Stress Analysis of Steam Methane Reformer Tubes

By

Nik Afifi Bin Nik Abd Rahim

Dissertation submitted in partial fulfilment of
the requirements for the
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(Mechanical Engineering)

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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(MECHANICAL ENGINEERING)

Approved by,

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(Dr. Azmi b. Abdul Wahab)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
June 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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NIK AFIFI BIN NIK ABD RAHIM

ABSTRACT

Steam methane reformer is used to produce bulk hydrogen for industrial synthesis of ammonia and methanol. In steam methane reforming process, steam react with methane at high temperature of about 700˚C to 1000˚C to yield carbon monoxide and hydrogen. Adding hydrogen in the next stage at low temperature with carbon monoxide produced carbon dioxide and hydrogen.

This project is to perform stress analysis of steam methane reformer tubes using finite element method. This project will consider the variation in stresses along the tube length and thickness due to temperature and pressure. Analytical calculations of steam methane reformer tubes were performed to determine the stress distributions on the tube which varies along the tube length. The thermal stress equations, Lame's equations, stress due to tube weight equation and the Tresca stress equation were used in the analytical calculations to obtain the stress of the tube with respect to temperature, internal pressure, and distance from the top flange of the tubes. The effective stress was high at the inner surface, decreased toward the middle of the tube diameter, and increased again to the outer surface of the tubes.

The results obtained using analytical equations were compared to results obtained using finite element method. In finite element method, the ANSYS software was used to determine the effective stress on the steam methane reformer tubes. It was assumed that the geometry, loadings, boundary conditions and materials were symmetric with respect to an axis. Thus the problem in this project was solved as an axis-symmetric problem.

It was observed that the stress of steam methane reformer tubes obtained using either techniques had the same pattern. It was observed that the lowest stress was at the middle of the tube thickness and highest stress was at the outer of the tube.

ACKNOWLEDGMENTS

First and foremost, I would like to praise to God the Almighty for His guidance. With His guidance and blessings bestowed upon me, I managed to overcome all obstacles in reaching at the end of this project.

Here, I would like to use this special opportunity to express my heartfelt gratitude to everyone that has contributed to the success of the project.

My deepest appreciation and gratitude goes to my Final Year Project Supervisor, Dr Azmi Abdul Wahab for his supervision, commitment, professionalism, advice and friendship throughout the completion of final year project.

The author also would like to thanks to the examiners, Dr Saravanan and Dr Bambang for his commitment and advice on evaluating this final year project.

Last but not least, special thanks to those who had helped me directly or indirectly in undertaking this project throughout the year end. The contributions and insights are highly appreciated.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Steam reforming of light hydrocarbons, especially natural gas, is an industrially important chemical reaction and is a key step for producing hydrogen and syngas for ammonia and methanol productions, hydrocracking and hydrotreating, oxo-alcohol and Fischer-Tropsch synthesis and other important processes in the petroleum and petrochemical industries [1].

The design of the steam methane reformer tubes is conventionally based upon the stress rupture properties of the tube material extrapolated using parametric techniques such as the Larson-Miller parameter to operating conditions [2]. Safety factors typically based upon the operating temperatures and pressures. By use of minimum stress rupture properties, further conservatism is frequently obtained.

The influence of thermal stress explains the observation that many failures tend to initiate close to the inside wall and it will go further to the outside wall. There is a temperature gradient across the tube wall since the reformer tubes are heat exchangers transferring heat from the external furnace atmosphere to the process reactants in the tubes; hence there is a temperature gradient across the tube wall.

1.2 PROBLEM STATEMENT

Steam-methane reformer tubes operate at temperatures exceeding 800°C and internal pressures exceeding 2 MPa. These tubes are also designed to last about 100,000 hours of service. In order to reliably predict the performance of the tube, good estimation of the stresses acting at any point along the tube length and thickness, is required.

1.3 OBJECTIVES AND SCOPE OF STUDY

The objective of this project is to perform stress analysis of steam methane reformer tubes using finite element method.

The analysis should consider the variation in stresses along the tube length and thickness due to temperature and pressure differences, and due to lengthy service life.

In this project, analytical methods and finite element methods were used to perform stress analysis of steam methane reformer tubes. The analytical method used thermal stress equations, Lame’s equations, stresses due to tube weight, and Tresca stress. The result from these methods was the effective stress of the tube.

The finite element analysis was performed using ANSYS software. Firstly, the geometry of the tubes was drawn using the software. The effective stress along the tube finally obtained using finite element method.

The effective stress from both, analytical and finite element methods was compared and analyzed. So the information of the stress along the steam methane reformer tubes was obtained directly at the end of this project.

CHAPTER 2

LITERATURE REVIEW

2.1 STEAM METHANE REFORMER

Steam methane reforming is the most common method of producing commercial bulk hydrogen as well as the hydrogen used in the industrial synthesis of ammonia. It is also the least expensive method. At high temperatures (700 – 1100 °C) and in the presence of a metal-based catalyst (nickel), steam reacts with methane to yield carbon monoxide and hydrogen [3]. These two reactions are reversible in nature.

$$CH_4 + H_2O \rightarrow CO + 3\ H_2$$

Additional hydrogen can be recovered by a lower-temperature gas-shift reaction with the carbon monoxide produced. The reaction is summarized by:

$$CO + H_2O \rightarrow CO_2 + H_2$$

The first reaction is endothermic (consumes heat), the second reaction is exothermic (produces heat) [4]. The heat flow will affect the thermal stress. Thus it requires stress analysis to optimise the process and prevent failure of the equipment.

Figure 1 shows the flow diagram of steam methane reformer process. The process as follows: 1- Feed Pre-Treatment, 2- Reforming & Steam Generation, 3- High Temperature Conversion, 4- Heat Exchanger Unit, 5- Purification Unit which is optional, depending on reformer design a either heat exchanger for low pressure reformer or compression to 1 bar for high pressure reformer [5].

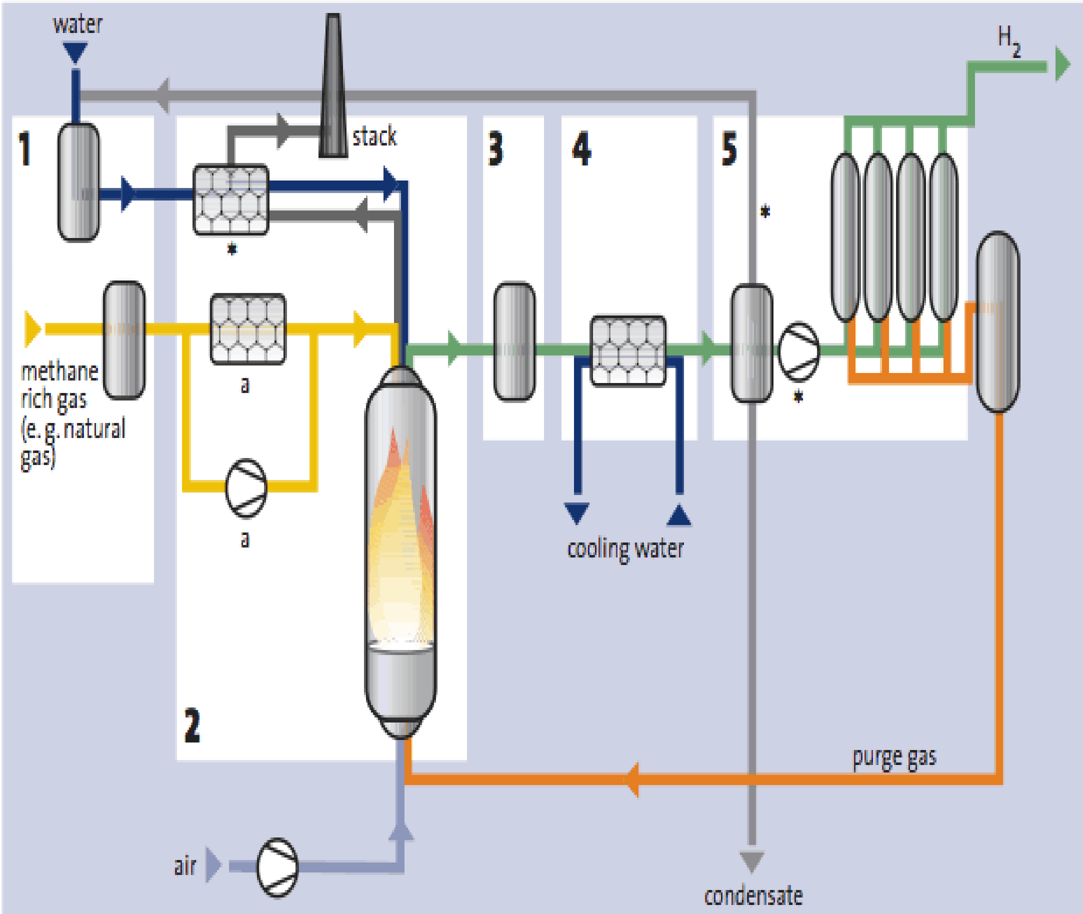

Figure 1: Flow Chart of a Steam Reformer.

Figure 2 shows the exemplary layout of modular reformer for high pressure type [5].

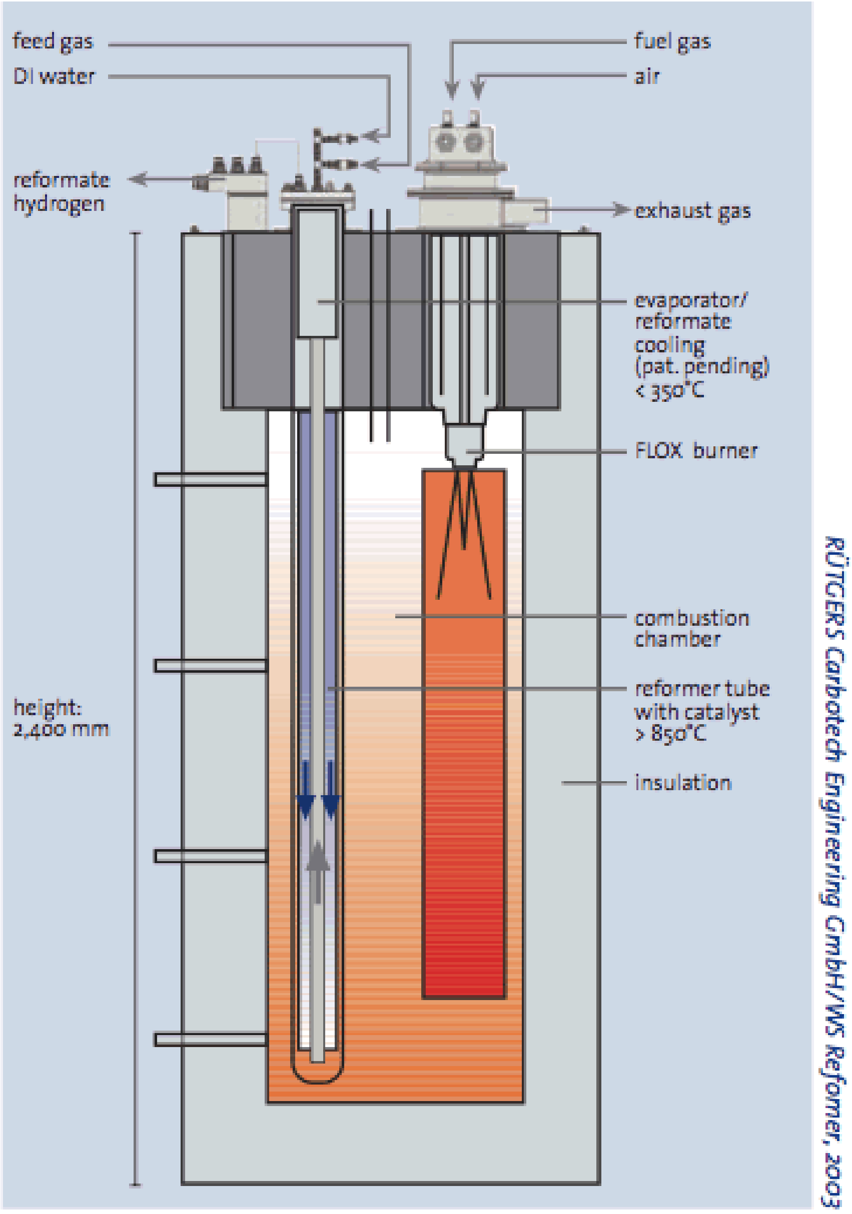

Figure 2: Exemplary Layout of Modular Reformer (High Pressure Type)

2.2 MATERIAL

For this study, the steam methane reformer material is Schmidt-Clemens Centralloy CA4852-Micro centrifugal cast tubes as it material. Data for CA4852-Micro were taken from ref [6]. The typical mechanical properties of CA4852 are as follows:

Density, $\rho = 8.0$ g/cm^3
Thermal Conductivity, $k_T = 14.6$ W/mK
Poisson's ratio, $v = 0.3$

The figures in the following pages represent typical mechanical properties of CA4852-Micro.

