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Improving Thermal Power Plant Efficiency

Bandi DayaSagar[1], Research Scholar, DJR college of Engineering and Technology, Vijayawada & India.

Akkimsetti Somaraju[2], Assistant Professor, DJR college of Engineering and Technology, Vijayawada & India.

ABSTRACT - Energy is the most important requirement for the growth and development of a nation since it is the basic necessity for every sector. The most common form of energy used is electricity. Thus, generation of electricity is the most significant requirement. Thermal electric power generation is one of the major methods for generation of electricity. In this research a tube from power plant steam condenser is considered and analysed to improve the heat transfer rate in the tube through computational fluid dynamics a volume model of tube with 28mm Diameter and 13.4 m Length is considered from the literature and then the model is simulated for mass flow of 10000kg/s to 29000 kg/s further research is done to optimise the shape of the pipe to increase heat transfer rate for this a corrugated tube concept is considered and analysed the corrugations on the tube is introduced at each 150mm pitch from the inlet to investigated the Flow and temperature distribution along the pipe results from the simulation is presented and discussed in the Project.

Keywords: Computational Fluid dynamics , Steam condenser Tube , Heat transfer , Ansys Fluent

I. THERMAL POWER PLANTS- AN OVERVIEW

Power and more specifically electricity is the most aspect of human life today on earth. All the nations around the globe are driven by electricity, be it any sector, any industry, commercial or noncommercial. Thermal power plants are the most conventional source of electricity generation. Thermal power plants use primary energy sources like coal, natural gas, nuclear and pother similar sources to generate secondary energy that is electricity.

Thermal power plants are the basis of electric power industry. These power plants produce electric energy by transformation of thermal energy freed while fossil fuel is burned. On the basis of the type of equipment, thermal power plant can be steam-turbine, steam-gas, gas-turbine, and diesel power plants. The elementary parts of power plant are turbines, boiler, electric units, compressors, pumps, heat exchangers and other such equipment. Steam-turbine Thermal power plants are of two types namely combined heat and power generation plants and condensation power plants.

As explained by Kumar, (2016),the working of the thermal power plant involves burning of fuel (for example coal) which releases energy in form of heat. This heat is used to boil water and convert it into steam of high pressure and temperature. The steam thus generated is used to rotate the turbine which is connected to a generator. The generator here converts the kinetic energy of turbine into electric energy.

II. NEED TO IMPROVE THERMAL POWER PLANT EFFICIENCY

Generation of electricity is of at most importance to mankind due to the immense dependence of human race on electricity. Generation of electricity is not an easy task, and requires huge investments in terms of finances and resources at the expense of environment. Since there are so many aspects associated with the generation of electricity, it is of great importance that the process of generation of electricity is of maximum efficiency and effectiveness. Since generation of electricity is mostly contributed by thermal power plants globally, there efficiency is to be maintained and to be improved even more with changing technology and related developments.

The efficiency of a power plant describes the output of the power plant relative to the heat value of the fuel used (total electrical efficiency).

The efficiency of a power plant presents its ability to use fuel for generation of electricity. The better is the use of the fuel; the greater is the efficiency of the thermal power plant. As per (Khatib, 2012), the efficiency of a power plant can be defined as "the percentage of energy contained in the fuel that is converted into electricity. The rest is lost during conversion or in the form of exhaust heat. The greater the efficiency, the less carbon dioxide (CO_2) released per generated kilowatt-hour". The efficiency of power plant can be improved by reducing the above stated "rest" in the definition.

Thermal power plants are known to undergo a lot of wastage. As a matter of fact, thermal power plants cannot

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transform all of their heat energy into electricity which then reduces their efficiency. For example, the loss of heat from gas turbine power plants with exhaust gases leads to reduction in its thermal efficiency. The loss of energy in the environment not only causes financial losses but also degrades the environment. Further, it hits hard on the sustainable development of human race. This is because the fuel which is mainly non-renewable, is not being utilized to its fullest thereby wasting the important resources. Finally the commercial aspect comes into picture that is the ever increasing demand of electricity in the world. To meet the increasing demand, with presence of limited resources at expense, all the efforts are to be made to increase the efficiency of thermal power plants.

The use of steam is most common for turning the turbines in these power plants. This is mainly because highest specific heat and highest heat transfer coefficient along with highest latent heat. It is easy to control and distribute while being cheap.

III. Literature Review

Hong & Lee, (2018b) suggested that to improve the efficiency of power plant, efficiency of the Rankine cycle has to be improved. The efficiency of the Rankine cycle can be improved by optimizing the pressure at the boiler, steam temperature and the pressure at the turbine outlet. The temperature at which boiling takes place is increased by increasing the main steam pressure at the boiler which raises the heat added to the steam. This increases the efficiency of the system but with a flaw that is it increases the wet steam at the turbine outlet. This leads to the corrosion of turbine blade which then reduces the efficiency of the system. A solution to this decreasing efficiency can be compensated via using a reheat cycle. The reheat cycle stops the wet steam formation at the high-pressure turbine outlet. The larger second turbine in the reheat cycle decreases the harm caused by moisture to the blades and has a lower pressured output thereby increasing the efficiencies of the system. The other way to increase efficiency of thermal power plant is raising the heat of the boiler's steam input. As the temperature of the feed water is raised, the amount of heat input required of the boiler is reduced. A feed water heater is used to heat the wet steam leaving the feed water and the extraction steam. This system is called the regeneration cycle. The regeneration cycle consists of many high and low-pressure feed water heaters along with a deaerator for heating and removing air. The efficiency of the cycle is enhanced by increasing the number of feed water heaters. The use of a reheat cycle provides the benefit of evading corrosion and frictional losses in the turbine and the regeneration cycle increases the thermal efficiency. Therefore, combining these two cycles in form of a regenerative reheat cycle can improve the efficiency as well as facility operation.

