Design and Development of a Vacuum Chamber for Resin Infusion Process

By

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

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Mechanical Engineering Programme
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Approved by,

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(Muhamad Ridzuan Abdul Latif)
Main Supervisor

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

Jan 2009

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 FARHAN BIN YAHYA

ABSTRACT

Resin Infusion Process (RIP) process and its variant was becoming a popular process in manufacturing composite structures. To build up the capability of Universiti Teknologi PETRONAS (UTP) in this processing technique, a cost-effective method must be outlined. A vacuum chamber used in this process could be costly. Therefore, the objective of this project was to produce low cost vacuum degassing chambers which also function as a resin trap for RIP. The main scope for this study would cover the design analysis and development of the Vacuum Chamber. The literature of design of vacuum chamber was reviewed. The design of new vacuum chamber would cover the design specification, the analysis for thickness of vacuum chamber which was 3mm, and the thickness of lid which used 20mm Prespex. Fabrication and installation of fittings was done after all the analysis got the result. Lastly, run the leak test to analyze the performance of the vacuum chamber. The design and development of the vacuum chamber will enable future studies on resin infusion process in UTP. Thus it would lead to a cost-effective RIP study and understanding of RIP process.

ACKNOWLEDGEMENT

Alhamdullilah, the author has come to the completion of my Final Year Project signaling the nearing of the end of the journey at UTP.

First and foremost, this is a great opportunity to express his deepest appreciation for his supervisor, Muhamad Ridzuan Abdul Latif whom has given the author continuous support throughout his time under his supervision. The author is truly fortunate to have his guidance through the tough time.

A big thank to family for their prayer and moral support that have kept the author strong until the end of this project. To the technicians at the lab and workshop that have given the author advice and assistance in their respective arenas.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

This chapter is dedicated to introduce and explain of the project topic,"Design and Development of a Vacuum Chamber for Resin Infusion Process". A background about this FYP project is given followed by statement of the problem to be addressed and lastly the objectives and scope of the work are pointed out. Generally, Resin Infusion Process (RIP) is the process that use a both side of the mold panel. There are two mold panels that will work together here. The lower side of the panel is rigid and the upper side of the mold can be either rigid or flexible. These two sides can make a mold cavity. With the complete equipment for the RIP process, the resin can be transfer to the mold cavity to perform RIP process. See Figure 1 and Figure 2 for a schematic of this vacuum infusion process model. These FYP project will design and develop a vacuum chamber which is one of the equipments of RIP process.

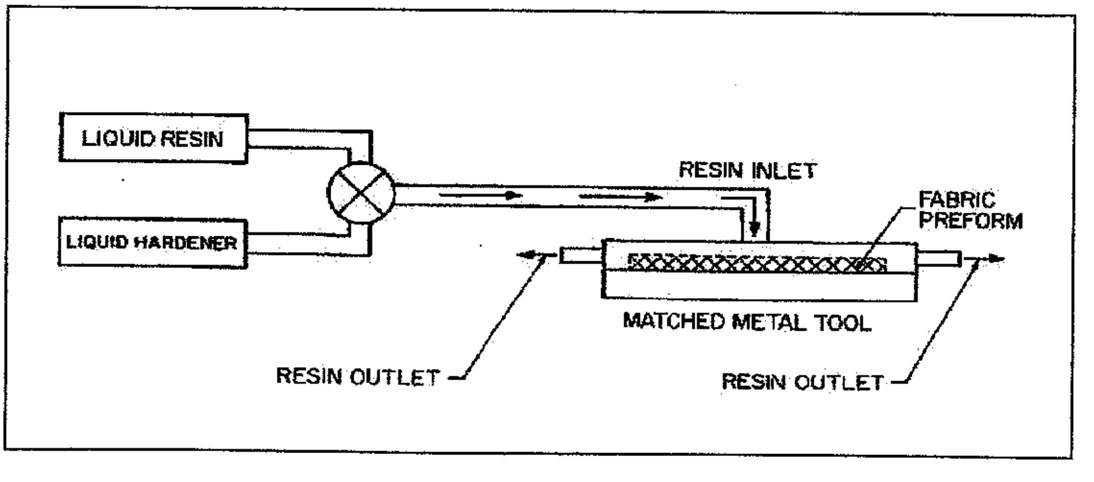

Figure 1: RIP Processing Schematic [1]

There are some advantages of using Resin Infusion process rather than use other traditional composite process technique. Some of the advantages are:

- Accuracy of the dimension can be obtained due to the fix accuracy of the mold.
- A large and complex shape can also be made via this process.

