IARJSET

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

ISO 3297:2007 Certified

Vol. 3, Issue 11, November 2016

Design and Thermal Analysis of Steam Boiler used in Power Plants

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Abstract: In this thesis the steam flow in steam boiler tubes is modeled using PRO-E design software. The thesis will focus on thermal and CFD analysis with different velocities (25, 30, 35& 40m/s).Thermal analysis done for the steam boiler by steel, stainless steel& brass at different heat transfer coefficient values. These values are taken from CFD analysis at different velocities. In this thesis the CFD analysis to determine the heat transfer coefficient, heat transfer rate, mass flow rate, pressure drop and thermal analysis to determine the temperature distribution, heat flux with different materials. 3D modeled in parametric software Pro-Engineer and analysis done in ANSYS.

Keywords: Finite element analysis, steam boiler, CFD analysis, thermal analysis.

I. INTRODUCTION

STEAM BOILER: Steam boilers heat water to produce steam, which is then used to generate energy or heat for other processes.

GENERAL INFORMATION

Boilers are used to generate steam that then provides heat or power. Water is converted to steam in the boiler. This steam travels through the heating apparatus which can be any piece of equipment that requires steam for operation. The cooled steam is then condensed into water and returns to the boiler to start the cycle again.

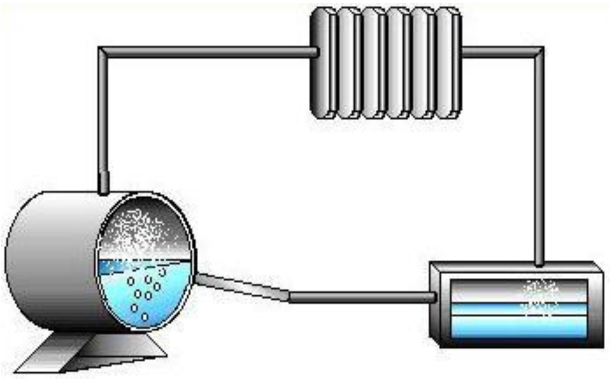

Fig1: Boiler Diagram

EQUIPMENT DESIGN

There are three main types of steam boilers: Fire tube, water tube, and cast iron.

In fire tube boilers, the combustion gases travel within the tubes to heat the surrounding water. In water tube boilers, on the other hand, the water travels inside the tubes and the heat on the outside, as shown above. The diagram below shows the components of a fire tube boiler.

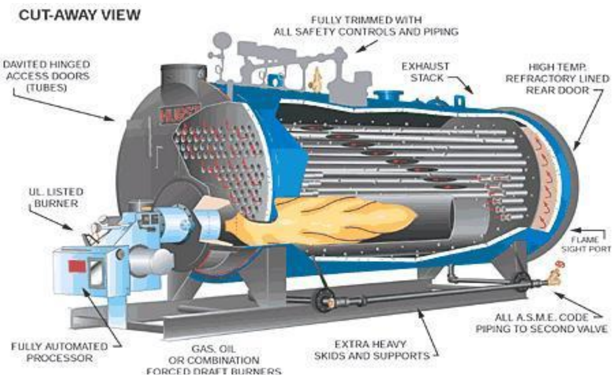

Fig2: Fire Tube Boiler Diagram

II. LITERATURE REVIEW

Finite Element Analysis of Steam Boiler Used In Power Plants

A boiler or steam generator is a closed vessel used to generate steam by applying heat energy to water. During the process of generating steam, the steam boiler is subjected to huge thermal and structural loads. To obtain efficient operation of the power plant, it is necessary to design a structure to withstand these thermal and structural loads. Using CAD and CAE software is the advanced methodology of designing these structures before constructing a prototype. In this project finite element analysis of the steam boiler was carried out to validate the design for actual working conditions. The main tasks involved in the project are performing the 3D modeling of the boiler and finite element analysis. In this project, design optimization of the Boiler is also done based on the results obtained from the thermal and structural analysis. PRO-E software is used for design and 3D modeling. ANSYS software is used for doing finite element analysis.

