



Modeling and Determination of the Stresses and Deflections on a Boiler Using Finite Element Approach (ANSYS)

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ABSTRACT

A boiler is the device in which steam is generated by applying heat energy to water. Generally, a boiler consists of water container and some heating devices. To generate steam, the steam boiler is subjected to huge thermal and structural loads. The objective of the paper is to perform a 3D model and stimulate the boiler using ANSYS software to determine the loads and deflections on it. To obtain maximum efficient operation condition of the boiler, it is important to design a structure that can withstand the operating conditions of the thermal and structural loads on the boiler. ANSYS Workbench Model NX 8.0 was used to design the 3D model and also used for the analysis. The modeling process includes the static structural analysis, steady-state thermal analysis and modal analysis. The activities in the ANSYS modeling was categorized into three processes, namely, the preprocessor, the solution and the post processor. Generation of the model was conducted in the preprocessor, which involves material definition, creation of a solid model, and the meshing. In the solution stage, analysis type was defined and the boundary conditions were specified and the solution was done. The results were generated from the post processor stage. From the analysis, it was concluded that the steam boiler has stresses and deflections within the design limits of the material used. Hence, the designed steam boiler is safe under the given operating conditions. The result obtained shows a maximum tensile stress and deformation of the boiler as 308.90 MPa and 1.93 mm respectively. From the results, the tensile stress obtained is below the yield strength of the material used, which makes it safe for operation under those conditions.

Keywords: *Modeling, Stresses, Deflections, Boiler, Finite Element (Ansys)*

1. INTRODUCTION

A boiler is the device in which steam is generated by applying heat energy to water. Generally, a boiler consists of a water container and some heating devices (Rayner Joel, 1966). To generate steam, the steam boiler is subjected to huge thermal and structural loads. To obtain maximum efficient operation condition of the boiler, it is important to design a structure that can withstand the operating conditions of the thermal and structural loads that the boiler is to carry.

Finiteelement (ANSYS) is a useful programming tool, used to design and determine these structural loads before constructing a prototype.

The ANSYS enables a connections of all controls of material science, vibration, liquid elements, heat exchange and electromagnetic for Engineers. Finite element empowers Engineers to reproduce plans, before assembling models of items. (Figes A.S., 2016). ANSYS programming with its secluded structure gives an open door for taking just required elements (Figes A.S., 2016). The objectives of the paper are to perform a 3D model and stimulate the boiler using ANSYS

software to determine the loads and deflections on it. ANSYS Workbench Model NX 8.0 was used to design the 3D modeling and also used for the analysis.

The modeling process includes the static structural analysis, steady-state thermal analysis and modal analysis. The workflow of design analysis and stimulation is presented in fig. 1.

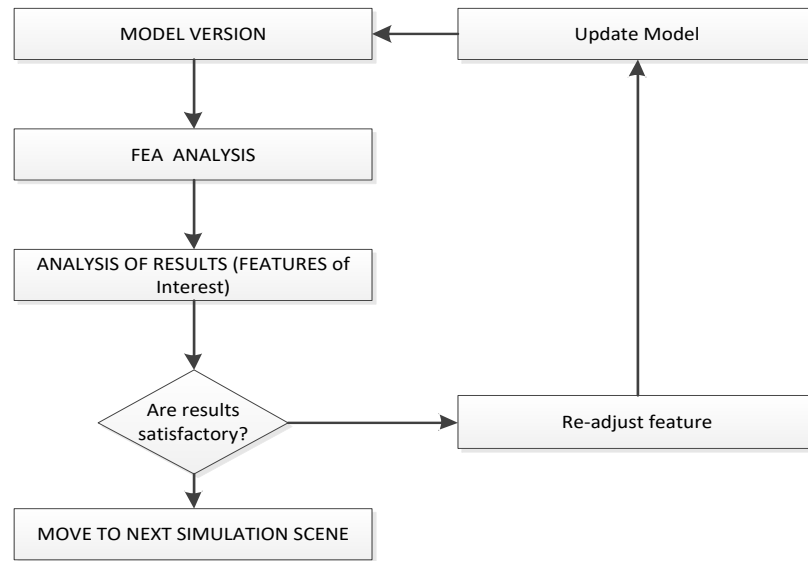


Fig. 1 Flow Diagram for Design Analysis

2. MATERIALS AND METHODS

Two materials were selected for the construction of the boiler and the furnace. Mild steel was used to construct the furnace whilst stainless steel was used to build the boiler. The properties of the materials used are presented in Table 2 below.

