Performance Analysis and Optimization of Cooling Tower

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DOI: 10.29322/IJSRP.8.4.2018.p7631
http://dx.doi.org/10.29322/IJSRP.8.4.2018.p7631

Abstract- Cooling tower is an integral part of every thermal power generation plant. Basically cooling tower are heat rejection devices used to transfer heat from hot water to the atmosphere air. Investigation involves experimental and two-dimensional computational fluid dynamics analysis of an actual industry operated cooling tower. Inlet water temperature and mass flow rate of water and air are having main influence on the performance of counter flow induced draft cooling tower. Effectiveness of the cooling tower can be increased up to 20% by optimizing the liquid to gas ratio (L/G) of the cooling tower. Likewise other parameters such as range, tower characteristic ratio can also be increased considerably.

Index Terms- counter flow induced draft cooling tower, CFD analysis, tower characteristic ratio, range, effectiveness of cooling tower, liquid to gas (L/G) ratio.

I. INTRODUCTION

The cooling tower (CT) is the most important piece of industrial equipment whose primary purpose is to remove the heat while minimizing water usage. They are often used in power generation plants to cool the condenser feed-water. In cooling tower water is made to trickle down drop by drop, or form a thin layer over flat surface so that it comes into direct contact with air moving upwards in opposite direction. The heat transfer from the water to the air steam raises the air's temperature and its relative humidity to 100% and this air is discharged to the atmosphere. As a result of this some water is evaporated and is taken away from the bulk of water, which is thus cooled. Thus evaporative cooling technique is used in the case of cooling towers. Cooling towers fall into two main categories: Natural draft and Mechanical draft. Mechanical draft towers are available in the following airflow arrangements: Counter flows induced draft, Counter flow forced draft. Cross flow induced draft. In the counter flow induced draft design, hot water enters at the top, while the air is introduced at the bottom and exits at the top. Both forced and induced draft fans are used. In cross flow induced draft towers, the water enters at the top and passes over the fill. The air, however, is introduced at the side either on one side (single-flow tower) or opposite sides (double-flow tower). An induced draft fan draws the air across the wetted fill and expels it through the top of the structure.in the present study the effect of various input parameters.

The cooling tower taken for the study is the cooling tower of an integrated titanium dioxide plant. The cooling tower used in this industry is a counter flow induced draft cooling tower. In this study we consider the effect of mass flow rate of air by adjusting the fan pitch angle. A 2D CFD model is created and is then validated with previously taken experimental values. This model is used to study effects of other input parameters of the cooling tower.

II COOLING TOWER CALACULATIONS

A cooling towers primary purpose is to remove heat and minimize water usage. Heat is transferred by two mechanisms. A portion of cooling water generally 1 to 3% actually evaporates as it readily mixes with air; latent heat is given up in this phase. Sensible heat transfer in which heat exchanged without a phase change makes up the balance. The relative humidity of the incoming air plays a great role in determining the rate of heat transfer.

According to thermodynamics

Heat removed from water = heat absorbed by surrounding air

$L (T1 - T2) = G (h2 - h1)$

$L/G=(h2-h1)/ (T1-T2)$

Where,

L = mass flow rate of water entering the tower, G = mass flow rate of air through the tower, T1 = hot water temperature

T2 = cold water temperature, Temperature of air water vapor mixture at the inlet wet bulb temperature = 32.7°c

Temperature of air water vapor mixture at the exhaust wet bulb temperature =35°c

h_2= enthalpy of air water vapor mixture at the exhaust wet-bulb temperature = 98.4kj/kg

h1 = enthalpy of air – water vapor mixture at the inlet wet bulb temperature = 97.8Kj/kg

Relative humidity = 90%

The values of h1 and h2 are obtained from psychometric chart at 95% relative humidity corresponding to inlet and exhaust wet – bulb temperature of air-water vapor mixture.

L = 2400 cubic meter/hr.

The flow of water is regulated by using 4 pumps whose combined efficiency is 85% and each pump has capacity to regulate 600 cubic meter/hr.

Therefore L= 600*4 = 2400 cubic meter/hr. the pumps are 85% efficient

Therefore L= 2400*(85/100) =2040 cubic meter/hr.