Vandani, Bidi, & Ahmadi, (2015) conducted a research on understanding the influence of heat recovery of blow down of the boiler on the total efficiency of Rankine cycle of power plant. Herein the energy and exergy investigation of boiler blow down heat recovery was conducted. A steam power plant in Iran was selected for the research. For conducting the research and increase the plant efficiency, two optimization algorithms were used namely genetic algorithm and particle swarm optimization algorithm. The decision variables used in the study were pressure and temperature of boiler outlet stream and extraction pressure from steam turbine. The results found that using blow down recovery technique, 0.72% increase in the net generated power was observed. Also energy efficiency of the system increase by 0.23 and that of exergy increased by 0.22. The temperature and pressure of boiler outlet stream presented a higher impact on the exergy efficiency of the system in respect to the other decision variables. In this paper, a flash tank was used to recover the wasted energy from blow down water. It was found that the flash tank enhanced the net power by 0.72%. Further, as a resultant of using flash tank, the energy efficiency of the system increased from 31.68% to 31.91% while saving 25444.47 cubic meters water per year. In terms of exergy efficiency, a 0.72% increase was achieved.

A research was conducted by Liu & Bansal, (2014) to improve the utilization neural network based optimization strategies to improve the efficiency of boiler in coal fired power plant. The researcher concentrated on removing combustion related problems such as slagging to enhance the use of neural network based optimization strategies. Slagging can decrease the boiler efficiency and can have extreme impacts on heat transfer rate. Further, slag build-up is difficult to measure. Thus, the research presented a method of integrating non-dominated sorting genetic algorithm (NSGA II) based multi-objective optimization with computational fluid dynamics (CFD) to decrease or even avoid slagging inside a coal fired boiler furnace. Such approach facilitates in improving boiler combustion efficiency thereby increasing the efficiency of the power plant. The suggested process optimizes and controls the fields of flue gas properties like velocity of primary and secondary air and temperature field inside a boiler by adjusting the temperature in a coal fired power plant boiler control systems.

Urosevic, Gvozdenac, & Grkovic, (2013) did a research to calculate the power loss of a steam turbine in a cogeneration power plant which was easily applicable in industrial practice. The research was done in a 10 megawatts combined cycle gas turbine power plant. The calculation process suggested by author does not require any special additional measurements and are applicable in real industrial conditions.

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Raval & Patel, (2013) offered ways to reduce the power plants start-up power by optimization of auxiliary power consumption. The author suggested that in thermal power plants, different auxiliaries like pumps and compressors, consume a part of energy generated by the thermal power plant. This consumption is very high. The reason for this condition can be attributed to aspects in the power plant like bad design of the equipment or poor operation. Thus, the researcher in the study tried to improve the efficiency of these auxiliaries. To improve the performance of the pumps, researcher suggested methods like de-staging, impeller trimming, and installation of variable frequency drives. For improving the efficiency of compressor, the researcher suggested to select the receiver or the storage tank of appropriate size which can fit even in the times of high demand so that the pressure drop below the minimum required pressure can be avoided. The drop in the pressure causes the tools in an improper way which then decreases the efficiency of the system. Also, the energy which is then required to increase the pressure to the appropriate point can be saved and used in generation of power. Further, the layout and design of the air delivery system should be a straight path thereby avoiding looping and sharp bends. This is because looping and sharp bends reduce the pressure thereby reducing the efficiency of the system. The author suggested using series of multiple small compressors instead of a single big compressor. This increases the efficiency. Also, whenever not required, some of the smaller compressors can be turned off thereby saving energy. The author further suggested undergoing regular repair of the leaks (even the smallest ones) so that the air is not lost and pressure in the compressor is maintained.

Mansouri, Ahmadi, Kaviri, & Jaafar, (2012) conducted a research to study the effect of Heat Recovery Steam Generator (HRSG) pressure levels on exergy efficiency of combined cycle power plants. The researcher acquired the change in the heat recovery steam generator at different pressure levels. Two pressure levels and three pressure levels in the same generator were studied. The researcher concurrently calculated and compared the exergy of both pressure levels. Hence, three types of gas turbine combined cycles, with the same gas turbine as a topping cycle are evaluated. The results presented that the heat transfer causing exergy destruction and the stack gas exergy decrease as the number of pressure levels of steam generation increases. Also, the increases the heat recovery from the flue gas as a resultant of the increase of pressure levels of steam generation in HRSG leads to increase in the energetic efficiency of the cycle. The study found that as the number of pressure levels of steam generation in HRSG increases, the exergy destruction rate of the cycle decreases. The economic analysis found that increasing the number of pressure levels of steam generation increases specific investment cost and the total investment cost of the plant by almost 4% and 6% respectively. It also leads to the increase in the net present value of the plant by 7% for triple pressure reheat when compared with the double pressure. Thus the study stated that economically it is justifiable in HRSG to increase the number of pressure levels of steam generation.