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III. PROBLEM DESCRIPTION

The objective of this project is to make a 3D model of the steam boiler and study the CFD and thermal behavior of the steam boiler by performing the finite element analysis.3D modeling software (PRO-Engineer) was used for designing and analysis software (ANSYS) was used for CFD and thermal analysis.

The methodology followed in the project is as follows:

- Create a 3D model of the steam Boiler assembly using parametric software pro-engineer.
- Convert the surface model into Para solid file and import the model into ANSYS to do analysis.
- Perform thermal analysis on the steam Boiler assembly for thermal loads.
- Perform CFD analysis on the existing model of the surface steam boiler for Velocity inlet to find out the mass flow rate, heat transfer rate, pressure drop.

IV. INTRODUCTION TO CAD/CAE:

Computer-aided design (**CAD**), also known as **computer-aided design and drafting** (**CADD**), is the use of computer technology for the process of design and design-documentation.

INTRODUCTION TO PRO-ENGINEER

Pro/ENGINEER Wildfire is the standard in 3D product design, featuring industry-leading productivity tools that promote best practices in design while ensuring compliance with your industry and company standards. Integrated Pro/ENGINEER CAD/CAM/CAE solutions allow you to design faster than ever, while maximizing innovation and quality to ultimately create exceptional products.

Different modules in pro/engineer

Part design, Assembly, Drawing& Sheet metal

INTRODUCTION TO FINITE ELEMENT METHOD:

Finite Element Method (FEM) is also called as Finite Element Analysis (FEA). Finite Element Method is a basic analysis technique for resolving and substituting complicated problems by simpler ones, obtaining approximate solutions Finite element method being a flexible tool is used in various industries to solve several practical engineering problems. In finite element method it is feasible to generate the relative results.

V. RESULTS AND DISCUSSIONS

Models of steam boiler using pro-e wildfire 5.0: The steam boiler is modeled using the given specifications and design formula from data book. The isometric view of steam boiler is shown in below figure. The steam boiler outer casing body profile is sketched in sketcher and then it is revolved up to 360^0 angle using revolve option and tubes are designed and assemble to in steam boiler using extrude option.

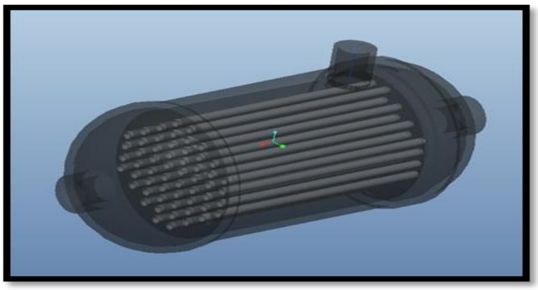

Fig: 3 steam boiler 3d model

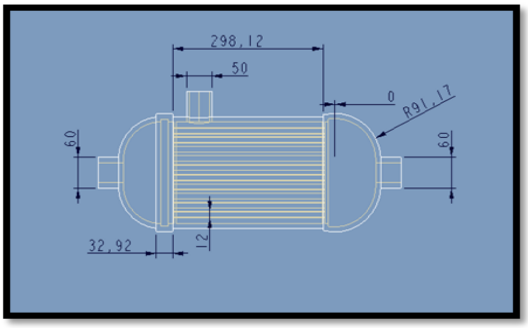

Fig: 4 Steam boiler 2D model

CFD ANALYSIS OF STEAM BOILER VELOCITY – 25m/s

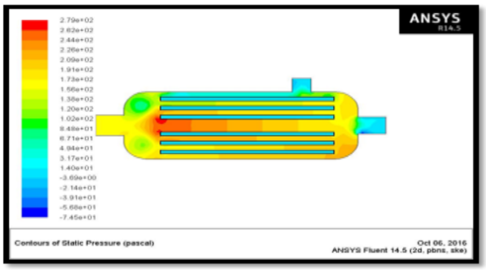

Fig: 5 static pressure

According to the above contour plot, the maximum static pressure inside of the steam boiler at one end of the tubes because the applying the boundary conditions at inlet of the steam boiler tubes and minimum static pressure at the steam outlet and exhaust outlet. According to the above contour plot, the maximum pressure is 2.79e+02Pa and minimum static pressure is -7.45e+01Pa.