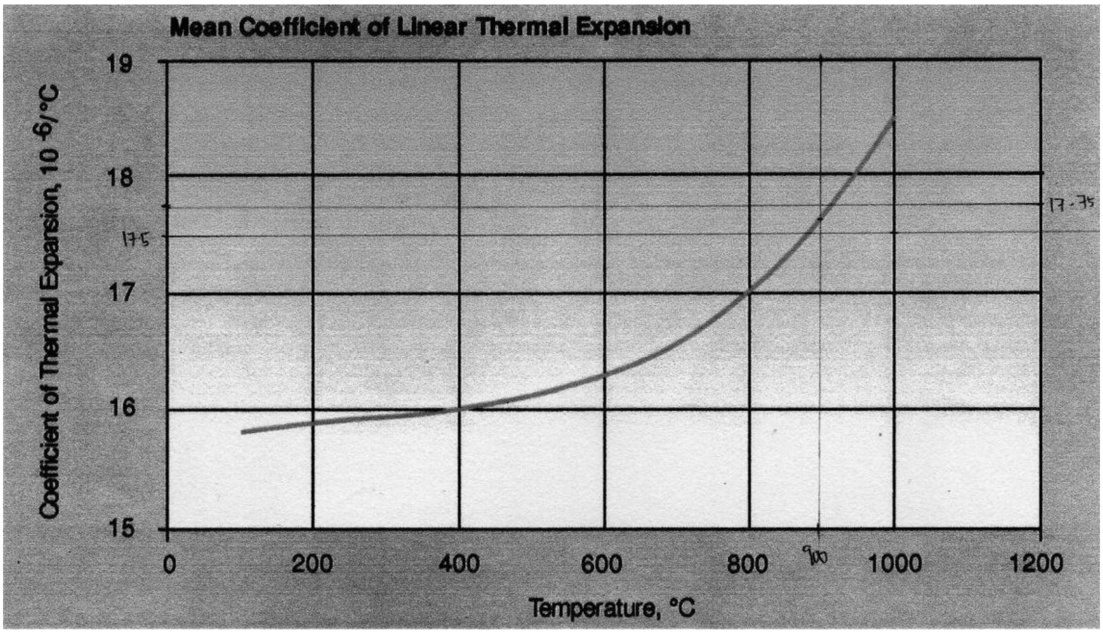

Figure 3: Coefficient of linear thermal expansion for Schmidt-Clemens Centralloy CA4852-Micro

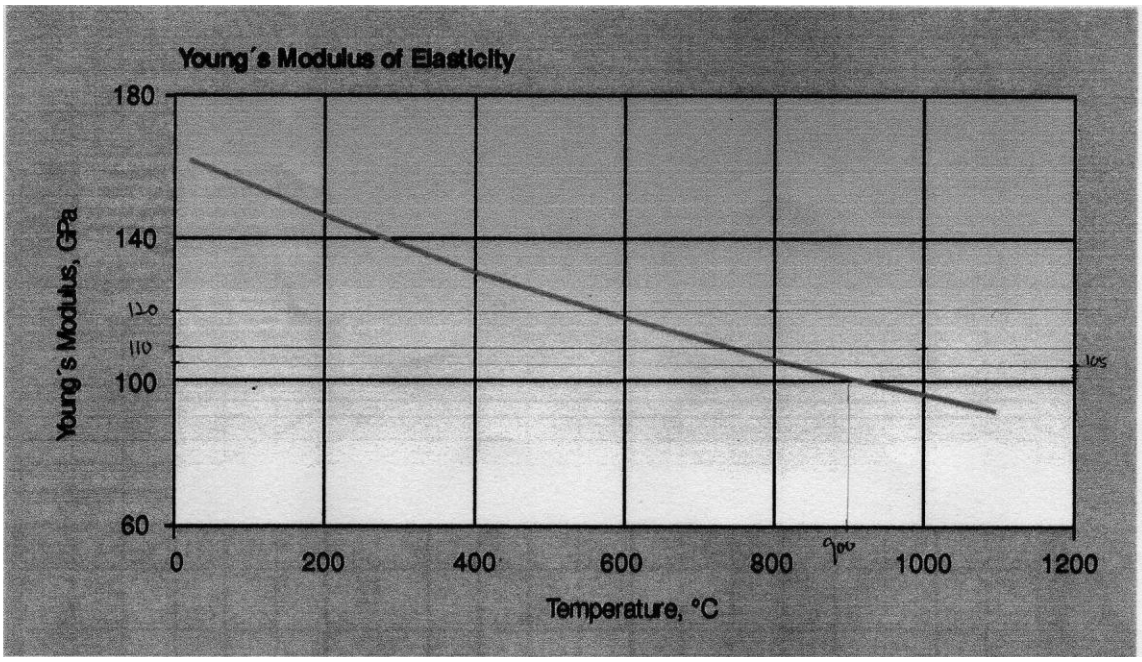

Figure 4: Modulus of Elasticity for Schmidt-Clemens Centralloy CA4852-Micro.

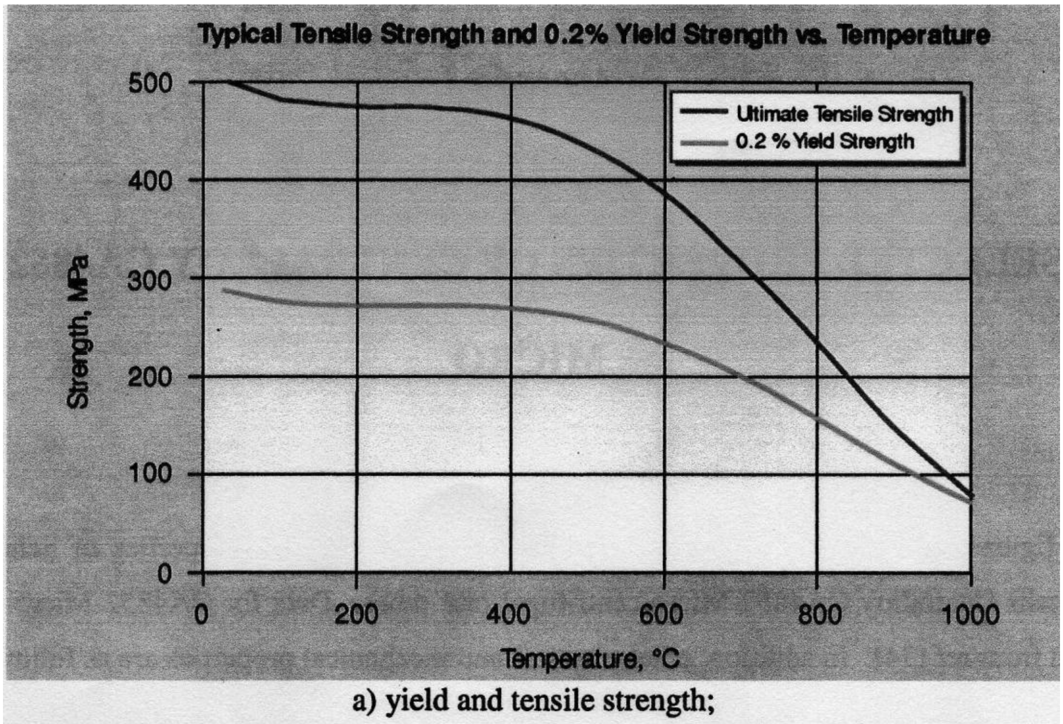

Figure 5: Typical Tensile Strength and 0.2% Yield Strength vs. Temperature

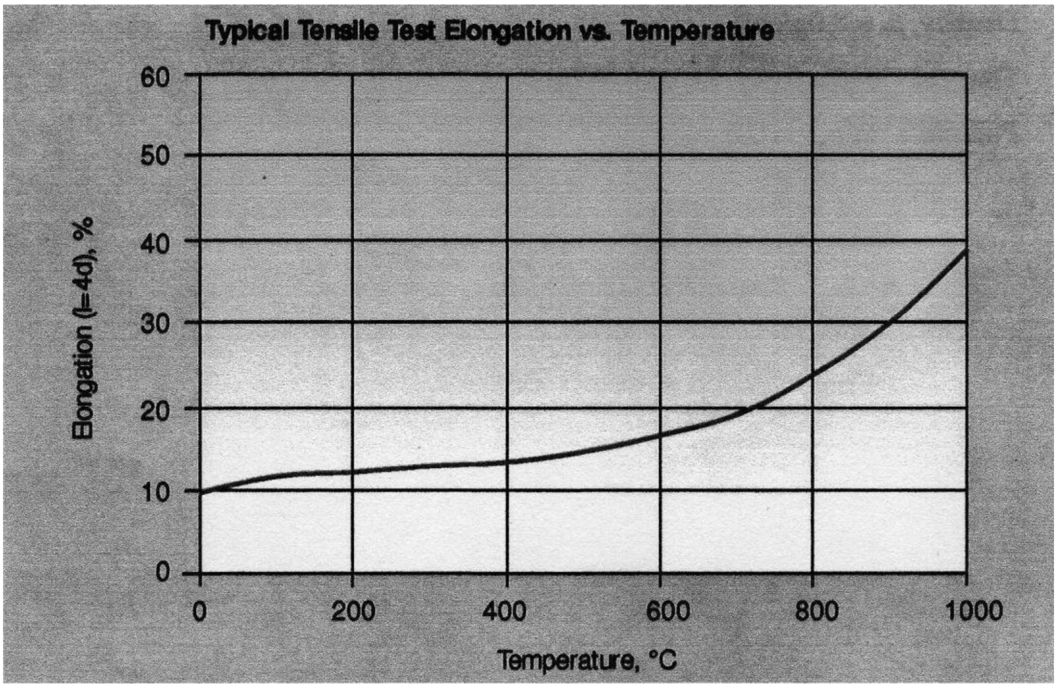

Figure 6: Typical Tensile Test Elongation vs. Temperature

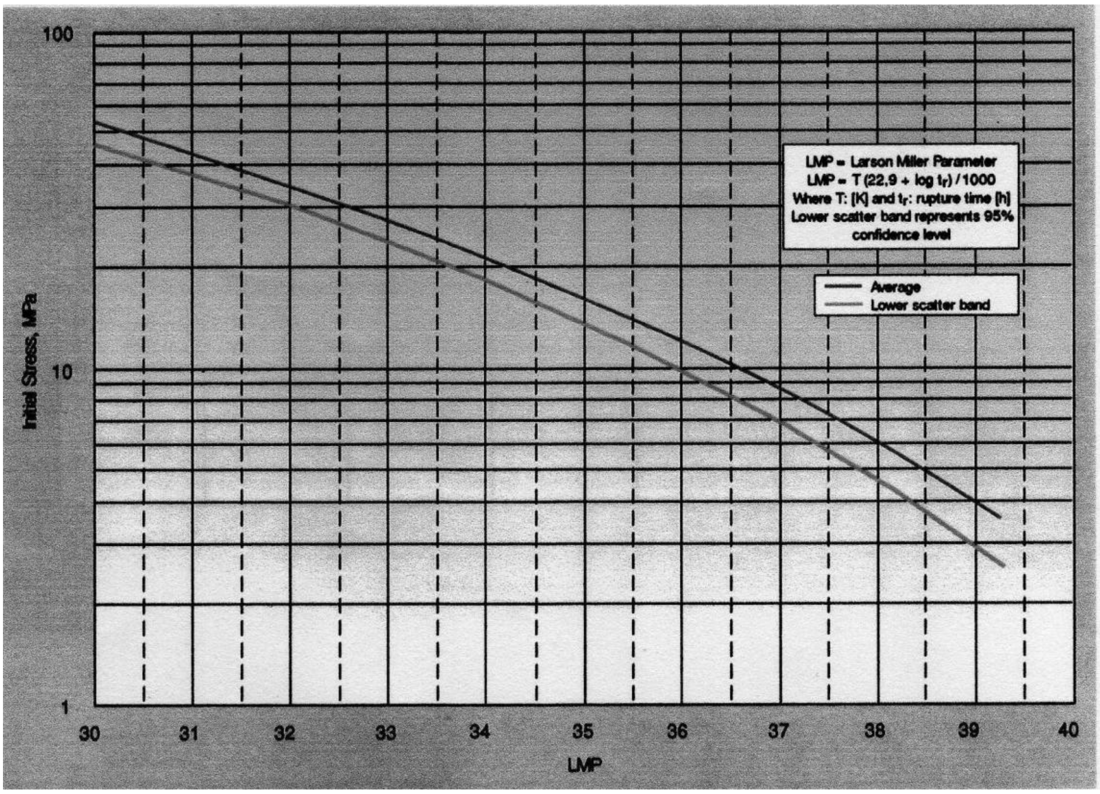

Figure 7: Parametric stress rupture strength for Schmidt-Clemens Centralloy CA4852-Micro.

2.3 STRESS CALCULATION IN STEAM METHANE REFORMER TUBES

The analyses also have to be done analytically by using equation of thermal stress equation, Lame’s equations, stress due to tube weight, and Tresca stress.