Average hot water temperature to the tower and average cold water temperature from the tower checked in each hour a day for last 6 days is given below

Day	Cold water temperature	Hot water temperature
8/01/2018	33	41
9/01/2018	34	43
10/01/2018	32	40
11/01/2018	31	40
12/01/2018	33	42
13/01/2018	33	42

Table 1 Temperature reading (KMML CT)

Thermodynamics also dictate that the heat removed from the water must be equal to the heat absorbed by the surrounding air:

$L (T_1 - T_2) = G (h_2- h_1)$

Where L, G are the mass flow rate of water and air respectively

Average cold water temperature (T_1) = 32.7°C, Average hot water temperature (T_2) = 41.3°C

Inlet wet bulb temperature of air T_{wb1} = 28, Exit wet bulb temperature of air T_{wb2} = 34

Corresponding to inlet and exit wet bub temperatures the enthalpies are taken from psychometric chart

h2 = enthalpy of air-water vapor mixture at exhaust wet-bulb temperature = 120KJ/KG

h1 = enthalpy of air-water vapor mixture at inlet wet-bulb temperature = 94KJ/KG

566(41.3 – 32.7) = G (120 -94)

G = 187Kg/s

V = volume of air entering = 9008 cubic meter/minute

Calculation of Makeup water required:

Total loss = drift losses + evaporative losses + blow down losses + supply of hot water to MS plant

D = drift losses = 0.15% of water supply = (0.15/100)*2040 = 3.06 cubic meter/hr.

E = evaporative losses = 0.00085*water flow rate*(T1 –T2)

= 0.00085*2040*(41.3 – 32.7) = 14.91 cubic meter/hr.

Blow down losses = [E - {(C -1)*D}]/(C-1)

Where C = cycles = solids in circulating water / solids in making up water

Assume that the level of chlorides in the makeup water = 250ppm

And do not want level to go beyond 750 ppm14.91 cubic meter/hr.

Therefore blow down losses = [14.91 - {(3 -1)*3.06}] / (3-1)

= 4.395 cubic meter/hr.

Day	Water supplied
08/01/2018	1065 cubic meter/day
09/01/2018	1094 cubic meter/day
10/01/2018	1131 cubic meter/day
11/01/2018	900 cubic meter/day
12/01/2018	692 cubic meter/day
13/01/2018	1123 cubic meter/day

Table 2 Hot water supply to MS plant for 6 days

Average water supplied to MS plant = 1001 cubic meter/day.

= 41.7cubic meter/hr.

Therefore make up water required = 3.06 + 14.91 + 4.395 + 41.7 = 64.065cubic meter/hr.

Efficiency (E) = [(hot water temperature cold water temperature)/ (hot water temperature – wet bulb temperature)*100

= [(41.3-32.7)/ (41.3-28)]*100

=64.46%

Analysis of air flow through existing aluminum alloy fan:

Calculation of air velocity and flow rate through the cooling tower

Pitch angle (ɵ) = 11°

Pitch distance = r tanɵ = 6 tan 11 = 1.166

Pitch distance and velocity are connected by the following relation,

1.166 = [12*V]/[S*RPM]

V = air velocity (foot/minute)

RPM (Rotations per minute) = 420

S (fan series) = 70

1.166 = [12*V] / [70*420]

Air Velocity = 2795 ft /minute = 14m/sec.

To calculate ACFM (Actual cubic flow per minute),

V = [1.27*(ACFM)] / [DR^2 –(S/12)^2]

DR – diameter of fan ring in feet = 13ft

2795 = [1.27 (ACFM)] / [132 – (70/12)2]

ACFM = 318082.5 Cubic feet per minute

= 9020 meter cube per min

Analysis of air flow rate by variable pitch FRP fan:

FRP fan used are variable pitch axial fan. And as the pitch angle increases the volume of air drawn by the axial fan also increases. As the mass flow of air increases the amount available to water molecules also increases, as a result the heat transfer rate also increases

Pitch angle (ɵ) = 14°

Pitch distance = r tanɵ = 6 tan 14 = 1.495

2.75 = [12*V]/[S*RPM]

V = Velocity

RPM = 420

S = 70

2.75 = [12*V] / [70*420]

Air Velocity = 3665.12ft./minute = 18m/sec.

