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Design and Thermal Analysis of a Supercritical Cfb Boiler

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ABSTRACT

A boiler is a closed vessel in which water or other fluid is heated. The fluid does not necessarily boil. The heated or vaporized fluid exits the boiler for use in various processes or heating applications, including central heating, boiler-based power generation, cooking, and sanitation.

Supercritical Circulating Fluidized Bed (CFB) boiler becomes an important development trend for coal-fired power plant and thermal-hydraulic analysis is a key factor for the design and operation of water wall.

In this thesis, a simple boiler and a CFB boiler are compared for the better heat transfer performance. The 3D modeling of simple boiler and CFB boiler is done in Pro/Engineer and Heat transfer analysis is done in Ansys.

The material used for boiler is steel. In this thesis, it is to be replaced with copper and brass. Thermal analysis is done to verify the better heat transfer rate by comparing simple and CFB boilers and better material. And even CFD analysis is done for verifying the heat transfer in the CFB boiler.

1. INTRODUCTION

SUPERCRITICAL BOILER:-A supercritical boiler is a type of steam generator that operates at supercritical pressure, frequently used in the production of electric power. In contrast to a subcritical boiler, a supercritical steam generator operates at pressures above the critical pressure — 3,200 psi or 22 MPa — in which bubbles can form. Instead, liquid water immediately becomes steam. Water passes below the critical point as it does work in a high pressure turbine and enters the generator's condenser, resulting in slightly less fuel use and therefore less greenhouse gas production. Technically, the term "boiler" should not be used for a supercritical pressure steam generator as no "boiling" actually occurs in the device.

Working of a Supercritical Boiler:-A supercritical boiler burns pulverized coal and is a once-through boiler, meaning that it doesn't require a drum to separate steam from water. Rather than boiling water to produce steam and then using that steam to turn a plant's turbine, a supercritical boiler operates at such high pressure (3,208 psi/221.2 bar or above) that the fluid matrix in it ceases to be liquid or gas. Instead, it becomes what is known as a "supercritical fluid."

This supercritical fluid turns the turbine that generates electricity. As it does so, it drops below the critical pressure point and becomes a mix of steam and water, passing into a condenser. In the process, less fuel is consumed than in a traditional drum boiler, making supercritical boilers more efficient than their subcritical counterparts.

Benefits of Supercritical Boilers:-It's hard to believe, but supercritical boiler technology is almost 100 years old. Granted, it didn't look anything like what it does today when Mark Benson first obtained a patent to convert water into steam at high pressure levels in 1922, but the drive to improve the power industry's ability to burn coal through supercritical means has been constant throughout the history of modern boiler engineering.

Improved Efficiency:-Supercritical and ultra-supercritical boilers' ability to operate at much higher pressures and temperatures than subcritical boilers translates into noticeably better efficiency ratings.

Subcritical boilers typically run at 2400 psi/1000°F. By way of contrast, modern supercritical units can go as high as 3900 psi/1100°F. The even more advance ultra-supercritical units reach pressures and temperatures as high as 4600 psi/1120°F. Current research goals are set as high as 5300 psi/1300°F and seem to be on the horizon.

So how does all of this play out in terms of efficiency ratings? Well, the reports vary when it comes to the exact percentages, but here is a chart that summarizes the ranges that are usually cited. As a benchmark, the rating given by the 2007 MIT "The Future of Coal" study is also included.

Boiler Type	Efficiency Rating Spread	MIT Efficiency Rating
Subcritical	32–38%	34.3%
Supercritical	37–42%	38.5%
Ultra-supercritical	42–45%	43.3%

Reduced Emissions:-Improved plant efficiency also translates into reduced emissions, particularly of CO2 and mercury, which are difficult to manage otherwise. The general rule of thumb is that each percentage point of efficiency improvement yields 2–3% less CO2.

Lower Operating Costs:-For all fossil fuel–fired plants, fuel represents the largest operating cost. By reducing the amount of fuel needed to yield the requisite energy, supercritical plants make a noticeable dent in bottom lines when compared to subcritical plants.