Table 2: Material Specification of the Extractor

Properties	Stainless Steel (3 mm)	Mild Steel (3 mm)
Name	ASMT A240 TP316L	AISI 1018
Ultimate Tensile Strength	480 MPa	440 MPa
Yield tensile strength	485 MPa	370 MPa
Poisson ratio	0.27-0.30	0.29
Young’s modulus	200 GPa	205 GPa
Yield Strength	205 MPa	200 MPa
Percentage elongation	40.00%	50%
Linear Coefficient of thermal Expansion	16.6x10 ⁻⁶ cm//°c	-
Thermal conductivity	16.3 W/m.K	51.9 W/m.K
Density	7900 (kg/m ³)	7870 (Kg/ m ³)

The ANSYS software was used to model the extractor. Figure 2 shows the flow chart for the modeling of the boiler.

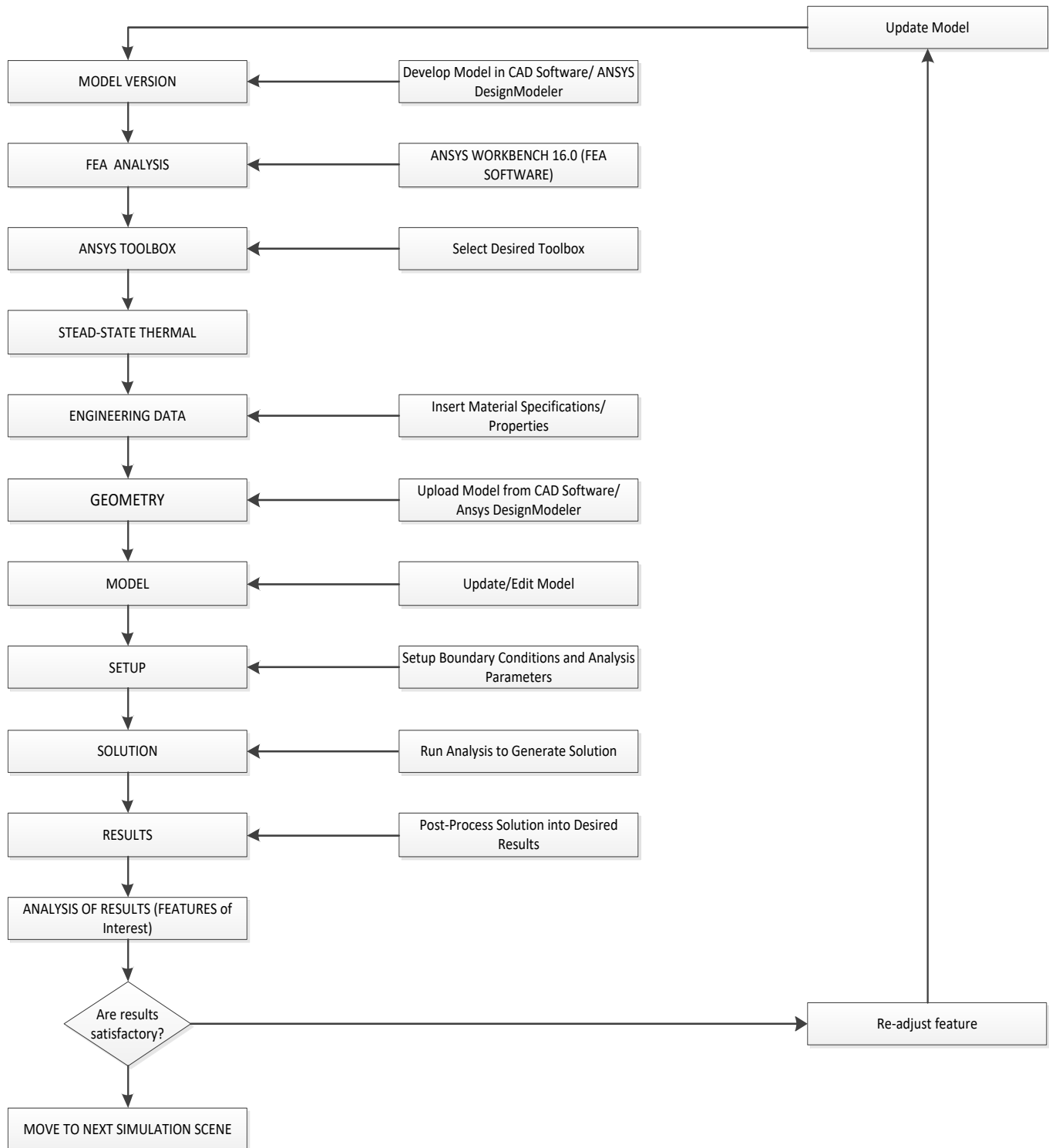


Figure 2: Modeling flow chart

The activities in the ANSYS modeling was categorized into three processes, namely, the preprocessor, the solution and the post processing. Generation of the model was conducted in this preprocessor, which involves material definition, creation of a solid model, and the meshing. In the solution stage, analysis type was defined and the boundary conditions were specified and the solution was done. The results were generated from the post processor stage. The 3D model of the steam boiler assembly was developed using NX-8.0 software. Steam boiler assembly converted to surface model for analysis. Modal analysis is used to determine a structure's vibration characteristics, natural frequencies and mode shapes. The modal analysis of the steam boiler assumes a fixed support at the base of the boiler. The vibrations were set to ten modes.

