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Design and Thermal Analysis of Steam Boiler (Without & With Baffles) Used in Small Power Plants

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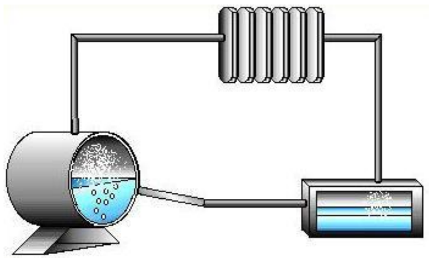
ABSTRACT: Steam boiler is a closed vessel in which water or other fluid is heated under pressure and the steam released out by the boiler is used for various heating applications. The main considerations in the design of a boiler for a particular application are Thermal design and analysis, Design for manufacture, physical size and cost. In this thesis the steam flow in steam boiler (without baffles & with baffles) is modeled using CREO parametric design software. The thesis will focus on thermal and CFD analysis with different inlet velocities (20, 30, 40& 50m/s). In this thesis the CFD analysis to determine the heat transfer coefficient, heat transfer rate, mass flow rate, pressure drop. Thermal analysis to determine the temperature distribution, heat flux for both models steam boiler without baffles and steam boiler with baffles. Finding which model is best one.3D modeled in parametric software CREO and analysis done in ANSYS.

KEYWORDS: CFD, CREO, ANSYS,

I.INTRODUCTION

STEAM BOILER:

Steam boilers heat water to produce steam, which is then used to generate energy or heat for other processes.
A steam boiler is a closed vessel, generally made of steel, in which water is heated by some source of heat produced by combustion of fuel and ultimately to generate steam. The steam produced may be supplied at low pressure for industrial process work in cotton mills, sugar industries etc. and for producing hot water which can be used for heating installations at much low pressure. [1]
Logically a steam boiler should have a minimum capacity of containing 10 liters of water and its minimum working pressure should be 3.4 Kgf/cm2



Boiler Diagram

Classification of Boiler :

Boilers can be classified in a number of ways, but the following are important from the subject point of view:
1. Horizontal, vertical and inclined boilers

2. Stationary, portable and marine boilers

3. Water tube and fire tube (shell tube) boilers

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4. Single tube and multi tube boilers

5. Internally fired and externally fired boilers

6. Naturally circulated and forced circulated boilers

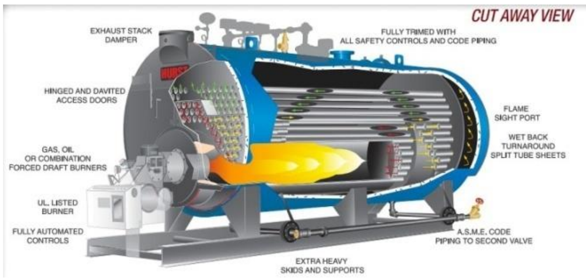
7. Source of heat (solid fuel, liquid and gaseous fuel, electrical and nuclear energy)

8. Low pressure, medium pressure and high pressure boilers

1) BOILER USED: FIRE TUBE (shell tube) BOILER:

2) EQUIPMENT DESIGN

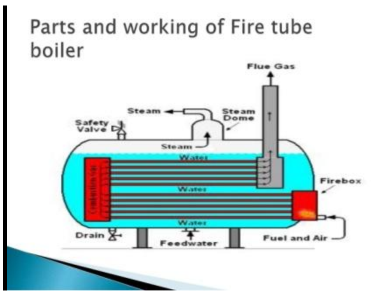
There are three main types of steam boilers: Fire tube(shell tube), water tube, and cast iron.
In fire tube boilers, the combustion gases travel within the tubes to heat the surrounding water.
In water tube boilers, on the other hand, the water travels inside the tubes and the heat on the outside, as shown above.
Cast iron boilers are similar to water tube boilers, but the water is contained in cast iron sections instead of in tubes.
The diagram below shows the components of a fire tube boiler.



Fire Tube (shell tube) Boiler of package type boiler.

