Numerical Investigation on Heat Transfer Enhancement of Fluidized Bed and Cost Estimation with CuO as a Nanofluid

Syed Zainul Abdin Yar [1], Nitin Dubey [2]
M. Tech Scholar[1], Prof. [2]
Department of Mechanical Engineering[1,2]
ALL SAINTS' College of Technology Bhopal, India

Abstract — Cooling tower operation is based on evaporative cooling as well as exchange of sensible heat. During evaporative cooling in a cooling tower, A small amount of the water this is being cooled is evaporated in a transferring flow of air to chill the relaxation of the water. Also when heat water comes in contact with cooler air, there can be realistic warmness transfer in which the water is cooled. A cooling tower is a warmth exchanger designed to lessen the temperature of water used in commercial and business programs. The method rejects waste warmth into the ecosystem through the cooling of a water movement to a decrease temperature.

With the advances in computational power and numerical techniques, Computational Fluid Dynamics (CFD) has emerged as a powerful tool to optimize design. In present study, Numerical simulations of cooling tower with different shaped fluidized bed are used to identify the temperature distribution with variation in mass fraction in nanofluid (ZnO). Within it has been found out Different mass fraction levels have also been found out at different fluidized bed in the cooling tower. The model of the fluidized bed cooling tower has been created in unigraphics 8.0 and analysis has been performed using ANSYS 15.0. The simulation has been done for both temperature and effectiveness. Obtained results have been validated with the available base paper experimental work.

The maximum amount of heat transfer is achieved on numerical simulation as the results obtained with respect to temperature on different mass fraction of nanofluid, thus 6.8% of average temperature is obtained on circular shaped fluidized bed and 13% average effectiveness is obtained in wavy plane shaped fluidized bed, hence the results shows convergence to base paper experimental investigation, The cost evaluation has been evaluated in present study for determination of breakeven cost and payback period.

Keywords— *Fluidized Bed, Cooling Tower, CFD, Nano fluid, Concentric Shaped Bed, Effectiveness, Temperature Distribution*

I INTRODUCTION

A cooling tower is a specialised warmth exchanger wherein air and water are delivered into direct touch with every different a good way to reduce the water's temperature. As this takes place, a small extent of water is evaporated, decreasing the temperature of the water being circulated via the tower. Water, which has been heated by way of an industrial method or in an air-conditioning condenser, is pumped to the cooling tower via pipes. The water sprays thru nozzles onto banks of material referred to as "fill," which slows the float of water via the cooling tower, and exposes as lots water floor region as feasible for max air-water contact. As the water flows thru the cooling tower, it is exposed to air, which is being pulled via the tower by way of the electrical motor-pushed fan. When the water and air meet, a small amount of water is evaporated, creating a cooling movement. The cooled water is then pumped lower back to the condenser or procedure system in which it absorbs warmth. It will then be pumped returned to the cooling tower to be cooled once again. Cooling towers are a unique sort of heat exchanger that permits water and air to come in contact with each different to lower the temperature of the new water. During the cooling tower working manner, small volumes of water evaporate, reducing the temperature of the water that's being circulated at some point of the cooling tower. The warm water is normally resulting from air con condensers or other industrial tactics. That water is pumped thru pipes at once into the cooling tower. Cooling tower nozzles are used to spray the water onto to the "fill media", which slows the water flow down and exposes the maximum quantity of water floor region viable for the nice air-water contact. The water is exposed to air as it flows at some stage in the cooling tower. The air is being pulled by using an motor-driven electric powered "cooling tower fan". When the air and water come together, a small quantity of water evaporates, developing an motion of cooling. The chillier water gets pumped again to the manner/gadget that absorbs warmth or the condenser. It repeats the loop again and again once more to constantly quiet down the heated equipment or condensers. For more information and mastering approximately cooling towers visit Cooling Tower Fundamentals by way of SPX Cooling.

Cooling tower is device to lessen outlet temperature of water flow into thru using the use of extracting warmth from water by way of manner of the use of addition of sensible heat to air as lots as Saturated scenario and evaporation of water itself which burn up to environment and CT implemented in chemical, petrochemical industries, air conditioner and refrigeration system. The significant common performance of cooling tower with one-of-a-type parameter like WBT, entropy, exergy and temperature of water contain which affected the element which includes drift eliminator, fill region and purpose is to growth warmth switch charge of water with direct touch of air. The vital reason to reduce warmness transfer is scaling and fouling of every problem of cooling tower.

II Cooling Tower Classification

Cooling towers can be classified in many different ways as follows

1 Classification by build

- Package type
- Field Erected type

2 Classification based on heat transfer method

- Wet cooling tower
- Dry Cooling tower
- Fluid Cooler

3 Classification based on type of Fill

- Spray Fill
- Splash Fill
- Film Fill

4 Classification based on air draft

- Atmospheric tower
- Natural Draft Tower
- Mechanical Draft Tower
  - Forced Draft
  - Induced Draft

5Classification based on air flow pattern

- Crossflow
- Counterflow.

III Cooling Tower Types

Cooling towers fall into two main categories:-

- Natural draft - Natural draft towers use very massive concrete chimneys to introduce air through the media. Due to the large size of these towers, they may be normally used for water waft quotes above 45,000 m3 /hr. These forms of towers are used most effective via utility energy stations.