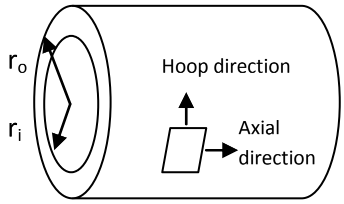

Figure 8: Schematic of long thick walled cylinder

Consider the reformer tube is a long thick-walled cylinder symmetric about the tube axis with a tube wall temperature distribution of *T = T(r).* Assuming a steady heat flux through the wall, with α_T, *E and v* also being constant across the wall, the hoop, radial and axial thermal stresses can be approximated by [6]:

$$\sigma_{hT} = \frac{\alpha_T E (T_i - T_o)}{2(1-v)} \left[\frac{1 - \ln \frac{r_o}{r}}{\ln \frac{r_o}{r_i}} - \frac{\left(\frac{r_o}{r}\right)^2 + 1}{\left(\frac{r_o}{r_i}\right)^2 - 1} \right]$$

$$\sigma_{rT} = \frac{\alpha_T E (T_i - T_o)}{2(1-v)} \left[\frac{- \ln \frac{r_o}{r}}{\ln \frac{r_o}{r_i}} + \frac{\left(\frac{r_o}{r}\right)^2 - 1}{\left(\frac{r_o}{r_i}\right)^2 - 1} \right]$$

$$\sigma_{aT} = \frac{\alpha_T E (T_i - T_o)}{2(1-v)} \left[\frac{1 - 2\ln \frac{r_o}{r}}{\ln \frac{r_o}{r_i}} - \frac{2}{\left(\frac{r_o}{r_i}\right)^2 - 1} \right]$$

where α_T = coefficient of thermal expansion

E = modulus of elasticity

r = radial distance to point interest

r_i = tube internal radius

r_o = tube external radius

v = Poisson's ratio

T_i = inside wall temperature

T_o = outside wall temperature

Stresses due to internal pressure are calculating using Lame's equations: hoop, radial, and axial stresses due to internal pressure, p in a long thick-walled cylinder:

$$\sigma_{hp} = \frac{pr_i^2}{r_o^2 - r_i^2}\left(1 + \frac{r_i^2}{r^2}\right)$$

$$\sigma_{rp} = \frac{pr_i^2}{r_o^2 - r_i^2}\left(1 - \frac{r_i^2}{r^2}\right)$$

$$\sigma_{ap} = \frac{pr_i^2}{r_o^2 - r_i^2}$$

where p = internal pressure

The axial stress due to tube weight is:

$$\sigma_{aW} = 0.25x\frac{W_t}{A_t} = 0.25x\frac{p_t g A_t l_t}{A_t} = 0.25xp_t g l_t$$

where W_t = weight of tube

A_t = cross sectional area of tube

p_t = density of reformer tube

g = gravitational acceleration

l_t = vertical distance from top flange to point of interest

Effective stress (Tresca stress) was calculated using the Tresca criterion as follows:

$$\sigma_{TS} = MAX\ \left\{ |\sigma_1 - \sigma_2|, |\sigma_1 - \sigma_3|, |\sigma_2 - \sigma_3| \right\}$$

where

$\sigma_1 = \sigma_{hT} + \sigma_{hp}$

$\sigma_2 = \sigma_{rT} + \sigma_{rp}$

$\sigma_3 = \sigma_{aT} + \sigma_{ap} + \sigma_{aW}$

2.4 FINITE ELEMENT ANALYSIS / ANSYS

By using ANSYS, the author solves numerically mechanical problems, the stress analysis. The mechanical properties of Centralloy CA4852-Micro helps the author to do an analysis by using engineering software ANSYS. This will help author by obtain the parameter of the tube, size, thickness, material, mechanical properties, boundary condition and fixed point on the tube. It is all in pre-processing step. After that, the author has to run the software by solve the problem. Next, the author obtain the require result to do stress analysis base on the finite element method.

In this project, the author assumed the geometry, loadings, boundary conditions and material are symmetric with respect to an axis. Thus the problem in this project can be solved as an axis-symmetric problem by using ANSYS.

CHAPTER 3

METHODOLOGY

3.1 FLOW CHART

The methodology used in this project is summarized in Figure 9. Calculations of the stresses of the reformer tube were first carried out using the analytical method presented in Chapter 2. The process is continued throughout the project. Next, the geometry of the tube was drawn using ANSYS. Then, all the mechanical properties of the material and boundary conditions were set up on the geometry during pre-processing stage. Next, the stress analyses were performed using ANSYS solver. In post-processing stage, stress data were obtained and the effective stress was then calculated. Finally, comparisons were done on results obtained via both methods.

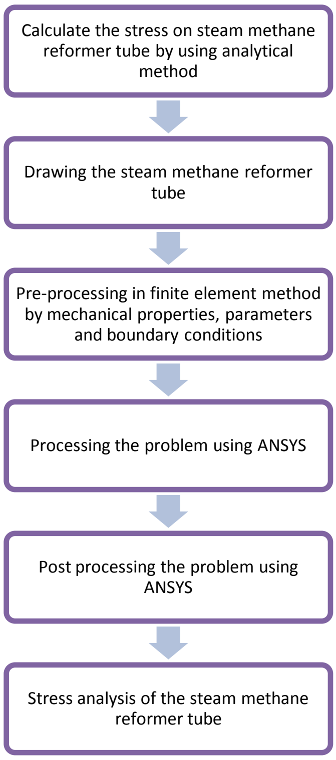

Figure 9: Flow chart for Final Year Project

3.2 WORK PROCEDURE

Firstly, the information needed was mechanical properties, tube dimensions, process occur on the steam methane reformer tube and boundary conditions obtained in the beginning of the project by research and literature review on journal. The literature review is done on the journal related to steam methane reformer, material books, internet journals and articles.

Then, the project continued by calculating the stress of the tubes based on analytical method using the mechanical properties, parameter and boundary conditions of the steam methane reformer tube. The stress analysis of the steam methane reformer tube was done using stress equations due to temperature, length of the tube and Lame's equations. Next, the results of the analytical calculation solution were plotted for analysis.

Next, the stresses of the tube were determined using finite element methods. In this method, the element geometry was drawn according to the tubes dimensions. The geometry need to be created first in order to conduct a simulation of the stress on the tubes. In this study, ANSYS software was used to model the geometry of the tubes axis-symmetry as well as used to generate a mesh of the geometry. A geometry model must undergo the mesh process first before being read and solved by the solver. Mesh is defined as an area or face of a geometry that is divided into discrete cells.

Assumptions were made before proceeding with the simulation so that the main area of concern can be focused. The geometry, loadings, boundary conditions and material are assumed to be symmetric with respect to an axis. Thus the problem in this project can be solved as an axis-symmetric problem by using ANSYS.

The tools and equipment which are required in this final year project are a Windows based PC together with the programs such as Microsoft Office and ANSYS which is used to analyse the data obtained in the research from the internet and other references

A cross section of the steam methane reformer tube is shown in the figure below:

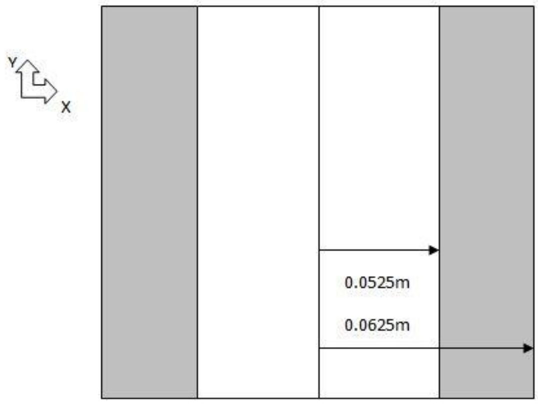

Figure 10: Cross section of the steam methane reformer tube

Let consider the height of the tube wall is arbitrary and use 1m in height for finite element model. The geometry is shown below:

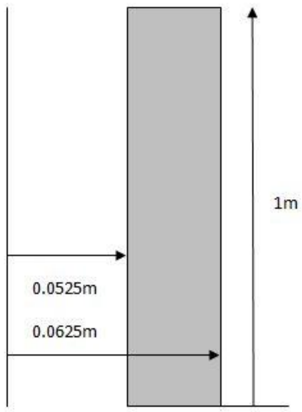

Figure 11: Geometry of the tube element

Steps in modelling a geometry using ANSYS software:

1. ANSYS start-up: using quadrilateral element with axis-symmetric behavior. It is because the geometry, loadings, boundary conditions and material are symmetric with respect to an axis were assumed