Many researchers have conducted researches to optimize the numerous parameters in heat recovery steam generator to increase efficiency of combined cycle power plants (Carapellucci & Giordano, 2013; Kaviri, Jaafar, Lazim, & Barzegaravval, 2013; Naemi, Saffar-Avval, Kalhori, & Mansoori, 2013).

IV. METHODOLOGY

The Design of Pipe has the significant effect on heat transfer rates in the heat exchanger Where the Flow inside the pipe and the heat exchange between the out side Hot fluid and cold fluid inside the pipe will perform heat transfer based on the Flow and parameters in side the pipe in the chapter the Design of Corrugated pipe for Improving the heat transfer rate to improve condenser efficiency in order to improve Thermal Efficiency in Power plant. From The literature Produced by Mehmet Tontu where it is discussed about performance of a large scale steam Condenser in a steam power plant the parameters considered for design and analysis is considered from this The diameter of the pipe is considered as 24 mm Diameter and length is 13.4 meters it is said that a total of 20372 Tubes is required to transfer heat in the Particular condenser, As limitations in the Computational methods A single Tube is considered for optimized flow parameter for the above said diameter and length simulation is done for the Mass Flows of 10000 to 29000 Kg/s.

i. Computational Fluid Dynamics and Fluent:

Computational fluid dynamics essentially mean computational transport phenomenon which involves fluid dynamics, heat and mass transfer or any phenomenon involving transport phenomenon. CFD is about “numerical simulation of governing equations for some transport. phenomenon. Computational fluid is applied in many fields of science like aerospace, biomedical, automobile, chemical industry, electronics, marine engineering, material processing , micro fluids, turbo machines etc. Fluent is a CFD code used for flow modeling applications. Fluent needs some input data and domain drawn from various softwares like GAMBIT,CATIA,PRO-E and other design software. Now fluent can analyze the given domain with boundary conditions and solve the governing equations for the flow giving the different flow parameters. Steps for analysis in the fluent are:

Preprocessing: It involves building a model or importing one from a CAD package, applying.

A Pipe Diameter of 28mm is drawn in 2d And is the Converted in to solid model using Extrude Option with a

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depth of 13.4 meter which is an actual length of the tube a similar Model with semi corrugated and corrugated bumps also designed which is shown in Fig 3.1 , 3.2 and 3.3 Respectively.

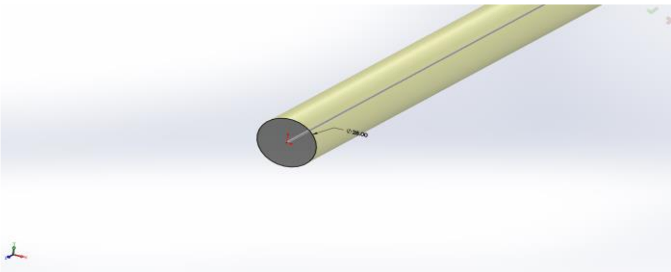

Fig 1 Plain Pipe Geometry

The above figure represents the Pipe diameter and conversion of a 2d circle to 3d model in the solid works software where an extrude feature is used to make the 23 D model

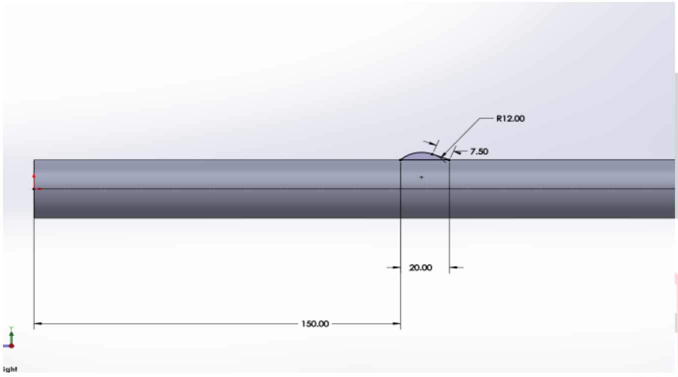

Fig 2 Semi Corrugated Pipe Geometry.

A Corrugated sketch of dimensions shown in the above figure is used make the pipe corrugated using revolve and pattern features.

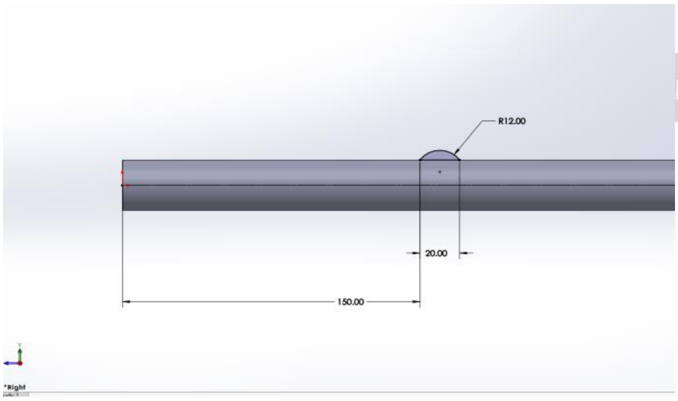

Fig 3 Corrugated Pipe Geometry

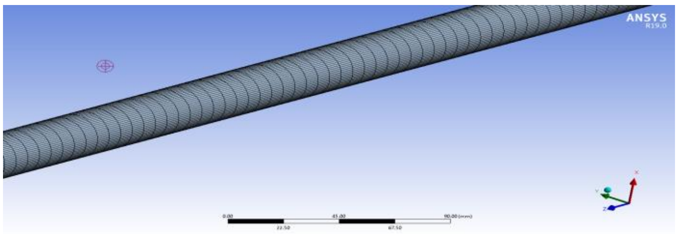

Fig 4 Meshing of the Plain Pipe.