To calculate ACFM (Actual cubic flow per minute),

V = [1.27*(ACFM)] / [DR2 –(S/12)2]

DR – diameter of fan ring in feet = 13ft

3665= [1.27 (ACFM)] / [132 –70/12)2]*

ACFM = 416891.7 Cubic feet per minute

= 11804.9 meter cube

Percentage increase in volume flow rate of air = [(11804.9 – 9020) / 9020] * 100 = 30.8%

III NUMERICAL MODEL

The numerical analysis conducted is a multiphase model, consisting of two phases' water and air. Air is considered as the working fluid. The flow is considered to be transient, turbulent with constant fluid properties. Evaporation and condensation technique is used. Condensation frequency is kept nil. Standard k-epsilon turbulent model is used due to the presence of high vorticities. The main objective of this study is to determine the effect of increased mass flow rate of air achieved by the use of FRP fans instead of aluminum alloy fans.

Effects of varying the mass flow rate of water and air along with the effect of inlet water temperature are studied. For optimizing inlet air temperature are kept constant and mass flow rate of water and air are taken as optimizing variables. The above mentioned conditions, together with the boundary conditions form a set of coupled non-linear partial differential equations and will be solved using FLUENT 15.5

Description of Model

A 2D CFD model of a counter flow forced draft cooling tower is made. Its dimension are cooling tower height 608 inches diameter of fan 144 inches, water inlet pipe diameter 8inches, water basin length 400 inches, the cooling tower consist of 7 cells and the area of the fill is taken as 80900 square inches. Operating conditions include initial air velocity of 14m/sec, volume flow rate of water 2040 cubic meter per hour, inlet water temperature of 314k. The CFD model created is validated with the experimental results. And validated CFD model is used to determine the effect of inlet water temperature and effect of L/G ratio on heat transfer rate.

Geometry

Initially 2-D, CFD model of counter flow forced draft cooling tower is created considering important details some assumption were made to take into account the main features of real construction of cooling tower. 2-D symmetric model is developed; fixing the fill corresponding to real arrangement, Cooling tower shell is considered as a wall with zero thickness, Assuming symmetrical thermal and flow field in the model, only one half of the cooling tower is modeled with a symmetry boundary condition, The outlet of the peak cooler cells is created with rectangular cross- Reference conditions

- Tower height 15m

- Air inlet height 5m,10m
- Fill depth 1 m
- Tower basin diameter 10 m
- Water inlet height 11.5 m
- Water flow rate .566 lit/s
- Water inlet temperature 314K, 316k
- Ambient air temperature 304K
- Ambient air humidity 60 %

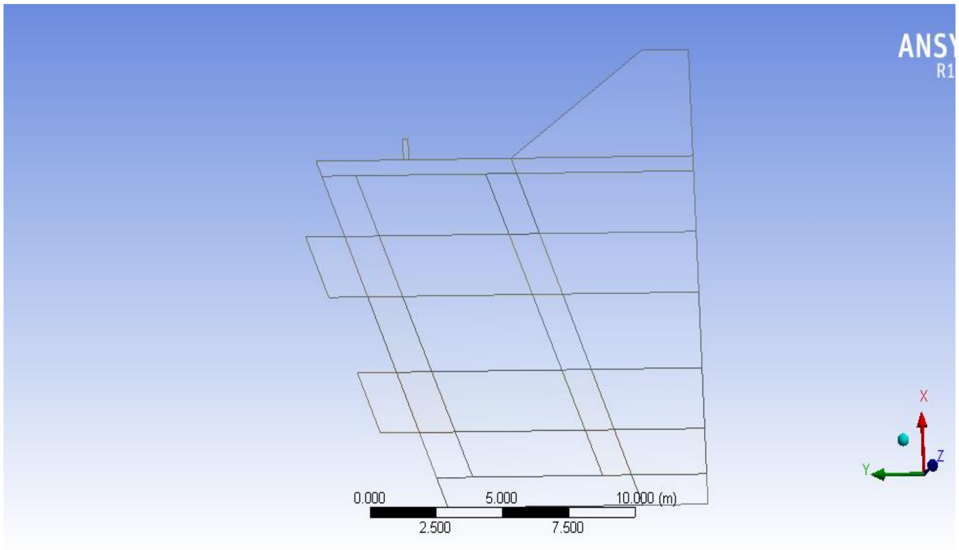

Fig 1.Geometry

Generation of mesh

Much attention is to be paid with mesh quality requirement recommendation in FLUENT 15.5. In order to have an appropriate resolution of the flow field inside the cooling tower the computational domain is defined into a large number of finite volume cells. Different parts are meshed with different element sizing. Fill zone are fine meshed. By using mapped face meshing the model with appropriate element sizing is created. After mesh generation naming of different parts of cooling tower is done. Grid independence study is conducted to ensure quality of the CFD model. Orthogonal quality, skewness, etc. were in the acceptable range