- Mechanical draft- Mechanical draft towers make use of big fans to force or suck air via circulated water. The water falls downward over fill surfaces, which assist boom the contact time among the water and the air - this facilitates maximize warmth transfer among the 2. Cooling costs of Mechanical draft towers depend upon their fan diameter and velocity of operation

IV LITERATURE REVIEW

Imani-Mofrad etal. (2016) [1] - the experimental research at the effect of numerous types of stuffed beds at the thermal universal overall performance of a wet cooling tower through the usage of zinc oxide (ZnO)/water nanofluid. Different concentrations of ZnO/water Nano fluid had been prepared through -step approach thru the usage of natural water with electric powered powered powered conductivity of two lS/cm. First, through manner of the use of ZnO/water Nano fluid (0.08 wt%), effect of six great stuffed beds were investigated at the thermal typical performance of the cooling tower. Moreover, after each check the completed stuffed bed end up reviewed so that you can have a study any aggregation or settlement of nanoparticles on the surfaces of the mattress. It changed into decided that the usage of metal reticular bed (Bed 1) is the first-rate desire while ZnO/water nanofluid is used. In the possibility word Bed 1 results better thermal inclinations for cooling tower and masses a incredible deal a lot less settlement of nanofluids. Then outstanding consciousness of ZnO/water Nano fluidin the shape of zero.02–zero.1 wt% is hired within the cooling tower thru manner of using Bed 1. The results showed thatby using nanofluids, cooling variety, tower function (TC) and effectiveness of cooling tower are enriched in comparison to water.

Satish Kumar (2016) [2]- this studies in most of the locations, the water deliver is confined and thermal pollution is also a severe mission. Considering the trendy boom of interest in reading the ones troubles and solving them for the well-being of the environment, this artwork is an try to cope with the era, applications of cooling towers. In this gift test, the elements affecting the performance like environmental situations, cooling water fine had been studied on Induced draft cooling tower of 32 Mw thermal strength plant. The regular overall performance parameters like variety, method, cooling capability, evaporation loss liquid to gasoline ratio were evaluated at the same time as the plant is operated at whole load and detail load beneath the equal water go with the glide costs.

Donald R.Bakeretal.(2016) [3] - the research in predicting cooling tower common regular overall performance are right away associated with the precision this is required. There is not any extraordinarily-modern-day-day settlement on what constitutes the best diploma of accuracy. The clients are reluctant to permit a tolerance of one⁄2° in technique on the identical time as recognition assessments are involved. Cooling tower potential is more as it should be expressed in terms of water rate for a given set of situations. This capacity is about proportional to variations in approach even as distinct situations are ordinary, so 1⁄2° corresponds to a distinction of 10 in keeping with cent in functionality for a five° approach. This gives an illustration of what constitutes an much less costly maximum restrict of proper tolerance.

A. Vijayaragavan et al. (2016) [4] - the research while cooling the refrigerant, the cold water will become the current water. The heat water temperature is decreased through manner of cooling towers. When warmth water enters into the delivered approximately draft cooling tower and sprayed through nozzles. So heat water is converted into bloodless water .The powerful cooling of water is based upon upon the dry bulb temperature and wet bulb temperature, length, height of the cooling tower and speed of air .The mission deals with the overall typical overall performance have a check and assessment of delivered on draft cooling tower, this is one of the identifying elements used for developing the electricity plant performance moreover modelling and evaluation of waft the use of software program application software .A cooling tower is an enclosed tool for the evaporative cooling of water through contact with the air. Cooling tower is a warm temperature rejection device. Common software application program includes cooling the circulating water utilized in oil refineries, petrochemical, and honestly considered one of a type chemical plants, thermal energy stations and HVAC device for cooling homes. The performance and effectiveness of cooling tower is primarily based upon on big form of parameter like inlet air attitude, inlet and outlet temperature of air and water, fill substances, fan speed.

A. Ataeietal. (2008) [5] - this research common common overall performance evaluation of moist cooling tower is finished. To attain this cause, first, thermal behavior of counter-drift moist cooling tower is studied thru a simulation model. The effect of the environmental conditions on the thermal overall performance of the cooling tower is investigated. The cooling tower common normal performance is simulated in terms of severa air and water temperatures, and of the ambient situations. This version lets in the use of a variety of packing materials. Second, the exergetic assessment is executed to study the cooling tower functionality of preferred overall performance development

V METHODOLOGY

3.1 Introduction

For growing the cooling effectiveness we have taken into consideration the bench mark of a cooling tower with size 13m×10m×14m and evaluating two one-of-a-kind designs reticular and wavy aircraft which changed into identified the great performance on base paper. After evaluation we suppose to calculate the application feasibility and calculate fee. For these types of purposes we can use CAD and ANSYS as simulating device.

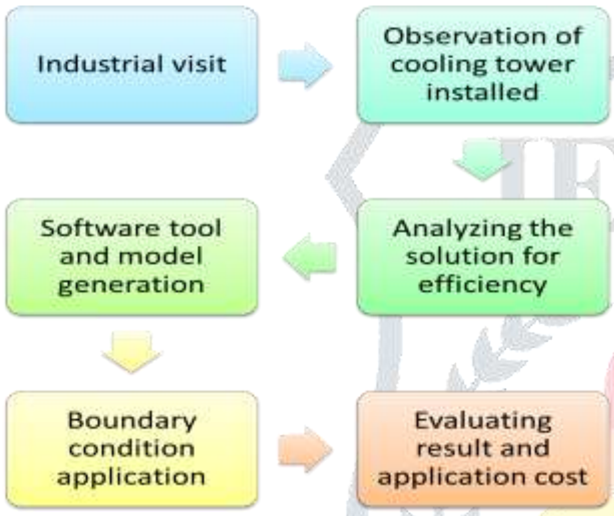

Figure 3.1 - Flow chart of methodology on cooling tower.