All Hex mesh is done on the plain pipe using Ansys 3D mesher with Fine elements to ensure accurate results the number of elements generated on the pipes is discussed in the Table 1 with each individual design meshing details

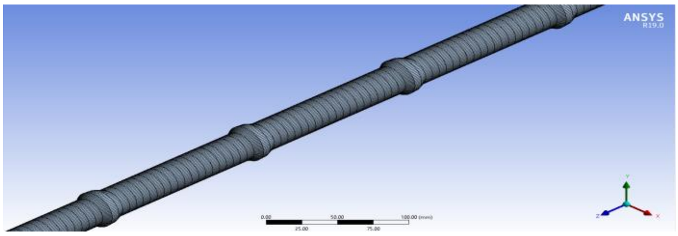

Fig 5 Meshing of the Semi Corrugated Pipe.

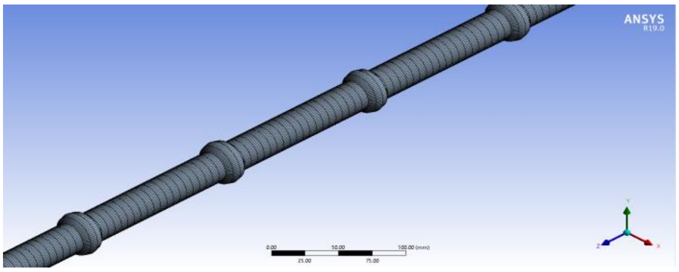

Fig 6 Meshing of the Corrugated Pipe.

Table 1 Mesh Details of the Simulations.

Description	Element Type	Nodes	Elements
Plain Pipe	Hexahedron	1299532	1236110
Semi Corrugated	Hexahedron	1602888	1533021
Corrugated	Hexahedron	1704447	1633580

B) Calculation: Once the numerical model is prepared fluent performs the necessary calculations and produces the desire results.

Table 3 Assumptions Considered.

The assumptions considered to setup the problem in fluent

Specifications	Qty	Units
Material	Titanium	
Number of Passes	1	
Number of Tubes	20372	
No of Tubes Considered	1	
Dimensions	28*0.5*13400	mm
Cooling Water Temperature	290	K
Cooling Water Rate for all Tubes	10000 to 29000	Kg/s
Cooling Water Rate For 1 Tube	0.5 to 1.5	Kg/s
Free stream temperature	500	K

C) Post-processing : it involves organization and interpolation of the data and images.

It can handle :

Transient and steady flow

Laminar and turbulent flow

Newtonian and non-Newtonian fluid

Single and multiphase flow

Chemical reactions including combustion

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Flows through porous media
Heat transfer
Flow induced vibration

The project basically deals with turbulent flow of water through a Helical Coil.It also contains heat transfer and single phase flow.

ii. Basic Principle That Govern The Implementation of CFD:

Fundamental principles of conservation which governs the basic equation that we commonly used for cfd and not only cfd in analytical fluid dynamics are :

Continuity equation : A Mass Conservation Equation.

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$$ (For 2D incompressible flow)…………………1

Navier-stokes equation: A Momentum Conservation Equation

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{\partial p}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) \quad ……..2$$

(for 2D incompressible flow in X-direction)

Energy equation : Energy Conservation Equation

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \frac{K}{\rho C_P}\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) \quad ………..3$$

iii. Fluid Flow and Heat Transfer :

As a fluid moves, it carries heat with it -- this is called convection

Thus, heat transfer can be tightly coupled to the fluid flow solution

Additionally:

The rate of heat transfer is a strong function of fluid velocity

Fluid properties may be strong functions of temperature

Conduction Heat Transfer:

Conduction is the transfer of heat by molecular interaction

In a gas, molecular velocity depends on temperature

hot, energetic molecules collide with neighbors, increasing their speed

In solids, the molecules and the lattice structure vibrate

Amount of heat transfer of condenser can be found in three different methods: through the energy balance for water , steam or heat transfer rate in the condenser . Figure 3.7 illustrates condensation process and temperature changes through condenser lengths. The theory of thermodynamics needs that the rate of heat transfer from the steam be equal to the rate of heat transfer to the cooling water side. Also, different methods can be performed for thermal analysis of condenser. In this study, Heat transfer of the condenser is investigated based on CFD Results, logarithmic mean temperature difference.

$$\dot{Q} = \dot{m}_{cw} \times c_{p,cw} \times (T_{cw,e} - T_{cw,i}) \quad …………..4$$

