

**Stress Concentration Factors at Two Radial Adjacent Nozzle-Header
Connections of a Cylindrical Pressure Vessel.**

By

Mohd Fadhlan bin Ismail 7978

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

JULY 2008

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CERTIFICATION OF APPROVAL

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Approved by,

.....

(Dr Khairul Fuad)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

JULY 2008

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.

.....

(MOHD FADHLAN BIN ISMAIL)

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First and foremost, I would like to thank ALLAH for being with me throughout ups and downs of this project. Without His grace, the project would be nothing more than a title on the writing pad.

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ABSTRACT

There are three major phases in completing project named, “Stress Concentration Factors at Two Radial Adjacent Nozzles Header Connections of a Cylindrical Pressure Vessel”. These three phases are; parameters specification, design and Finite Element Analysis (FEA). This report basically will summarize the activities that have been done to complete this project. In parameter specification phase, data acquired to design a two radial adjacent nozzles header connection of cylindrical pressure vessel was extracted from the standard nozzles and piping codes used in the industry. The required data and information for this project also been gathered by using all available resources. In design phase, the author will compiles all data and parameters gained and design a nozzles-pressured vessel configuration which will be the basis for the whole project. Finally, a FEA simulation will be done by using ANSYS to analyze the model and complete these project objectives. The design of nozzles in a pressure vessel is subjected to the internal pressure acting from all direction. But in this study, only the internal pressure effect will be considered. This project objectives are to analysis and investigate the stress concentration factors of two radial adjacent nozzles header connection of cylindrical pressure vessel result that come from internal pressure by using ANSYS and To study the result and effect of different nozzles inner diameter and size and displacement of these two nozzles so that, recommendation can be made to improve the design of two radial adjacent nozzle header connection of cylindrical pressure vessel. From this project, it is decided that stress concentration factor most occur at low value of L/d ratio which the distance between the two nozzle are closer.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

A pressure vessel is a closed, rigid container designed to hold gases or liquids at a pressure different from ambient pressure. The pressure vessels used in industry a leak-tight pressure container, usually cylindrical or spherical in shape with various head configurations. It commonly used as a boiler or tank where pressured are needed to be maintained. One of the most crucial matters to be investigated when considering a pressure vessel configuration and design are the stress analysis of the vessel as it is important to determine the allowable stress for a pressure vessel to be designed.



Figure 1.1: Typical Cylindrical Pressure Vessel

Nozzle is a mechanical device which design to control the pressure of fluid as it enters or exit a pressure vessel. A nozzle is often a pipe or tube of varying cross-sectional area and it can be used to direct or modify the flow of fluid. Nozzle also often been used to control the flow rate, speed, direction, mass and the pressure of steam that emerges from them. The connection of nozzle headers is one of the crucial parts to be considered in designing a pressure vessel.

Finite Element Analysis (FEA) method will be the method to be used in this project since it is the best method to resolve the solution in stress analysis matter. Software such as ANSYS is considered as a very useful for this project.

1.2 Problem Statement

The design of nozzles in a pressure vessel is subjected to the internal pressure acting from all direction. For the FEA of nozzles on a pressure vessel, any applied loads can take form of internal pressure or vacuum, external pressure or vacuum, or independent forces and moment acting on the intersection. In this study, only the internal pressure effect will be considered.

It is important to study on the stress concentration factor of two radial adjacent nozzles header which on pressure as it will ease the design, manufacturing and operation of such pressure vessel configurations. Currently, there are only study on longitudinal adjacent nozzles header on cylindrical pressure vessel, nozzles header on spherical pressure vessel and also singular nozzle header connection on a cylindrical pressure vessel. This project will come out with the best solution in determining the stress concentration factors for two radial adjacent pressure vessels using the FEA software called ANSYS and other interpretation in order to achieve a reliable and accurate result.

1.3 Objective and Scope of Study

1.3.1 Objective

- i. To analysis and investigate the stress concentration factors of two radial adjacent nozzles header connection of cylindrical pressure vessel result that come from internal pressure by using ANSYS.
- ii. To study the result and effect of different nozzles inner diameter and size and displacement of these two nozzles so that, recommendation

can be made to improve the design of two radial adjacent nozzle header connection of cylindrical pressure vessel.

1.3.2 Scope of Study

For this project, the characterization and initial specification of various nozzles displacement and inner diameter of nozzles have been done to standardize the nozzles and pressure vessel configuration which will be used throughout this project. The specification also includes other relevant assumptions. Prior to this standardization, other properties such as the material that will be used and the operating pressure will be determined after some serious researches are done. Analysis will be made after the simulation been done by using FEA software; ANSYS.

CHAPTER 2

LITERATURE REVIEW AND THEORY

Nowadays, there are so many bodies and organization that come out with a design that is physically and operationally acceptable and reliable to be implementing in various project in engineering fields that known as a standard code design procedure include in pressure vessel. Before these standard codes been introduced, the early operation of pressure vessel resulted with many incidents such explosion of pressure vessel, loss of life and properties damage. In 1925, the American Society of Mechanical Engineers (ASME) formed a committee for the purpose of establishing minimum safety rule for pressure vessel design and construction [1]. This code consist of basic rules specifying design methods, design loads, allowable stress, acceptable materials and fabrication-inspection certifications requirements for pressure vessel construction. The design method, known as ‘Design by Rule’, uses design pressure, allowable stress, and design formula compatible with the geometry of the part to calculate the minimum thickness of the part [1]. The American National Standard Institute (ANSI) has approved that the ASME code can be used as reference. Other organization such the American Petroleum Institute (API) also has developed standard code for low pressure storage tanks, and these also are part of ANSI standard [2].

2.1 Thin-Walled Pressure Vessels

Thin-walled pressure vessels are one of the most typical applications of plane stress. Thin wall refers to a vessel having an inner-radius-to-wall-thickness ratio of 10 or more. Consider a cylindrical pressure vessel with radius r and wall thickness t subjected to an internal gage pressure p . Due to the uniformity of this loadings, an element of the vessel that is sufficiently removed from the ends and oriented, is subjected to normal stresses, σ_h in the circumferential or hoop direction and σ_l in the longitudinal or axial direction. The coordinates used to describe the cylindrical vessel can take advantage of its axial symmetry. It is natural to align one coordinate

along the axis of the vessel (i.e. in the longitudinal direction). To analyze the stress state in the vessel wall, a second coordinate is then aligned along the hoop direction. With this choice of axisymmetric coordinates, there is no shear stress. The hoop stress σ_h and the longitudinal stress σ_l are the principal stresses. [3] See Figure 2.1.

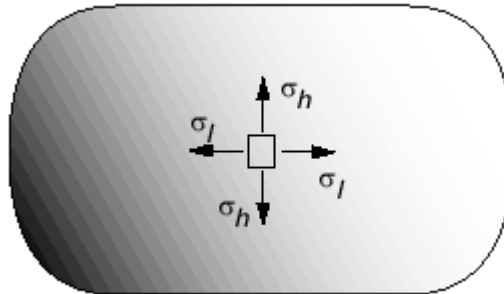


Figure 2.1: *Stresses Acting on Pressure Vessel Surface*

To determine the longitudinal stress σ_l , we make a cut across the cylinder similar to analyzing the spherical pressure vessel. Also, the thickness of pressure vessel is t . The free body, see Figure 2.2 and 2.3, are in static equilibrium. This implies that the stress around the wall must have a resultant to balance the internal pressure across the cross-section. Since the mean radius is approximately equal to the vessel's inner radius, equilibrium in the y direction requires;

$$\begin{aligned} \Sigma F_y = 0; \quad & \sigma_l(2\pi r t) - p(\pi r^2) = 0 \\ \text{So,} \quad & \sigma_l = pr/2t \end{aligned} \quad (2-1)$$