3.2 Software tool and model generation ANSYS (Fluent)

Computation Fluid Dynamics consists of several domains to solve fluid flow problem like CFX, fluent (poly flow), fluent (blow moulding), fluent, fluent solver works under computational fluid dynamics, it obeys the three governing equation with respect to base equation (Eulerian equation) i.e. energy equation, momentum equation and continuity equation by applying or solving through this algorithm, the further results were obtained and variation could be determine.

Boundary condition for solving problem on fluent solver: In a finite volume method with respect to governing equation, boundary conditions were applied to simulate to present model, "inlet" this boundary conditions indicate the inlet of fluid with a desire velocity on a model, "outlet" this definition of fluid indicates that the outlet flow of fluid, further heat flux, radiation, convection, mixed (conduction + convection) were applied on present model for simulation.

3.3 Boundary Conditions applications

Boundary condition needs to be defined for getting the output result. The computational domain employed is shown in Figure 3.3. The flow is assumed to be three-dimensional, incompressible, steady, turbulent and since the heating is low, constant air properties. Radiation effect is ignored.

Table 3.1: Boundary conditions

Boundary Conditions	Governing Equations
Inlet	Air with varying velocity for different cases
Outlet	Pressure with value 1 atm
Turbulence Model	K-ε Model
Number of Iteration	500
Convergence Criteria	Semi-Implicit Pressure Linked Equation

3.4 Finite volume method

Finite Volume Method is used to clear up the fluid float issues by way of acquiring the convergence of Eulerian equation and governing equation, this approach works on extent of fluid or volume of fraction, it includes electricity equation, momentum equation and continuity equations with respect to stress force, viscous force or gravity force to resolve the fluid float problem, in case of warmth exchanger, radiation, turbulence, laminar flows, acoustics and also deals with aerodynamics, HVAC.

3.5 Governing equations:

3.5.1 Continuity equation:

$$A_1V_1=A_2V_2$$

A_1 = area of inlet

V_1= velocity at inlet

A_2= area of outlet

V_2= velocity at outlet

This equation shows the flow is pressure based or density based i.e. if a flow is pressure based the vortices and stream line of fluid is normal, if the flow is density based the fluid flow and stream line is in a high pressure.

3.5.2 Momentum Equation

This equation justified that the flow of fluid consists of definite mass and product of velocity with respect to mass to determine the momentum of fluid flow.

$$\frac{\partial}{\partial x_i}(\rho u_i u_j) = \frac{\partial}{\partial x_i}\left(\mu \frac{\partial u_i}{\partial x_j}\right) - \frac{\partial p}{\partial x_j} \quad (4.1)$$

3.5.3 Energy Equation

This equation works on present simulation model when heat flux and radiation were applied on boundary condition to determine the temperature variation on fluid flow and on heat transfer solid element to determine temperature variation.

$$\frac{\partial}{\partial x_i}(\rho u_i T) = \frac{\partial}{\partial x_i}\left(\frac{k}{C_p}\frac{\partial u_i}{\partial x_i}\right) \quad (4.2)$$

3.6 Procedure for solving problem with fluent:

- Pre- processor
- Solver
- Post- processor

3.6.1 Pre-processor

It is a process on which model is created for simulation, meshing of the domain is done and boundary conditions were applied i.e. inlet, outlet, heat flux, wall, etc.

3.6.2 Solver

It is used to apply the governing equation and base equation on pre-processor to determine the variation on fluid flow.

3.6.3 Post processor

It is used to determine the results obtaining from fluent solver in a form of contour plots, in a form of a velocity and stream line contour plots etc.

3.7 MODELLING AND ANALYSIS

Geometry was modeled in CREO 5.0 and then imported to ANSYS workbench 15.0 where meshing was done, then the mesh was exported to FLUENT. The boundary conditions, material properties and encompassing properties were set through parameterized case files. FLUENT solves the problem until either the convergence limit is met or the amounts of iterations specified by the user are complete.

The procedure for resolving any problem is:

- Create the geometry.
- Meshing of the domain.
- Set the material properties and boundary conditions.
- Obtaining the solution

3.8 Preparation of the CAD Model

The dimensions of the computational domain which consist of cooling tower were based on the base paper experimental work. After this process, the constraints are applied and this way the model is achieved in CREO 5.0. Table 4.1 & Table 4.2 show the parameters of Fluidized bed cooling tower.

Table 3.2 Geometric Parameters of Fluidized bed cooling tower

Diameter of Fluidized bed cooling tower(mm)	Height of Fluidized bed cooling tower (mm)
160	400

Discreatization

the discreatization is done to apply governing equation for evaluation of effectiveness and temperature distribution the fluent solver is used for analyzing the present cooling tower model with respect to navier-stokes equation.

Boundary Conditions

Boundary condition needs to be defined for getting the output result. The computational domain employed is shown below in table. The flow is assumed to be three-dimensional, incompressible, steady, turbulent and since the heating is low, constant air properties. Radiation effect is ignored.

Boundary Conditions	Governing Equations
Inlet	Air with varying velocity for different cases
Outlet	Pressure with value 1 atm
Turbulence Model	K-ε Model
Number of Iteration	500
Convergence Criteria	Semi-Implicit Pressure Linked Equation

- **Continuity equation:**

$$A_1 V_1 = A_2 V_2$$

A_1 = area of inlet

V_1= velocity at inlet

A_2= area of outlet

V_2= velocity at outlet

This equation shows the flow is pressure based or density based i.e. if a flow is pressure based the vortices and stream line of fluid is normal, if the flow is density based the fluid flow and stream line is in a high pressure.