Density: 7850 – 8000kg/m³
 Thermal Conductivity: 14.6 W/mk
 Model Version:1.0
 Ultimate Tensile Strength: 480 MPa
 Yield Stress: 170 MPa
 Poisson ratio: 0.27- 0.30
 Elongation at break 40%
 Coordinate System (UCS)

Assumptions

Boiler Material Property Shell Body
 Boiler weight: (70 kg)
 No. of simulation scenarios 14
 The methodology followed in modeling the static structural is shown in fig. 2 above

2.1. Static Structural Description

This analysis assumes a fixed support at the base of the boiler and the analysis parameters were;
 Material: ASMT A240 TP316L Stainless Steel

Fig. 2.1.1 below shows parameters used for the generation of the meshed boiler which assumes a fixed support at the base.

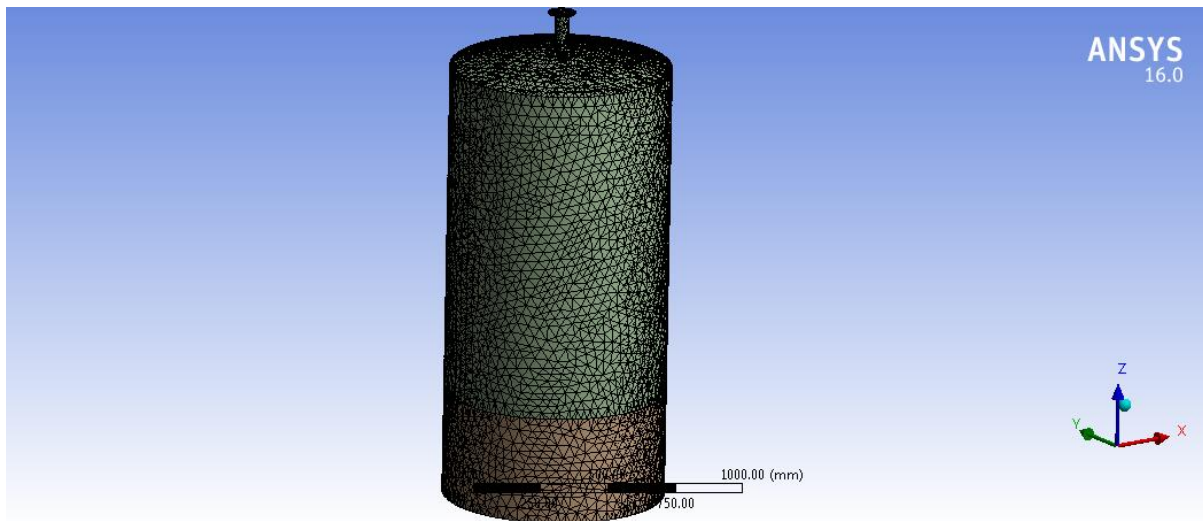


Fig 2.1.1 Meshed Boiler Mounted on a Furnace

The simulation setup with fixed support was generated from the meshed boiler and presented in fig 2.1.2 below

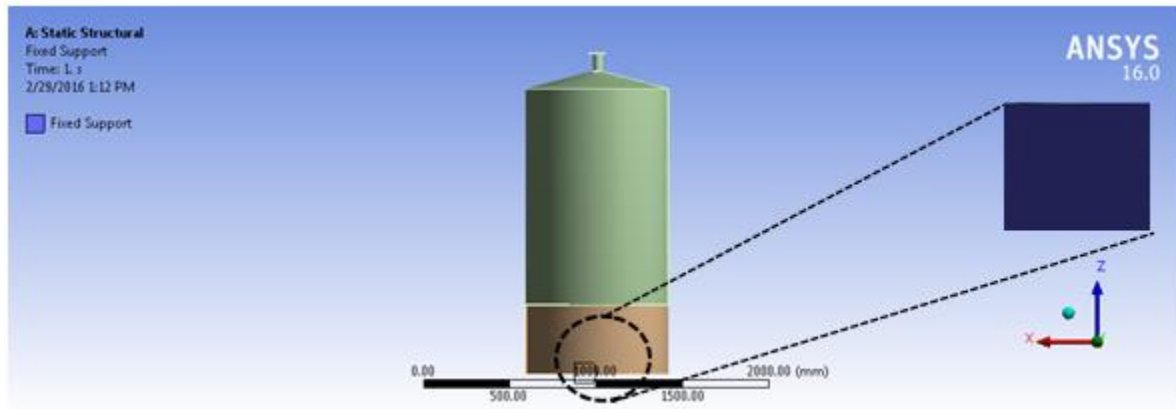


Fig. 2.1.2 Simulation setup

Figure 2.1.3 Present the 3D model of the steam boiler.