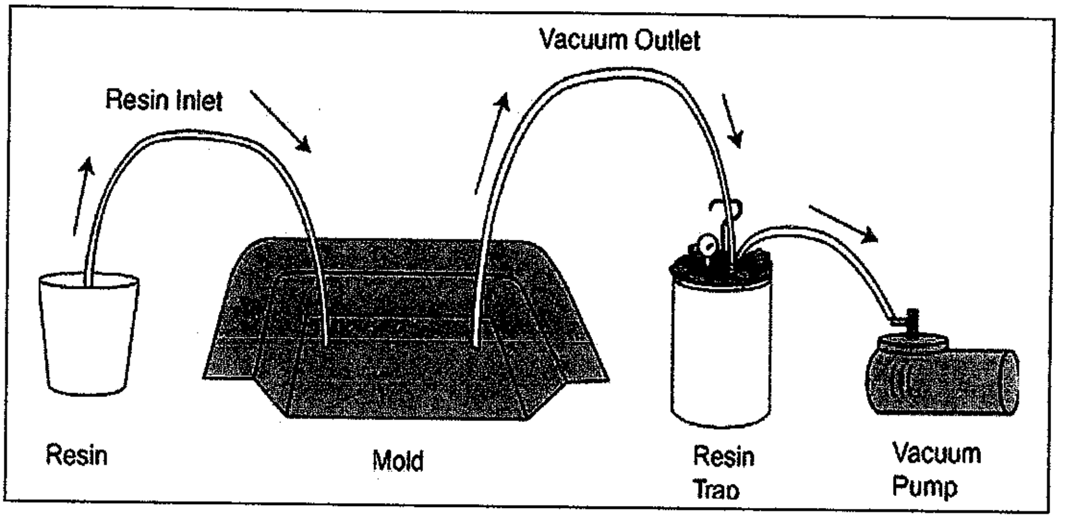

Figure 2: RIP Process Model [1]

See Figure 3 for the example of large shape item that use this Resin Infusion Process.

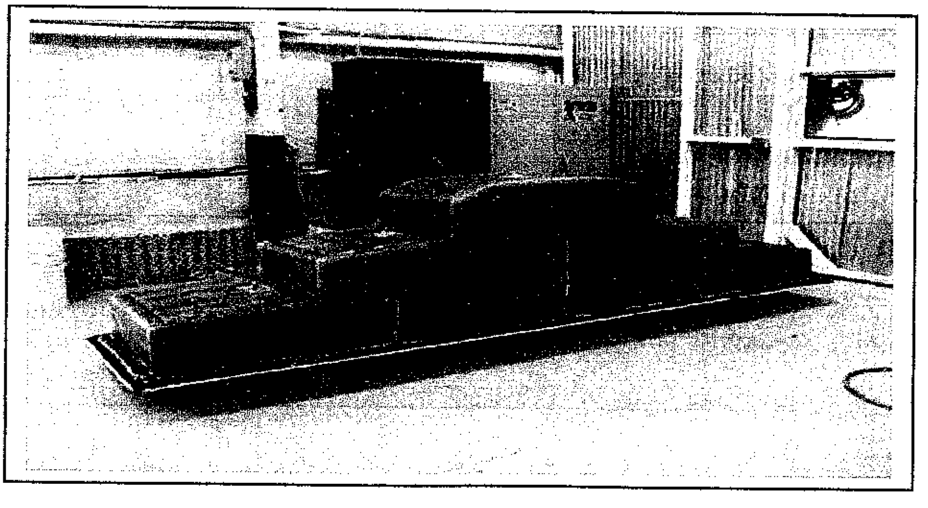

Figure 3: Example of Large Product [1]

1.2 Problem Statement

Resin Infusion Process is a good process for vacuum assisted resin transfer molding. To buy the new set of the equipment is quite expensive. As a result, the author decides to develop his own vacuum chamber to reduce the cost rather than buy a new one. The vacuum chamber that available at the market is not suitable to be used in UTP because of the size of the vacuum chamber is for a big production. The vacuum chamber that the author proposes is the vacuum chamber that only to be used as a further study in the Resin Infusion Process in UTP. The cost can be reduced to a large of number.