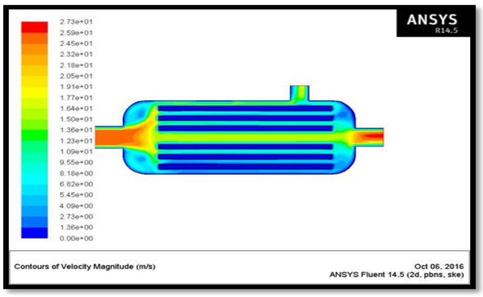

Fig: 6 velocity

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According to the above contour plot, the maximum velocity magnitude of the steam at inlet and outlet of the boundaries, because the applying the boundary conditions at inlet of the steam boiler tubes and minimum velocity magnitude at inside the steam boiler tubes. According to the above contour plot, the maximum velocity is 2.73e+01m/s and minimum velocity is 1.36e+00m/s.

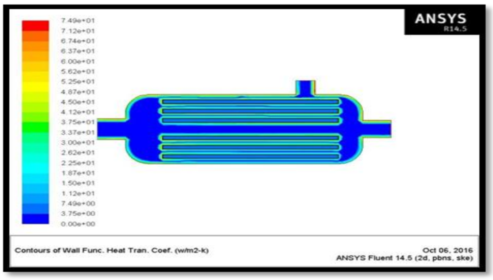

Fig: 7 heat transfer coefficient

According to the above contour plot, the maximum heat transfer coefficient of the steam boiler at surface edges of the steam boiler and tubes and minimum heat transfer coefficient inside the tubes and steam boiler

According to the above contour plot, the maximum heat transfer coefficient is7.49e+01w/m^2-k and minimum heat transfer coefficient is 3.75e+00w/m^2-k.

MASS FLOW RATE

Mass Flow Rate	(kg/s)
exhaust_outlet	-0.65603697
inlet	0.89999998
interior-_trm_srf	-2.0488691
steam_outlet	-0.2508648
wall-_trm_srf	0
Net	-0.0069018006

HEAT TRANSFER RATE

Total Heat Transfer Rate	(w)
exhaust_outlet	-100040.41
inlet	137242.72
steam_outlet	-38848.602
wall-_trm_srf	0
Net	-1646.2891

THERMAL ANALYSIS OF STEAM BOILER

Used Materials steel, copper, brass & stainless steel, copper material for tube

Steel, brass & stainless steel for boiler casing

MATERIAL PROPERTIES:

Copper material properties
Thermal conductivity = 385w/m-k
Specific heat = 0.385j/g^{0}C
Density =0.00000776kg/mm^3

Steel material properties
Thermal conductivity = 93.0w/m-k
Specific heat = 0.669j/g^{0}C
Density = 0.0000075kg/mm^3

Stainless Steel material properties
Thermal conductivity = 34.3w/m-k
Specific heat = 0.620j/g^{0}C Density = 0.00000901kg/mm^3

Brass material properties
Thermal conductivity = 233w/m-k
Specific heat = 0.380j/g^{0}C
Density =0.00000760kg/mm^3