2. Material property data for Centralloy CA4852-Micro: enter material property data for steel.

The Poisson's ratio, $v = 0.3$

Young's modulus = $1.01\text{x}10^{11}$Pa

Density of the material = 8000kg/m^3

Coefficient of thermal expansion = $17.625\text{x}10^{-6}/°\text{C}$

Thermal Conductivity, $k_T = 14.6$ W/mK

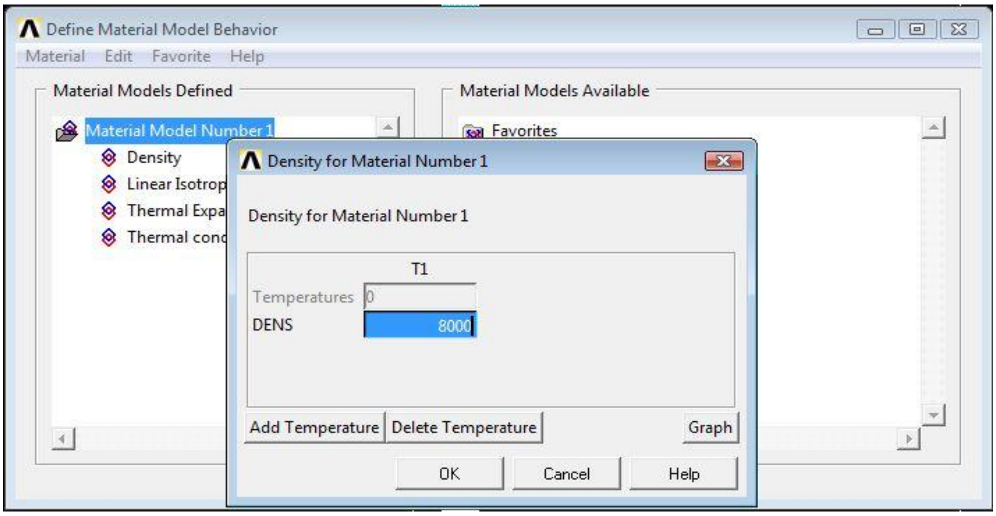

Figure 12: Density of Centralloy CA4852-Micro

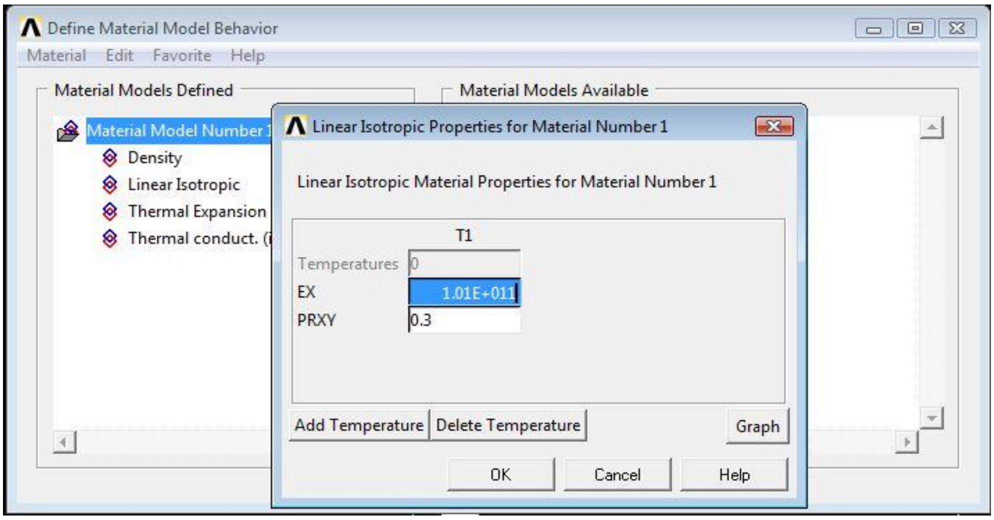

Figure 13: Poisson's ratio and Young's modulus of Centralloy CA4852-Micro

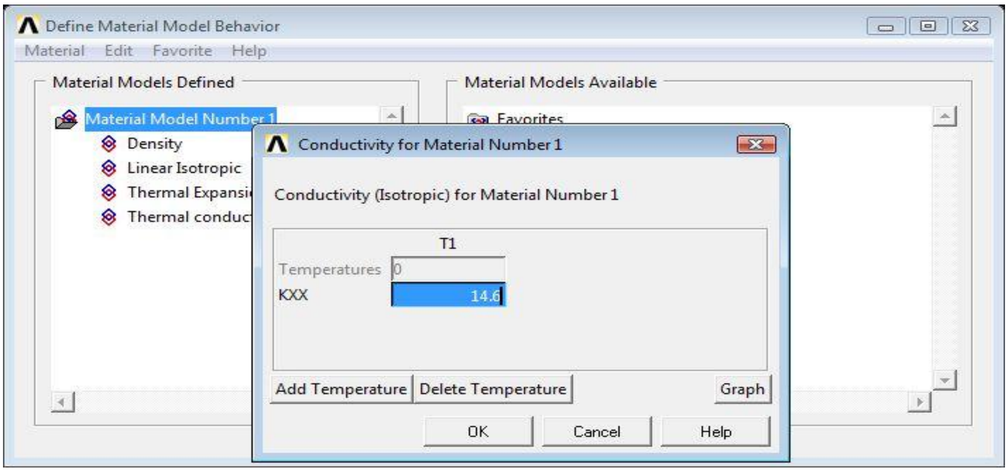

Figure 14: Thermal conductivity of Centralloy CA4852-Micro

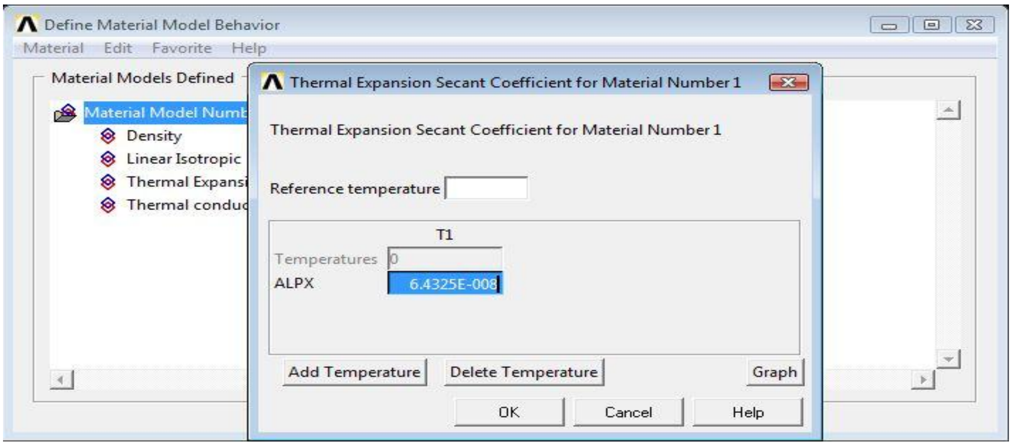

Figure 15: Coefficient of thermal expansion of Centralloy CA4852-Micro

3. Create geometry: create geometry for rectangle 1 m by 0.0625 m starting 0.0525 m from Y axis. In ANSYS the Y axis is always the axis of symmetry for axis-symmetric problems.

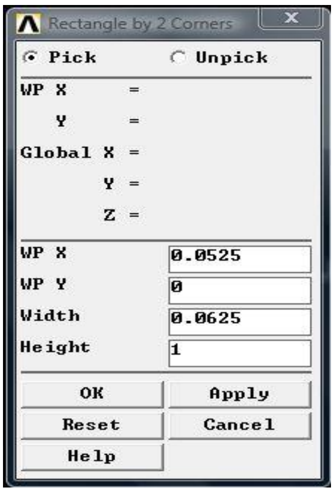

Figure 16: Create geometry box for rectangle

4. Mesh creation: meshes the area and applies boundary conditions on the element.

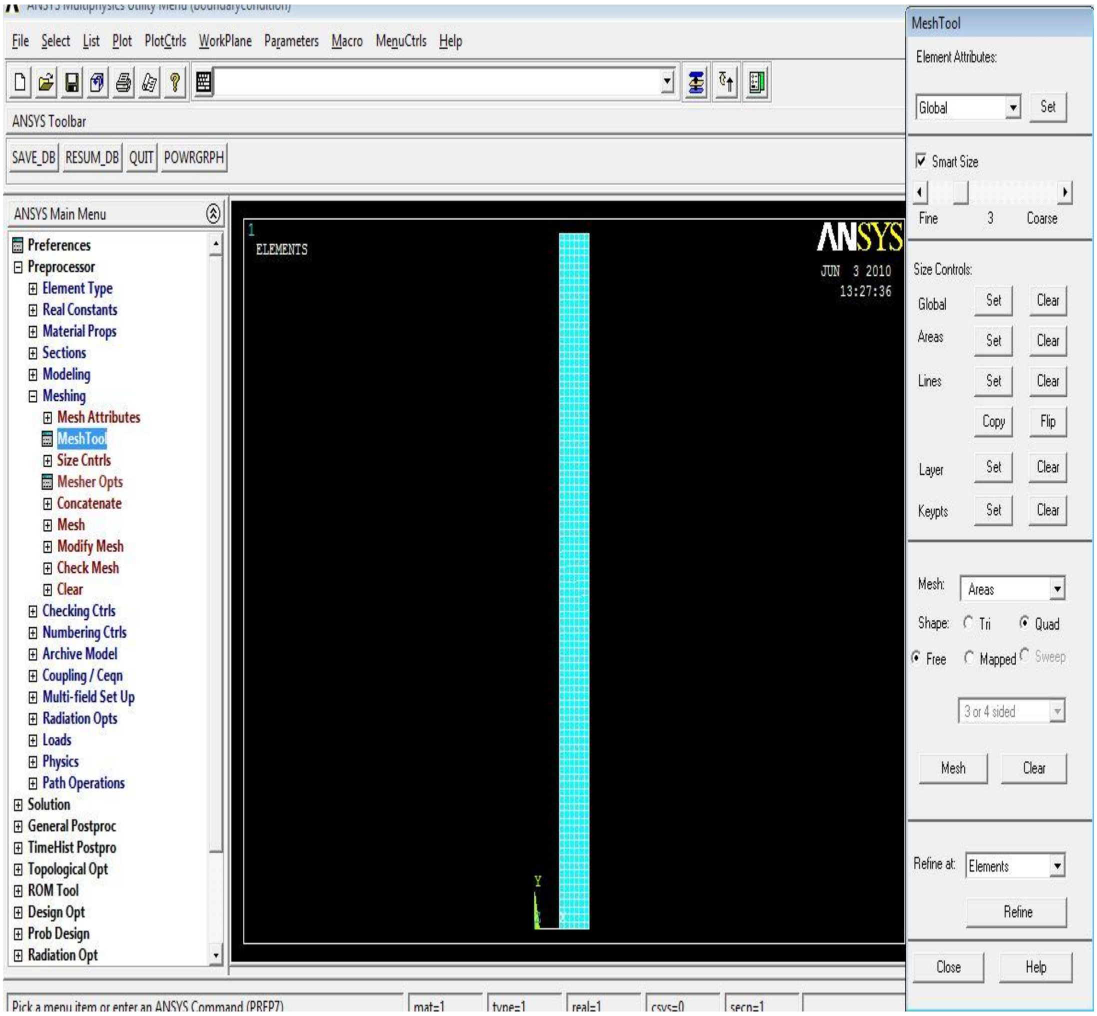

Figure 17: Mesh creation of geometry

5. Apply boundary conditions: which are displacement, pressure and temperature. Pick the upper and bottom line of the rectangle, **uy = 0** along this line. This simply prevents rigid body motion in the Y direction. No other displacement boundary conditions are required. The radial movement is prevented by the 'hoop' tension in the cylinder. Then pick the left hand line of the rectangle and enter a value of pressure. Repeat the step to apply temperature on both left and right line of the triangle.

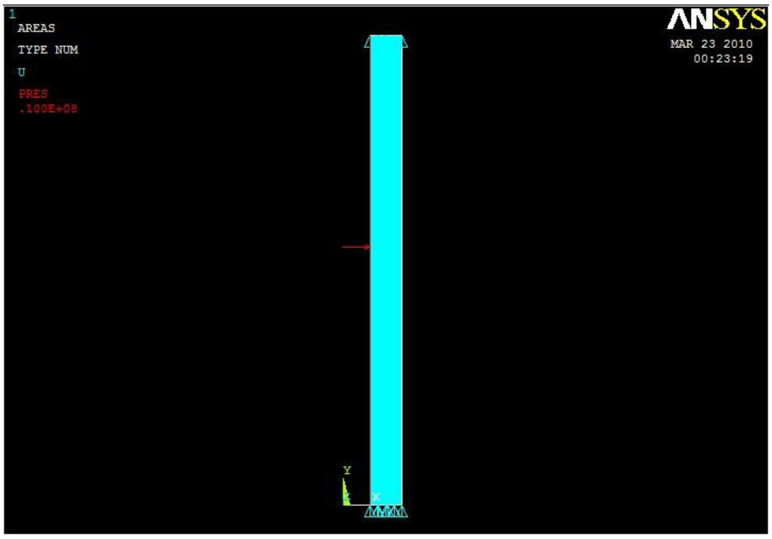

Figure 18: Mesh and applies boundary conditions on the element

6. Run solver. In all of the approaches used, the same basic procedure is followed to solve a problem. During pre-processing, the geometry of the problem is defined which means the volume occupied by the fluid is divided into discrete cells (the mesh).

Steps involved in solving problem using ANSYS software:

1. Click on solution, solve, current LS and OK to start solving the problem.

2. Check the deformed shape to see if it's reasonable. (The dotted line is the undeformed shape.)

3. Examine the stresses. The SX stress is the radial stress that is equal to the pressure set on the interior of the cylinder and is zero on the exterior. The SY stress is the axial stress in the cylinder. SZ is the 'hoop' stress perpendicular to the plane of this rectangle.

4. Examine the stresses more closely at the boundaries. Firstly, number the nodes and elements.

5. Then, list the ANSYS results.

3.3 GANTT CHART

Shown below in Figure 19 is the Gantt chart for this semester in Final Year Project part 2.

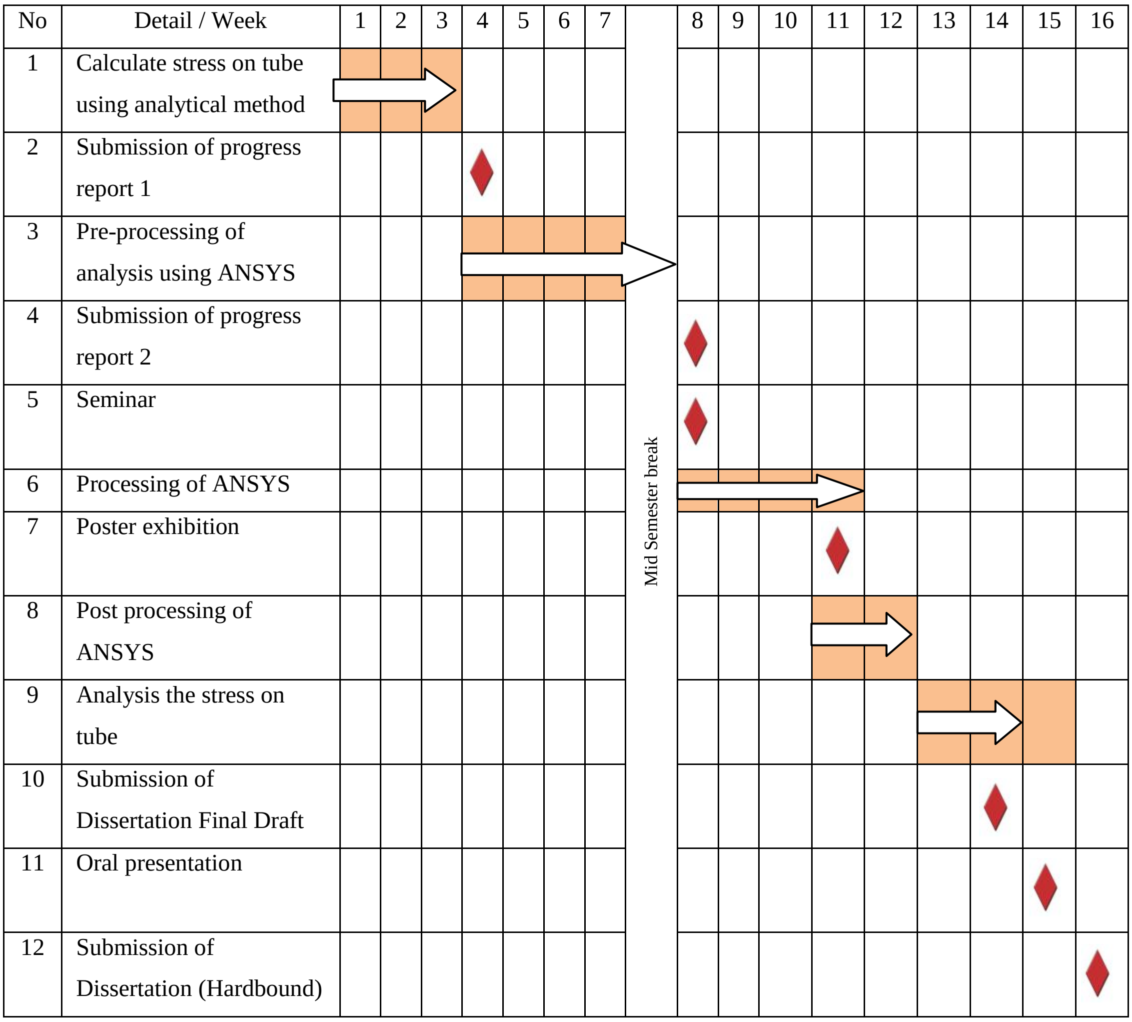

Figure 19: Gantt chart for Final Year Project 2

3.4 ANALYTICAL CALCULATION PARAMETER

For analytical calculation, the stress analysis was performed using stress equation due to temperature, length of the tube and Lame's equation. The parameters used are as follows:

The tube internal radius, r_i = 52.5

the tube external radius, r_o = 62.5 mm

The thickness of the tube, t = 10 mm

The length of the reformer tube, l = 12.5 m.