1.3 Objective of the Study

- To design and develop a vacuum chamber which also function as a resin trap for use in resin infusion process.
- To analyze the performance of the vacuum chamber by means of a leak test

1.4 Scope of the Study

In this study, the scope shall cover the design, analysis and development of the vacuum chamber. Any criteria or requirement that needs to be follow for the vacuum chamber should be applied. The right selection for the vacuum chamber material should be covered in this study.

CHAPTER 2

LITERATURE REVIEW AND/OR THEORY

2.1 Resin Infusion Process

Conventional Resin Transfer Molding (RTM) has seen remarkable growth over the past few years. This increase has led to several variants of the traditional process. A detailed list of the more famous variations used today can be found in [1]. Of these processes, RIP is the most common in industry due to its use of low (vacuum) pressure. An overview of the current RIP literature is presented here.

Resin pressure distributions and flow front progress were predicted in vacuum-assisted RTM (VARTM) by Kim et al. in [2]. Darcy's Law and the finite element/control volume (FE/CV) method were used in the estimate of this better RTM process. The mold-filling pressure and consolidation pressure were effectively restricted by the autoclave. A neat spacer was placed between consolidation plates to make sure consolidation after mold filling. The function of the smart spacer was to maintain a proper gap between the top and bottom platens during the filling stage, providing high void volume of the performed for an effective resin filling. Polyethylene (PE) was the materials used as smart spacers.

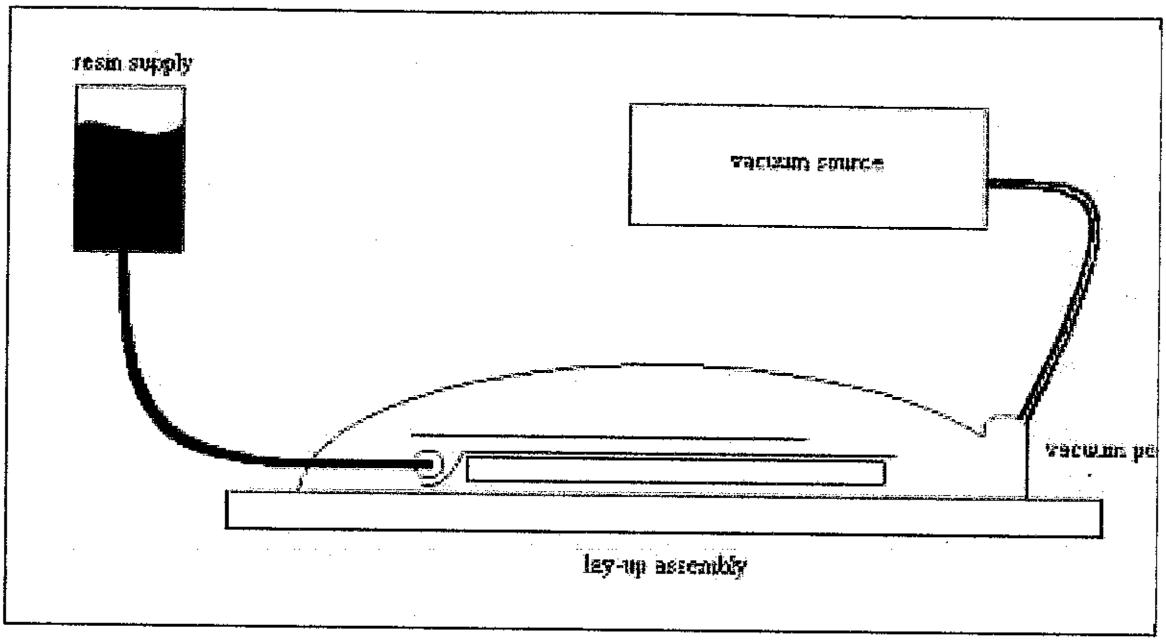

Figure 4: Model of RIP [3]

Pike et al. in [3] developed a RIP process as a low-cost technique for manufacturing structural laminates with included armor for ground fight vehicle hulls. This technique co-cured epoxy prepregs, ceramic armor tiles, and liquid resins in a solo elevated temperature cure cycle. RIP resulted in a 21% unit cost savings. The resins used for this RIP method met the structural design requirements, and had typical ballistic penetration resistance when compared to traditional manufacturing methods. Please refer to Figure 4 to know the recent model of Resin Infusion Process.