What It Takes to Go Supercritical:-You're probably wondering: How much does a supercritical boiler really cost? Some estimates put it at 2–5% more than a subcritical unit, but the truth is, it's impossible to say because the price is really dependent on project scope and specifications. More and more plants are employing the technology, though, which is making it more and more affordable. It's also becoming more of a necessity as emissions regulations continue to tighten

Circulating Fluidized Bed:-Circulating Fluidized Bed combustion has given boiler and power plant operators a greater flexibility in burning a wide range of coal and other fuels. All this without compromising efficiency and with reduced pollution. How does the boiler work?

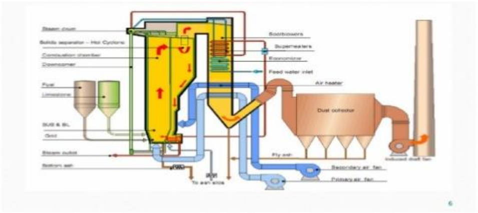
Fluidized Bed:-At the bottom of the boiler furnace there is a bed of inert material. Bed is where the coal or fuel spreads. Air supply is from under the bed at high pressure. This lifts the bed material and the coal particles and keeps it in suspension. The coal combustion takes place in this suspended condition. This is the Fluidized bed.

Special design of the air nozzles at the bottom of the bed allows air flow without clogging. Primary air fans provide the preheated Fluidizing air. Secondary air fans provide pre-heated Combustion air. Nozzles in the furnace walls at various levels distribute the Combustion air in the furnace.

Circulation:-Fine particles of partly burned coal, ash and bed material are carried along with the flue gases to the upper areas of the furnace and then into a cyclone. In the cyclone the heavier particles separate from the gas and falls to the hopper of the cyclone. This returns to the furnace for recirculation. Hence the name Circulating Fluidized Bed combustion. The hot gases from the cyclone pass to the heat transfer surfaces and go out of the boiler.

Bed Material:-To start with the bed material is sand. Some portion is lost in the ash during the operation and this has to be made-up. In coal fired boilers the ash from the coal itself will be the makeup material. When firing bio fuels with very low ash content sand will be the makeup bed material. For high Sculpture coals Limestone addition to the bed material reduces SO2 emissions.

CFBC uses crushed coal of 3 to 6 mm size. This requires only a crusher not a pulverize. From storage hoppers Conveyer and feeders transport the coal to feed chutes in the furnace. Startup is by oil burners in the furnace. Ash spouts in the furnace remove the ash from the bottom of the furnace. Different boiler manufacturers adopt different methods of cyclone separation, the fluidizing nozzles etc. But the basic principles remain the same.



Schematic figure of a Circulating Fluidized Bed

2. CAD/CAE

CATIA:-CATIA also known as **Computer Aided Three-dimensional Interactive Application** and it is software suit that developed by the French company call Desalt Systems.

CATIA is a process-centric computer-aided design/computer-assisted manufacturing/computer-aided engineering (CAD/CAM/CAE) system that fully uses next generation object technologies and leading edge industry standards. CATIA is integrated with Desalt Systems Product Lifecycle Management (PLM) solutions. It allows the users to simulate their industrial design processes from initial concept to product design, analysis, assembly and also maintenance. In this software, it includes mechanical, and shape design, styling, product synthesis, equipment and systems engineering, NC manufacturing, analysis and simulation, and industrial plant design. It is very user friendly software because CATIA Knowledge ware allows broad communities of user to easily capture and share know-how, rules, and other intellectual property assets.

Engineering Design:-CATIA V5 offers a range of tools to enable the generation of a complete digital representation of the product being designed. In addition to the general geometry tools there is also the ability to generate geometry of other integrated design disciplines such as industrial and standard pipe work and complete wiring definitions. Tools are also available to support collaborative development.

A number of concept design tools that provide up-front Industrial Design concepts can then be used in the downstream process of engineering the product. These range from conceptual Industrial design sketches, reverse engineering with point cloud data and comprehensive freeform surface tools.

Different Modules in CATIA 5:-

- ✓ Sketcher
- ✓ Part Modeling
- ✓ Surfacing
- ✓ Sheet Metal
- ✓ Drafting
- ✓ Manufacturing
- ✓ Shape designs

ANSYS:-The ANSYS program is self-contained general purpose finite element program developed and maintained by Swanson analysis systems Inc .the program contain many routines, all inter related and all for main purpose of achieving a solution to an engineering problem by finite element method.