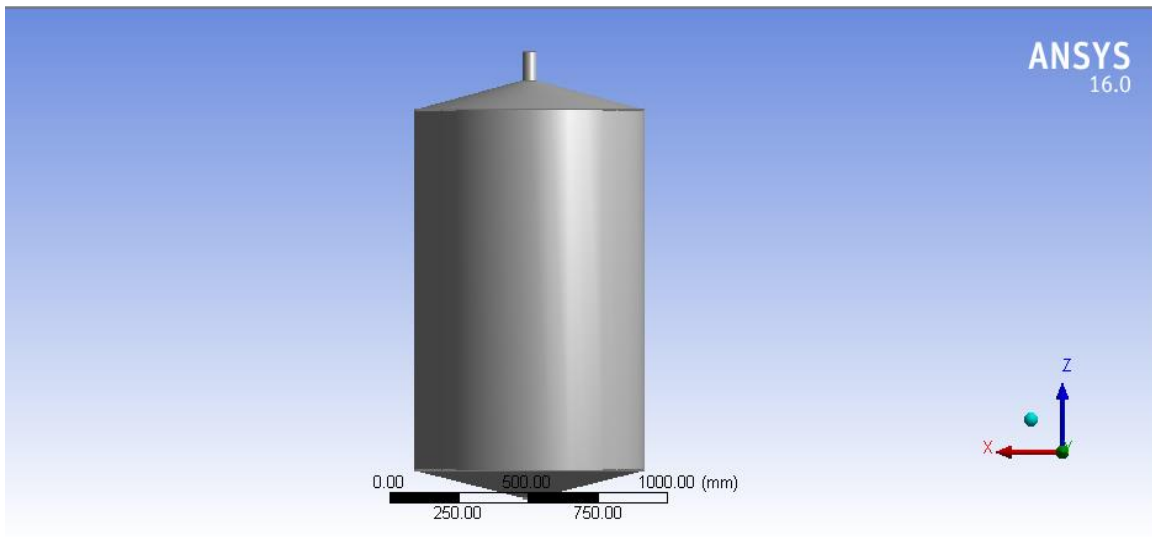


Figure 2.1.3 present the 3D model of the steam boiler.

The equivalent elastic strain on the boiler was generated and presented in fig.2.1.4.

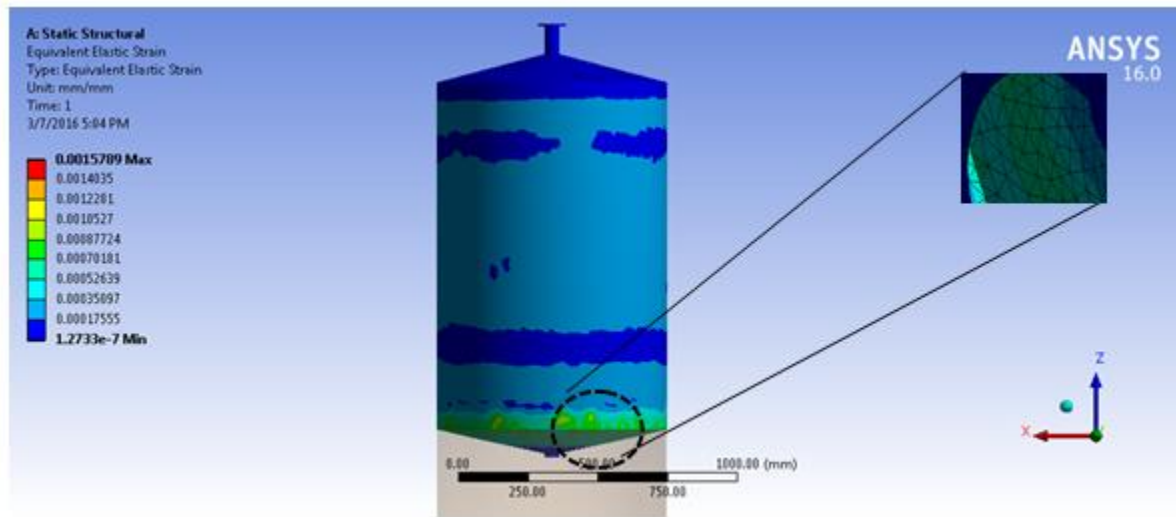


Fig. 2.1.4 Equivalent Elastic strain on boiler

Strain or deformation is defined as the deformations of a solid due to stress. As the boiler operates at higher pressures and

temperatures deformation sets in. The deformations on it were determined and presented in figure 2.1.5 below.