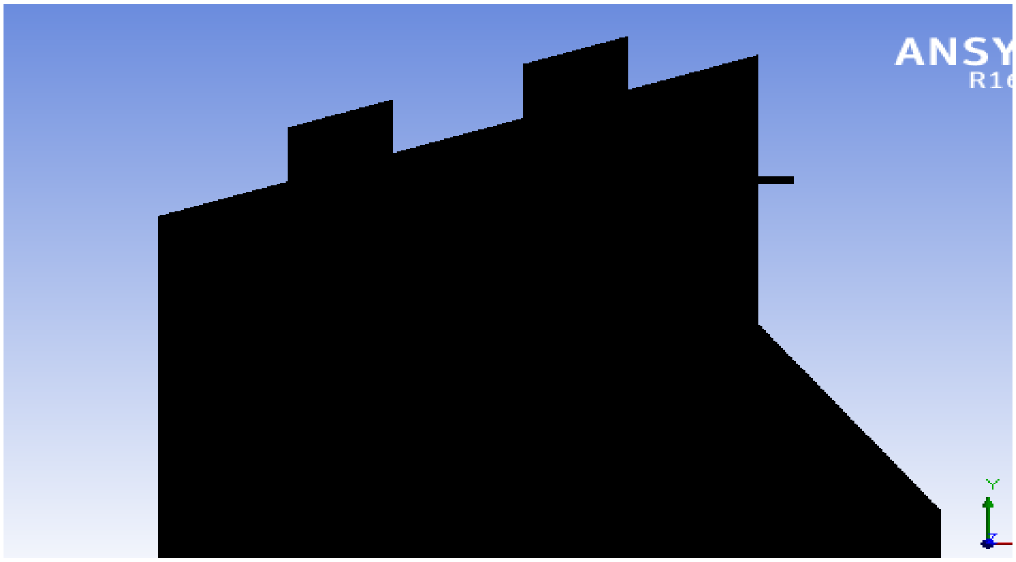

Fig 2.Meshing

Sl No	Case
Case 1	Initial air mass flow rate of 9020 meter cube per minute and inlet water temperature of 314k
Case 2	Increased air mass flow rate of 11805 meter cube per minute and inlet water temperature of 314k
Case 3	Initial air mass flow of 9020 meter cube per minute and inlet temperature Of 316k
Case 4	Increased air mass flow rate of 11805 meter cube per minute and inlet water temperature of 316k
Case 5	Increased air mass flow rate of 11805 meter cube per minute and Mass flow rate of water is reduced to .512 meter cube per minute