ANSYS finite element analysis software enables engineers to perform the fallowing tasks:

Performing a typical Annoys analysis:-The ANSYS program has many finite element analysis capabilities, ranging from a simple, linear, static analysis to a complex, nonlinear, transient dynamic analysis. The analysis guide manuals in the ANSYS documentation set describe specific procedures for performing analysis for different engineering disciplines. A typical ANSYS analysis has three distinct steps:

- Build the model
- Apply loads and obtain the solution
- Review the results

The following table shows the brief description of steps followed in each phase.

PRE-PROCESSOR:-The input data for an ANSYS analysis are prepared using a preprocessor. The general preprocessor (PREP 7) contains powerful solid modelling and mesh generation capabilities, and is also used to define all other analysis data with the benefit of data base definition and manipulation of analysis data. Parametric input, user files, macros and extensive online documentation are also available, providing more tolls and flexibility for the analyst to define the problem. Extensive graphics capability is available throughout the ANSYS program, including isometric, perceptive, section, edge and hidden-line displays of three-dimensional structures-y graphs of input quantities and results, and contour displays of solution results.

SOLUTION PROCESSOR:-Here we create the environment to the model, i.e. applying constraints & loads. This is the main phase of the analysis, where the problem can be solved by using different solution techniques. Here three major steps involved:

POST PROCESSOR:-Post processing means the results of an analysis. It is probably the most important step in the analysis, because we are trying to understand how the applied loads affects the design, how food your finite element mesh is, and so on.

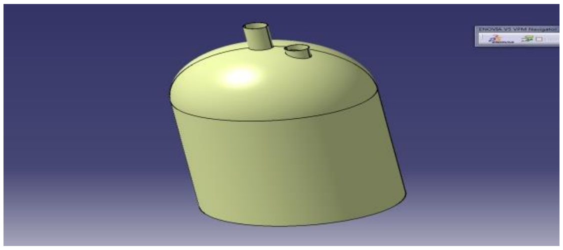
REVIEW THE RESULTS:-Once the solution has been calculated, we can the ANSYS post processor to review the results. Two post processors are available: POST 1 and POST 26. We use POST 1, the general post processor to review the results at one sub step over the entire model or selected portion of the model. We can obtain contour displays, deform shapes and tabular listings to review and interpret the results of the analysis. POST 1 offers many other capabilities, including error estimation, load case combination, calculation among results data and path operations

MESHING:-Before meshing the model and even before building the model, it is important to think about whether a free mesh or a mapped mesh is appropriate for the analysis. A free mesh has no restrictions in terms of element shapes and has no specified pattern applied to it. Compare to a free mesh, a mapped mesh is restricted in terms of the element shape it contains and the pattern of the mesh. A mapped area mesh contains either quadrilateral or only triangular elements, while a mapped volume mesh contains only hexahedron elements. If we want this type of mesh, we must build the geometry as series of fairly regular volumes and/or areas that can accept a mapped mesh.

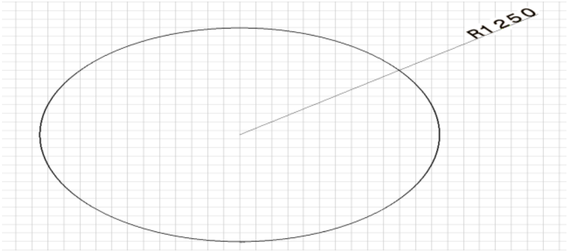
STRUCTURAL STATIC ANALYSIS:-A static analysis calculates the effects of study loading conditions on a structure, while ignoring inertia and damping effects, such as those caused by time varying loads. A static analysis can however include steady inertia loads and time varying loads that can be approximated as static equivalent loads. Static analysis is used to determine the displacements, stresses, strains and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed, i.e. the loads and the structure's responses are assumed to vary slowly with respect to time. The kinds of loading that can be applied in static analysis include:

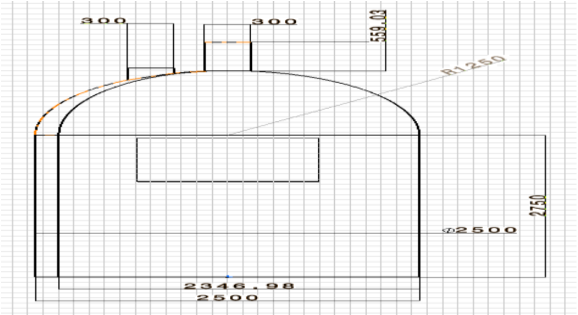
- Externally applied forces and pressures.
- Steady state inertial forces.
- Imposed displacement.
- Temperatures.
- Fluencies (for nuclear swelling).