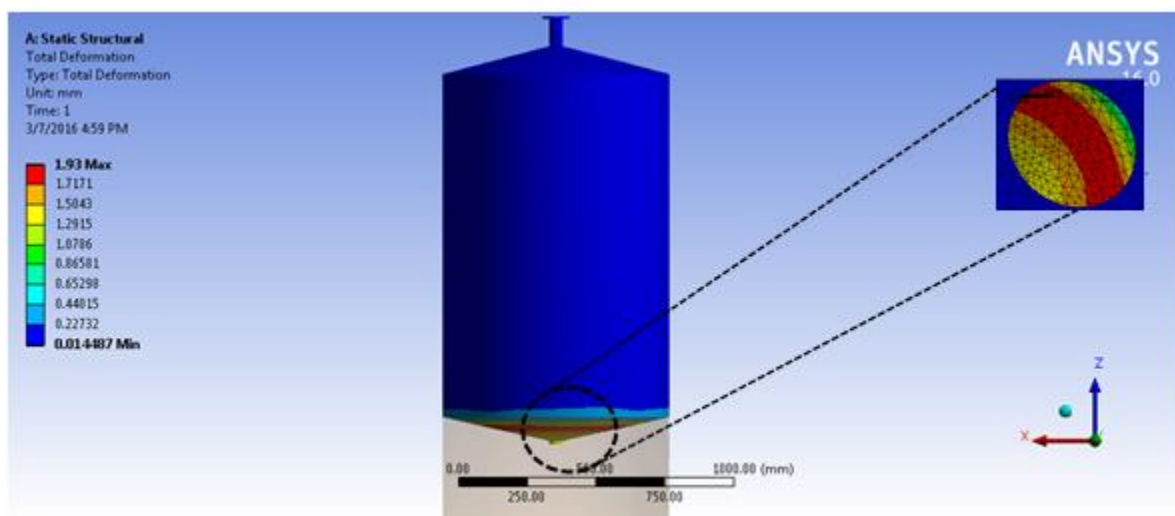


Figure 2.1.5 Deformation on boiler

Von Mises stress is often used in determining whether an isotropic and ductile metal will yield when subjected to a complex loading condition (Von Mises, R., 1913). This is accomplished by calculating the Von Mises stress and comparing it to the material's yield stress, which constitutes the Von Mises Yield criterion (Hencky, H. Z., 1924). The objective is to develop a yield criterion for ductile metals that works for any complex 3-D loading condition, regardless of

the mix of normal and shear stresses. The Von Mises does this by boiling the complex stress state down into a single scalar number that is compared to a metal's yield strength (Dowling, N.E., 1993). Figure 2.1.6 shows the equivalent (Von-Mises) Stress on boiler.