- **Momentum Equation**

This equation justified that the flow of fluid consists of definite mass and product of velocity with respect to mass to determine the momentum of fluid flow.

$$\frac{\partial}{\partial x_i}(\rho u_i u_j) = \frac{\partial}{\partial x_i}\left(\mu \frac{\partial u_i}{\partial x_i}\right) - \frac{\partial p}{\partial x_j} \qquad (4.1)$$

- **Energy Equation**

This equation works on present simulation model when heat flux and radiation were applied on boundary condition to determine the temperature variation on fluid flow and on heat transfer solid element to determine temperature variation.

$$\frac{\partial}{\partial x_i}(\rho u_i T) = \frac{\partial}{\partial x_i}\left(\frac{k}{c_p}\frac{\partial u_i}{\partial x_i}\right)$$

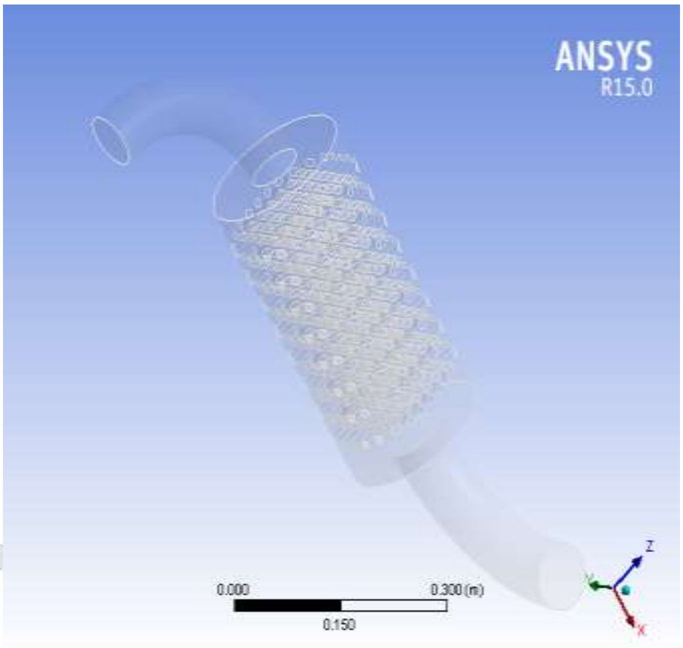

Fig. 3.3 (a): Metal reticular shaped fluidized bed cooling tower.

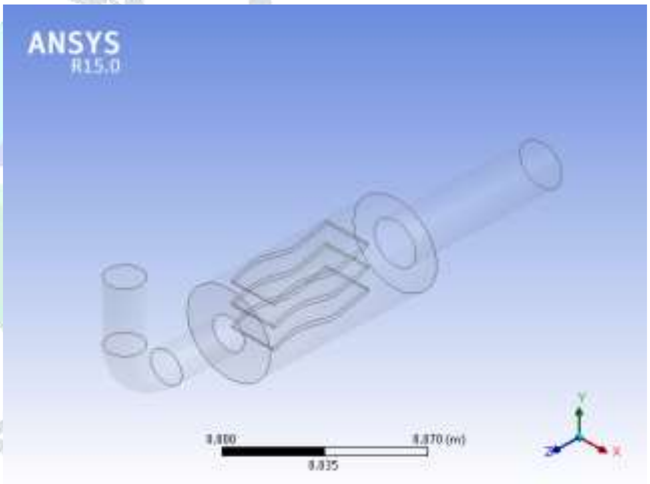

Figure 3.3 (b): 3D Model of Metal wavy planes shaped fluidized bed cooling tower.

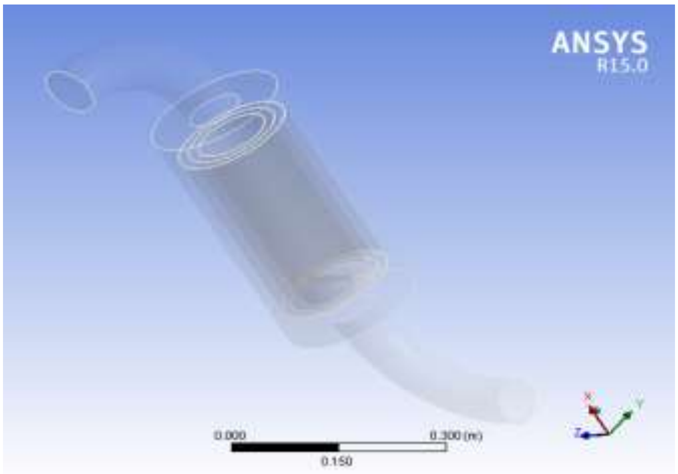

Figure 3.3 (c): 3D Model of Circular shaped fluidized bed cooling tower.

Above shown figure 3.3 (c) represent a CAD model of Circular shaped fluidized bed here it is shown inlet and outlet pipes which is connected to the cooling tower shell also three concentric fluidized bed shells.

3.9 Meshing of the Domain

After modelling the geometry in CREO, it was imported to ANSYS workbench layout modular for its discretization. Meshing is dividing the complete geometry of hobby into small components. Mesh density varies primarily based upon the assigned refinement component. Mesh is the critical issue part of a excessive remarkable convergence. There are 3 sorts of meshing. These are Hexahedral Cartesian, Hexahedral Unstructured and Tetrahedral meshes. Hexahedral Cartesian mesher generates definitely dependent meshes. It's suitable for gratis form of geometries. But beside the factor for fashions in which curved surfaces exist. Hexahedral Unstructured mesher creates nodes and parts of hexahedral cells dominantly and tetrahedral cells anywhere essential. Tetrahedral mesmerise is designed for very difficult geometries where the other two cannot be used. For models related to spheres or ellipsoids hexahedral mash are vain.