DESIGN OF BASIC BOILER

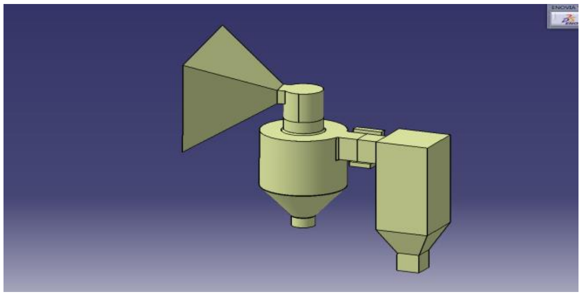


Draft of basic model

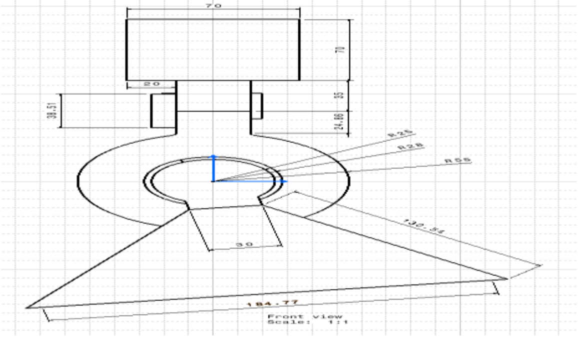


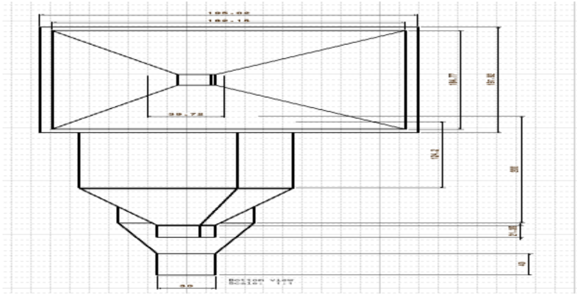


CFB BOILER DESIGN



Draft of cfb boiler





MATERIAL PROPERTIES

1. BRASS:-

Thermal conductivity: 233W/mk
Melting point: 1030ºC
COMPOSITION OF BRASS:
Aluminum: 0.421%
Antimony: 0.09%
Arsenic: 0.123%
Bismuth: 1.27%
Copper: 68.7%
Iron: 0.114%
Zinc 30.3%

2. COPPER:-

Thermal conductivity: 385W/mk
Melting point: 1083.6ºC

COMPOSITION OF COPPER

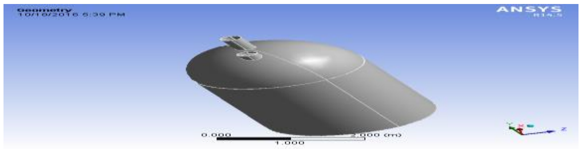
Copper 100%

3. REPORT

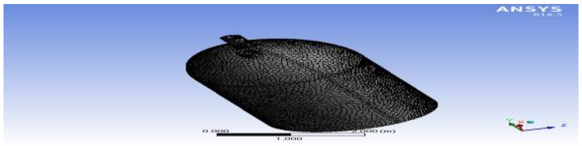
Transient Thermal Analysis of Basic Model of Boiler