The most general vacuum degassing chamber is a cylindrical vessel, fitted with vacuum control valve, vacuum release valve, vacuum dial gauge, "L" type gasket and a clear acrylic or metal lid. Favorite and market sizes are in diameters of 6", 8", 10", 12", 18" and 24" with heights ranging from 6" up to 24" [4]. Refer to Figure 5 to illustrate the existing product in the market. The cost of cylindrical vacuum chambers tends to increase far more with increases in diameter than length. Horizontal chambers will also be more than corresponding vertical chamber due to the need for hold supports and lid hinging. This orientation is preferred if the product is easier to load and monitor.

Vacuum degas chambers are most commonly made from 304 stainless steel however some offers vertical chambers also in aluminum and all clear acrylic for full monitoring. The market price for vacuum chamber range is in $246 to $350. Below is the example of the product that available in the market. But it is not suit the author's specifications.

Figure 5: Example Vacuum Chamber Available [4]

2.2 Comparison

Majority of the consumables and equipment for resin infusion process available in the market is suitable for the industrial production. For education application in UTP, a simpler unit of RIP process equipment is needed. A simple and cheap product for this process can be obtained by developing a new one from off-shelf products.

Material selection also plays an important role in other to reduce the cost for the fabrication process. The available equipment in the market used material such as stainless steel, aluminum and clear acrylic. For the learning purpose, a cheap but has a good quality is enough to develop a vacuum chamber. This is the major different between the available products at the market with the author's proposed product.

2.3 Theory

The Vacuum Chamber wall has the same condition with the thin walled pressure vessel application. Thus, the author has to relate between this two topics. The vacuum chamber has a thin wall, and in order to calculate the minimum thickness of the vacuum chamber of the wall, the author has to use the hoop stress analysis. Hoop stress is mechanical stress distinct for rotationally-symmetric things being the effect of forces acting circumferentially (at a 90 degree angle both to the axis and to the radius of the object) [5]. These components of force induce corresponding stresses: radial stress, axial stress and hoop stress, respectively. Please refer to Figure 6 to see the axial stress and Figure 7 to see the hoop stress illustration.

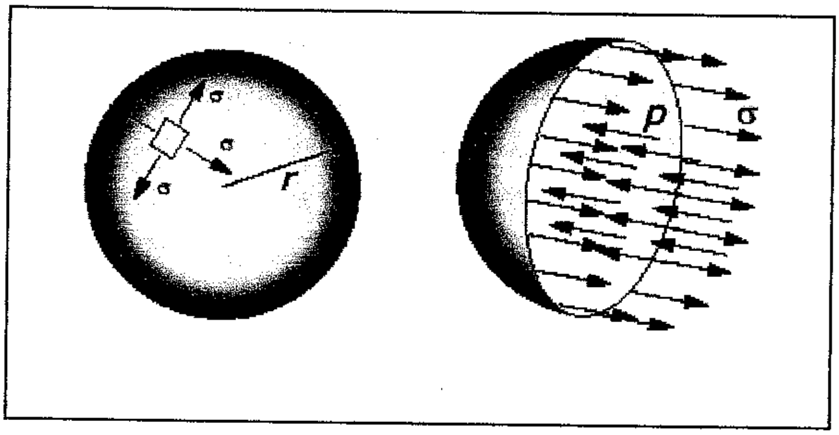

Figure 6: Schematic of Axial Stress [5]