Working of boiler:

Both gas and oil fired boilers use controlled combustion of the fuel to heat water. The key boiler components involved in this process are the burner, combustion chamber, heat exchanger,
and controls



The burner mixes the fuel and oxygen together and, with the assistance of an ignition device, provides a platform for combustion. This combustion takes place in the combustion chamber, and the heat that it generates is transferred to the water through the heat exchanger. Controls regulate the ignition, burner firing rate, fuel supply, air supply, exhaust draft, water temperature, steam pressure, and boiler pressure.
Hot water produced by a boiler is pumped through pipes and delivered to equipment throughout the building, which can include hot water coils in air handling units, service hot water heating equipment, and terminal units. Steam boilers produce steam that flows through pipes from areas of high pressure to areas of low pressure, unaided by an external

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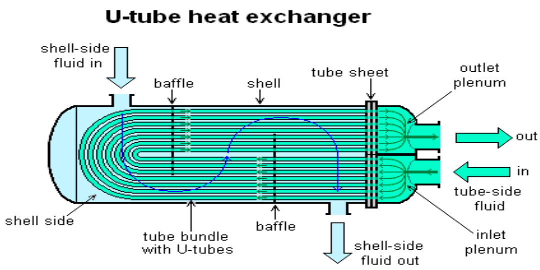
energy source such as a pump. Steam utilized for heating can be directly utilized by steam using equipment or can provide heat through a heat exchanger that supplies hot water to the equipment.[2]

BAFFLES:

Baffles are flow-directing or obstructing vanes or panels used in some Industrial plants process.
Baffles are an integral part of the shell and tube heat exchanger design.
A baffle is designed to support tube bundles and direct the flow of fluid for maximum efficiency.
Baffles are used to increase the fluid velocity by diverting the flow across the tube bundle to obtain higher transfer co-efficient. The distance between adjacent baffles is called baffle-spacing. The baffle spacing of 0.2 to 1 times of the inside shell diameter is commonly used. Baffles are held in positioned by means of baffle spacers. Closer baffle spacing gives greater transfer co-efficient by inducing higher turbulence. [3]The pressure drop is more with closer baffle spacing. In case of cut-segmental baffle, a segment (called baffle cut) is removed to form the baffle expressed as a percentage of the baffle diameter. Baffle cuts from 15 to 45% are normally used. A baffle cut of 20 to 25% provide a good heat-transfer with the reasonable pressure drop. The % cut for segmental baffle refers to the cut away height from its diameter.

TYPES OF BAFFLES:
a). Cut-segmental baffle
b). Disc and doughnut baffle
c). Orifice baffle



II. LITERATURE SURVEY

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[5]. 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[4]. 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[6] . In this project, design optimization of the Boiler is also done based on the results obtained from the thermal and structural analysis. CREO software is used for design and 3D modeling. ANSYS software is used for doing analysis

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 CREO
- Convert the surface model into Para solid file and import the model into ANSYS to do analysis.

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- 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.

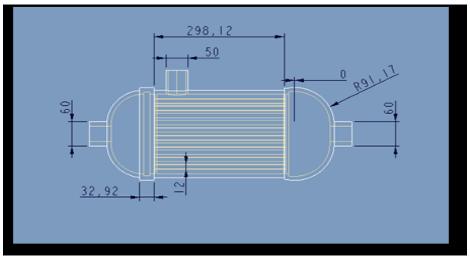
IV MODELING &ANALYSIS:

Models of steam boiler using CREO

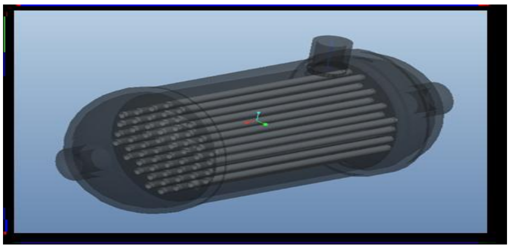
The steam boiler is modeled using the given specifications and design formula from data book. The isometric view of steam boiler is shown in below figure. The steam boiler outer casing body profile is sketched in sketcher and then it is revolved up to 360^0 angle using revolve option and tubes are designed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

LINE DIAGRAM

Steam boiler 2D diagram:



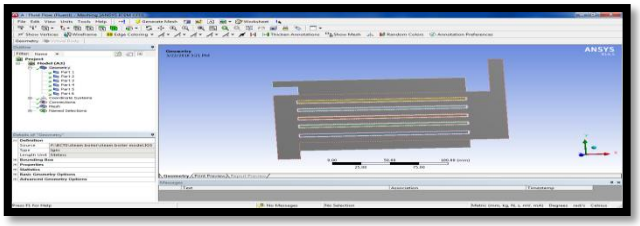
Steam boiler 3D diagram:



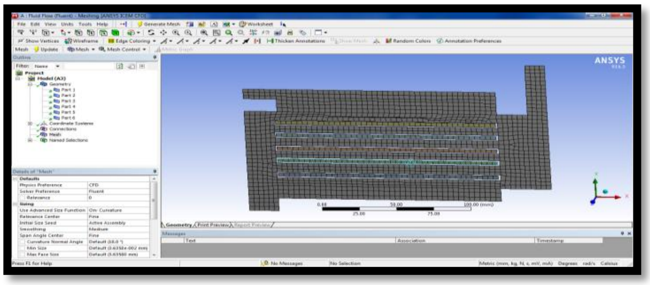
V.CFD ANALYSIS OF STEAM BOILER

VELOCITY – 20, 30, 40& 50m/s
FLUID – STEAM

→→Ansys → workbench→ select analysis system → fluid flow fluent → double click
→→Select geometry → right click → import geometry → select browse →open part → ok

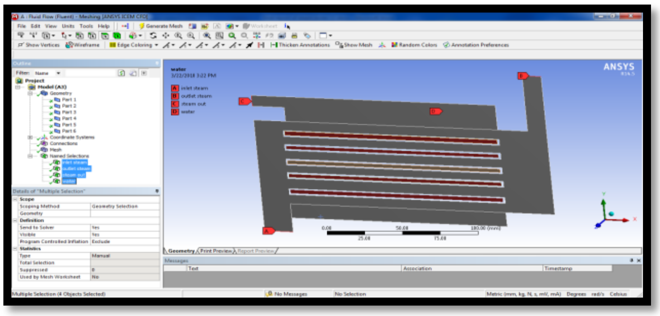


→→ select mesh on work bench → right click →edit → select mesh on left side part tree → right click → generate mesh →



The model is designed with the help of pro-e and then import on ANSYS for Meshing and analysis. The analysis by CFD is used in order to calculating pressure profile and temperature distribution. For meshing, the fluid ring is divided into two connected volumes. Then all thickness edges are meshed with 360 intervals. A tetrahedral structure mesh is used. So the total number of nodes and elements is 6576 and 3344.

Select faces → right click → create named section → enter name → water inlet
Select faces → right click → create named section → enter name → water outlet

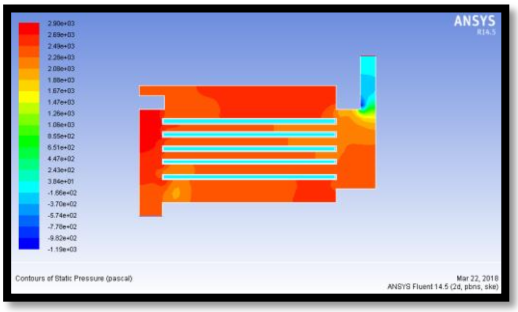


Model → energy equation → on.
Viscous → edit → k- epsilon
Enhanced Wall Treatment → ok

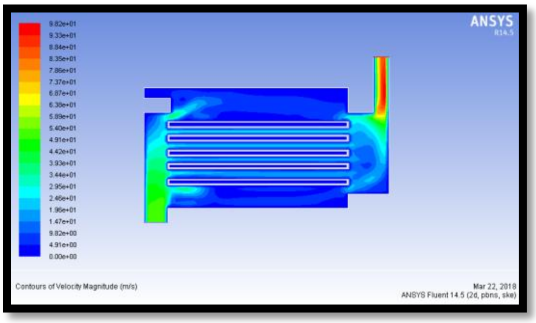
Materials → new → create or edit → specify fluid material or specify properties → ok
Select air and water
Boundary conditions → select water inlet → Edit → Enter Water Flow Rate → 2Kg/s and Inlet Temperature – 353K
Solution → Solution Initialization → Hybrid Initialization →done
Run calculations → no of iterations = 50 → calculate → calculation complete
→→ **Results → graphics and animations → contours → setup**