Made Of Brass

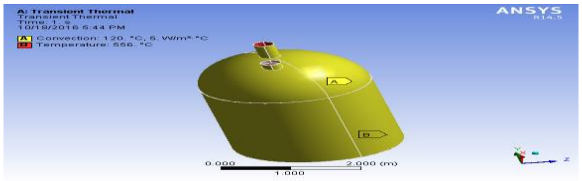
Imported Model



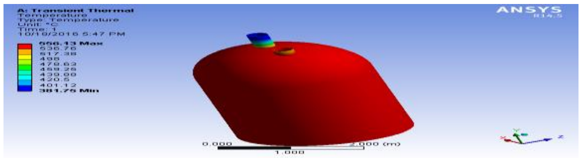
MESHED MODEL



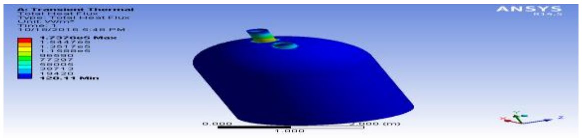
BOUNDARY CONDITIONS



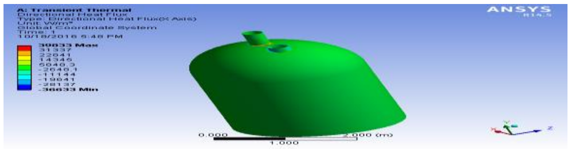
TEMPERATURE DISTRIBUTION



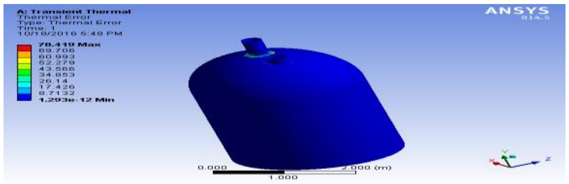
THERMAL FLUXES



DIRECTIONAL HEAT FLUX

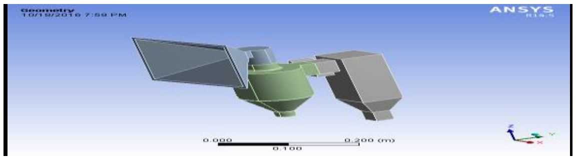


THERMAL ERROR

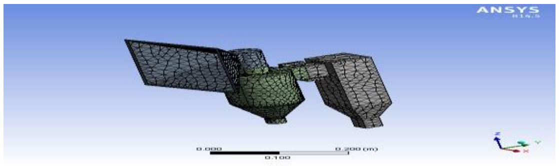


TRANSIENT THERMAL ANALYSIS OF CFB MODEL OF BOILER MADE WITH COPPER

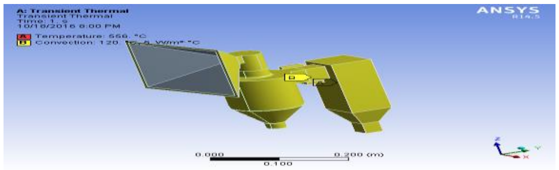
IMPORTEDMODEL



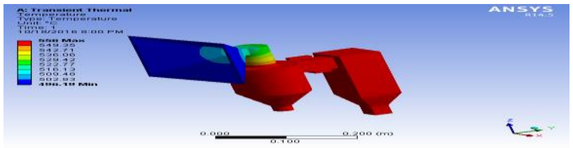
MESHED MODEL



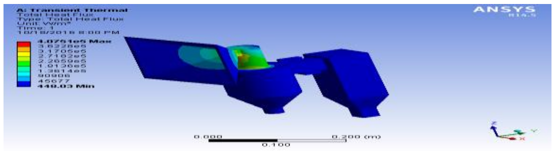
BOUNDARY CONDITIONS



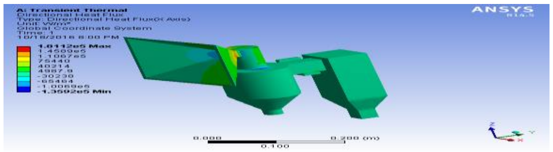
TEMPERATUREDISTRIBUTION



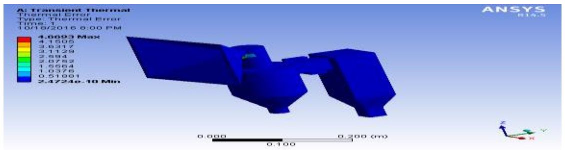
THERMALFLUXES



DIRECTIONALHEATFLUX



THERMAL ERROR



4. CFD ANALYSIS OF SIMPLE BOILER

MATERIAL DATA


Create/Edit Materials

Name: water-liquid

Material Type: fluid

Order Materials by: ● Name ○ Chemical Formula

Chemical Formula: h2o<l>

Fluent Fluid Materials: water-liquid (h2o<l>)