Table 3: Various cases studies

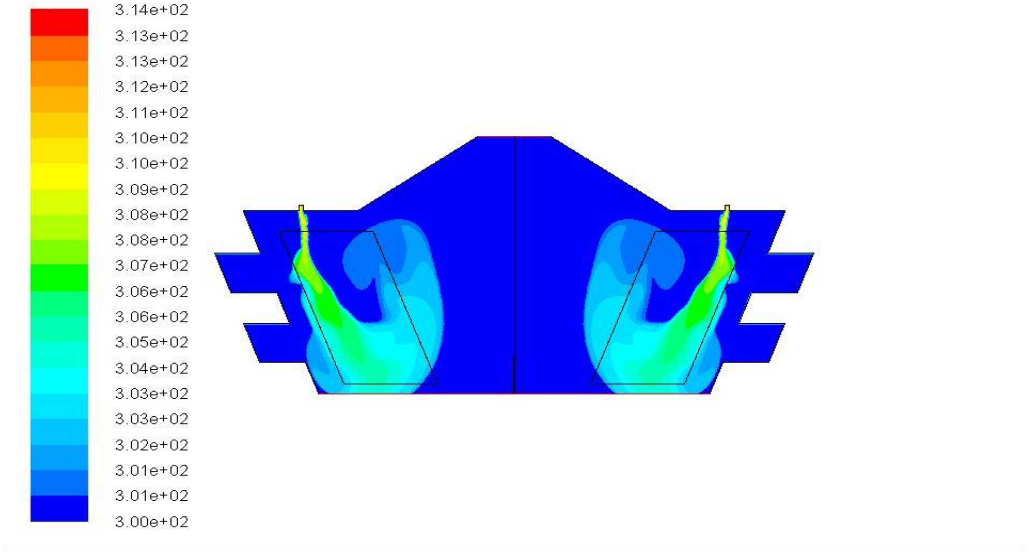

Fig (3) for case 1

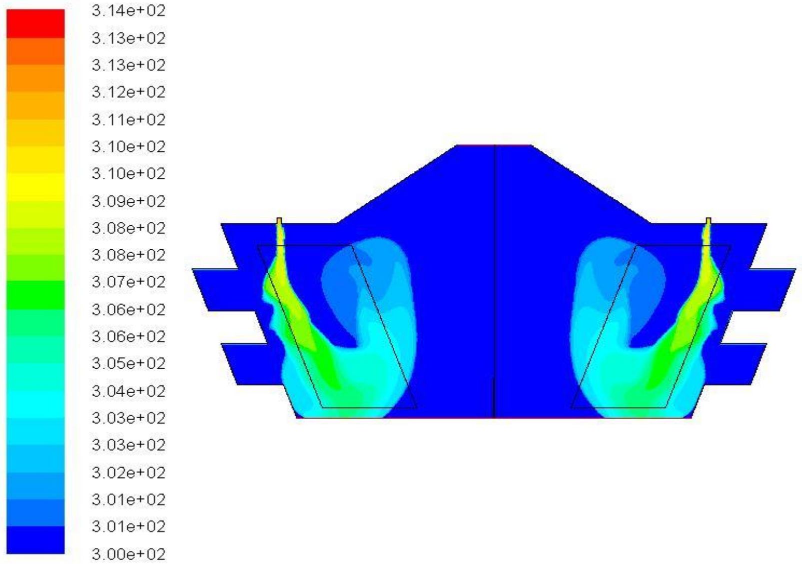

Fig (4) for case 2

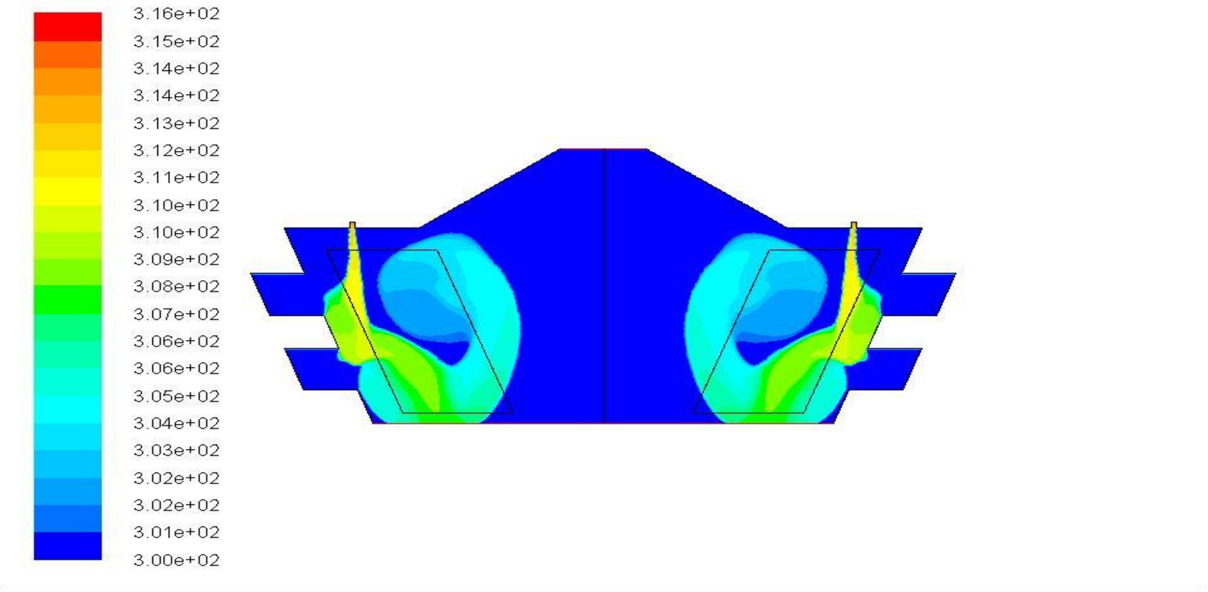

Fig (4) for case 3

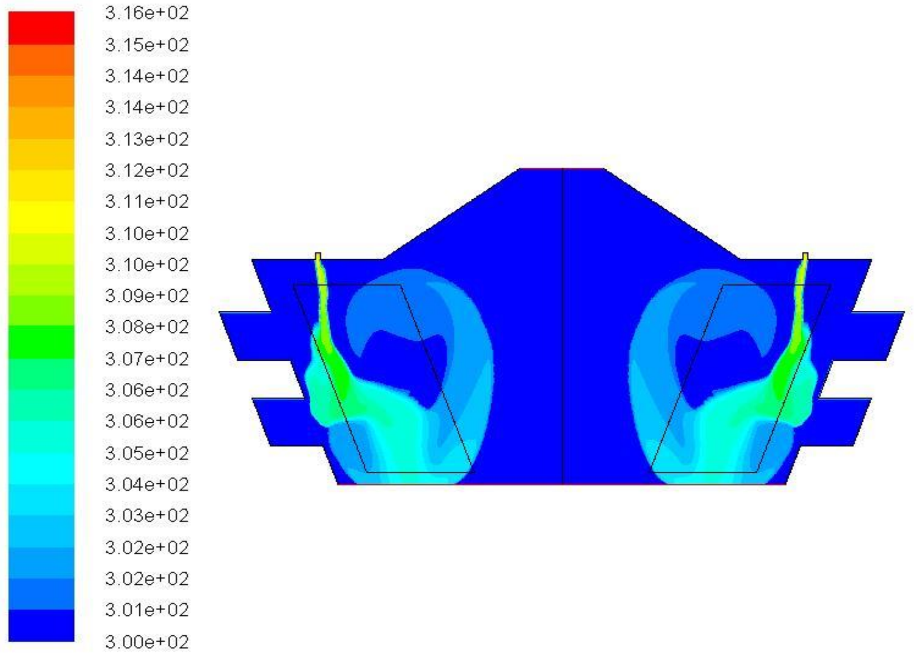

Fig (5) for case 4