VELOCITY – 50m/s

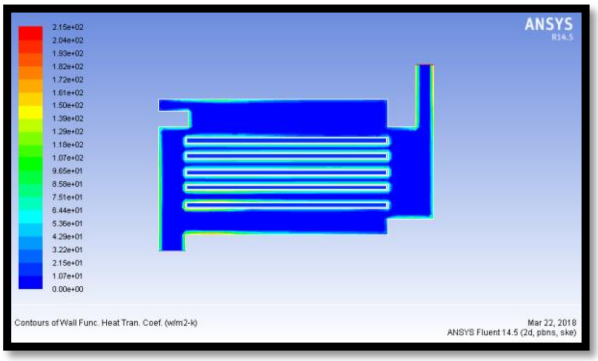
PRESSURE



VELOCITY



HEAT TRANSFER CO-EFFICIENT



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MASS FLOW RATE

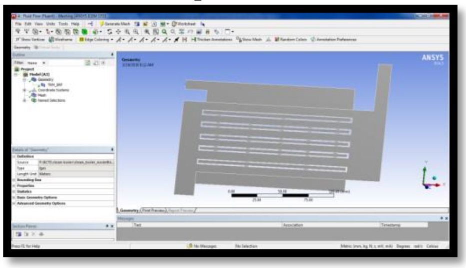
Mass Flow Rate	(kg/s)
inlet_steam	0.55886209
interior-part_1	-7.5209637
interior-part_1-water	-0.0065074284
interior-water	-4.238658
outlet_steam	-0.56094575
steam_out	0
wall-part_1	0
wall-water	0
Net	-0.0020836592

HEAT TRANSFER RATE

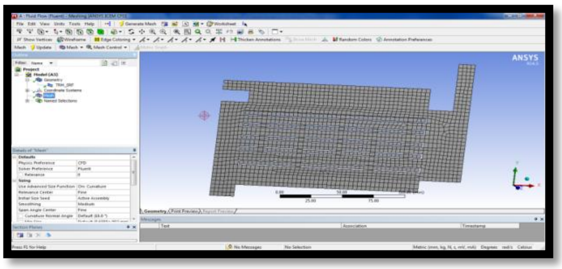
Total Heat Transfer Rate	(w)
inlet_steam	78543.602
outlet_steam	-78658.797
steam_out	0
wall-part_1	0
wall-water	0
Net	-115.19531

CFD ANALYSIS OF STEAM BOILER WITH BAFFLES

Imported model

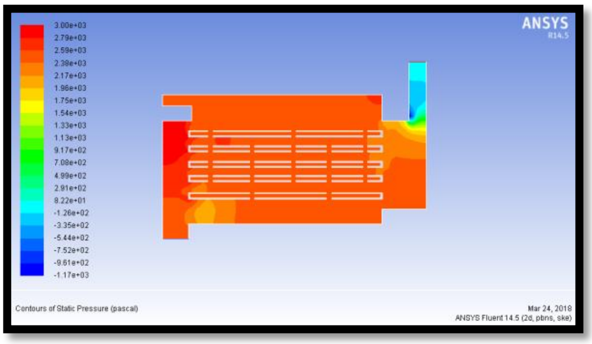


Meshed model



INLET VELOCITY – 50m/s

Pressure



Velocity

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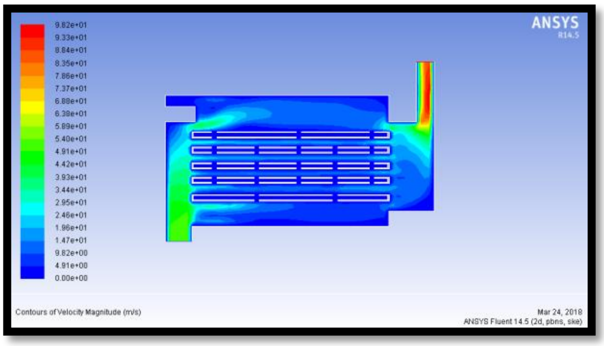
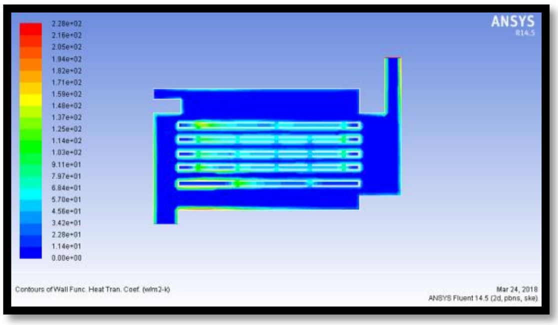