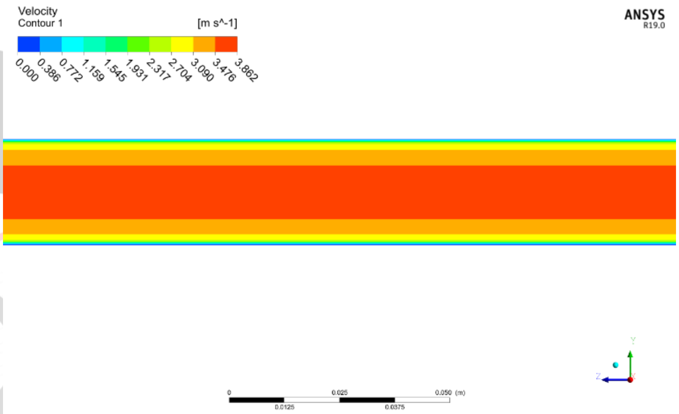
$$TTD = T_s - T_{cw,e} \quad ……………………5$$

Where Q is the Heat transfer Rate.
Cp is the Specific Heat of Water
Te is the Exit Cooling Water Temperature.
Ti is The Inlet Cooling Water Temperature.
TTD is the Terminal Temperature Difference.

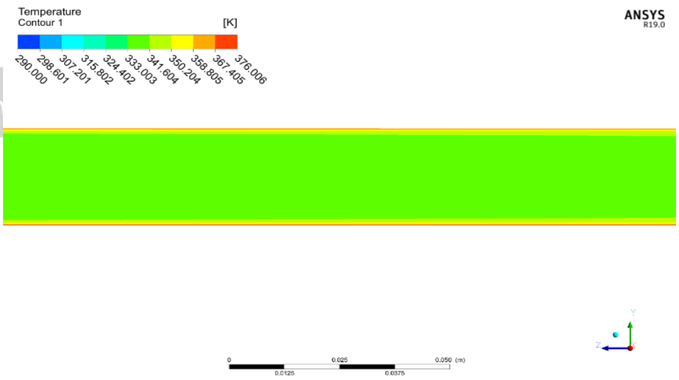
TTD is defined as the saturation temperature of the Extraction steam minus the feed water outlet temperature An increase in TTD Indicates a reduction is Heat transfer and decreas indicates Increase in Heat transfer.

V. RESULTS

I. Plain Pipe with 29000 Kg/s.



(a)



(b)

Fig 7 Contours of Velocity and Temperature With m=29000Kg/s

(a)Velocity Distribution in the Plain Pipe (b) Temperature Distribution of the Plain Pipe

The Above Figures represents the Velocity and Temperature distribution of the water inside a plain Pipe Where the Red Coloured region indicates high Velocity or the temperature from the figures The Velocity of the water in the single pipe with mass of 29000 Kg/s is 3.862 m/s after

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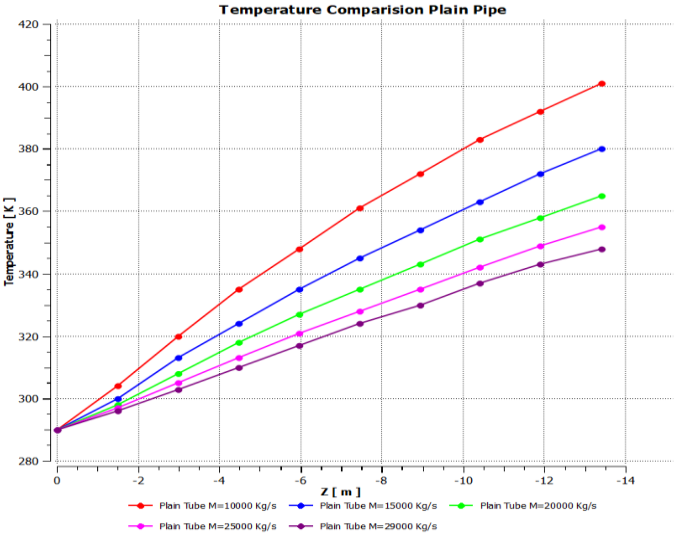
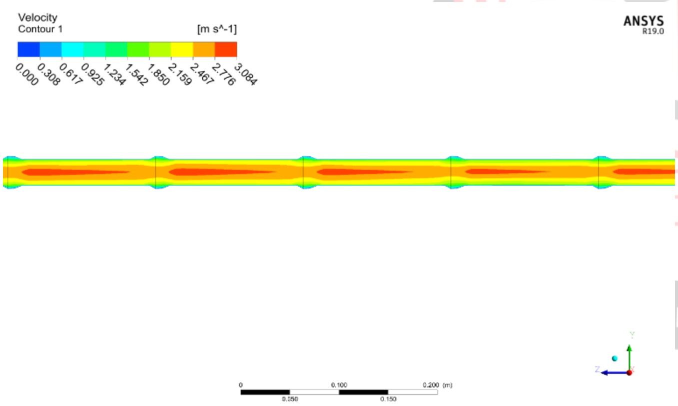
heat transfer in a steady state and the Exit cold water temperature 349.762 K.