- **Description of mesh**

There are 3 types of meshing. These are Hexahedral Cartesian, Hexahedral Unstructured and Tetrahedral meshes. Hexahedral Cartesian mesher generates totally structured meshes. It's appropriate for free kind of geometries for metal reticular.

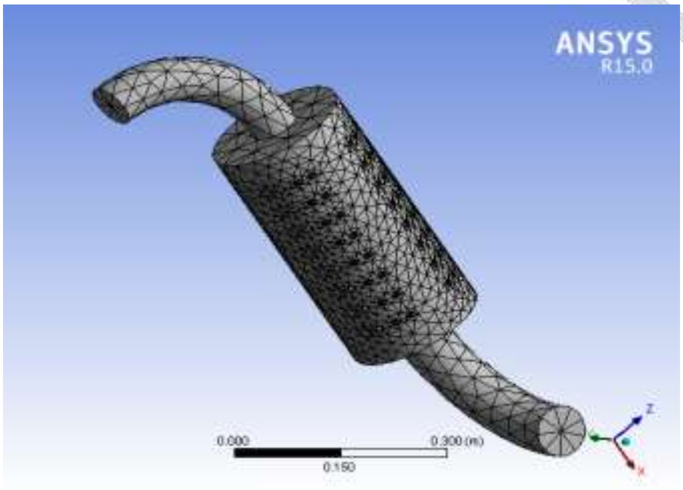

Figure 3.4 Metal reticular shaped fluidized bed cooling tower.

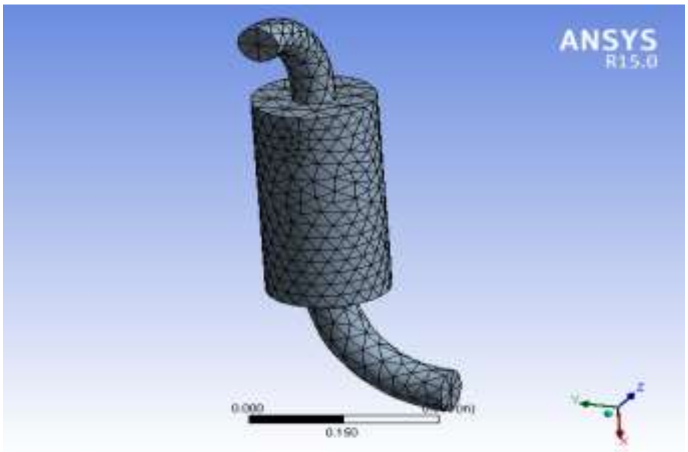

Figure 3.5 Metal wavy planes shaped fluidized bed cooling tower.

There are 3 types of meshing. These are Hexahedral Cartesian, Hexahedral Unstructured and Tetrahedral meshes. Hexahedral Cartesian mesher generates totally structured meshes. It's appropriate for free kind of geometries for concentric fluidized bed.

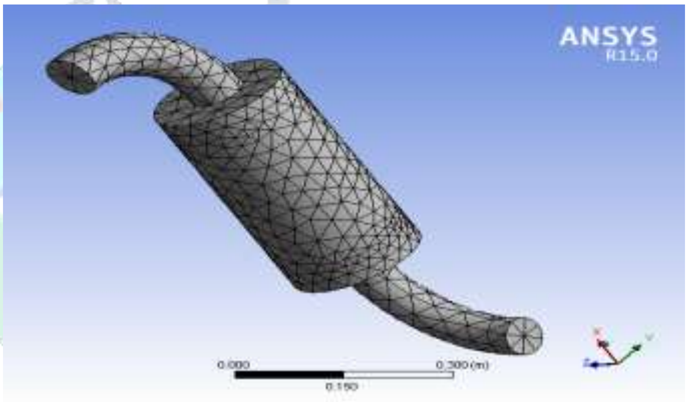

Figure 3.6 Circular shaped fluidized bed cooling tower.

3.10 Material Properties

(i) Material

(a) Air (fluid) [Zone]

(b) ZnO (semi-Liquid)

Table 3.3: Materials Properties

Properties	**Air**	ZnO (semi-Liquid)
Density, ρ	1.225 Kg/m^3	5.606 gm/m^3
Thermal Conductivity, K	0.0242 W/m-K	571 W/m-K
Specific Heat, C_p	1006.43 J/Kg-K	0.51 J/g ^0C
Viscosity, μ	$1.7894x10^{-5}$	-----------------

3.11Boundary Conditions

Boundary condition needs to be defined for getting the output result. The computational domain employed is shown in Figure 3.3. The flow is assumed to be three-dimensional, incompressible, steady, turbulent and since the heating is low, constant air properties. Radiation effect is ignored.

Table 3.4: Boundary conditions

Boundary Conditions	Governing Equations
Inlet	Air with varying velocity for different cases
Outlet	Pressure with value 1 atm
Turbulence Model	K-ε Model
Number of Iteration	500
Convergence Criteria	Semi-Implicit Pressure Linked Equation

Table no. 3.3 represents the boundary conditions and governing equations for analysis of fluidized bed cooling tower system i.e. inlet, outlet, also the turbulence model is used with hydraulic diameter to apply actual conditions of cooling tower, the convergence criteria is used as semi-implicit pressure linked equation..