Mixture: none

Properties

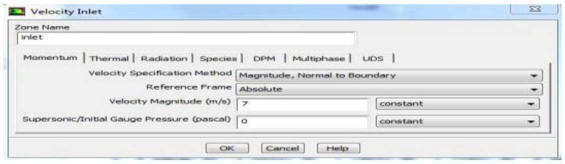
Density (kg/m3): constant 998.2

Cp (Specific Heat) (j/kg-k): constant 4182

Thermal Conductivity (w/m-k): constant 0.6

Viscosity (kg/m-s): constant 0.001003

BOUNDARY CONDITION


Velocity Inlet

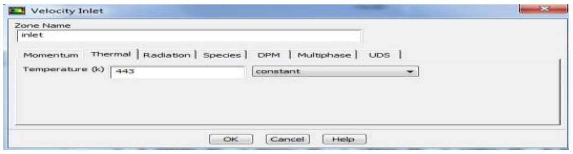
Zone Name: inlet

Velocity Specification Method: Magnitude, Normal to Boundary

Reference Frame: Absolute

Velocity Magnitude (m/s): 7 constant

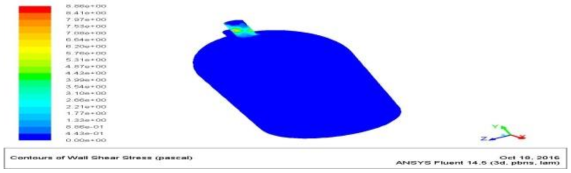
Supersonic/Initial Gauge Pressure (pascal): 0 constant


Velocity Inlet

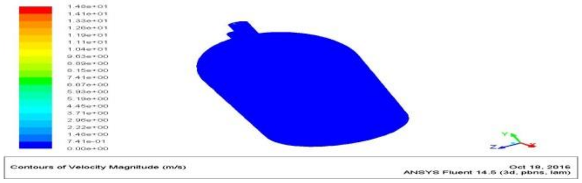
Zone Name: inlet

Temperature (k): 443 constant

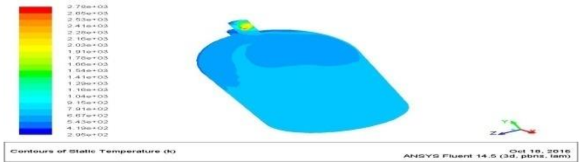
Wall shear stress



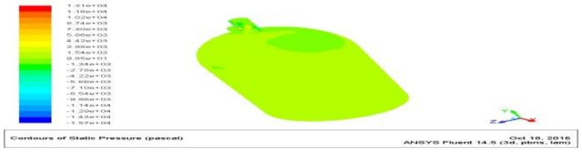
VELOCITY MAGNITUDE



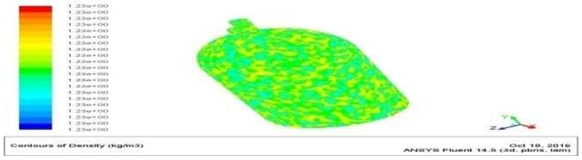
STATIC TEMPRATURE



STATICPRESSURE



DENSITY

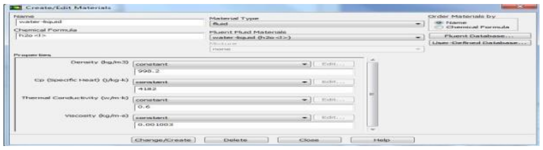


Mass Flow Rate	**(kg/s)**
Inlet	0.03907967
Interior-body.3__	0.41825375
Outlet	-0.0007242717
Wall-body.3__	0
Net	0.038355398

Total Heat Transfer Rate	**(w)**
Inlet	5696.9536
Outlet	-3965.0188
Wall-body.3__	0
Net	1731.9348

CFD ANALYSIS OF CIRCULATING FLUIDIZED-BED BOILER

MATERIAL DATA


Create/Edit Materials

Name: water-liquid

Chemical Formula: h2o <l>

Material Type: fluid

Fluent Fluid Materials: water-liquid (h2o <l>)

