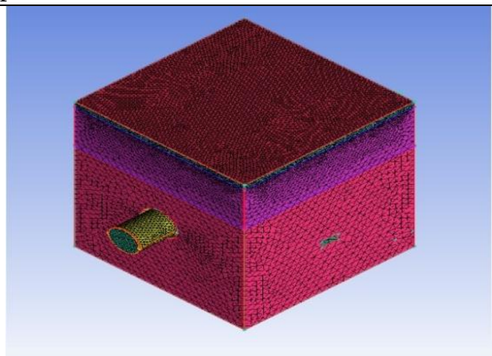

Fig.8.Meshed Model Of Cooling Tower

Boundary Conditions Applied
Inlet Temperature Of Hot Water = 303K
Mass Flow Rate Of Water = 89 Kg/S
Inlet Mass Flow Rate Of Air = 221.04 Kg/S
Inlet Air Pressure = 1.013 Bar
Inlet Wet Bulb Temperature Of Air= 295K
Fills Porosity = 50%

4.3. Analysed Cooling Tower Models

The Imported Cooling Tower Models Are Solved By Applying Boundary Conditions, The Solutions Have Been Initialized And Temperature Contours Have Been Obtained. The Analysed Cooling Tower Models Are Shown:

Case 1. Air Inlet Pipe At 0° Without Nozzle

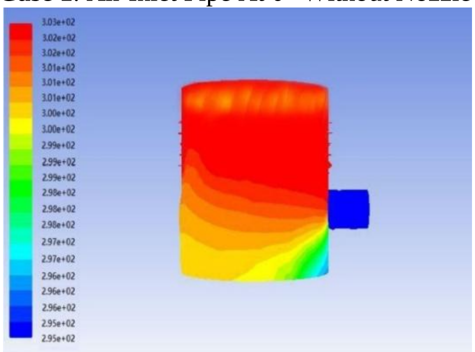

Fig.9. Temperature Contours- Air Inlet Pipe At 0°

Case 2. Air Inlet Pipe At 30°Inclined Horizontally

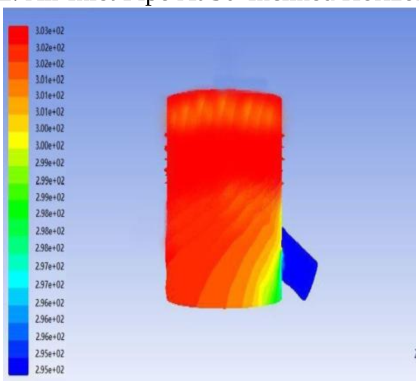

Fig.10. Temperature Contours- Air Inlet Pipe At 30° Horizontally Inclined

Case 3. Air Inlet Pipe At 30°Inclined Vertically

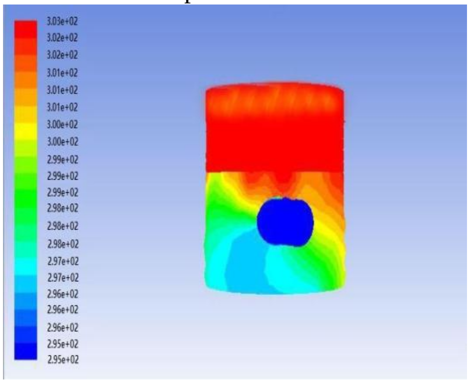

Fig.11. Temperature Contours- Air Inlet Pipe At 30° Vertically Inclined

V. RESULTS AND CALCULATIONS

From The Analysis, The Outlet Water Temperature Has Been Obtained On The Basis Of Which The Effectiveness Of All Cooling Tower Models Have Been Estimated By The Formula

$$€ = \frac{Range}{Range\ +approac\ h}$$

Inlet Temperature Of Water = 303K
Inlet Wet Bulb Temperature Of Air = 295K

Table 4. Data Obtained From Analysis And Calculation

Case	Outlet Temp. Of Water	Range	Approach	Effectiveness
1	298.6K	4.4K	3.6K	55%
2	299.2K	3.8K	4.2K	47.5%
3	298.8K	4.2K	3.8K	52.5%

Conclusion

1. The Design Of Cooling Tower Is Closely Related To Cooling Tower Characteristics Which Is Unique For A Particular Tower And Loading Factor Which Depends On Hot Water Temperature.
2. The Rate Of Heat Loss By Water Never Equals To Rate Of Heat Gain By Air Due To Different Types Of Heat Losses.
3. It Is A Almost Possible To Use CFD To Carry About Performance Analysis Of Cooling Tower In Terms Of Effectiveness. Results Clearly Demonstrates That With Increase In Air Inlet Angle In Any Direction, Outlet Water Temperature Increases And Thus Cooling Effectiveness Gets Reduced.

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