VII RESULT AND DISCUSSION

4.1 Temperature distribution on cooling tower with different fluidized bed:

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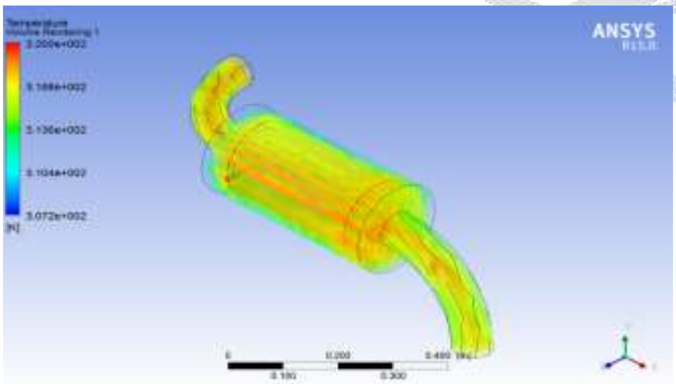

Figure: 7.1 Temperature variation in circular shaped fluidized bed cooling tower at variable mass fraction of ZnO nanofluid.

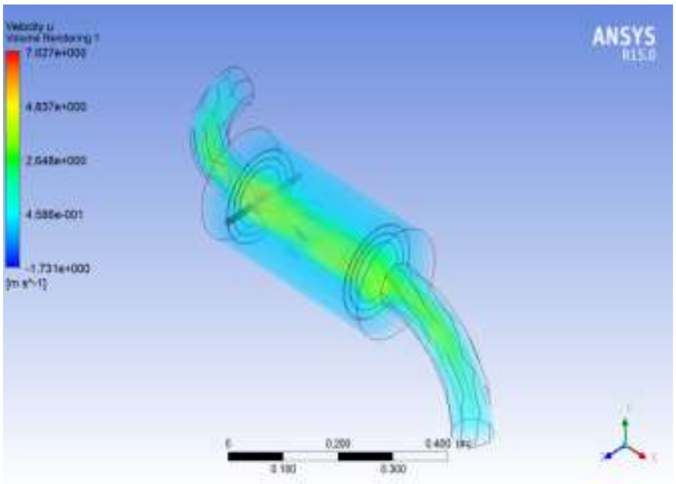

Figure*: 7.2 Velocity variation in circular shaped fluidized bed cooling tower at variable mass fraction of ZnO nanofluid.*

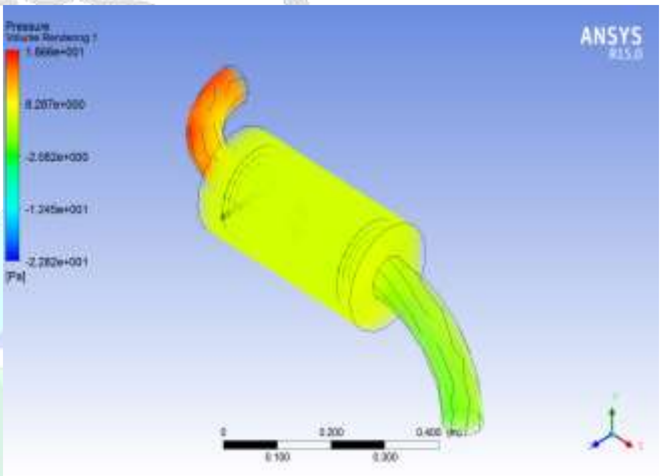

Figure: 7.3 Pressure variation in circular shaped fluidized bed cooling tower at variable mass fraction of ZnO nanofluid.