ρ_t = density of reformer tube = 8000 kg/m3

g = gravitational acceleration = 9.81 m/s2

The Poisson's ratio, v = 0.3

Axial stress per length of tube, σ_{aW} / l_t = -19.62 x 10^{-3}MPa/m

CHAPTER 4

RESULT AND DISCUSSIONS

4.1 TABULATED DATA AND GRAPH BY STRESS ANALYTICAL CALCULATION

Below is a graph of effective stress vs. tube radial position with a different range of tube length:

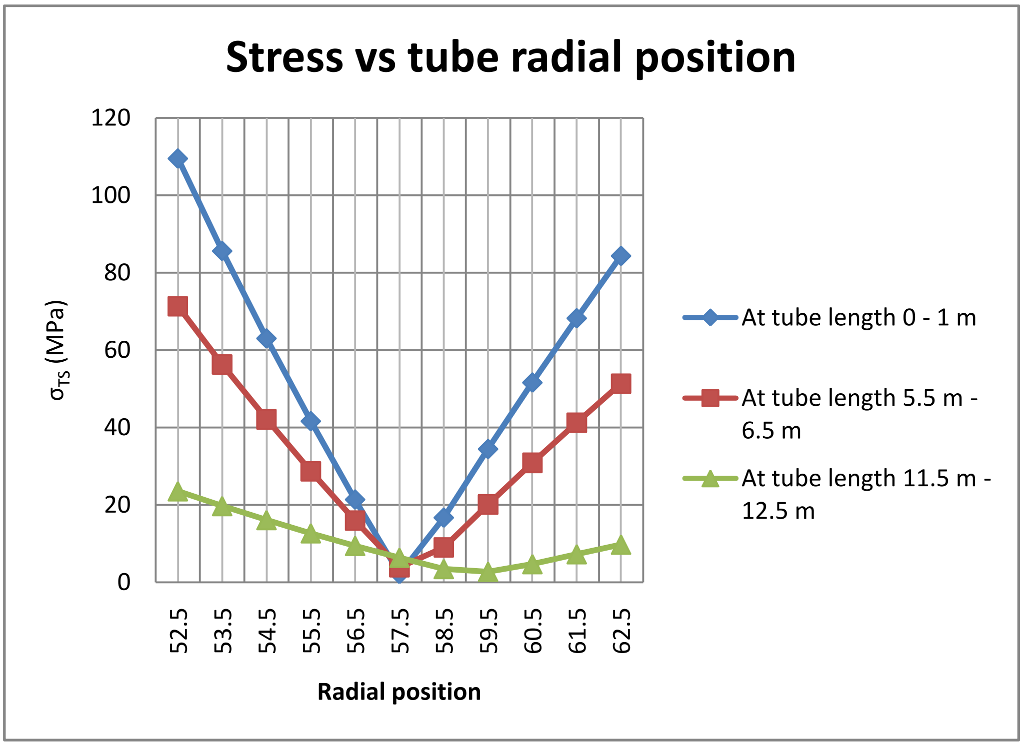

Figure 20: Graph Tresca stress vs. tube radial position (Analytical)

For the analytical method the author assumed that the fluid flow through the tube is steady heat flux, fixed at both end of the tube. The calculations were repeated at positions 5.5m – 6.5m and 11.5m – 12.5m along the tube measured from the top flange.

From Figure 20, it is shown that the minimum effective stress is 2.09MPa at tube radial position 57.5mm and maximum effective stress is 109.5MPa at tube radial position 52.5mm which is at inner tube position. It means that the stress is not same at any radial position. We can see that the lowest is at the middle of the tube thickness and higher is at the outer of the tube. The stress is decreasing toward the middle radial position and increasing back toward outer diameter of the tube. The highest stresses occurred at the inner wall which is where failures usually occur.

4.2 FINITE ELEMENT ANALYSIS

4.2.1 Result at tube length 0 – 1m.

Figure 21 shows the radial stress on the radial position of the steam methane reformer tube. The temperature of the inner tube diameter is set to be 913K and outer tube diameter is set to be 983K. The inner pressure is set to be 2210000Pa. The stress legend show the maximum stress is 280388Pa and minimum stress is -0.233×10^7Pa. It can be observed that the radial stress along the radial position of the tube is increasing.

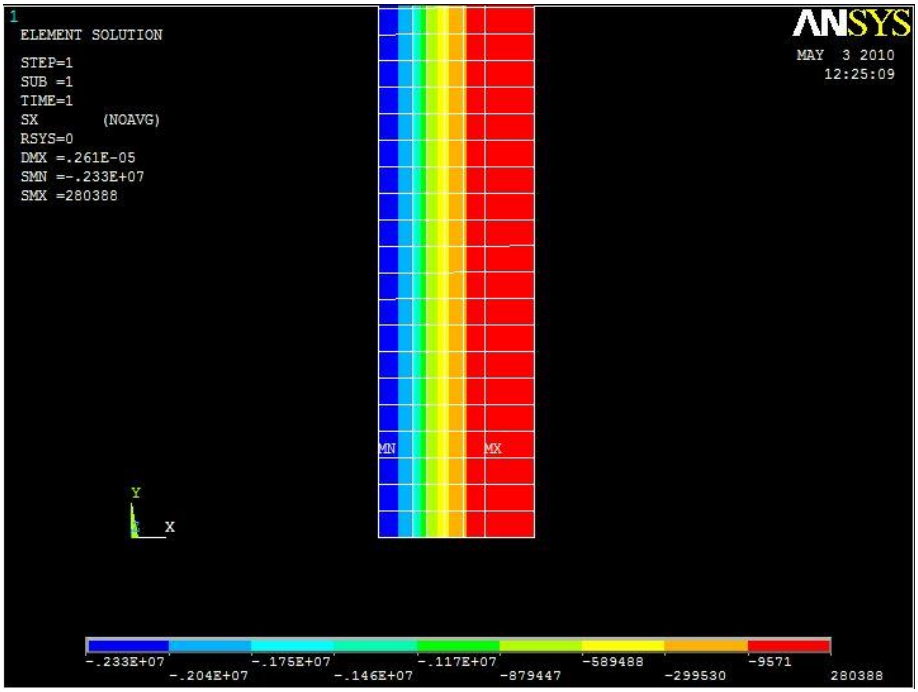

Figure 21: Radial stress on element by using ANSYS (0-1m)

Figure 22 shows the axial stress on the radial position of the steam methane reformer tube. The temperature of the inner tube diameter is set to be 913K and outer tube diameter is set to be 983K. The inner pressure is set to be 2210000Pa. The stress legend show the maximum stress is 805291Pa and minimum stress is $-0.83x10^7$Pa. It can be observed that the axial stress along the radial position of the tube is increasing toward the middle of radial position of the tube and decreasing from the middle to the outer diameter of the tube.

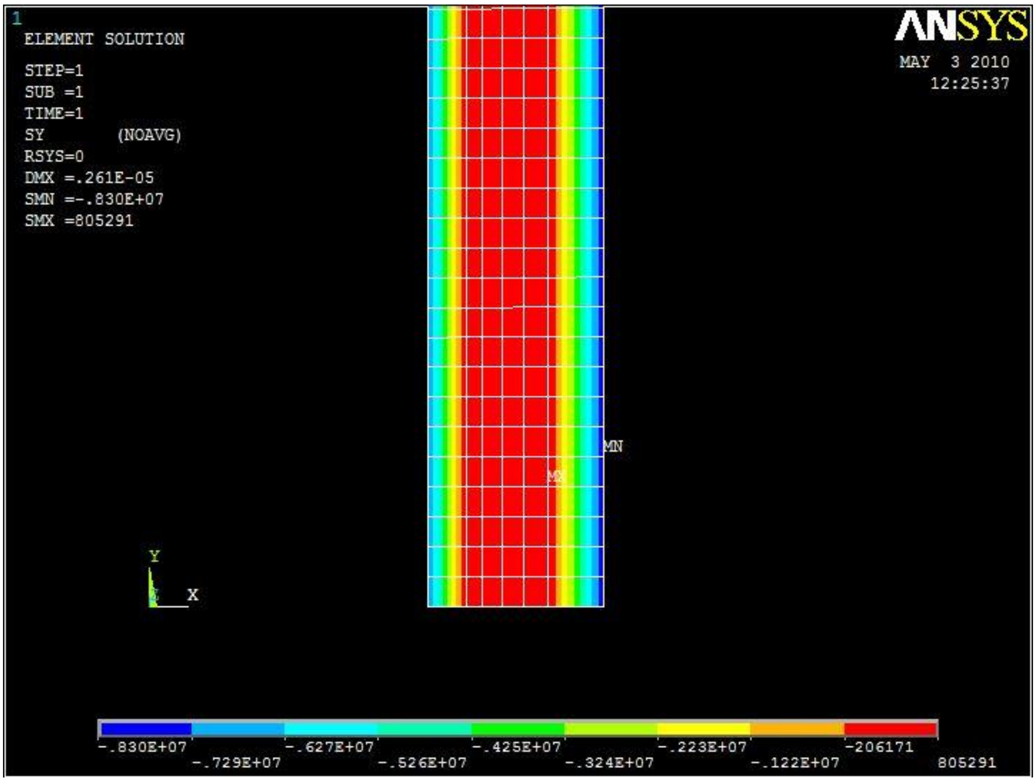

Figure 22: Axial stress on element by using ANSYS (0-1m)

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Figure 23 shows the hoop stress on the radial position of the steam methane reformer tube. The temperature of the inner tube diameter is set to be 913K and outer tube diameter is set to be 983K. The inner pressure is set to be 2210000Pa. The stress legend show the maximum stress is 0.453×10^7Pa and minimum stress is -0.649×10^7Pa. It can be observed that the hoop stress along the radial position of the tube is increasing toward the middle of radial position of the tube and decreasing from the middle to the outer diameter of the tube.

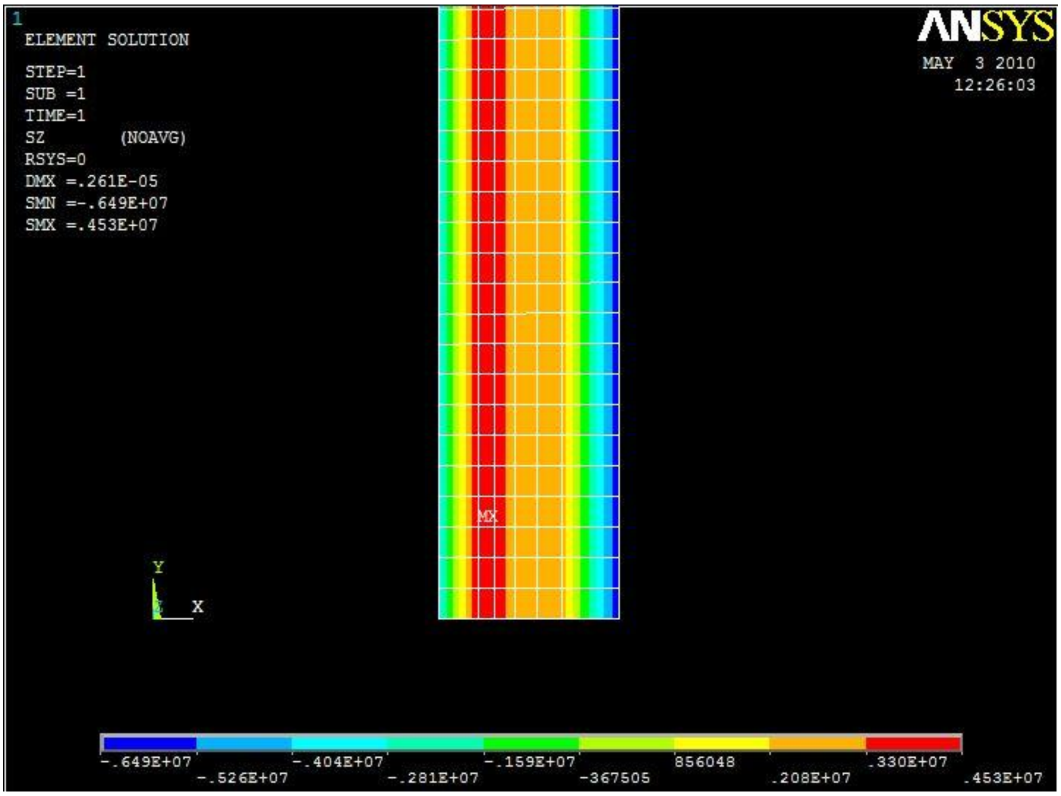

Figure 23: Hoop stress on element by using ANSYS (0-1m)

4.2.2 Result at tube length 5.5m – 6.5m.

Figure 24 shows the radial stress on the radial position of the steam methane reformer tube. The temperature of the inner tube diameter is set to be 1103K and outer tube diameter is set to be 1148K. The inner pressure is set to be 2200000Pa. The stress legend show the maximum stress is 355688Pa and minimum stress is -0.236x10^{7}Pa. It can be observed that the radial stress along the radial position of the tube is increasing.