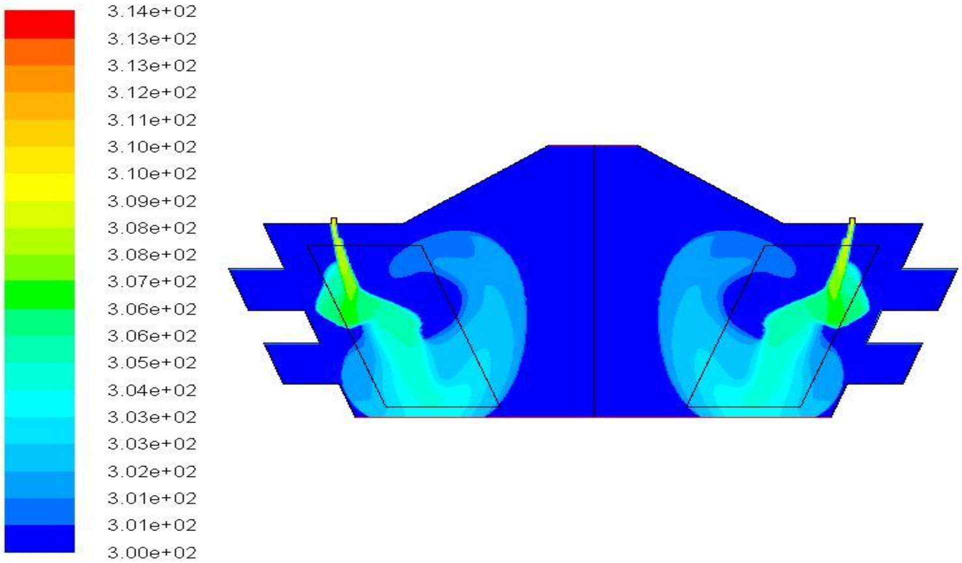

Fig (6) for case 5

IV RESULTS & DISCUSSIONS

The problem was modelled and solved in Ansys Fluent 15.5 and the results obtained are presented in Table 4. The Figure 4 shows the average outlet temperature of cooled water from the cooling tower in each case.