Heat transfer coefficient



Mass flow rate

Mass Flow Rate	(kg/s)
inlet	0.55886209
interior-_trm_srf	-0.89335215
outlet	-0.56423342
steam_out	0
wall-_trm_srf	0
Net	-0.0053713322

Heat transfer rate

Total Heat Transfer Rate	(w)
inlet	78543.602
outlet	-79298.641
steam_out	0
wall-_trm_srf	0
Net	-755.03906

VI. THERMAL ANALYSIS:

THERMAL ANALYSIS OF STEAM BOILER

Open work bench 14.5>select **steady state thermal** in analysis systems>select geometry>right click on the geometry>import geometry>select **IGES** file>open

Used Materials steel, copper, brass & stainless steel
Copper material for tube
Steel, brass & stainless steel for boiler casing

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

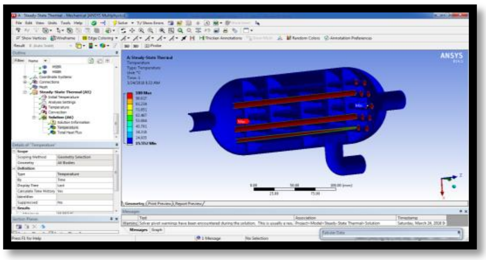
Thermal conductivity = 34.3w/m-k
Specific heat = 0.620j/g^{0}C
Density = 0.00000901kg/mm^3

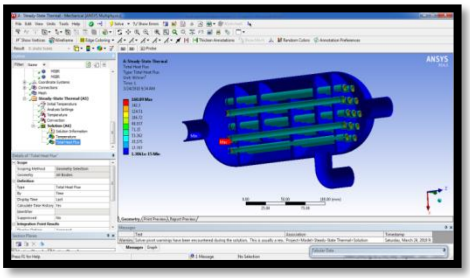
Brass material properties

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

THERMAL ANALYSIS OF STEAM BOILER WITH BAFFLES

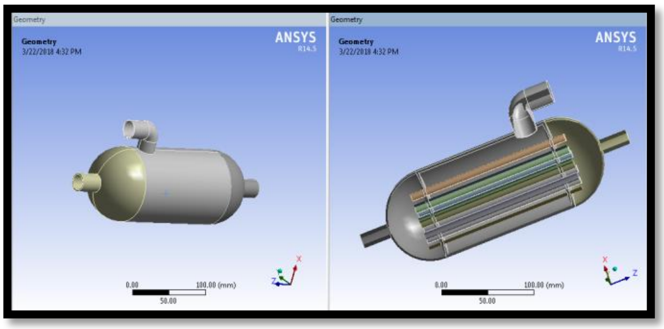
TEMPERATURE DISTRIBUTION



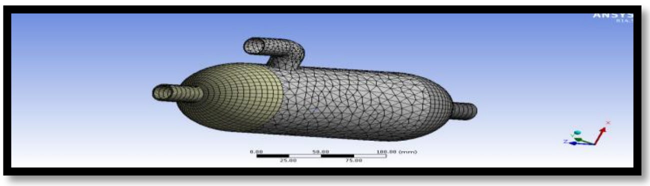


HEAT FLUX

VII. IMPORTED MODEL



MESHED MODEL



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 is the mesh, the more accurate the results, but more computing power is required.