Mixture: none

Order Materials by: ● Name ○ Chemical Formula

Properties

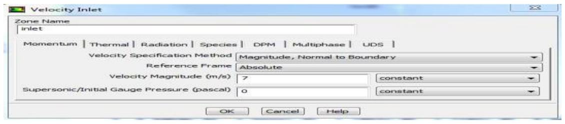
Density (kg/m3): constant — 998.2

Cp (Specific Heat) (j/kg-k): constant — 4182

Thermal Conductivity (w/m-k): constant — 0.6

Viscosity (kg/m-s): constant — 0.001003

BOUNDARY CONDITION


Velocity Inlet

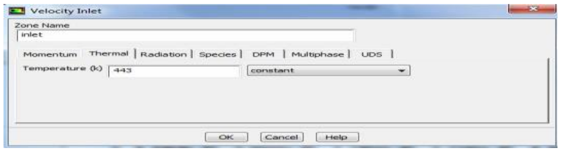
Zone Name: inlet

Velocity Specification Method: Magnitude, Normal to Boundary

Reference Frame: Absolute

Velocity Magnitude (m/s): 7 — constant

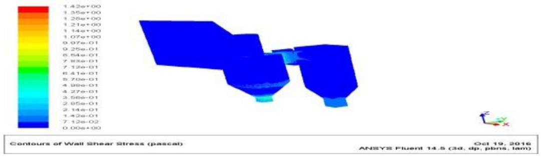
Supersonic/Initial Gauge Pressure (pascal): 0 — constant


Velocity Inlet

Zone Name: inlet

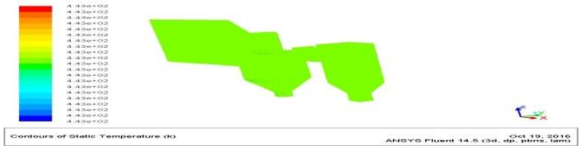
Temperature (k): 443 — constant

Wall shear stress

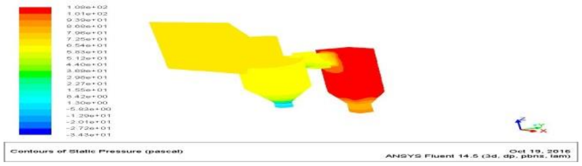


VELOCITY MAGNITUDE

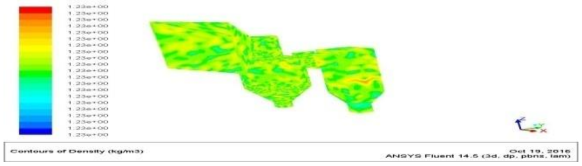
STATIC TEMPRATURE



STATIC PRESSURE



DENSITY



Mass Flow Rate	**(kg/s)**
Inlet	0.0044863865
Outlet	-0.0045054159
Wall-solid	0

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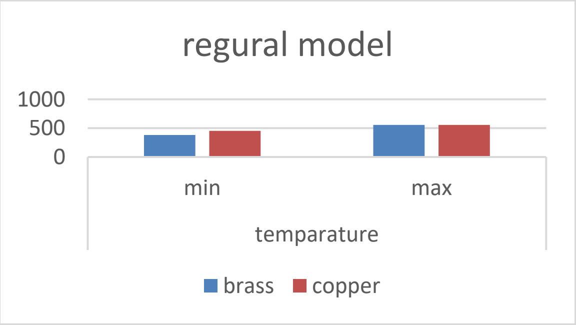
                ---------------- --------------------
                           Net      -1.9029379e-05