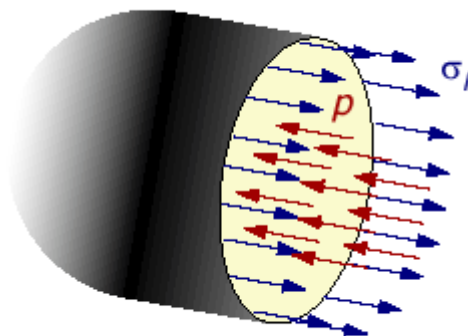


Figure 2.2: *Longitudinal Stress on a Cylindrical Pressure Vessel*

To determine the hoop stress σ_h , we make a cut along the longitudinal axis and construct a small slice as illustrated below. For equilibrium in the x direction, we require;

$$\Sigma F_x = 0; \quad 2[\sigma_h(tdy)] - p(2r dy) = 0$$

$$\sigma_h = pr/t \quad (2-2)$$

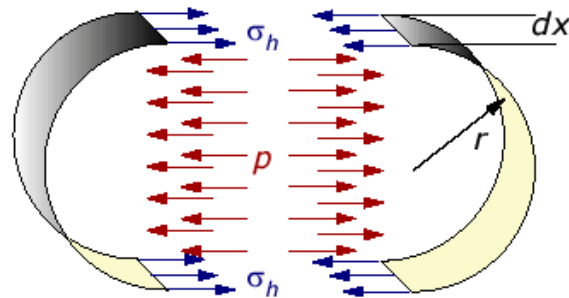


Figure 2.3: Hoop Stress on a Cylindrical Pressure Vessel

2.2 Design Loads and Allowable Stress

The force influenced pressure vessels design are internal/external pressure; dead loads due to the weight of vessel and content; external loads from piping and attachments; wind, snow and earth-quakes and also operating-type loads such as vibrations and sloshing of the contents[3]. The allowable stress used to determine the minimum vessel thickness is based on the tensile and yield strength of the material at room and design temperatures. These properties are adjusted by design factors that limit the hoop membrane stress to a value that precludes tensile rupture, excessive elastic and plastic deformations, and creep rupture [2]. See Table 2.1 for typical allowable stress for several carbon steels commonly used in for pressure vessels.

Table 2.1: Typical Allowable Stresses for Used in Pressure Vessel Design

Material Specification	Temperature Use Limit (°F)	Allowable Stress (psi)
SA-515 Gr. 60	700	14400
	800	10800
	900	6500
SA-516 Gr. 70	700	16600
	800	14500
	900	12000
SA-53 Gr. A	700	11700
	800	9300
	900	6500
SA-106 Gr. B	700	14400
	800	10800
	900	6500
SA-181 Gr. 1	700	16600
	800	12000
	900	6500

2.3 Material Selection

The material to be used in a pressure vessel must be selected from code-approved material specifications. The requirement is generally not a problem, since a large database of acceptable materials is available [4]. See Table 2.2 for several typical pressure vessel materials for noncorrosive environments and for service temperature between -50 and 1000°F.

Table 2.2: Acceptable Pressure Vessel Materials

Temperature Use Limit (°F)	Plate Material	Pipe Material	Forging Material
Down to -50	SA-516 All grades	SA 333 Gr. 1	SA 350 Gr. LF1, LF2
33 to 775	SA-285 Gr. C SA-545 Gr. 55, 60, 65 SA-516 All grades	SA-53 SA-106	SA-181 Gr. I, II
776 to 1000	SA-204 Gr. B, C SA-387 Gr. 11, 12 Class 1	SA-335 Gr. P1, P11, P12	SA-182 Gr. F1, F11, F12

2.4 Finite Element Analysis (FEA)

FEA consists of a computer model of a material or design that is stressed and analyzed for specific results. It is used in new product design, and existing product refinement. Equations of equilibrium, in conjunction with applicable physical considerations such as compatibility and constitutive relations, are applied to each element, and a system of simultaneous equation is constructed. The system of equations is solved for unknown values using the techniques of linear algebra or nonlinear numerical schemes, as appropriate. While being an appropriate method, the accuracy of the FEA method can be improved by refining the mesh using more elements and nodes [7].

2.5 Stress Concentration Factor

Stress concentration occur when a certain section of component have sudden change on of cross-sectional area. Stress concentration will be higher with more severe change in the cross-sectional area. The stress concentration factor, K_t is defined as a ratio of the maximum stress to the average stress acting at the smallest cross section area [5]. It is multiplying factor for applied stress that allow for the greatest stress in the region of the discontinuity to the nominal stress for the entire section [6]. For a typical load case, the stress concentration factor is given as;

$$K_t = \sigma_{max} / \sigma_{avg} \quad (2-3)$$

2.6 Nozzle-Pressure Vessel Stress Concentration Analysis

A recent study has been done to examine the stress concentration factors for a radial nozzle to a spherical shell connection. The stress concentration factors have been derived via FEM-models which ax symmetric ring elements. As a check and for completeness, the analytical solution for the spherical shell with bore has been included [5]. The non linear stress distribution of the undisturbed thick spherical shell and corresponding moment has been taken into account to expand the range of applicability. The nozzles force was modeled by an equivalent constant stress

distribution at the nozzle end; the corresponding force on the opening/bore was modeled by an equivalent shear stress at the bore surface with a specific diameter [6]. The simulation performed showed that in fatigue critical cases, local modeling requires special care-local changes [5].

2.7 Von Mises Equivalent Stress

Von Mises stress, is a scalar function of the components of the stress tensor that gives an appreciation of the overall magnitude of the tensor. Plastic yield initiates when the Mises stress reaches the initial yield stresses in uniaxial tension and for hardening materials, will continue provided the Mises stress is equal to the current yield stress and tending to increase. Mises stress can be then used to predict failure by ductile tearing. It is not appropriate for failure by crack propagation or fatigue, which depends on the maximum principal stress [10].

The principal stresses ($\sigma_1, \sigma_2, \sigma_3$) are calculated from the stress components by the cubic equation:

$$\begin{bmatrix} \sigma_x - \sigma_0 & \sigma_{xy} & \sigma_{xz} \\ \sigma_{xy} & \sigma_y - \sigma_0 & \sigma_{yz} \\ \sigma_{xz} & \sigma_{yz} & \sigma_z - \sigma_0 \end{bmatrix} = 0 \quad (2-4)$$

σ_0 = principal stress (3 values)

The three principal stresses are labeled σ_1, σ_2 , and σ_3 . The principal stresses are ordered so that σ_1 is the most positive (tensile) and σ_3 is the most negative (compressive).