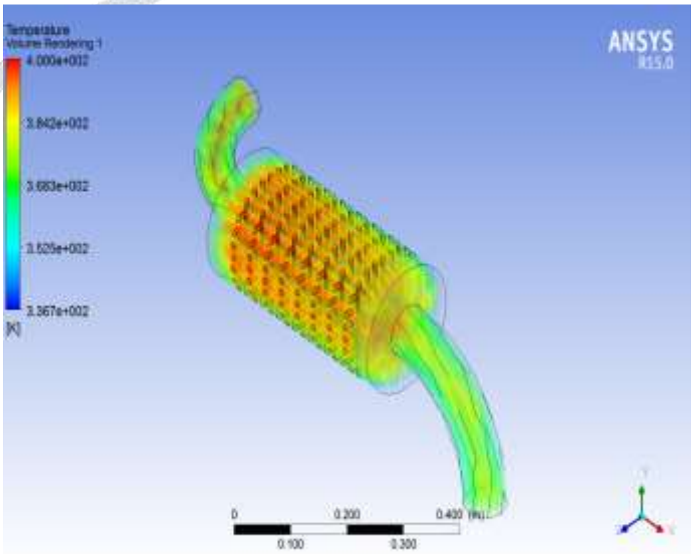

***Figure**: 7.4 Temperature variation of Metal Recticular Bed shape bed of cooling tower.*

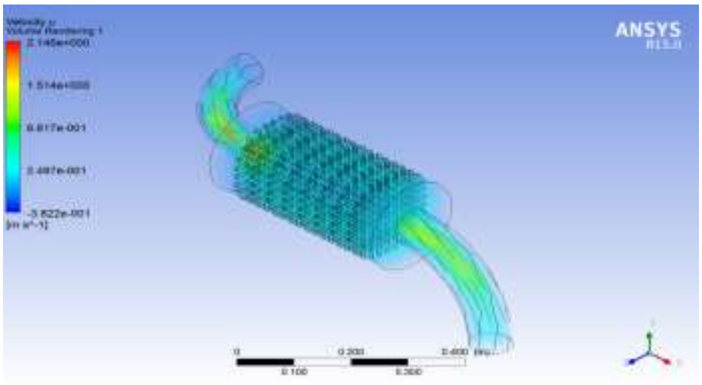

Figure: 7.5 Velocity variation of Metal Reticular Bed shape bed of cooling tower

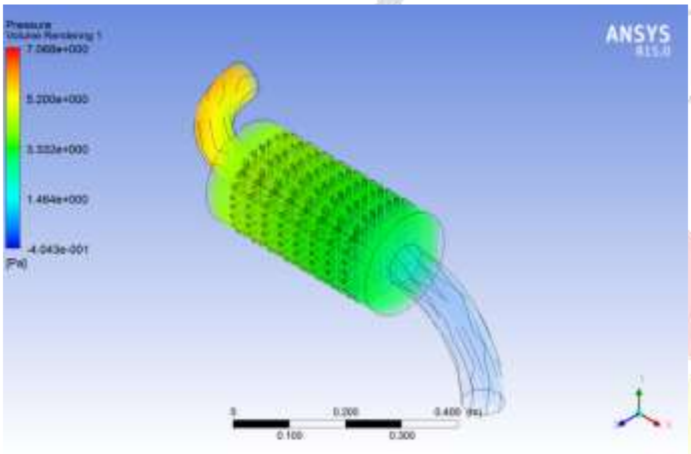

Figure: 7.6 Pressure variation of Metal Reticular Bed shape bed of cooling tower.

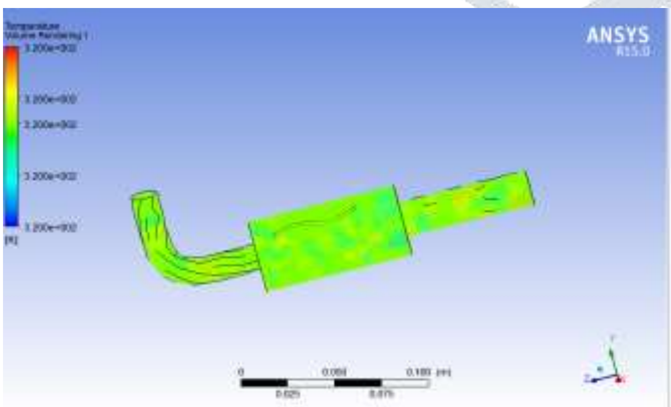

Figure: 7.7 Temperature variation of Metal Wavy Planes Bed of cooling tower.

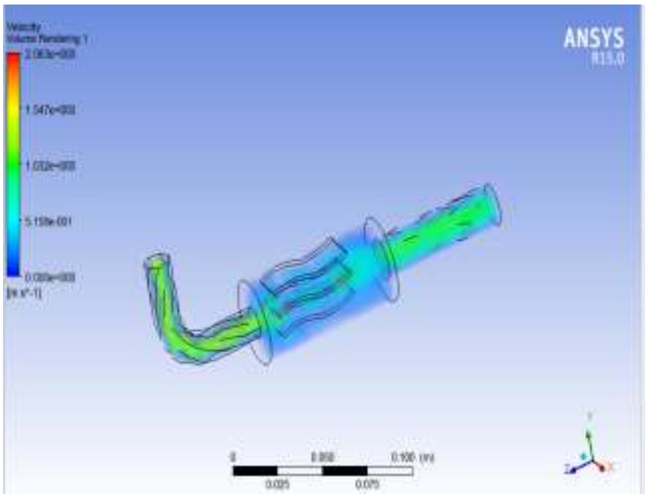

Figure : 7.8 Velocity variation of Metal Wavy Planes Bed of cooling tower.

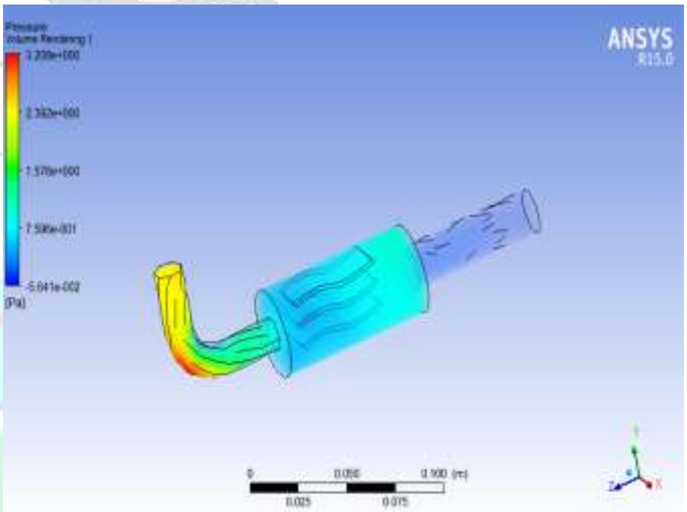

Figure : 7.9 Pressure variation of Metal Wavy Planes Bed of cooling tower.