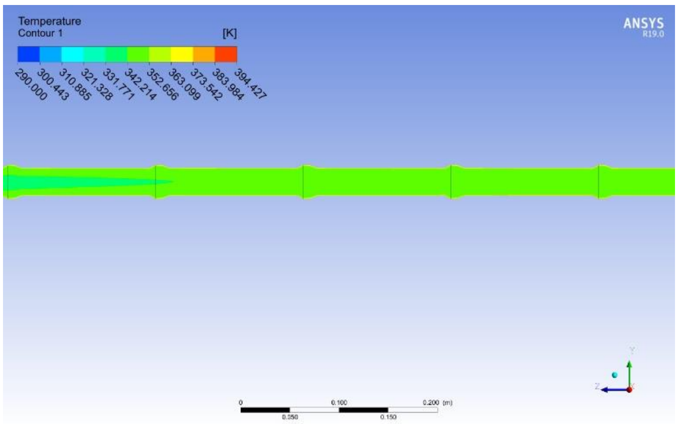
Plot 1 Temperature Distribution On the Plain Pipe at different Mass flows.

The above Plot represents the temperature distribution along the length of the pipe for plain pipe it is observed that the maximum temperature from all the mass flow rates is plotted in the plot higher temperature of the fluid is reached with mass flow 10000 kg/s and lower temperature is with 29000 Kg/s.

VI. SEMI CORRUGATED PIPE WITH 29000 KG/S.



(a)



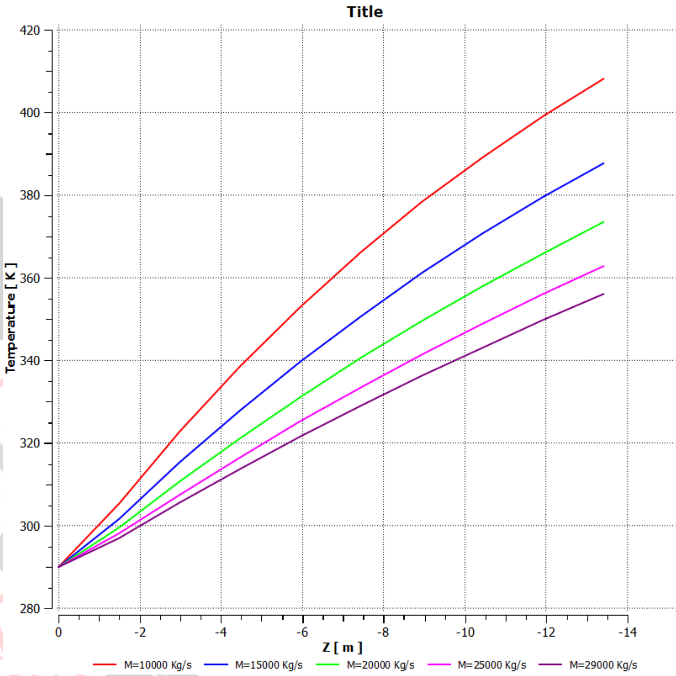
(b)

Fig 8 Contours of Velocity and Temperature With m=29000Kg/s

(a)Velocity Distribution in the Semi Corrugated Pipe (b) Temperature Distribution of the Semi Corrugated Pipe

The Above Figures represents the Velocity and Temperature distribution of the water inside a Semi Corrugated Pipe Where the Red Coloured region indicates high Velocity or the temperature from the figures The Velocity of the water in the single pipe with mass of 29000 Kg/s is 3.084 m/s after heat transfer in a steady state and the Exit cold water temperature 357.2459 K.

Velocity Distribution On the Semi Corrugated Pipe at different Mass flows.



Plot 2 Temperature Distribution On the Semi Corrugated Pipe at different Mass flows.

The above Plot represents the temperature distribution along the length of the pipe for Semi corrugated pipe it is observed that the maximum temperature from all the mass flow rates is plotted in the plot higher temperature of the fluid is reached with mass flow 10000 kg/s and lower temperature is with 29000 Kg/s.

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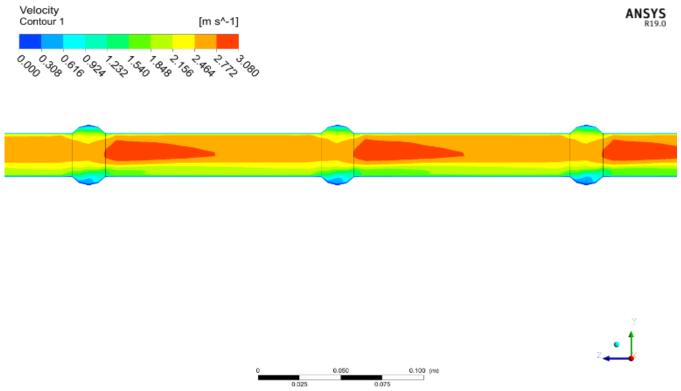
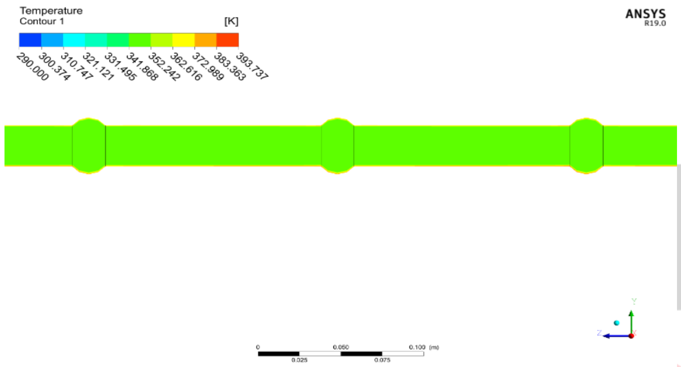
VII. Corrugated Pipe with 29000 Kg/s.