The Von Mises or equivalent stress σ_e is computed as:

$$\sigma_e = \left(\frac{1}{2} \left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 \right] \right)^{\frac{1}{2}} \quad (2-5)$$

But for this project, the author only considered the stresses are only come from two directions. So, the equation will become:

$$\sigma_e = \left(\frac{1}{2} [(\sigma_1 - \sigma_2)^2 + (\sigma_2)^2 + (\sigma_1)^2] \right)^{\frac{1}{2}} \quad (2-6)$$

By Thin-Walled Pressure Vessel Theory, the stresses are come from longitudinal stress and hoop stress. So, the Von Misses Equivalent stress will become;

$$\sigma_e = \left(\frac{1}{2} [(\sigma_l - \sigma_h)^2 + (\sigma_h)^2 + (\sigma_l)^2] \right)^{\frac{1}{2}} \quad (2-7)$$

CHAPTER 3

METHODOLOGY

3.1 Procedure Identification

Initially, the project is about designing and analysis of the stress concentration factors at two radial adjacent nozzle-header connections at a cylindrical pressure vessel. The project started with some research in pressure vessel. The research then went deeper in finding the design of the system by having the theoretical calculation. Then the design process started with the sketch of the system. After having the material selection, the 3D drawing has been done by using ANSYS Software. Then the analysis of the model with different pressure vessel diameter to nozzle diameter ratio had been done. See Figure 3.1 for the process flow of the project:

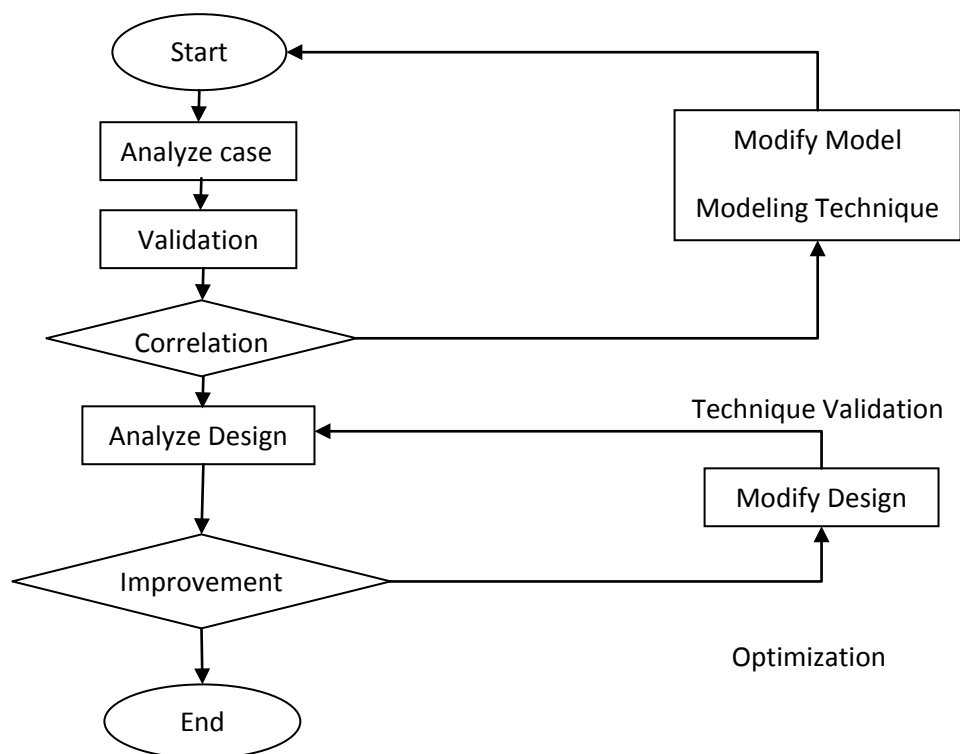


Figure 3.1: Process Flow for the Entire

3.2 Process Flow for Analysis of the Project

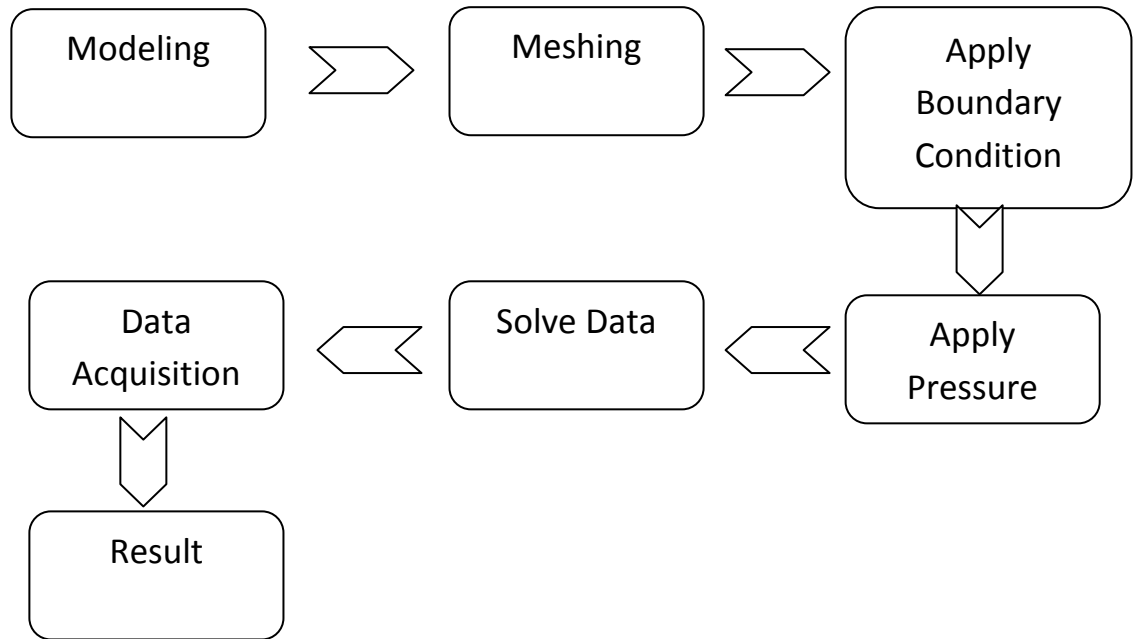


Figure 3.2: Process Flow for the Analysis of the Project

3.3 Modeling

3.3.1 Pressure Vessel Specification

As some of the parameters for the intended nozzle-header connection at cylindrical pressure vessel configuration have been set by the supervisor earlier, there is also some part of the configuration that needed to be calculated or validate with the ASME standard. For this project, the author has varies the ratio of pressure vessel diameter to nozzle diameter into two ratio which are ratio of 22, 20 and 18.

These are the specifications that are decided by the author for the pressure vessel according to the ratio of D/d:

Table 3.1: Pressure Vessel Specifications

	Ratio of D/d		
	22	20	20
Pressure Vessel Diameter, D (m)	2.2	2.0	1.8
Shell Thickness, t_p (m)	0.02	0.02	0.02
Nozzle Diameter, d (m)	0.05	0.05	0.05
Vessel length, h (m)	0.5	0.5	0.5
Nozzles Thickness, t_n (m)	0.004	0.004	0.004

For ratio of 22,

$$D/d = 22,$$

The author makes D as variable, as we know $d = 0.1$ m. So,

$$D/0.1 = 20$$

$$D = 2.2 \text{ m}$$

For ratio of 20,

$$D/d = 20,$$

The author makes D as variable, as we know $d = 0.1$ m. So,

$$D/0.1 = 20$$

$$D = 2 \text{ m}$$

For ratio of 18,

$$D/d = 18,$$

The author makes D as variable, as we know $d = 0.1$ m. So,

$$D/0.1 = 18$$

$$D = 1.8 \text{ m}$$

All the units of dimension of these models have been converted into millimeter in order to standardize the unit during the creation of these models.

3.3.2 Model Input

3D models have been created by using ANSYS Software according to their specification as stated in Table 3.1. Figures below show the sketch and 3D drawing of the pressure vessel.