IMPORTED MODEL

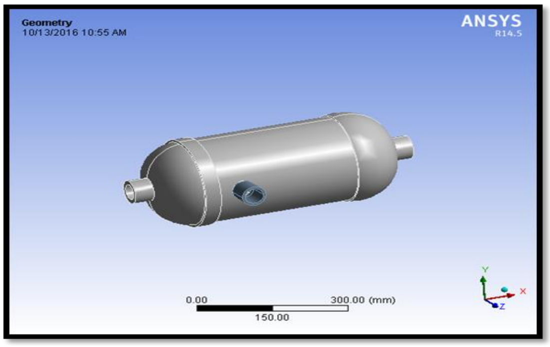

Fig 8 imported model

MESHED MODEL

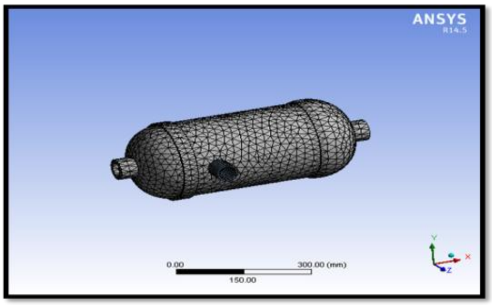

Fig 9 meshed model

Finite element analysis or FEA representing a real project as a "mesh" a series of small, regularly shaped tetrahedron connected elements, as shown in the above fig. And then setting up and solving huge arrays of simultaneous equations. The finer the mesh, the more accurate the results but more computing power is required.

BOUNDARY CONDITIONS

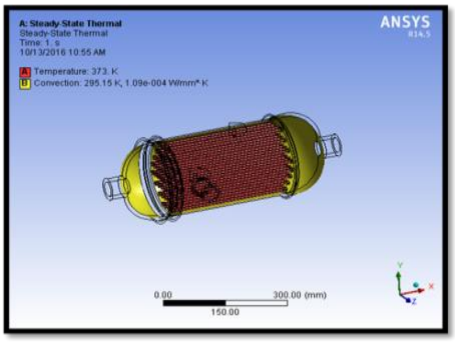

Fig 10 boundary conditions

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MATERIAL- STEEL FOR BOILER CASING, COPPER FOR TUBES

Velocity – 25m/s, Heat transfer co-efficient = 7.49e+01w/m^2-k
Temperature

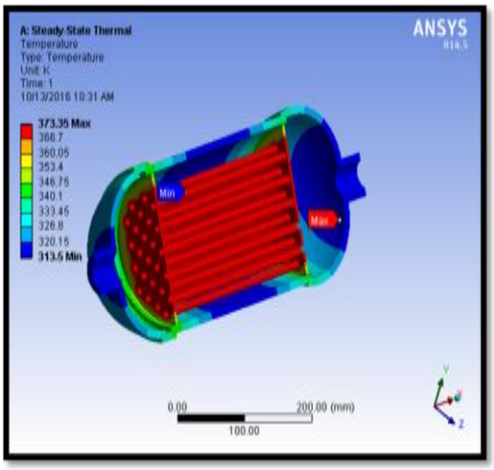


Fig 11 temperature

According to the contour plot, the temperature distribution maximum temperature at tubes because the steam passing inside of the tube. So we are applying the temperature inside of the tube and applying the convection except inside the tubes. Then the maximum temperature at tubes and minimum temperature at steam boiler casing.

Heat flux

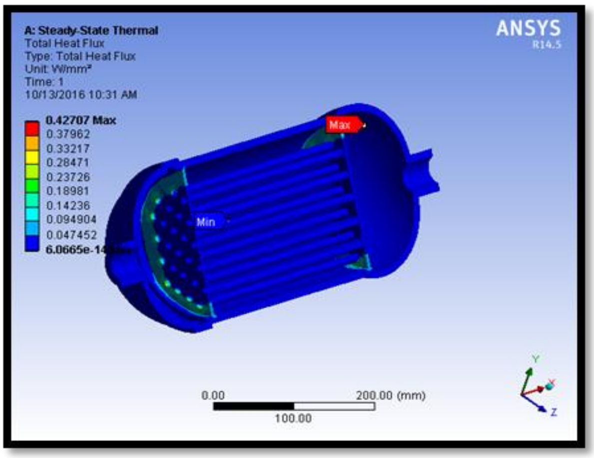


Fig 12 heat flux

According to the contour plot, the maximum heat flux at inside the tubes because the steam passing inside of the tube. So we are applying the temperature inside of the tube and applying the convection except inside the tubes. Then the maximum heat flux at inside the tubes and minimum heat flux at steam boiler casing and outside of the tubes. According to the above contour plot, the maximum heat flux is 0.42707w/mm^2 and minimum heat flux is 6.0665e-14w/mm^2.