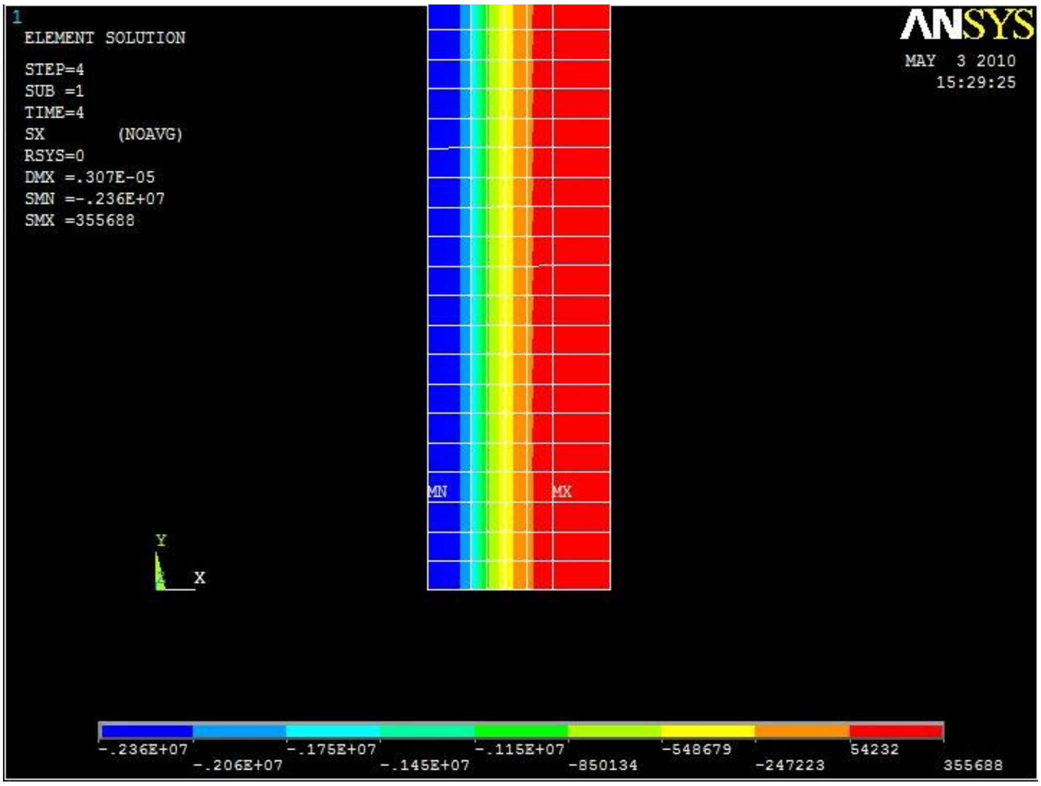

Figure 24: Radial stress on element by using ANSYS (5.5-6.5m)

Figure 25 shows the axial stress on the radial position of the steam methane reformer tube. The temperature of the inner tube diameter is set to be 1103K and outer tube diameter is set to be 1148K. The inner pressure is set to be 2200000Pa. The stress legend show the maximum stress is 897338Pa and minimum stress is -0.995x10^7Pa. It can be observed that the axial stress along the radial position of the tube is increasing toward the middle of radial position of the tube and decreasing from the middle to the outer diameter of the tube.

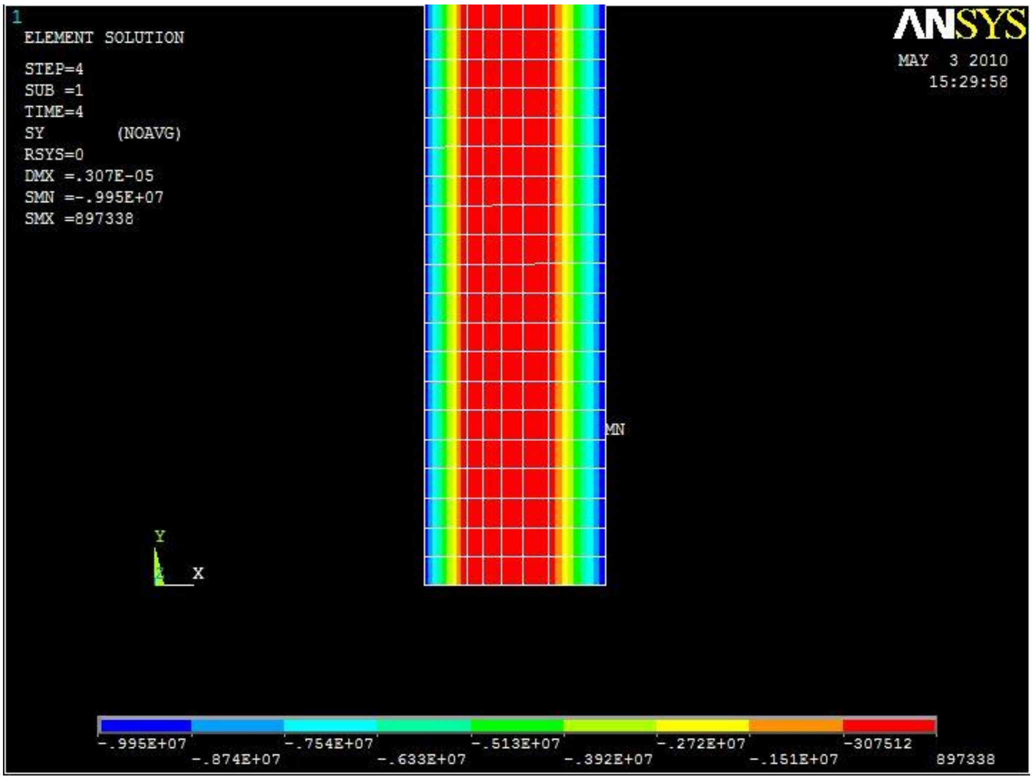

Figure 25: Axial stress on element by using ANSYS (5.5-6.5m)

Figure 26 shows the hoop stress on the radial position of the steam methane reformer tube. The temperature of the inner tube diameter is set to be 1103K and outer tube diameter is set to be 1148K. The inner pressure is set to be 2200000Pa. The stress legend show the maximum stress is 0.496×10^7Pa and minimum stress is -0.793×10^7Pa. It can be observed that the hoop stress along the radial position of the tube is increasing toward the middle of radial position of the tube and decreasing from the middle to the outer diameter of the tube.

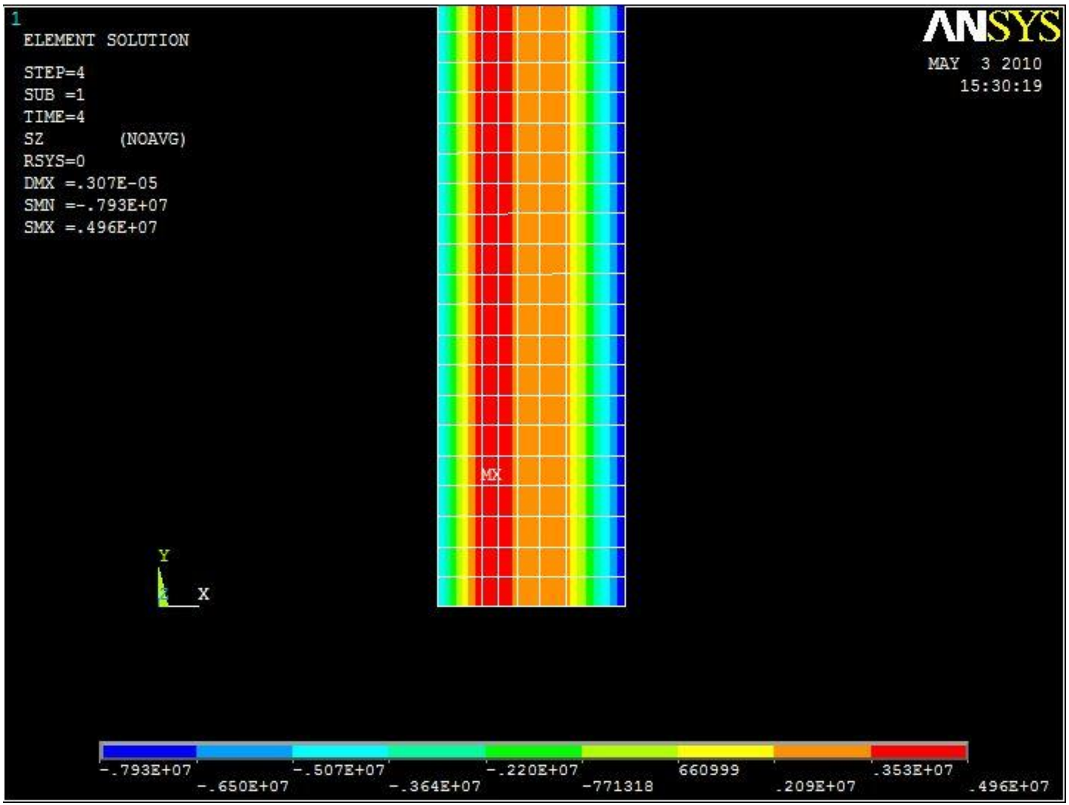

Figure 26: Hoop stress on element by using ANSYS (5.5-6.5m)

4.2.3 Result at tube length 11.5m – 12.5m.

Figure 27 shows the radial stress on the radial position of the steam methane reformer tube. The temperature of the inner tube diameter is set to be 1148K and outer tube diameter is set to be 1159K. The inner pressure is set to be 1840000Pa. The stress legend show the maximum stress is 366545Pa and minimum stress is -0.201x10^{7}Pa. It can be observed that the radial stress along the radial position of the tube is also increasing.

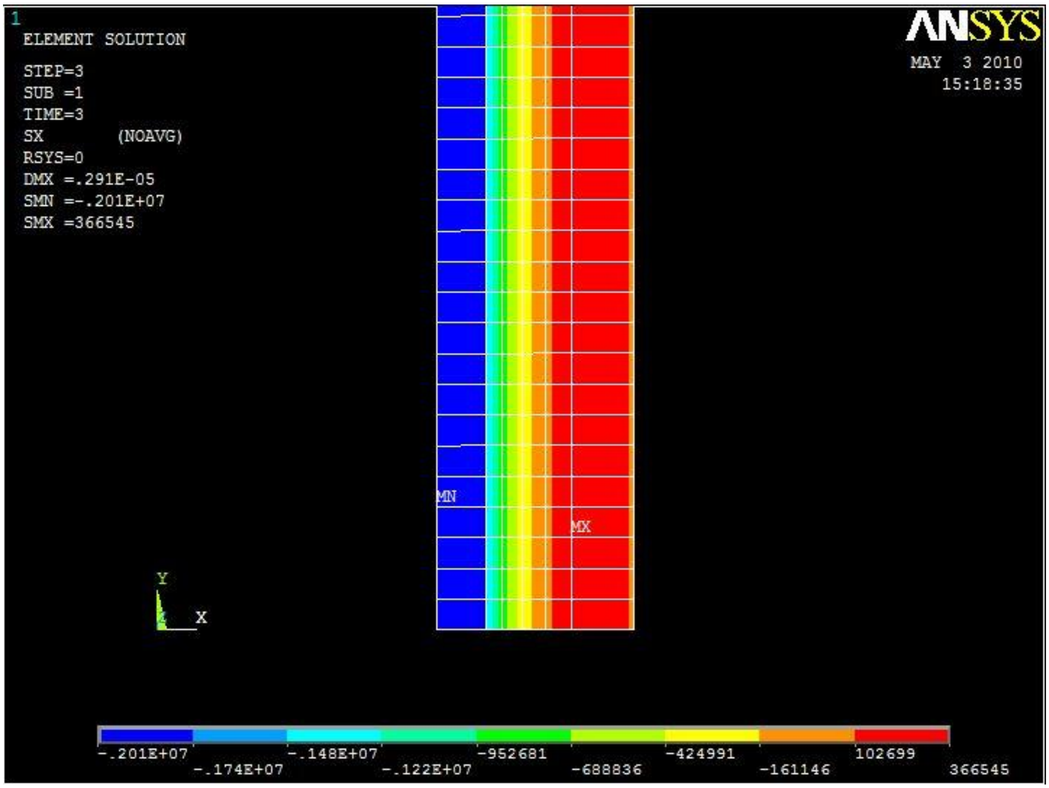

Figure 27: Radial stress on element by using ANSYS (11.5-12.5m)

Figure 28 shows the axial stress on the radial position of the steam methane reformer tube. The temperature of the inner tube diameter is set to be 1148K and outer tube diameter is set to be 1159K. The inner pressure is set to be 1840000Pa. The stress legend show the maximum stress is 836701Pa and minimum stress is -0.985x10^{7}Pa. It can be observed that the axial stress along the radial position of the tube is increasing toward the middle of radial position of the tube and decreasing from the middle to the outer diameter of the tube.