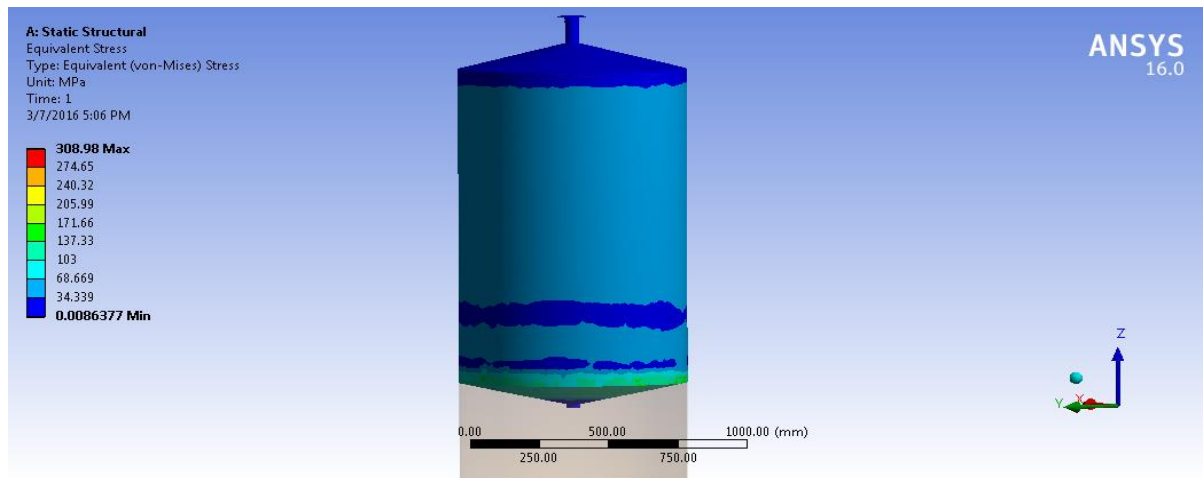


Figure 2.1.6 Equivalent (Von-Mises) Stress on boiler

Normal stresses also called axial stress σ_{xx} , σ_{zz} and circumferential or hoop stress is the stress which is set up in resisting the bursting effect of the applied pressure (AST

Lecture note on thin walled pressure vessels). Figure 2.1.7 shows the normal stresses on the boiler.

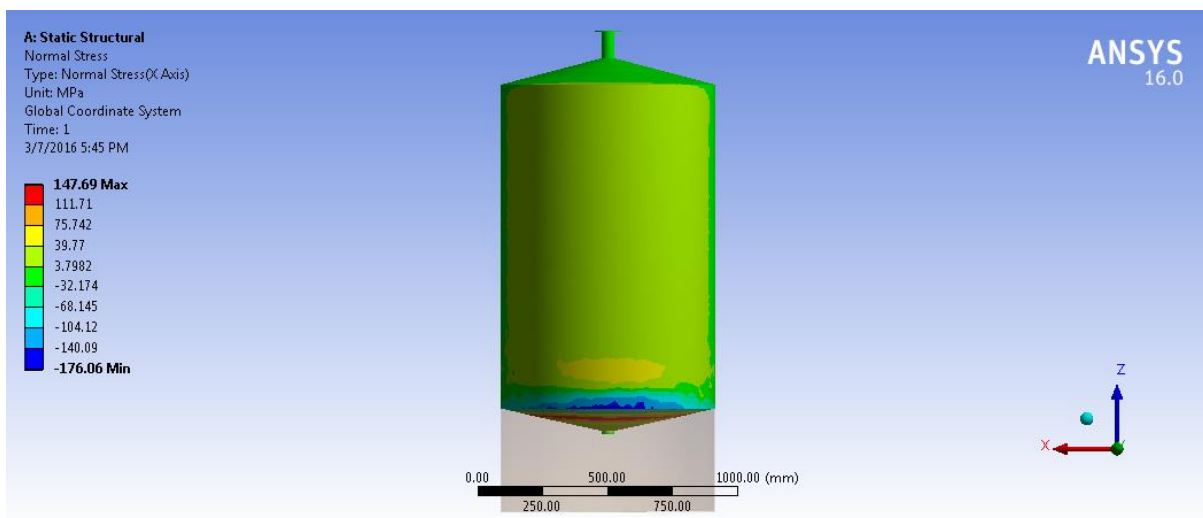


Figure 2.1.7 Normal Stress on boiler

2.2. Steady State Thermal Description

The steady-state thermal analysis assumes a fixed support at the base of the boiler with the same parameters of the static condition but with temperature distribution parameter.

The ANSYS/Multiphysics, ANSYS/Mechanical, ANSYS/FLOTRAN and ANSYS/Thermal products support steady-state thermal analysis. A steady-state thermal analysis calculates the effects of steady thermal loads on a system or

component. Analysis is often performed on a steady-state before doing a transient thermal analysis, to help establish initial conditions (ANSYS Modeling and meshing Guide).

The procedure used for doing the thermal analysis and obtaining the results shown in figure 2.1.8 below involves three main tasks. These are;

- Building the model

- Applying loads and obtain solution
- Reviewing the results.