VI. RESULTS AND DISCUSSIONS

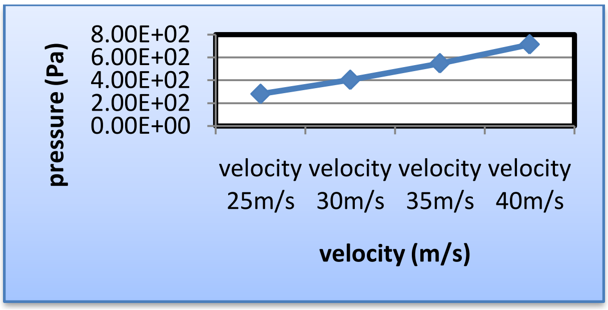
CFD ANALYSIS RESULT TABLE

Velocity (m/s)	Pressure(Pa)	Velocity (m/s)	Heat transfer co-efficient (w/m^2-k)	Mass flow rate (kg/s)	Heat transfer Rate(W)
25	2.79e+02	2.73e+01	7.49e+01	0.0069018	1646.2891
30	4.02e+02	3.27e+01	8.66e+01	0.005703	1511.3906
35	5.47e+02	3.82e+01	9.83e+01	0.010582	2394.7773
40	7.13e+02	4.37e+01	1.09e+02	0.01201278	2719.8281

THERMAL ANALYSIS RESULT TAB

Heat transfer coefficient (w/m^2-k)	result	Materials		
		steel	Stainless steel	brass
7.49e+01	Temperature(^{0}C)	373.35	373.48	373.26
	Heat flux(w/mm^2)	0.42707	0.17094	0.56179
8.66e+01	Temperature(^{0}C)	373.37	373.49	373.27
	Heat flux(w/mm^2)	0.45156	0.17639	0.60463
9.83e+01	Temperature(^{0}C)	373.39	373.5	373.29
	Heat flux(w/mm^2)	0.47265	0.18108	0.64226
1.09e+02	Temperature(^{0}C)	373.4	373.51	373.3
	Heat flux(w/mm^2)	0.4896	0.18485	0.67298

GRAPHS PRESSURE PLOT



Variation of maximum pressure for various velocities. A plot between maximum pressure and velocities by FEA approach is shown in above fig. From the plot the variation of maximum static pressure is observed. Maximum static pressure increases with increases in velocities.

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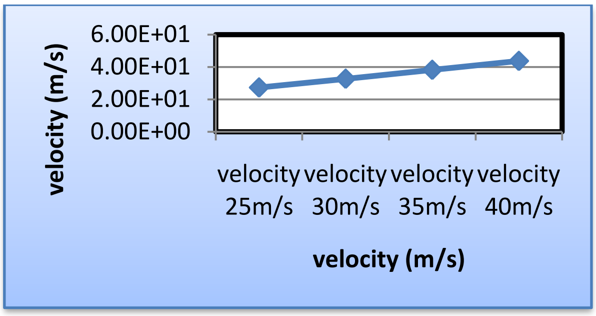
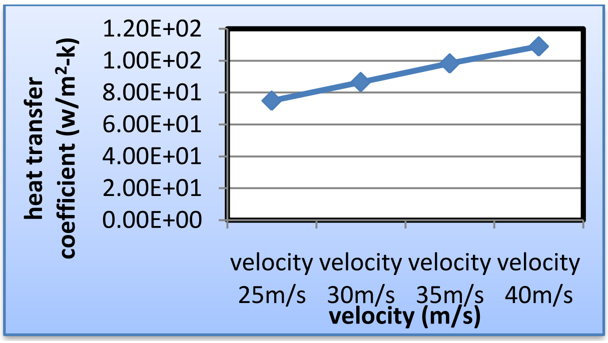
VELOCITY PLOT



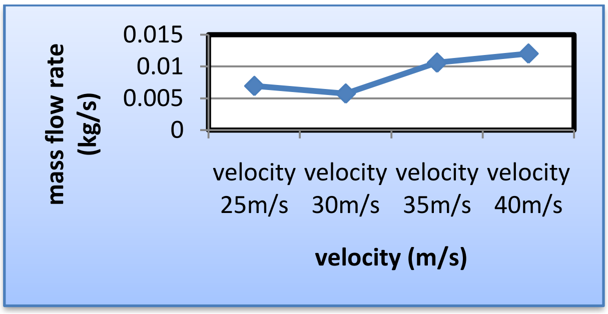
Variation of maximum velocity for various velocities. A plot between maximum velocity and velocities by FEA approach is shown in above fig. From the plot the variation of maximum static velocity is observed. Maximum velocity increases with increases in velocities.