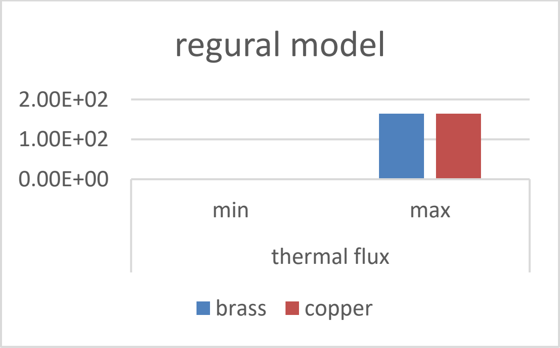
      Total Heat Transfer Rate                 (w)
-------------------------------- --------------------
Inlet          654.03164
Outlet          -656.80577
Wall-solid                  0
                ---------------- --------------------
                           Net         -2.774129
```

5. REGULAR MODEL GRAPHS

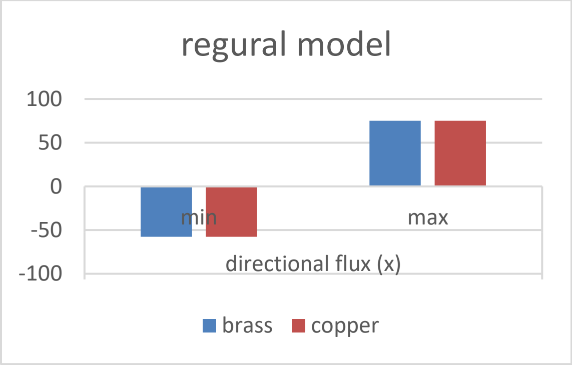
Temperature



Thermal fluxes

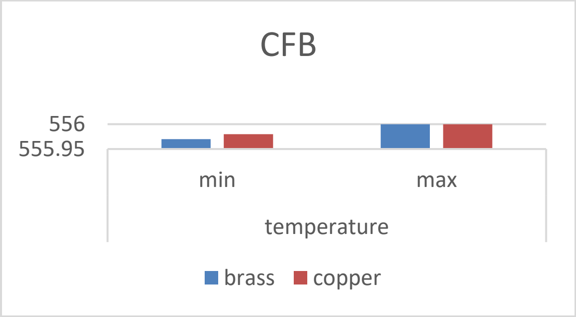


Directional thermal fluxes

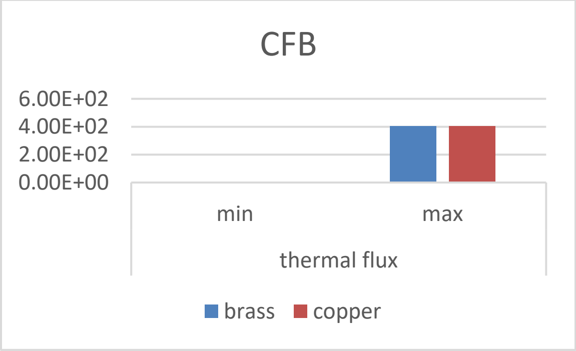


CFB BOILER GRAPHES

Temperature



Thermal fluxes



6. CONCLUSION

In this thesis, a simple boiler and a CFB boiler are compared for the better heat transfer performance. The 3D modeling of simple boiler and CFB boiler is done in Pro/Engineer and Heat transfer analysis is done in Annoys. The material used for boiler is steel. In this thesis, it is to be replaced with copper and brass. Thermal analysis is done to verify the better heat transfer rate by comparing simple and CFB boilers and better material.

As per the analysis done if we observe the results obtained for the simple boiler, we can find that the brass material is the best material for the simple boiler as the flux obtained is lees compared with the copper.

As in the other case a CFB boiler is considered and analysis is done, as if we compare the results of the CFB boiler we can see that the brass material CFB boiler is much better for the better life output as the stress is very minimum in this material. Her even CFD analysis is done to the CFB boiler to verify the stress and pressure and density values,

As if we compare both the results we can conclude that CFB boiler gives much better output for the material and even the temperature and the flux obtained is the best results for the boiler.

7. FUTURE SCOPE

As per the future scope here we have taken a simple boiler and CFB boiler, as boilers are mainly used in heavy industries, CFB boiler withstands at high boiler than normal boiler, but even if we see the better output of produces, a CFB boiler gives the product with better output.

As in many industries only simple boilers are being used, as CFB boiler is a costlier that a simple boiler, many of them are using a simple boiler, but as if we compare, initially the cost of the CFB boiler is high, but the total life output and better performance and the safety for a CFB boiler is very high than a simple boiler. So as we see in other boilers, the cost of the product initially is less, but later maintenance cost is high. So when we compare in all the modes we can result that if a CFB boiler is used in the place of other simple boilers, the life and output will be very better for a CFB boiler.

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