7.4.3 Effectiveness of different shaped Fluidized bed Cooling Tower

Effectiveness of different Fluidized Bed Cooling Tower		
Plane Wavy Bed	Metal Reticular Bed	Optimized bed
54.6	55	57.8
55.8	57	60.8
55	57.36	60.38
56.9	60	66.9
58.33	62.38	68.3

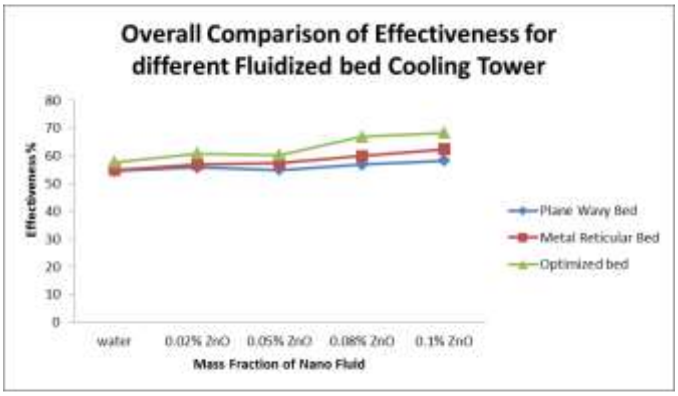

Figure : 7.10 Variation in Effectiveness of different Fluidized Bed Cooling Tower

7.5.1 Wall Fluxes of different shaped Fluidized bed Cooling Tower

Wall Fluxes of different Fluidized Bed Cooling Tower		
Plane Wavy Bed	Metal Reticular Bed	Optimized bed
0.037	0.031	0.27
0.121	0.115	0.109
0.226	0.223	0.215
0.379	0.370	0.359
0.565	0.560	0.538

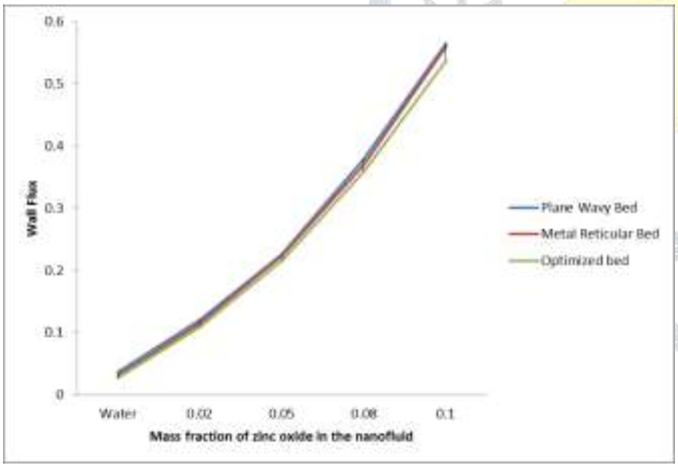

Figure: 7.11 Variation in Wall fluxes of different Fluidized Bed Cooling Tower

Annual saving Calculation		
year	**Saving in Rs**	**benchmark**
1	15768000	240000000
2	31536000	240000000
3	47304000	240000000
4	63072000	240000000
5	78840000	240000000
6	94608000	240000000
7	110376000	240000000
8	126144000	240000000
9	141912000	240000000
10	157680000	240000000
11	173448000	240000000
12	189216000	240000000
13	204984000	240000000
14	220752000	240000000
15	236520000	240000000

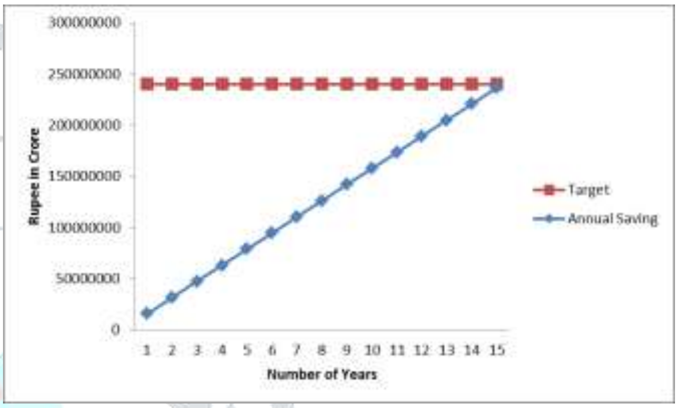

Figure 4.16 – Represents a Breakeven Pointwith respect to total number of years.

VIII CONCLUSION

1. Computational model has been developed in CREO 5.0 and analysis has been done in Fluent 15.0.
2. Numerical results are in good agreement with base paper results.
3. The internal consistency of the results confirms the validity of the CFD model.
4. From results, higher value of temperature is found out for metal reticular and plane wavy fluidized bedas compared to circular shaped fluidized bed.
5. Circular shaped fluidized bed shows more convergence than metal reticular and plane wavy fluidized bed thus result shows improvement of 6.8% average deviation on temperature.
6. Effectiveness of circular shaped fluidized bed shows 0.73% average on simulation results than base paper results thus convergence on effectiveness is achieved.

7. Circular shaped fluidized bed shows the minimum wall flux in comparison to other fluidized bed in the 0.02 mass fraction of Zinc oxide in the nano fluid

7. Thus numerical simulation of fluidized bed cooling tower with respect to mass fraction of ZnO nanofluid shows an optimum result on both temperature and effectiveness.

8. Breakeven point for cost has been achieved in a payback period of 15 years.

Future Scope

1. CFD analysis can also be done for traditional cooling tower using same Methodology and Boundary condition.
2. Inclination angle of fluidized bed can be further varied and its effect can be studied on its performance.
3. Same methodology can be used to check the performance of indirect type of variable shaped fluidized bed also.
4. Surface area of fluidized bed should be fixed on different angles to increase mass transfer and for better temperature distribution.
5. Velocity of fan could be increased in case of cooling tower process for a higher amount of temperature removal.
6. Production cost has to be reduced for polyurethane (PU) binder..

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