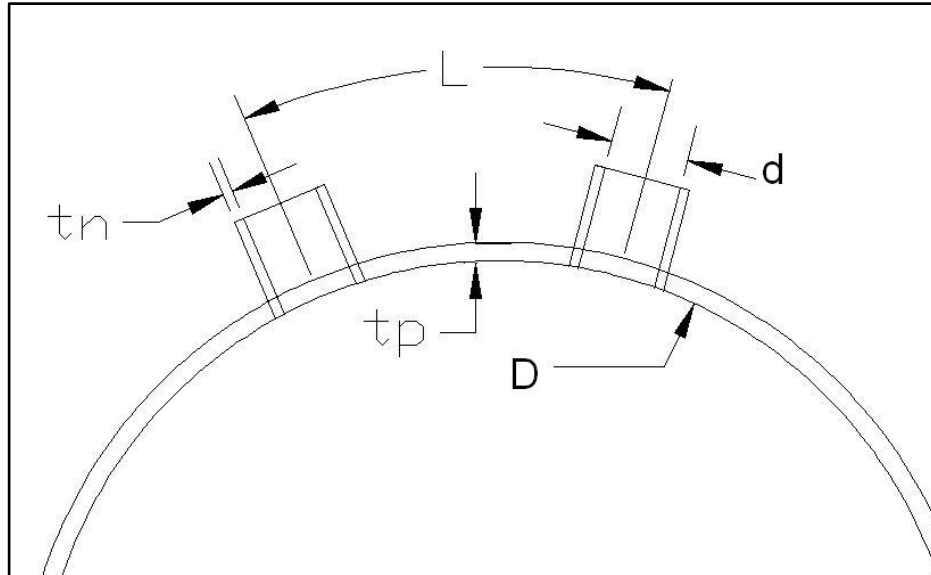


Figure 3.3: Cross-Sectional Area of the Pressure Vessel

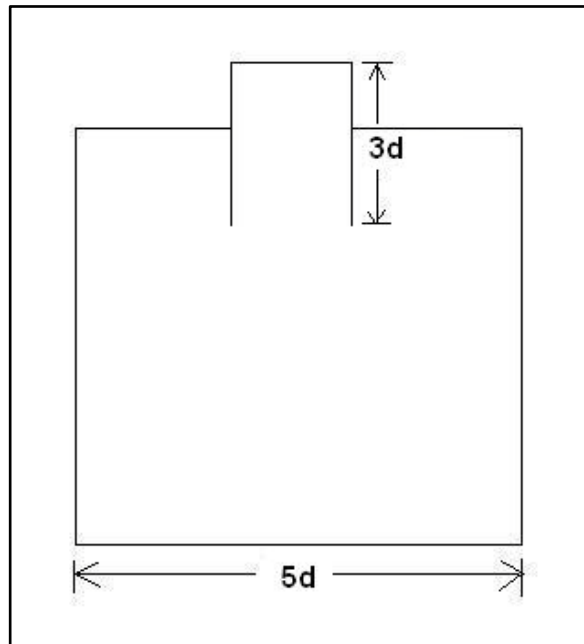


Figure 3.4: Side View of the Pressure Vessel

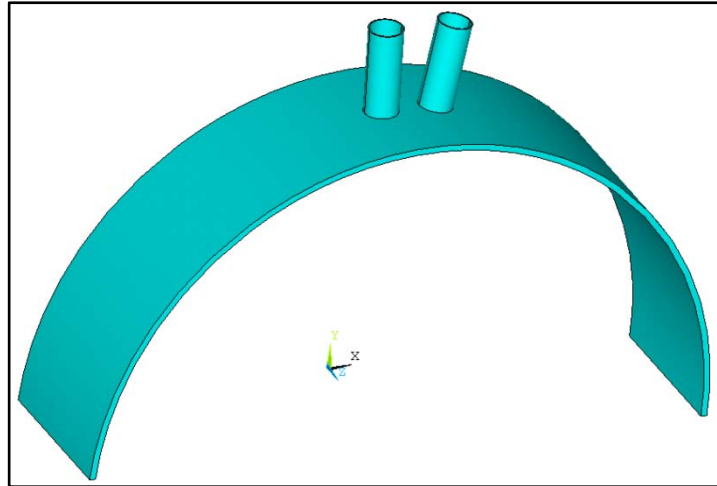


Figure 3.5: Model of the Pressure Vessel

The crucial part of this project was the various ratio of distance between the two nozzles (L) to the size of the nozzles (d). Eleven different of L/d ratio of pressure vessel been created. These pressure vessels were analyzed by ANSYS Software. The L/d ratios that been analyzed are;

- | | |
|---------|----------|
| 1. 1.50 | 9. 3.50 |
| 2. 1.75 | 10. 3.75 |
| 3. 2.00 | 11. 4.00 |
| 4. 2.25 | |
| 5. 2.50 | |
| 6. 2.75 | |
| 7. 3.00 | |
| 8. 3.25 | |

Below is the example calculation on how the ratio of L/d been applied in this project:

For ratio of 1.50

$$L/d = 1.50$$

As we know, $d = 0.1$ m. So;

$$L/0.1 = 1.50$$

$$L = 0.15 \text{ m}$$

So, the distance between these two nozzles is $0.15 \text{ m} = 150 \text{ mm}$

3.4 ANSYS Analysis Process Flow

After model been created by using ANSYS, the author has proceeded with meshing process in order to gain the result. See Chart 2 for the analysis that been divided into separate preprocessing, solution and post processing steps.

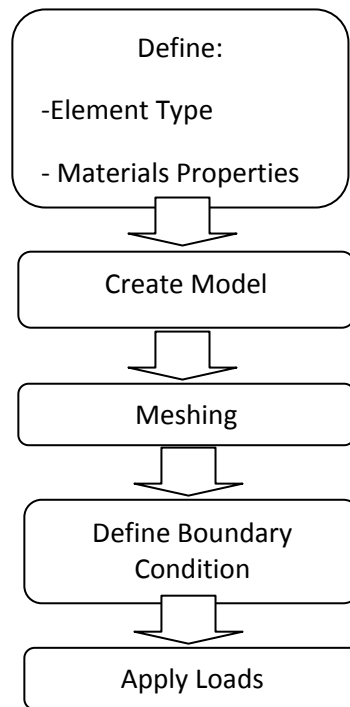


Figure 3.6: Steps Involved in the Analysis using ANSYS

3.4.1 Material Properties and Operating Pressure

Below are the material and its properties that been selected by author for the entire modeling and analysis. Also, specific operating pressure been selected.

Table 3.2: Material Properties and Operating Pressure

	Description
Material	SA 516 Gr. 70 (Carbon Steel)
Poisson's Ratio, ν	0.3
Modulus of Elasticity	28.1×10^3 kpsi
Operating Pressure, P	550 psi

3.4.2 Meshing Phase

Before meshing, the author has defined the material's modulus of Elasticity and Poisson's Ratio. To make the mesh finer, the author has refined the mesh on several critical areas around the nozzle. In meshing a model, more elements in the model are recommended to get more accurate result in the end of analysis. But due to the performance of the computer used matter, the author has decided to limit his elements into about 25, 000 elements only. Figures below showed the example of the model after the meshing phase:

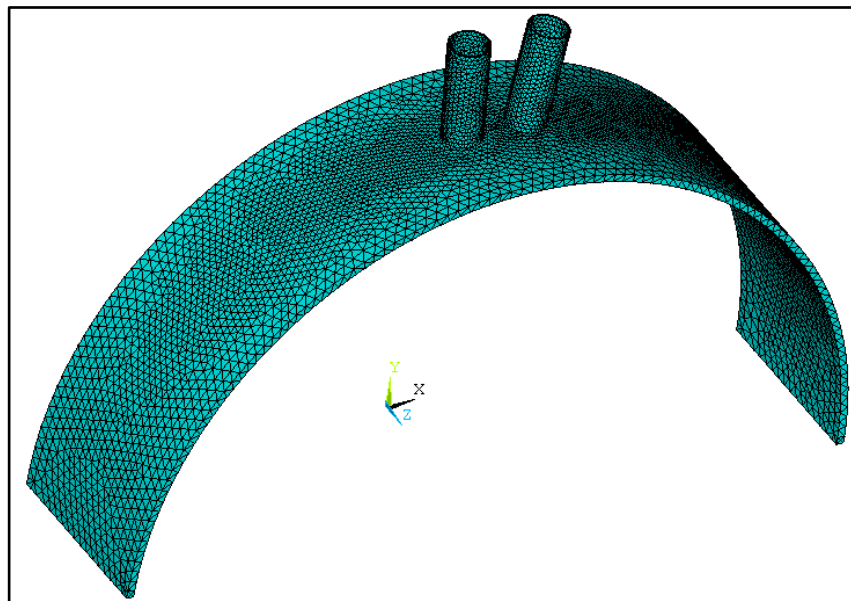


Figure 3.7: Meshing Phase

3.4.3 Boundary Condition Phase

After the model been meshed, the author had set the boundary condition for the model according to the condition been set by his supervisor. Below is the figure that shows the boundary conditions for all these models:

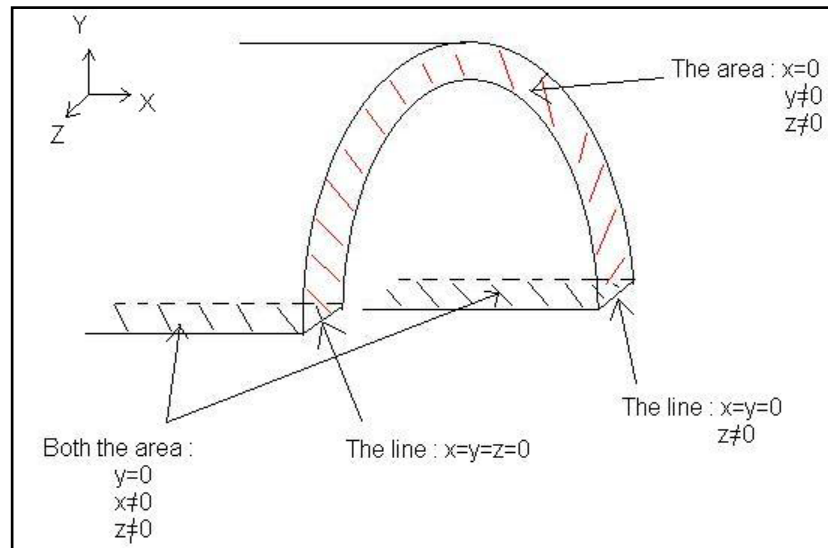


Figure 3.8: Boundary Condition Applied

3.4.4 Stress Phase

Next phase involve in ANSYS analysis was applying the stresses. There were two stresses that been apply to these models which was longitudinal stress. These stresses been applied at the pressure vessel and the nozzle. Figure 3.9 shows where the stress been applied.

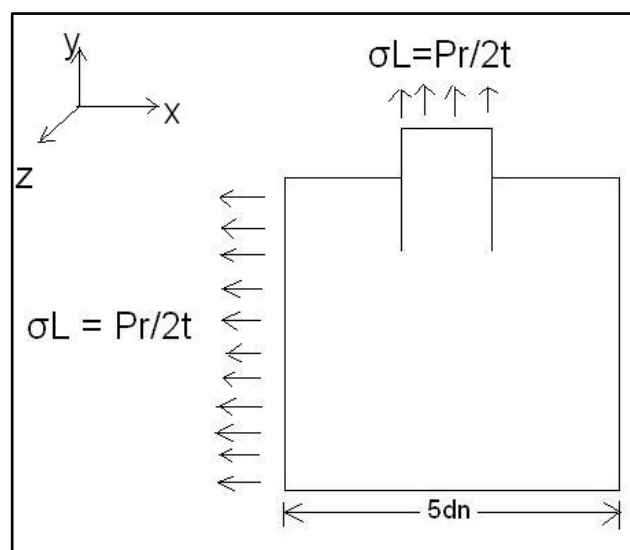


Figure 3.9: Stresses Applied

For the nozzle, the longitudinal stress is:

$$\sigma_2 = Pr / 2t$$

$$P = 500 \text{ psi} = 3.7921 \text{ MPa}$$

$$\text{So, } \sigma_2 = (3.7921 \text{ Mpa}) \times (50 \text{ mm}) / (2 \times 4 \text{ mm})$$

$$\sigma_2 = \mathbf{23.701 \text{ MPa}}$$

But for the pressure vessel, the longitudinal stress is not the same for these ratios due to the changes of their diameter according to the ratio as stated before.

For Ratio of 22,

$$\sigma_1 = Pr / 2t$$

$$P = 500 \text{ psi} = 3.7921 \text{ MPa}$$

$$\text{So, } \sigma_1 = (3.7921 \text{ Mpa}) \times (1100 \text{ mm}) / (2 \times 20 \text{ mm})$$

$$\sigma_1 = \mathbf{104.283 \text{ MPa}}$$

While for Ratio of 20,

$$\sigma_1 = Pr / 2t$$

$$P = 500 \text{ psi} = 3.7921 \text{ MPa}$$

$$\text{So, } \sigma_1 = (3.7921 \text{ Mpa}) \times (1000 \text{ mm}) / (2 \times 20 \text{ mm})$$

$$\sigma_1 = \mathbf{94.803 \text{ MPa}}$$

and for Ratio of 18,

$$\sigma_1 = Pr / 2t$$

$$P = 500 \text{ psi} = 3.7921 \text{ MPa}$$

$$\text{So, } \sigma_1 = (3.7921 \text{ Mpa}) \times (900 \text{ mm}) / (2 \times 20 \text{ mm})$$

$$\sigma_1 = \mathbf{85.322 \text{ MPa}}$$

Operating pressure, P also been applied to the inner surface of the model. The pressure need to convert into Mega Pascal unit (MPa) during the application of the stresses in order to synchronize the mm unit been used for the dimension of model. Below is the example of the model after all the boundary conditions and the stresses been applied:

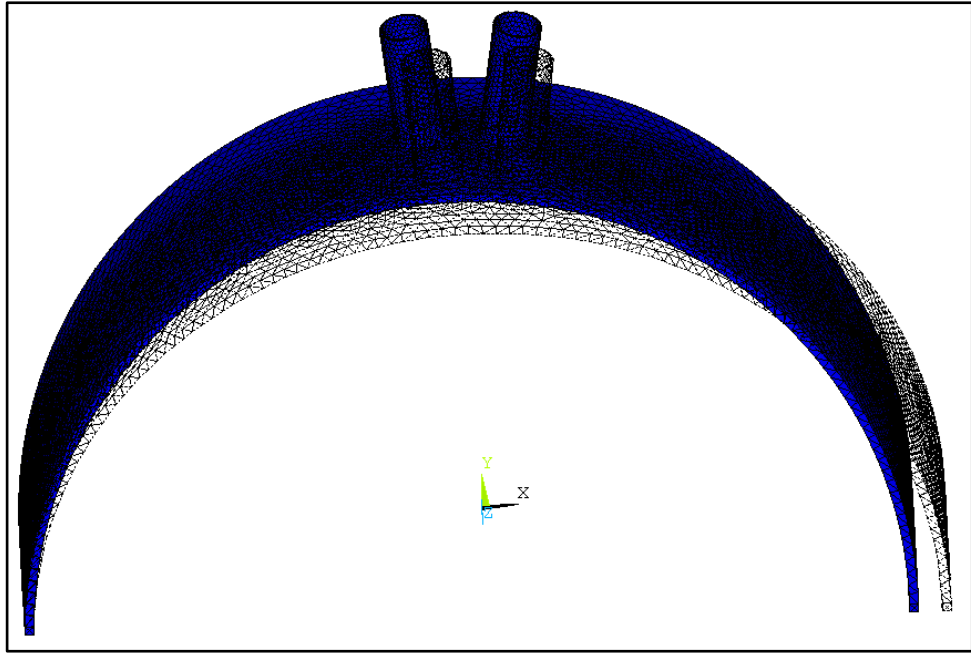


Figure 3.10: Stress Phase

3.4.5 Von Mises Phase

Von Mises Stress also been applied to the models in order to gain the visual affect of the pressure distribution on the model after boundary condition and stresses been applied. The minimum pressure and maximum pressure also can be known from this phase. Below is the example of the model after Von Mises stress been applied:

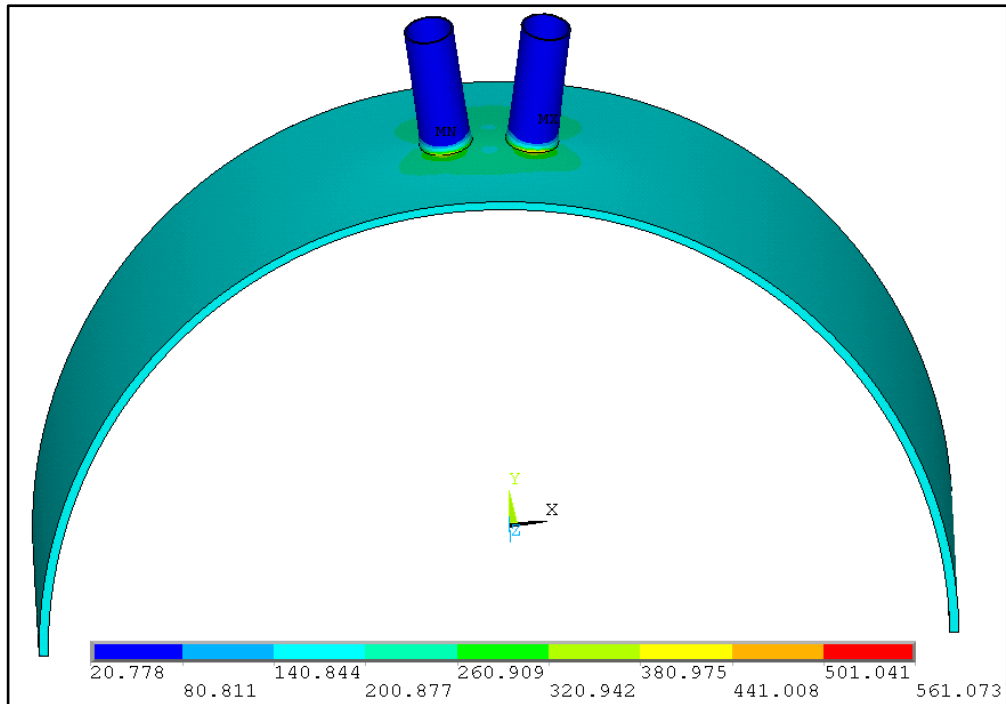


Figure 3.11: Von Mises Stress Phase

3.4.6 Cross Sectional

In this phase, it allow us to see the pressure distribution in the cross sectional area of the model. For this project, it is important to see the stresses that occur at the area around the nozzle. Below is the example of the model:

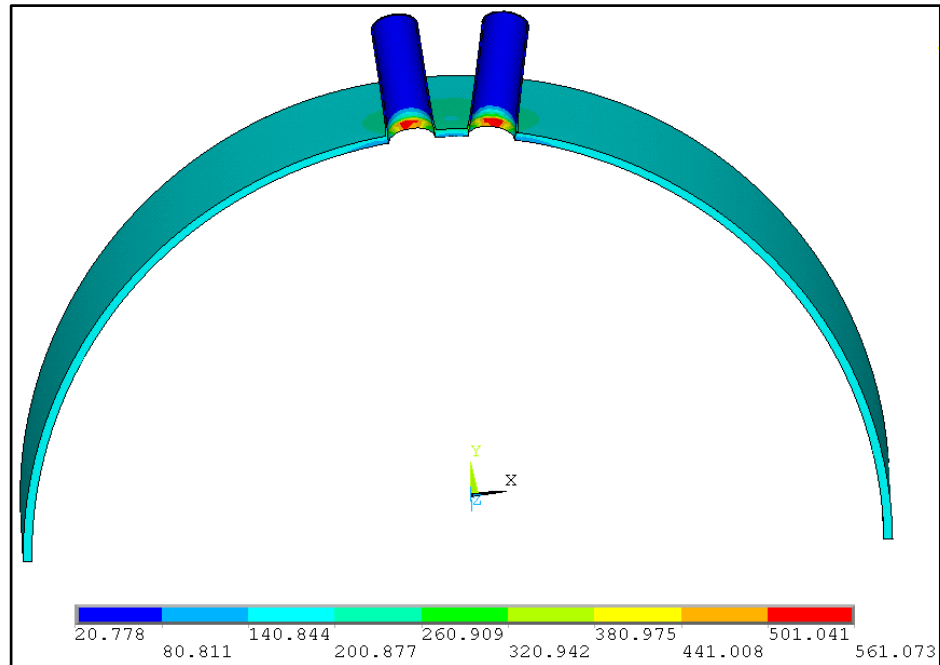


Figure 3.12: Cross Sectional of Model

3.5 Tool/Equipment Required

ANSYS Software is the only tool that been used in this project. Specifically, the software used for this project was ANSYS 11.

CHAPTER 4

Result and Discussion

4.1 Displacement of Models

From the analysis been made, the author has gain the displacement of the models after the boundary conditions and the stresses been applied. Table and graph below show the displacement for both ratios of pressure vessel diameter, D to the nozzle diameter, d.

Table 4.1: Displacement of Models

L/d Ratio	Displacement (mm) D/d Ratio		
	18	20	22
1.50	2.90	3.84	4.99
1.75	2.86	3.80	4.94
2.00	2.82	3.75	4.89
2.25	2.77	3.71	4.84
2.50	2.73	3.66	4.79
2.75	2.69	3.61	4.74
3.00	2.64	3.57	4.69
3.25	2.60	3.52	4.64
3.50	2.56	3.48	4.59
3.75	2.52	3.43	4.54
4.00	2.48	3.39	4.49