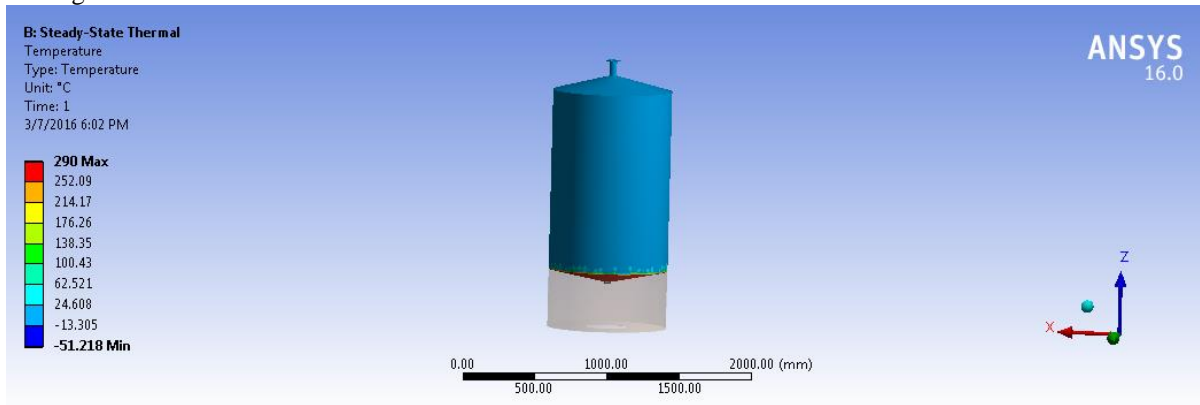


Figure 2.1.8 Temperature Distribution on boiler.

2.3. Modal solution

Modal analysis is used to determine a structure’s vibration characteristics, natural frequencies and mode shapes. The modal

analysis of the steam boiler assumes a fixed support at the base of the boiler. The vibrations were set to ten modes. The total deformation on the boiler is presented in fig. 2.1.9.

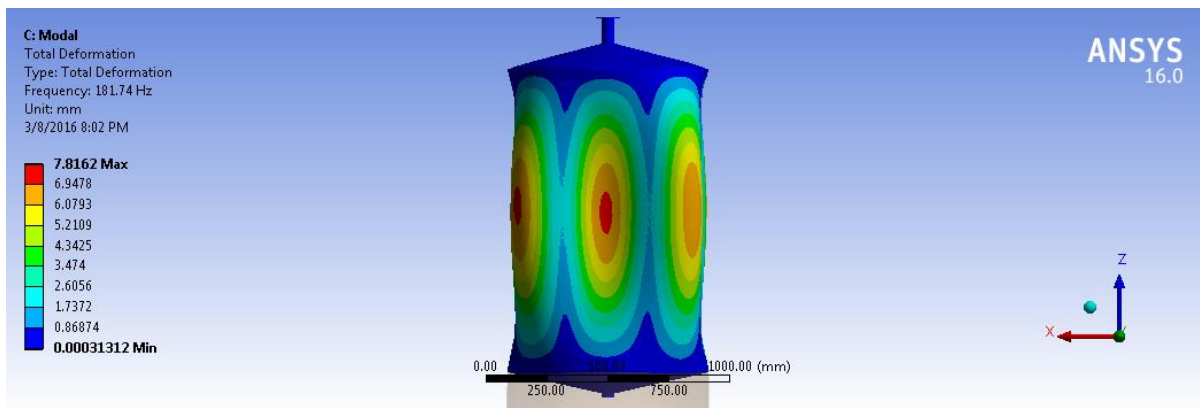


Figure 2.1.9 Total Deformation

The results for equivalent Von Mises stresses is shown in fig. 2.10

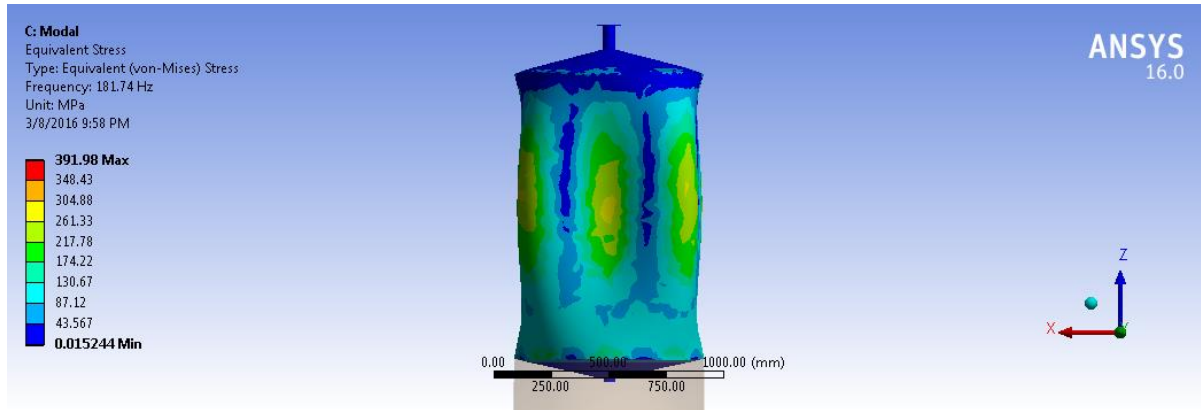


Figure 2.10 Equivalent (Von-Mises) Stress

3. DISCUSSION OF RESULTS

The result of the static structural total deformation of the boiler occurred at a maximum of 1.93 mm as shown in Figure 2.1.5.