VIII. RESULTS AND DISCUSSIONS

Without baffles	Temperature(^{0}C)	Max.	100
		Min.	15.711
	Heat flux(w/mm^2)		159.67
With baffles	Temperature(^{0}C)	Max.	100
		Min.	15.552
	Heat flux(w/mm^2)		160.09

CFD ANALYSIS RESULT TABLE

Steam boiler without baffles

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)
20	4.75e+02	3.93e+01	1.13e+02	0.0024522692	372.9043
30	1.07e+03	5.89e+01	1.50e+02	0.0021263063	157.38672
40	1.86e+03	7.90e+01	1.84e+02	0.0037876368	379.625
50	2.90e+03	9.82e+01	2.15e+02	0.0020856592	115.19531

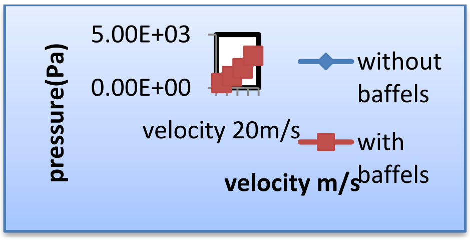
Steam boiler with baffles

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)
20	4.53e+02	3.86e+01	1.12e+02	0.0034194887	480.56836
30	1.08e+03	5.87e+01	1.47e+02	0.0030812621	433.06641
40	1.82e+03	7.80e+01	1.80e+02	0.00080680847	113.41797
50	3.00e+03	9.82e+01	2.28e+02	0.00537133	755.03906

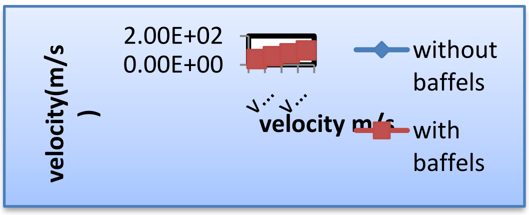
THERMAL ANALYSIS RESULT TABLE

IX.GRAPHS:

PRESSURE PLOT



VELOCITY PLOT



HEAT TRANSFER COEFFICIENT PLOT

MASS FLOW RATE PLOT

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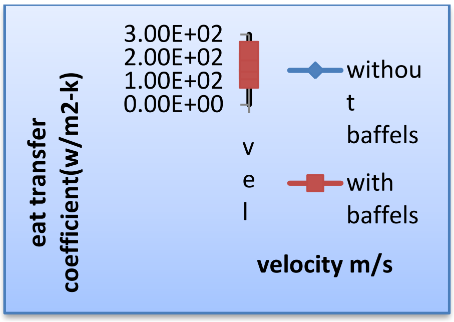
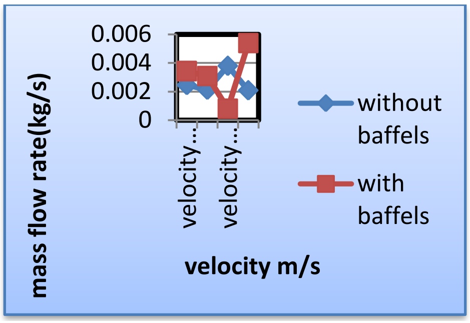
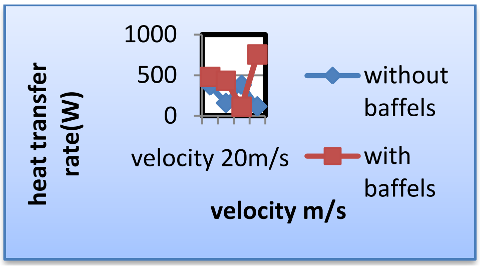
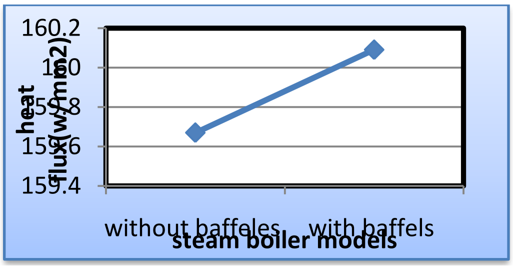




HEAT TRANSFER RATE PLOT



HEAT FLUX PLOT



X CONCLUSION

In this thesis the steam flow in steam boiler (without baffles & with baffles) is modeled using CREO parametric design software. The thesis will focus on thermal and CFD analysis with different inlet velocities (20, 30, 40& 50m/s). in this thesis the CFD analysis to determine the heat transfer coefficient, heat transfer rate, mass flow rate, pressure drop. Thermal analysis to determine the temperature distribution, heat flux for models of steam boiler without baffles and steam boiler with baffles. Observing the thermal analysis, the taken different heat transfer coefficient values are from CFD analysis. Heat flux value is more for steam boiler with baffles. So we can conclude the steam boiler with baffles model is better model.

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