HEAT TRANSFER COEFFICIENT PLOT



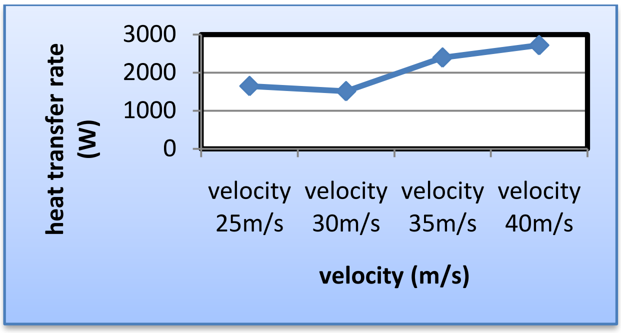
Variation of maximum heat transfer coefficient for various velocities A plot between maximum heat transfer coefficient and velocities by FEA approach is shown in above fig. From the plot the variation of maximum heat transfer coefficient is observed. Maximum heat transfer coefficient increases with increases in velocities.

MASS FLOW RATE PLOT



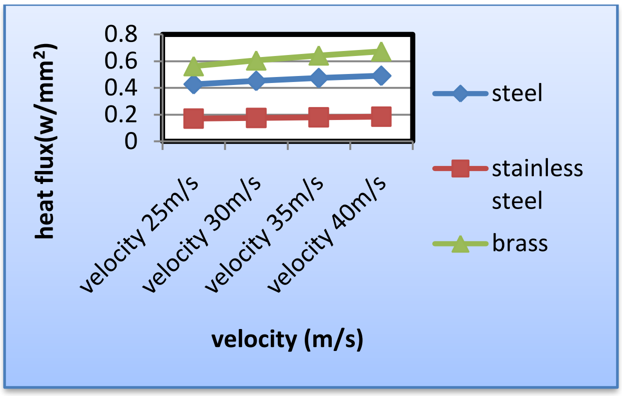
Variation of maximum mass flow rate for various velocities A plot between maximum mass flow rate and velocities by FEA approach is shown in above fig. From the plot the variation of maximum mass flow rate is observed. Maximum mass flow rate increases with increases in velocities.

HEAT TRANSFER RATE PLOT



Variation of maximum heat transfer rate for various velocities A plot between maximum heat transfer rate and velocities by FEA approach is shown in above fig. From the plot the variation of maximum heat transfer rate is observed. Maximum heat transfer rate increases with increases in velocities.

THERMAL ANALYSIS GRAPHS HEAT FLUX PLOT



Variation of maximum heat flux for various velocities A plot between maximum heat flux and velocities by FEA approach is shown in above fig. From the plot the variation of maximum heat flux is observed. Maximum heat flux increases with increases in velocities. Heat flux value is decreases stainless steel than steel &brass. Heat flux value is decreases steel than brass.

VII. CONCLUSION

In this thesis the steam flow in steam boiler tubes is modeled using PRO-E design software. The thesis will focus on thermal and CFD analysis with different velocities (25, 30, 35& 40m/s). Thermal analysis done for the steam boiler by steel, stainless steel& brass at different heat transfer coefficient values. These values are taken from CFD analysis at different velocities. By observing the CFD analysis the pressure drop, velocity, heat transfer coefficient, mass flow rate & heat transfer rate increases by increasing the inlet velocities. By observing the thermal analysis, the taken different heat transfer coefficient values are from CFD analysis. Heat flux value is more for brass

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material than steel& stainless steel. So we can conclude the brass material is better for steam boiler.

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