(a)

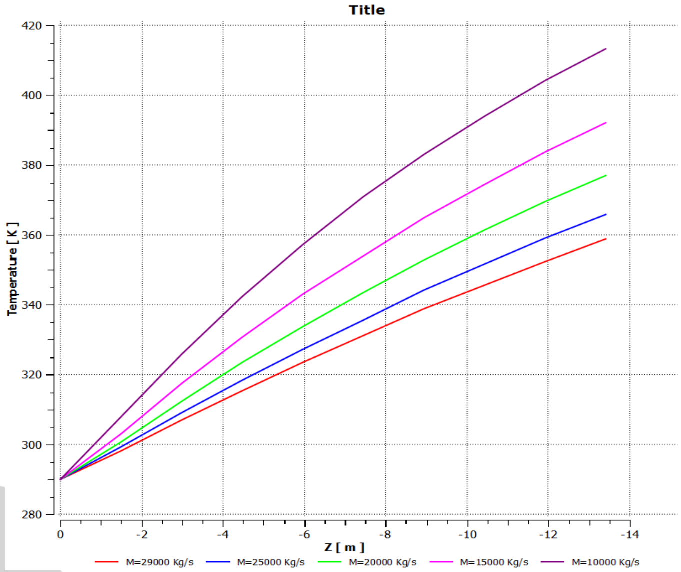


(b)

Fig 9 Contours of Velocity and Temperature With m=29000Kg/s

(a)Velocity Distribution in the Corrugated Pipe (b) Temperature Distribution of the Corrugated Pipe

The Above Figures represents the Velocity and Temperature distribution of the water inside a Corrugated Pipe Where the Red Coloured region indicates high Velocity or the temperature from the figures The Velocity of the water in the single pipe with mass of 29000 Kg/s is 3.080 m/s after heat transfer in a steady state and the Exit cold water temperature 359.6895K.



Plot 3 Temperature Distribution On the Corrugated Pipe at different Mass flows.

The above Plot represents the temperature distribution along the length of the pipe for corrugated pipe it is observed that the maximum temperature from all the mass flow rates is plotted in the plot higher temperature of the fluid is reached with mass flow 10000 kg/s and lower temperature is with 29000 Kg/s.

Table 5 Heat transfer Rate of Different Pipes

The Represents the comparison table of heat transfer rates between Plain pipe , semi corrugated , Corrugated tube from which it

Heat Transfer Rate (W)			
Mass Flow Cold Water(Kg/s) for 1 Pipe	Plain Tube	Semi Corrugated	Corrugated
0.490869821	231764.3378	246277.3476	255203.5732
0.73630473	281576.7772	306098.1965	317312.1231
0.981739643	315635.28	340294.3408	361490.093
1.227174553	340420.2809	380200.4987	393991.122
1.423522	355769.1188	400326.2075	414873.3713

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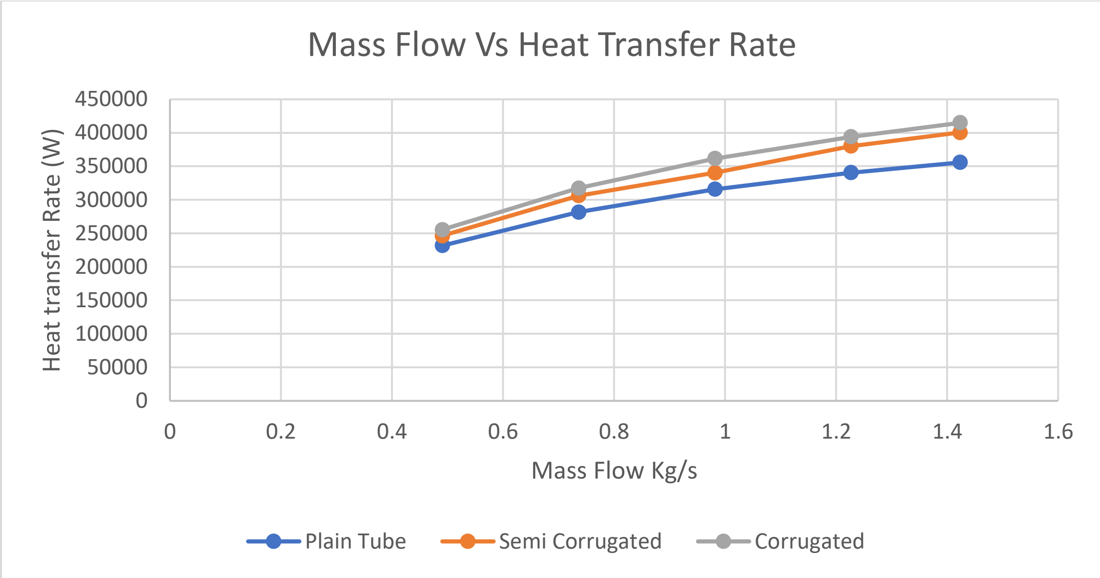
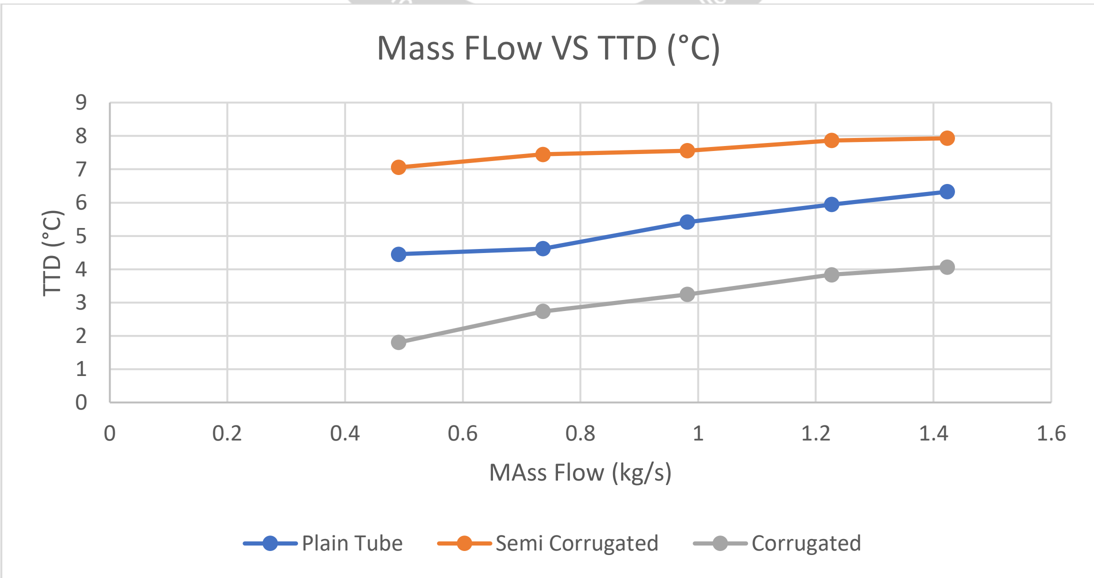