Sl No	Case	Average water outlet Temperature
Case 1	Initial air mass flow rate of 9020 meter cube per minute and inlet water temperature of 314k	306.4k
Case 2	Increased air mass flow rate of 11805 meter cube per minute and inlet water temperature of 314k	304.5k
Case 3	Initial air mass flow of 9020 meter cube per minute and inlet temperature Of 316k	307.8k
Case 4	Increased air mass flow rate of 11805 meter cube per minute and inlet water temperature of 316k	305.3k
Case 5	Increased air mass flow rate of 11805 meter cube per minute and Mass flow rate of water is reduced to .512 meter cube per minute	303.5k

Table 4 Average temperatures for each case

From the Table 4we can see that for case 5 the average water outlet temperature of the cooling tower is minimum and is 303.5 K. This is when the volume flow rate of air is increased by 30% with respect to initial case and mass flow of water is reduced to 0.512 cubic meter per hour.

The heat transfer rate of the cooling tower depends on liquid to gas ratio and by optimizing the liquid to gas ratio its performance can be increased. Initially the (L/G) ratio was 3.25 (in case 1, case 3) and it is reduced to 2.60 (in case 2, case 4, case 5). As the (L/G) ratio is reduced the amount of air available for each water droplets increases and more amount of heat is transferred from the hot water to air.In case 3 and case 4 the effect of inlet water temperature is studied, in both the cases the Outlet water temperature is increased. So the water inlet temperature is an important factor in cooling tower design .Objective of this experiment was to increase the performance of the cooling tower. Mass flow rate of water and air were taken as the optimizing variables.in case 5 the both the mass flow rate of air and water are varied to improve its performance. Three performance parameters are used to evaluate each case. The parameters considered are:

1. Effectiveness - 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)

2. Range of cooling towers - Cooling tower range is defined as the temperature difference between inlet water and outlet water temperature

3. Tower characteristic ratio - In a cooling tower, the heat transfer takes place due to two phenomena involving the sensible heat transfer and the evaporative heat transfer. Evaporative heat transfer further involves the mass transfer of water vapor into the air. This cumulative effect of both the heat transfer processes is accounted by tower characteristic ratio

Calculation of performance parameters for each cases:

Sl no	cases	Effectiveness of cooling tower = [(T1 – T2)/(T1 –WBT)]*100
1	Cases 1	65
2	Cases 2	83
3	Cases 3	57
4	Cases 4	78
5	Cases 5	88

Table 5 effectiveness of cooling tower for each case

Sl no	cases	Range of cooling tower (T1 – T2)
1	Cases 1	7.6
2	Cases 2	9.5
3	Cases 3	8.2
4	Cases 4	10.7
5	Cases 5	10.5

Table 6 range of cooling tower for each case

Sl no	cases	Tower characteristic ratio
1	Cases 1	0.8324
2	Cases 2	1.297
3	Cases 3	0.732
4	Cases 4	1.484
5	Cases 5	2.068

Table 7 tower characteristic ratio of cooling tower for each case

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VI CONCLUSION

The CFD analysis showed that by increasing the mass flow rate of air the performance of cooling tower can be improved. All the performance parameters such as cooling water range, effectiveness, tower characteristic ratio has increased. The increase in the effectiveness of cooling tower was about 20%. When the (L/G) ratio was reduced from 3.25 to 2.60. The outlet temperature of cooled water is reduced to 2k. The effect of inlet water temperature on the performance of cooling tower was studied keeping other parameters such as mass flow rate, injection height, and fill area constant it was found that effectiveness is reduced by 8%. The effect of water mass flow rate was also studied and it was found that by optimizing the mass flow rate of both water and air the effectiveness can be increased. But reducing the mass flow rate of water reduces the output of the cooling tower and inlet water temperature depends on the plant operations.

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