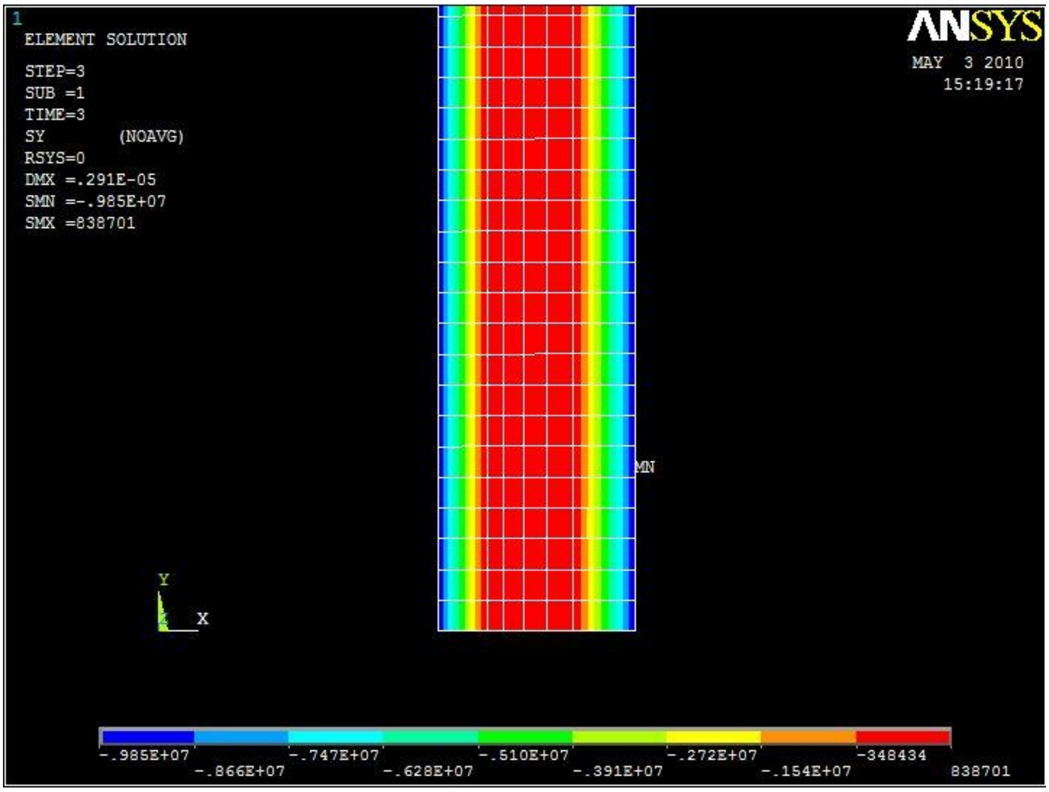

Figure 28: Axial stress on element by using ANSYS (11.5-12.5m)

Figure 29 shows the hoop stress on the radial position of the steam methane reformer tube. The temperature of the inner tube diameter is set to be 1148K and outer tube diameter is set to be 1159K. The inner pressure is set to be 1840000Pa. The stress legend show the maximum stress is $0.456 x 10^7$Pa and minimum stress is -$0.797 x 10^7$Pa. It can be observed that the hoop stress along the radial position of the tube is increasing toward the middle of radial position of the tube and decreasing from the middle to the outer diameter of the tube.

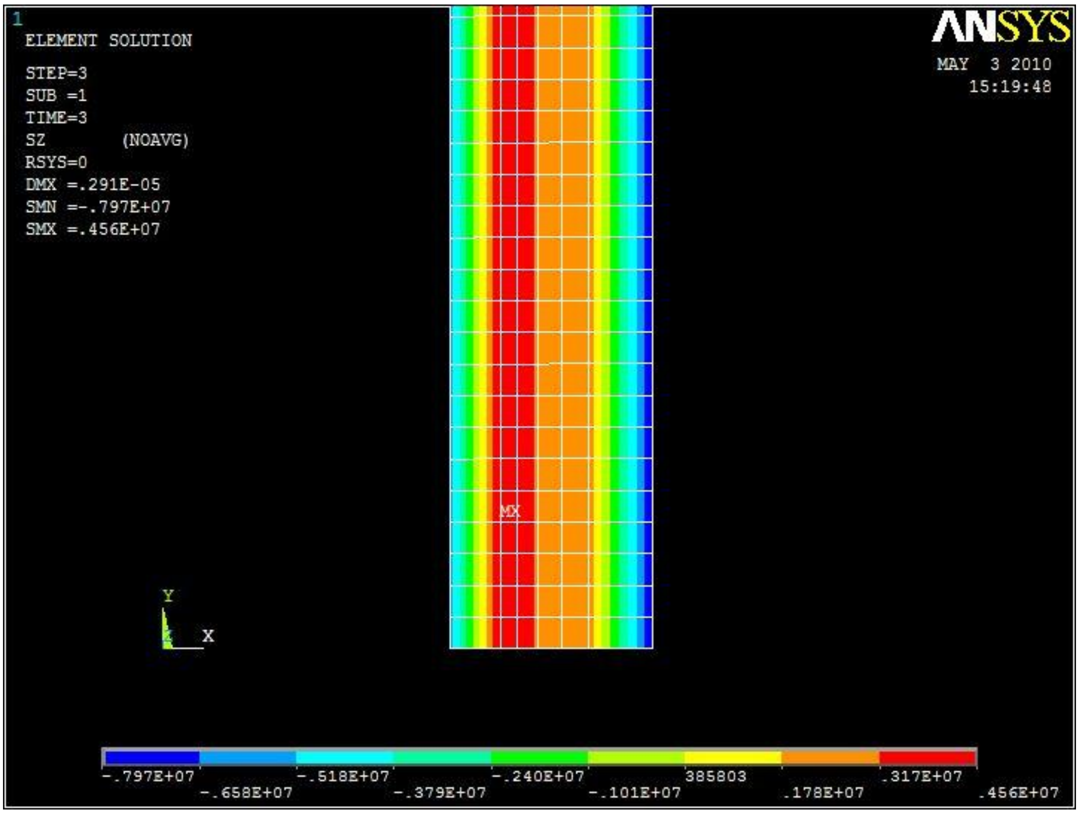

Figure 29: Hoop stress on element by using ANSYS (11.5-12.5m)

Figure 30 shows the plot of effective stress at three different position of the steam methane reformer. The blue colour represents the stress of the tube at 0m – 1m from top flange, the red colour represents stress of the tube at 5.5m – 6.5m from top flange, meanwhile green colour represents the stress of the tube at 11.5m – 12.5m from top flange. The result shows that the effective stress at all position of the steam methane reformer tube are decreasing from inner diameter to the middle of the radial position and increasing from middle of the radial position to the outer diameter of the tube.

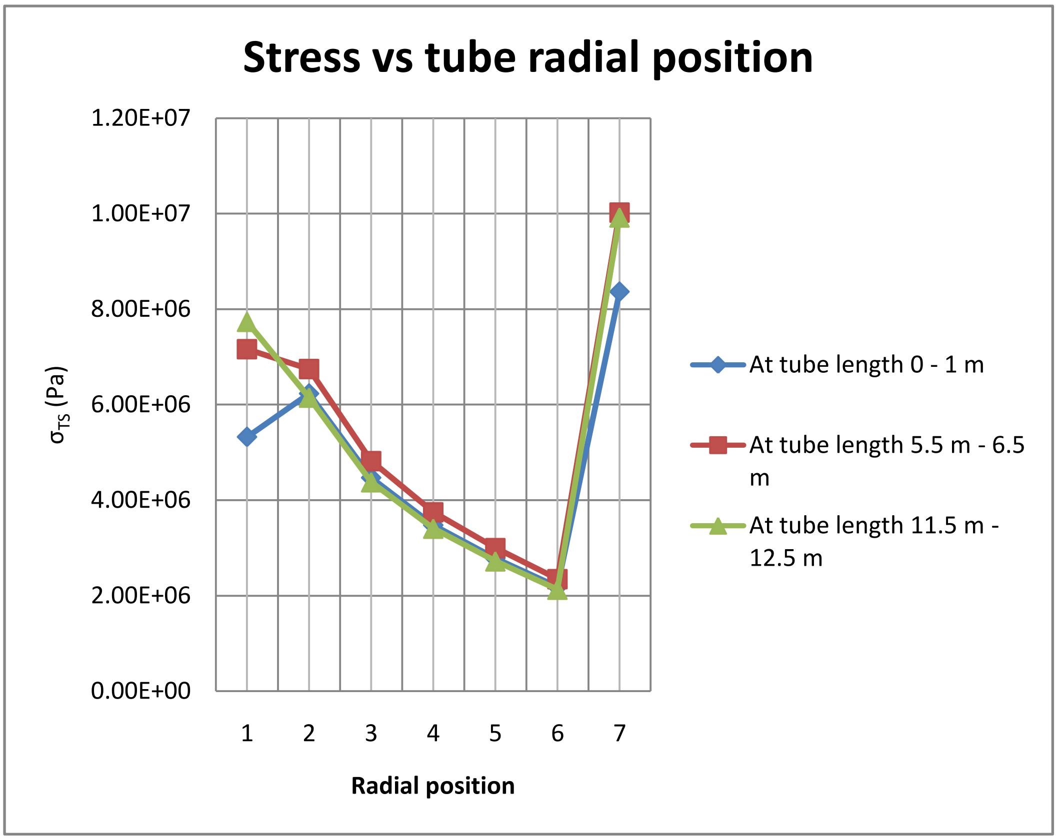

Figure 30: Graph Tresca stress vs. tube radial position (Finite Element)

From the graph, the minimum effective stress is $2.13x10^{6}$Pa at node 6 and maximum effective stress is $1x10^{7}$Pa at node 7 which is at outer tube position. It means that the stress is not same at any radial position. We can see that the lowest is at the middle of the tube thickness and higher is at the outer of the tube. The stress is decreasing toward the middle radial position and increasing back toward outer diameter of the tube.

Comparing both analytical and finite element, from the graph, it is observed that the stress of steam methane reformer tubes having a same pattern. The stress is not same at any radial position. It is observed that the lowest is at the middle of the tube thickness and higher is at the outer of the tube. The stress is decreasing toward the middle radial position and increasing back toward outer diameter of the tube.

The result is quite different possibly due to systematic and random errors. Systematic errors could be occurred during the pre-processing stage which is setting material and boundary conditions, creating geometry and meshing in ANSYS. Furthermore, in solving stage using ANSYS there are a lot of variables needed to be verified. In this case, systematic error is caused from inaccurately defined boundary conditions and operating conditions of the computational domain. Random errors also lead to the inaccuracy in the results. Random errors could have occurred at the initial stage of this study. Analytical method and finite element method give different stress result. However the trend of the results is similar.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

This project has analysed the stress on the steam methane reformer tubes. Throughout the research period all the information was gathered from reliable resources such as technical proceedings, journals and online resources. The main focus of this research is to investigate the stress profile along the tubes. The research is conducted by simulating using ANSYS software.

A pre-processor was used to draw the geometry and create the meshed geometry of the steam methane reformer tubes. ANSYS software has a solver that was used to set up the problem and simulate the stress of the steam methane reformer tubes. The problem has been set up based on the real operating condition during the steam methane reformer process. Finally, the result was analyzed to determine the effectiveness steam methane reformer process.

In this study, the operating conditions of the steam methane reformer are set according to the real operating condition. The inner and outer diameter temperature as well as the internal pressure of the steam methane reformer tubes is set varies according to real operating conditions.

The methodology which is used in this project can support the objectives in the project which are to analysis the stress of the tubes of steam methane reformer by analytical method and numerical method. At the end of this project, the author find that the problem solved by using analytical method and finite element method.

Results and findings from this project might be very useful in oil and gas industry. Hopefully, this project will help to improve the efficiency of the reformer tubes in the industry. The methodology of the stress analysis itself will help the engineer in plant to overcome the problem happen.

5.2 RECOMMENNDATIONS

The error occurs on this project result which is the differences data on analytical and finite element method. This is because the steam methane reformer tubes properties such as the exact operating conditions and tubes material are not consistent. Inconsistency of steam methane reformer tubes properties will produce different results of analysis.

This research found that by analyzed based on the real operating conditions is not appropriate since a steam methane reformer tubes process includes catalyst and the presence of other things inside the tube such as wire filter. Therefore to get a better result, a steam methane reformer process in the first place needs to study and reduce assumption on analysis. For the betterment of this project research, the steam methane reformer operating condition, process and geometry which is similar to the simulation conditions is recommended to be developed. In this research, gravity effect on the steam methane reformer tubes and the process flow has not been studied. In the real steam methane reformer tubes process, the fluid involved flow through the tube. It enters at the top tube and exits at the tube bottom which will be affected by gravity. Hence, in future study, gravity and the process effects must be investigated. The error also may occur because of some of the errors that may be present during analytical calculation and finite element method. Other than that, the skill in using the ANSYS software also may the cause of the error in the analysis. It is recommended that to repeat the analytical method and finite element method to reduce the error and to get the precise analysis.