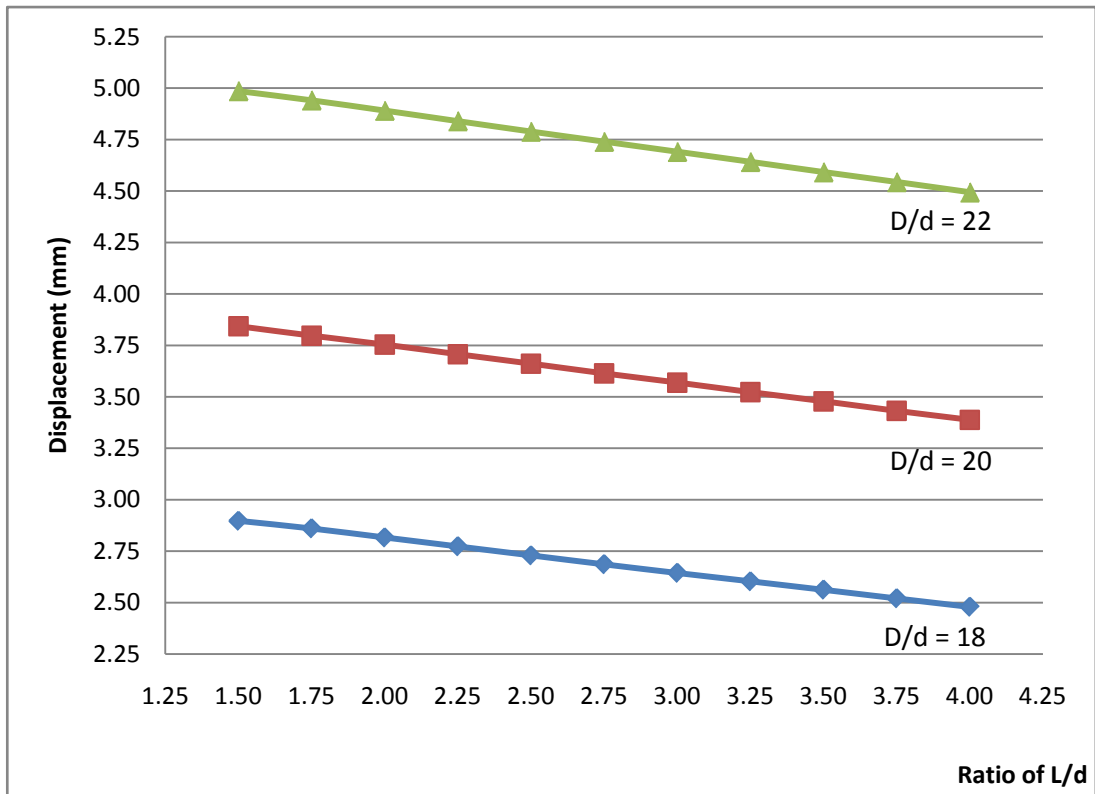


Figure 4.1: Displacement of Models

The displacement is representing how much the change of shape of the pressure vessel after stress been applied from its original shape. The displacement become smaller if the ratio of L/d becomes bigger. It means that, the more distance between the two nozzles, the pressure vessel can reduce the change of its shape from its original shape.

4.2 Maximum Stress

The most crucial result that the author gains from it project is the maximum stress that been absorb by the pressure vessel which will affect the concentration factor of these pressure vessel. Table and graph below shows the maximum stress absorbed with respect to their L/d ratios.

Table 4.2: Maximum Stress Absorbed

Ratio	Maximum Stress D/d Ratio		
	18	20	22
1.50	512.602	559.849	608.538
1.75	509.801	558.596	606.487
2.00	508.754	557.699	606.272
2.25	507.681	557.189	607.150
2.50	506.805	555.748	607.508
2.75	505.483	554.023	604.243
3.00	505.324	552.224	602.665
3.25	501.578	550.361	601.000
3.50	500.014	549.091	599.404
3.75	499.833	547.176	596.938
4.00	496.225	547.537	595.461

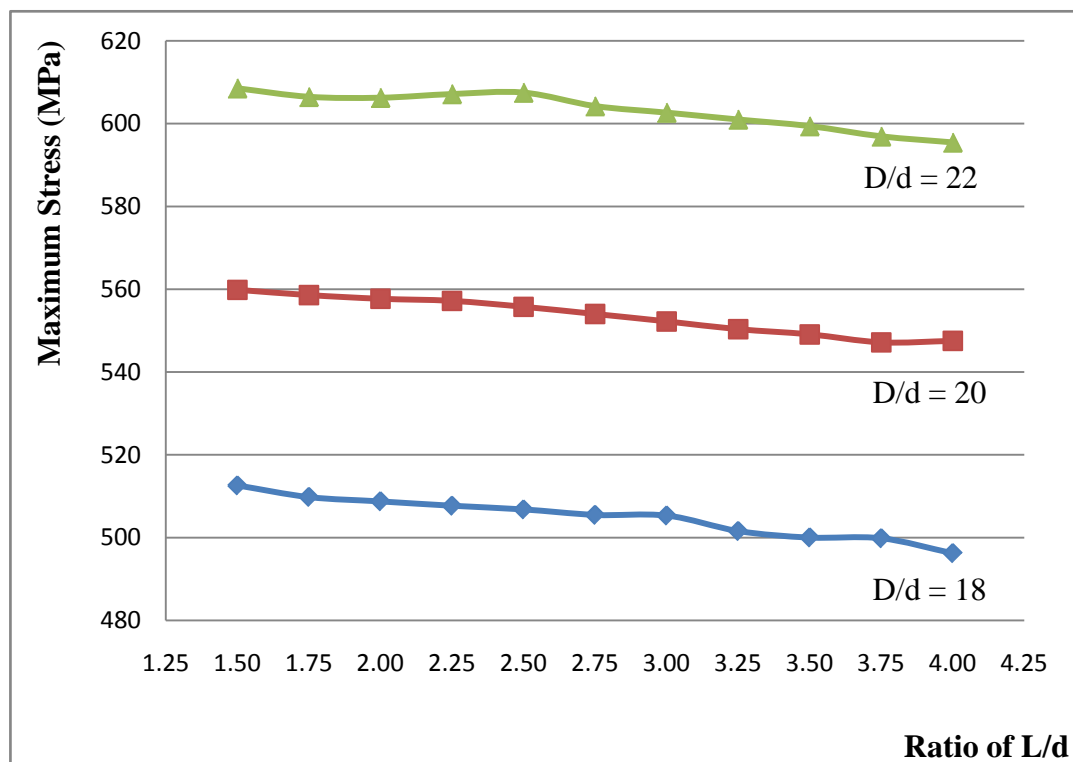


Figure 4.2: Maximum Stress Absorbed

From the graph, maximum stresses seem to occur at smaller value ratio of L/d. Low ratio of L/d is where the distant between these two nozzles are most close. As expected, the closer the nozzles, the more stress could occur.

4.3 Stress Concentration Factor

From the maximum stress, the author can gain the stress concentration factor, K_t of these pressure vessels which is the main objective of this project. K_t is gained by dividing maximum stress, σ_{max} absorbed by pressure vessel with the average stress of the pressure vessel, σ_{avg} . σ_{avg} is gained from the Von Mises equivalent stress of the pressure vessel. Sample calculation is shown below:

For ratio of D/d = 22,

$$\begin{aligned}\sigma_h &= Pr / t \\ &= (3.7921 \text{ MPa}) \times (1100 \text{ mm}) / 20 \text{ mm} \\ &= 208.566 \text{ MPa}\end{aligned}$$

$$\begin{aligned}\sigma_l &= Pr / 2t \\ &= (3.7921 \text{ MPa}) \times (1100 \text{ mm}) / (2 \times 20 \text{ mm}) \\ &= 104.283 \text{ MPa}\end{aligned}$$

From Von Mises equivalent stress equation,

$$\sigma_{avg} = \left(\frac{1}{2} [(\sigma_l - \sigma_h)^2 + (\sigma_h)^2 + (\sigma_l)^2] \right)^{\frac{1}{2}} \quad (2-7)$$

$$\sigma_{avg} = \left(\frac{1}{2} [(104.283 - 208.566)^2 + (208.566)^2 + (104.283)^2] \right)^{\frac{1}{2}}$$

$$\sigma_{avg} = 180.623 \text{ MPa}$$

For L/d = 1.50, $\sigma_{max} = 559.849 \text{ MPa}$

$$\begin{aligned}\text{So, } K_t &= \sigma_{max} / \sigma_{avg} \\ &= 559.849 \text{ MPa} / 180.623 \text{ MPa} \\ &= 3.37\end{aligned}$$

For ratio of D/d = 20,

$$\begin{aligned}\sigma_h &= Pr / t \\ &= (3.7921 \text{ MPa}) \times (1000 \text{ mm}) / 20 \text{ mm} \\ &= 189.605 \text{ MPa}\end{aligned}$$

$$\begin{aligned}\sigma_l &= Pr / 2t \\ &= (3.7921 \text{ MPa}) \times (1000 \text{ mm}) / (2 \times 20 \text{ mm}) \\ &= 94.801 \text{ MPa}\end{aligned}$$

From Von Mises equivalent stress equation,

$$\sigma_{avg} = \left(\frac{1}{2} [(\sigma_l - \sigma_h)^2 + (\sigma_h)^2 + (\sigma_l)^2] \right)^{\frac{1}{2}} \quad (2-7)$$

$$\sigma_{avg} = \left(\frac{1}{2} [(94.801 - 189.605)^2 + (189.605)^2 + (94.801)^2] \right)^{\frac{1}{2}}$$

$$\sigma_{avg} = 164.203 \text{ MPa}$$

For L/d = 1.50, $\sigma_{max} = 559.849 \text{ MPa}$

$$\begin{aligned}\text{So, } Kt &= \sigma_{max} / \sigma_{avg} \\ &= 559.849 \text{ MPa} / 164.203 \text{ MPa} \\ &= 3.41\end{aligned}$$