Plot 4 Mass flow Vs Heat transfer Rate in different Pipes

The above graph Represents the comparison table of heat transfer rates between Plain pipe , semi corrugated , Corrugated tube from which the maximum heat transfer rate is occurring in Corrugated tube semi corrugated tube is also performing better in terms of Plain pipe.

Table 6 Terminal Temperature Difference of Different Pipes

	TTD (°C)		
Mass Flow Cold Water(Kg/s) for 1 Pipe	Plain Tube	Semi Corrugated	Corrugated
0.490869821	4.45	7.0583	1.80544
0.73630473	4.6174	7.4495	2.7367
0.981739643	5.41585	7.56	3.2449
1.227174553	5.9467	7.86754	3.8373
1.423522	6.3277	7.9353	4.0682



Plot 6 Mass Flow VS TTD for Different Pipes

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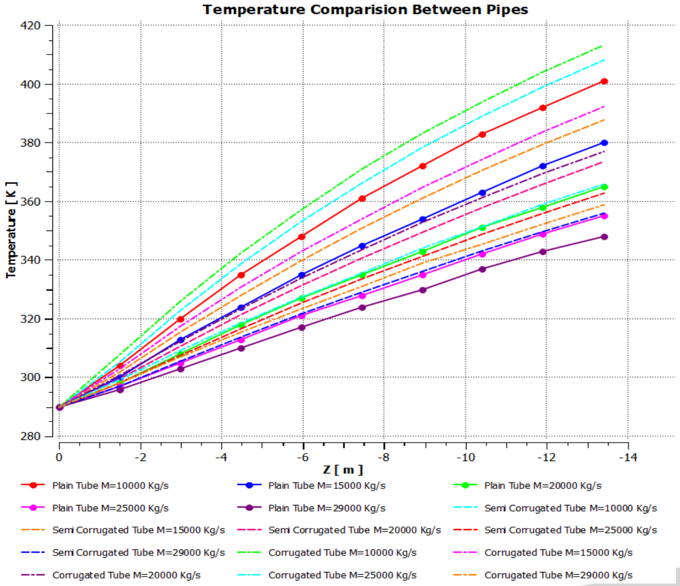
The above graph Represents the comparison table of Terminal Temperature difference between Plain pipe , semi corrugated , Corrugated tube from which the maximum TTD is occurring in Corrugated tube semi corrugated tube is also performing better in terms of Plain pipe



Plot 12 Temperature Distribution along the Length of the Pipe for Different Pipes.

VIII. CONCLUSION

1. Heat transfer Investigation of the Plain Condenser tube is done to Find out the heat transfer rate and terminal temperature difference for different Mass Flow Rates.
2. Based on the results obtained a new corrugated tube is designed in two aspects to investigate the heat transfer rate.
3. CFD analysis is done for all three models and the results obtained is tabulated.
4. From the heat transfer analysis it is observed that the heat transfer rate is increasing with corrugated tube than plain tube and the terminal temperature difference is Improving with corrugated tube.
5. There is an improvement in heat transfer rate with respect to tube Where For plain tube maximum heat transfer rate is 355769.1188 W at 29000 Kg/s and for corrugated Pipe 414873.3713 W.
6. It is observed that adding Corrugated Ribs on pipes will increase the heat transfer of the Pipe by 16.16 % if the Heat transfer of the Condenser is increased The overall thermal efficiency of power plant will also Increases.

IX. REFERENCES

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