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APPENDICES

Table 1: Analytical Calculations

1. Result at tube length 0 –1m.

r	σhT (MPa)	σrT (MPa)	σaT (MPa)	σhP (MPa)	σrP (MPa)	σaP (MPa)	σ_{aW} (MPa)
52.50	98.90	0.00	98.90	10.59	0.00	5.30	0.01
53.50	77.03	1.64	78.67	10.40	0.20	5.30	0.01
54.50	55.98	2.83	58.81	10.21	0.38	5.30	0.01
55.50	35.71	3.61	39.31	10.04	0.56	5.30	0.01
56.50	16.17	4.00	20.17	9.87	0.72	5.30	0.01
57.50	-2.69	4.05	1.35	9.71	0.88	5.30	0.01
58.50	-20.91	3.77	-17.14	9.56	1.03	5.30	0.01
59.50	-38.52	3.21	-35.31	9.42	1.17	5.30	0.01
60.50	-55.56	2.38	-53.18	9.29	1.31	5.30	0.01
61.50	-72.06	1.30	-70.76	9.16	1.44	5.30	0.01
62.50	-88.06	0.00	-88.06	9.03	1.56	5.30	0.01

r	σ1 (MPa)	σ2 (MPa)	σ3 (MPa)	σ1 -σ2	σ1 -σ3	σ2 -σ3	σTS (MPa)
52.50	109.50	0.00	104.21	109.50	5.29	-104.21	109.50
53.50	87.42	1.84	83.98	85.58	3.45	-82.14	85.58
54.50	66.19	3.21	64.12	62.98	2.07	-60.90	62.98
55.50	45.74	4.16	44.62	41.58	1.12	-40.46	41.58
56.50	26.04	4.72	25.47	21.31	0.56	-20.75	21.31
57.50	7.02	4.93	6.66	2.09	0.36	-1.73	2.09
58.50	-11.35	4.81	-11.83	-16.15	0.48	16.63	16.63
59.50	-29.10	4.38	-30.00	-33.49	0.90	34.39	34.39
60.50	-46.28	3.69	-47.88	-49.97	1.60	51.56	51.56
61.50	-62.91	2.74	-65.46	-65.65	2.55	68.20	68.20
62.50	-79.02	1.56	-82.75	-80.58	3.73	84.31	84.31

Table 1: Analytical Calculations (cont'd)

2. Result at tube length 5.5m – 6.5m.

r	σhT (MPa)	σrT (MPa)	σaT (MPa)	σhP (MPa)	σrP (MPa)	σaP (MPa)	σ_{aW} (MPa)
52.50	61.60	0.00	61.60	9.68	0.00	4.84	0.12
53.50	47.97	1.02	48.99	9.50	0.18	4.84	0.12
54.50	34.86	1.76	36.63	9.33	0.35	4.84	0.12
55.50	22.24	2.25	24.48	9.17	0.51	4.84	0.12
56.50	10.07	2.49	12.56	9.02	0.66	4.84	0.12
57.50	-1.68	2.52	0.84	8.88	0.81	4.84	0.12
58.50	-13.02	2.35	-10.67	8.74	0.94	4.84	0.12
59.50	-23.99	2.00	-21.99	8.61	1.07	4.84	0.12
60.50	-34.60	1.48	-33.12	8.49	1.20	4.84	0.12
61.50	-44.88	0.81	-44.07	8.37	1.31	4.84	0.12
62.50	-54.84	0.00	-54.84	8.26	1.43	4.84	0.12

r	σ1 (MPa)	σ2 (MPa)	σ3 (MPa)	σ1 -σ2	σ1 -σ3	σ2 -σ3	σTS (MPa)
52.50	71.28	0.00	66.55	71.28	4.72	-66.55	71.28
53.50	57.47	1.20	53.95	56.27	3.52	-52.75	56.27
54.50	44.20	2.11	41.59	42.09	2.61	-39.47	42.09
55.50	31.41	2.75	29.44	28.66	1.97	-26.69	28.66
56.50	19.09	3.15	17.52	15.94	1.57	-14.37	15.94
57.50	7.20	3.33	5.80	3.87	1.40	-2.48	3.87
58.50	-4.28	3.29	-5.71	-7.58	1.43	9.01	9.01
59.50	-15.38	3.07	-17.03	-18.45	1.65	20.10	20.10
60.50	-26.12	2.68	-28.16	-28.79	2.05	30.84	30.84
61.50	-36.51	2.12	-39.11	-38.64	2.60	41.24	41.24
62.50	-46.58	1.43	-49.88	-48.01	3.30	51.31	51.31

Table 1: Analytical Calculations (cont'd)

3. Result at tube length 11.5m – 12.5m.

r	σhT (MPa)	σrT (MPa)	σaT (MPa)	σhP (MPa)	σrP (MPa)	σaP (MPa)	$σ_{aW}$ (MPa)
52.50	14.69	0.00	14.69	8.82	0.00	4.41	0.24
53.50	11.44	0.24	11.69	8.66	0.16	4.41	0.24
54.50	8.32	0.42	8.74	8.50	0.32	4.41	0.24
55.50	5.30	0.54	5.84	8.36	0.46	4.41	0.24
56.50	2.40	0.59	3.00	8.22	0.60	4.41	0.24
57.50	-0.40	0.60	0.20	8.09	0.73	4.41	0.24
58.50	-3.11	0.56	-2.55	7.96	0.86	4.41	0.24
59.50	-5.72	0.48	-5.25	7.84	0.98	4.41	0.24
60.50	-8.25	0.35	-7.90	7.73	1.09	4.41	0.24
61.50	-10.71	0.19	-10.51	7.62	1.20	4.41	0.24
62.50	-13.08	0.00	-13.08	7.52	1.30	4.41	0.24

r	σ1 (MPa)	σ2 (MPa)	σ3 (MPa)	σ1 -σ2	σ1 -σ3	σ2 -σ3	σTS (MPa)
52.50	23.51	0.00	19.34	23.51	4.17	-19.34	23.51
53.50	20.10	0.41	16.33	19.69	3.77	-15.93	19.69
54.50	16.82	0.74	13.38	16.08	3.44	-12.64	16.08
55.50	13.66	1.00	10.49	12.66	3.18	-9.49	12.66
56.50	10.62	1.20	7.64	9.42	2.98	-6.44	9.42
57.50	7.69	1.33	4.85	6.35	2.84	-3.51	6.35
58.50	4.86	1.42	2.10	3.44	2.76	-0.68	3.44
59.50	2.12	1.45	-0.60	0.67	2.72	2.05	2.72
60.50	-0.52	1.44	-3.26	-1.97	2.73	4.70	4.70
61.50	-3.08	1.39	-5.87	-4.47	2.78	7.26	7.26
62.50	-5.56	1.30	-8.44	-6.86	2.88	9.73	9.73

Table 2: Finite element method results

At tube length 0 - 1 m							
Node	σ1 (MPa)	σ2 (MPa)	σ3 (MPa)	σ1 -σ2	σ1 -σ3	σ2 -σ3	σTS (Pa)
1	-3.45E+06	-2.33E+06	-7.65E+06	-1.12E+06	4.20E+06	5.32E+06	5.32E+06
2	4.45E+06	-1.78E+06	8.01E+05	6.23E+06	3.65E+06	-2.58E+06	6.23E+06
3	3.57E+06	-9.02E+05	7.99E+05	4.47E+06	2.77E+06	-1.70E+06	4.47E+06
4	3.07E+06	-4.04E+05	8.00E+05	3.48E+06	2.27E+06	-1.20E+06	3.48E+06
5	2.72E+06	-53665	8.01E+05	2.78E+06	1.92E+06	-8.55E+05	2.78E+06
6	2.43E+06	2.47E+05	8.03E+05	2.18E+06	1.63E+06	-5.56E+05	2.18E+06
7	-6.48E+06	65056	-8.30E+06	-6.55E+06	1.81E+06	8.36E+06	8.36E+06
At tube length 5.5 m - 6.5 m							
Node	σ1 (MPa)	σ2 (MPa)	σ3 (MPa)	σ1 -σ2	σ1 -σ3	σ2 -σ3	σTS (Pa)
1	-5.07E+06	-2.36E+06	-9.52E+06	-2.72E+06	4.45E+06	7.16E+06	7.16E+06
2	4.86E+06	-1.89E+06	8.92E+05	6.75E+06	3.97E+06	-2.78E+06	6.75E+06
3	3.89E+06	-9.28E+05	8.89E+05	4.82E+06	3.00E+06	-1.82E+06	4.82E+06
4	3.36E+06	-3.90E+05	8.90E+05	3.75E+06	2.47E+06	-1.28E+06	3.75E+06
5	2.98E+06	-12335	8.91E+05	3.00E+06	2.09E+06	-9.04E+05	3.00E+06
6	2.66E+06	3.15E+05	8.94E+05	2.35E+06	1.77E+06	-5.79E+05	2.35E+06
7	-7.93E+06	76974	-9.95E+06	-8.01E+06	2.01E+06	1.00E+07	1.00E+07
At tube length 11.5 m - 12.5 m							
Node	σ1 (MPa)	σ2 (MPa)	σ3 (MPa)	σ1 -σ2	σ1 -σ3	σ2 -σ3	σTS (Pa)
1	-5.78E+06	-2.01E+06	-9.74E+06	-3.78E+06	3.96E+06	7.74E+06	7.74E+06
2	4.46E+06	-1.69E+06	8.33E+05	6.15E+06	3.63E+06	-2.52E+06	6.15E+06
3	3.57E+06	-8.05E+05	8.30E+05	4.38E+06	2.74E+06	-1.63E+06	4.38E+06
4	3.09E+06	-3.17E+05	8.31E+05	3.40E+06	2.26E+06	-1.15E+06	3.40E+06
5	2.75E+06	26153	8.32E+05	2.72E+06	1.91E+06	-8.06E+05	2.72E+06
6	2.45E+06	3.27E+05	8.34E+05	2.13E+06	1.62E+06	-5.07E+05	2.13E+06
7	-7.97E+06	75452	-9.84E+06	-8.05E+06	1.88E+06	9.92E+06	9.92E+06

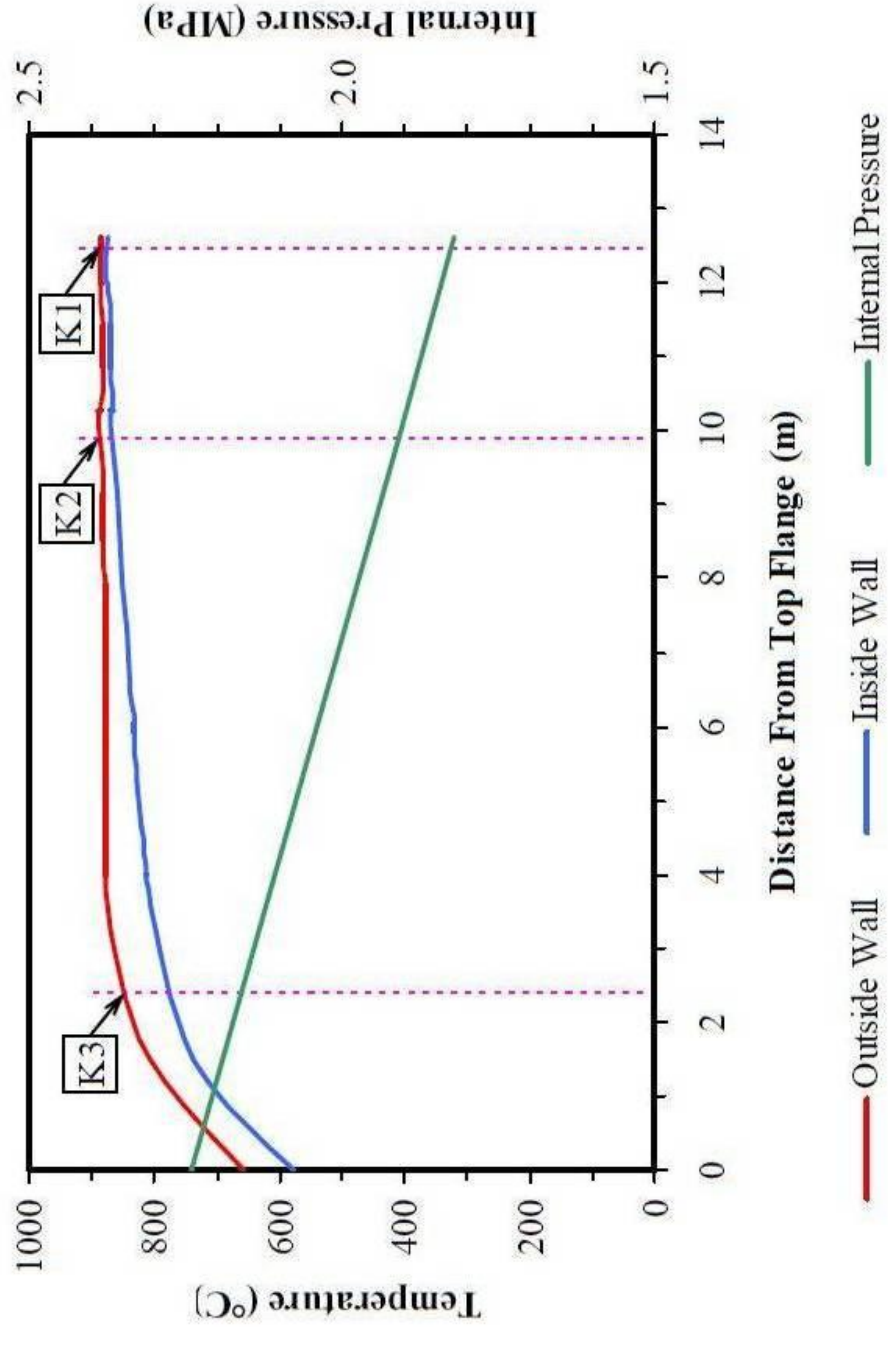

Figure 31: Temperature and Internal Pressure vs Distance from Top Flange