According to the Maximum yield stress theory, for a boiler to be safe for operation, the maximum Von Misses stress on the component should be lower than the yield strength of the material. Figure 2.1.6 present the results for the maximum Von Misses stresses on the operating boiler. The result for the normal static structural is also shown in Figure 2.1.7

The maximum tensile stress and deformation are 308.9 MPa and 1.93 mm respectively. From the results, the tensile stress obtained is below the yield strength of the material used. The stresses on the boiler’s top section were at its bearable minimum, whilst the stresses on the whole body of the boiler

was also at minimal values. According to the Maximum Yield Stress Theory, if the Von-Misses stress on the boiler is lower than the yield strength of the material used for its construction, then the boiler will be safe for that operation condition. Since the Von-Mises stress of the designed steam boiler is lower than the yield strength of the material used, it is safe for the above operating condition.

Figure 2.1.8 present the temperature distribution solution of the steady-state condition of the operating boiler where temperature load of 290 °C was applied to the furnace.

Figure 2.1.9 shows the modal deformation which indicates the total deformation at a frequency of 181.74 Hz and its Equivalent (Von-Misses) Stress is shown in Figure 2.10

The vibration modes were set to ten varying frequencies as shown in Table 3.

Table 3: Vibration Modes at varying Frequency

Mode	Frequency (Hz)	Deformation (mm) for Maximum values	Von Misses Stresses (MPa) for Maximum values
1	181.74	7.8162	391.98
2	183.69	8.0777	378.78
3	185.33	5.9935	207.43
4	185.35	5.9763	209.77
5	218.32	8.9472	674.39
6	220.60	8.2115	608.75
7	228.22	7.2397	348.33
8	228.73	7.9382	364.77
9	318.03	8.8852	991.03
10	321.61	8.7827	1821.4

A graph of vibration modes against frequency was plotted and presented in figure 3

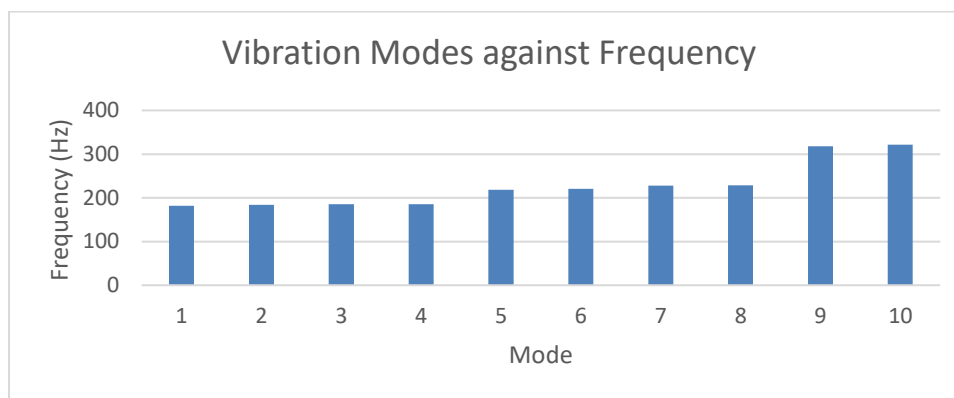


Figure: 3 Graph of Vibration Modes against Frequency

Figure 3 shows a graph of vibration modes against frequencies, which shows clearly that the higher the vibration mode the higher its frequency and the closer its possibility of collapsing.

The maximum tensile stress and deformation for the modal occurs at the side walls of the boiler with 391.90 MPa and 7.8162 mm respectively which occurred at a frequency of 181.74 Hz which is below maximum the tensile stress of the chosen material.

The stresses on the boiler's top section were at their bearable minimum, whilst the stresses on the whole body of the boiler was also at minimal values. Permissible frequency range for the operation of steam boilers is between 50-60 Hz. From the results, the minimum ANSYS frequency is 181.74 Hz which is greater than the permissible frequency range of the boiler. Hence the design of the steam boiler assembly is safe for the operating condition.

4. CONCLUSION

This paper presents the modeling and determination of stresses and deflections on a boiler Using Finite Element Approach (ANSYS). The modeled boiler was studied for three different stages

- static structural
- steady-state thermal
- modal analysis

From the above analysis, it can be concluded that the steam boiler has stresses and deflections within the design limits of the material used. Hence, the designed steam boiler is safe under the given operating conditions. The result obtained shows a maximum tensile stress and deformation of the boiler as 308.90 MPa and 1.93 mm respectively. From the results, the tensile stress obtained is below the yield strength of the material

used which is safe for operation under those conditions according to Maximum yield stress theory.

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