For ratio of D/d = 18,

$$\begin{aligned}\sigma_h &= Pr / t \\ &= (3.7921 \text{ MPa}) \times (900 \text{ mm}) / 20 \text{ mm} \\ &= 170.645 \text{ MPa}\end{aligned}$$

$$\begin{aligned}\sigma_l &= Pr / 2t \\ &= (3.7921 \text{ MPa}) \times (900 \text{ mm}) / (2 \times 20 \text{ mm}) \\ &= 85.322 \text{ MPa}\end{aligned}$$

From Von Mises equivalent stress equation,

$$\sigma_{avg} = \left(\frac{1}{2} [(\sigma_l - \sigma_h)^2 + (\sigma_h)^2 + (\sigma_l)^2] \right)^{\frac{1}{2}} \quad (2-7)$$

$$\sigma_{avg} = \left(\frac{1}{2} [(85.322 - 170.645)^2 + (170.645)^2 + (85.322)^2] \right)^{\frac{1}{2}}$$

$$\sigma_{avg} = 147.782 \text{ MPa}$$

For $L/d = 1.50$, $\sigma_{max} = 512.602 \text{ MPa}$

$$\begin{aligned} \text{So, } K_t &= \sigma_{max} / \sigma_{avg} \\ &= 512.602 \text{ MPa} / 147.782 \text{ MPa} \\ &= 3.47 \end{aligned}$$

Table and graph below show the stress concentration factor of pressure vessels with respect to their L/d ratio:

Table 4.3: Stress Concentration Factor of Pressure Vessels

Ratio	Kt		
	D/d Ratio		
	18	20	22
1.50	3.47	3.41	3.37
1.75	3.45	3.40	3.36
2.00	3.44	3.40	3.36
2.25	3.44	3.39	3.36
2.50	3.43	3.38	3.36
2.75	3.42	3.37	3.35
3.00	3.42	3.36	3.34
3.25	3.39	3.35	3.33
3.50	3.38	3.34	3.32
3.75	3.38	3.33	3.30
4.00	3.36	3.33	3.30

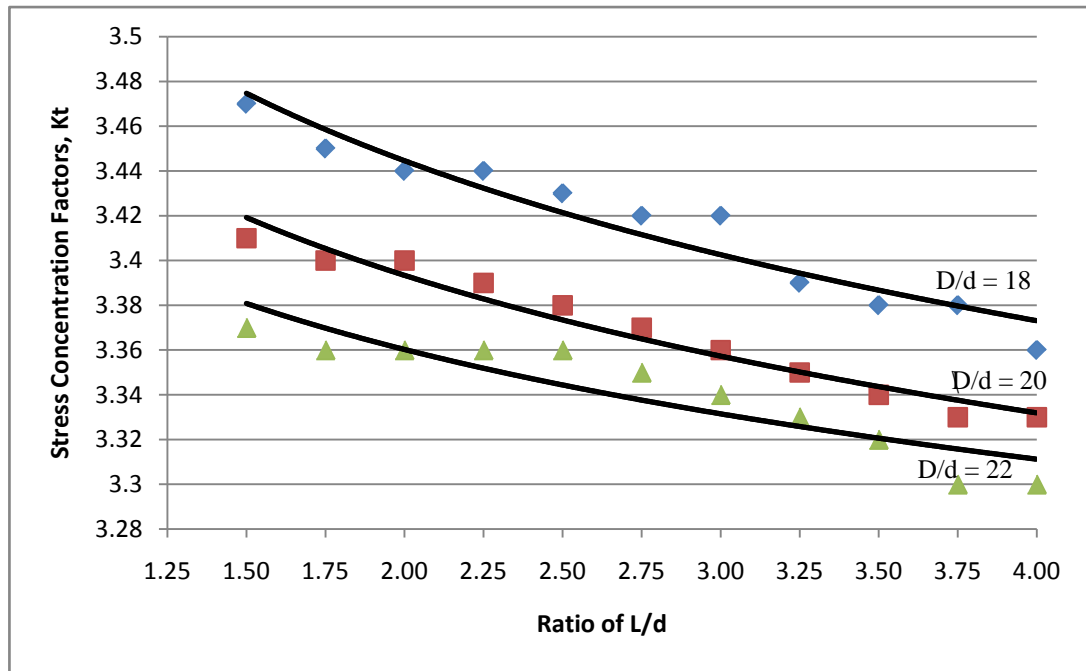


Figure 4.3: Stress Concentration Factors of Pressure Vessels

From the graph above, stress concentration factor, K_t has become smaller if the ratios of L/d become bigger. Bigger value of L/d means that the distance between two nozzles are bigger. If the ratios of D/d were compared, ratio of 18 gives higher value of K_t compare to ratio of 20. This is due to the shape of the pressure vessel. Ratio of 18 has smaller size of ratio of 20. So, the distance between two nozzles are closer and increase the stress concentration factor of the pressure vessel.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The proposed project can help in improvement of two radial adjacent nozzle-header connection of a cylindrical pressure vessel. Good understanding on stress concentration factor of design could be a platform in determining the impact of pressure distribution on cylindrical pressure vessel with adjacent nozzle header connection. Besides, full commitment towards completing the project tasks will be the most important factor in determining the success of the author. Through hard work and good engineering judgments, the objectives of this project can be fulfilled successfully.

From this project, it is showed that displacement of these cylindrical pressure vessels become higher with low value of L/d ratio and high value of D/d ratio. The maximum stresses also higher with low value of L/d ratio and high value of D/d ratio. Stress concentration factor most occur at low value of L/d ratio which the distance between the two nozzles are closer and at low value of D/d ratio which the size of cylindrical pressure vessel is smaller.

So, it is recommended that the design of adjacent nozzle header connections at cylindrical pressure vessel is considered to use high value of D/d which bigger size of these pressure vessel and high value of L/d which the distance between the two nozzles is bigger to decrease the stress concentration factor of the design. For future research of nozzle attached at pressure vessel, it is recommended to investigate the effect of stress concentration factor on pressure vessel due to combination of longitudinal and adjacent nozzle header connections. So that, more knowledge about the stress concentration factor that could occur in designing such pressure vessel with various nozzle header connection.

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APPENDIX



Project Milestone for the First Semester of 2-Semester Final Year Project

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14	
1	Selection of Project Topic	█	█						Mid-semester break								
2	Preliminary Research Work		█	█	█												
3	Submission of Preliminary Report				●												
4	Seminar 1 (optional)					█	█	█									
5	Project Work					█	█	█									
6	Submission of Progress Report										●						
7	Seminar 2 (compulsory)											█	█	█	█		
8	Project work continues										█	█	█	█	█		
9	Submission of Interim Report Final Draft															●	
10	Oral Presentation																●

● Suggested milestone
 █ Process

Project Milestone for the Second Semester of 2-Semester Final Year Project

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10		11	12	13	14	
1	Project Work Continue	█	█	█								Mid-Semester Break					
2	Submission of Progress Report 1				●												
3	Project Work Continue				█	█	█	█									
4	Submission of Progress Report 2								●								
5	Seminar (compulsory)										█			█			
5	Project work continue								█	█	█			█			
6	Poster Exhibition										●						
7	Submission of Dissertation (soft bound)													●			
8	Oral Presentation															●	
9	Submission of Project Dissertation (Hard Bound)																●

 Suggested milestone
 Process