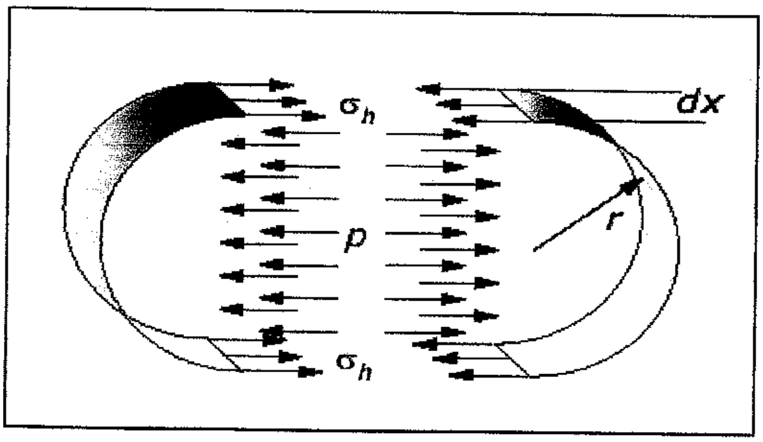

Figure 7: Schematic of Hoop Stress [5]

The typical example of hoop stress is the tension applied to the iron bands, or hoops, of a wooden drum. In a straight, closed pipe, any force applied to the cylindrical pipe wall by a pressure differential will give rise to hoop stresses. Similarly, if this pipe has flat end caps, any force applied to them by static pressure will induce a perpendicular axial stress on the same pipe wall. Thin sections often have negligibly small radial stress, but precise models of thicker-walled cylindrical shells need such stresses to be identified.

The common equation for hoop stress formed by an internal pressure on a thin wall cylindrical pressure vessel is:

$$\sigma_h = Pr/t \quad \text{--}(1)$$

Where

- P is the internal pressure, t is the wall thickness, and r is the inside radius of the cylinder.
- σ_h is the hoop stress.

Based on hoop stress theory, the thickness of the vacuum chamber wall can be determined [6]. The author can determine the minimum thickness of the wall need to be developed.

The vacuum chamber also deals with some loads that apply on the top and the side of the vacuum chamber wall. The author also needs to do the analysis on the Finite Element Analysis (FEA) to analyze the effect of the loads towards the vacuum chamber structure [7]. The FEA will be done during the Final Year Project II. The Finite Element Analysis is based on the premise that an approximate solution to any complex engineering problem can be reached by subdividing the problem into smaller, more manageable (finite) elements. Please refer to Figure 8 and Figure 9 to illustrate the example of FEA analysis. Using finite elements, complex partial differential equations that describe the behavior of structures can be reduced to a set of linear equations that can easily be solved using the standard techniques of matrix algebra.

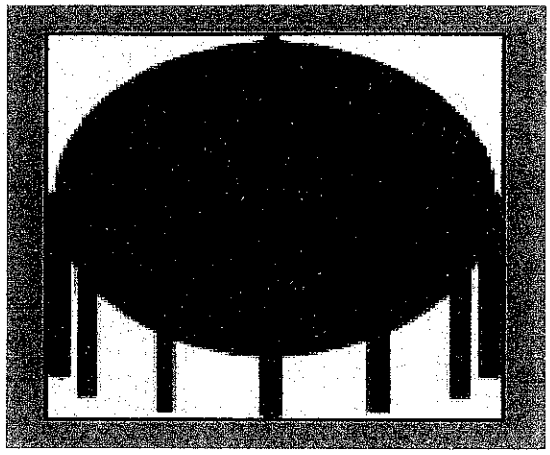

Figure 8: Example of FEA [7]

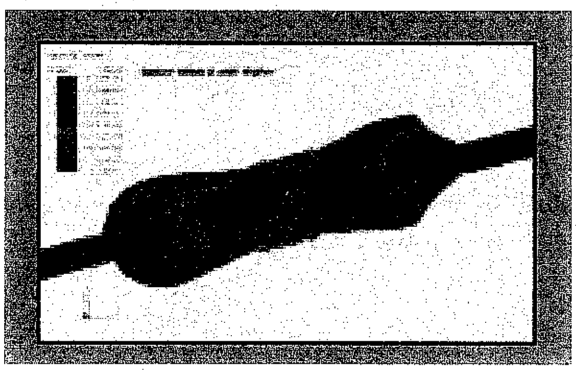

Figure 9: Example of FEA using ANSYS [7]

There are some reason why need to use the finite element method. It is because finite method is being used in virtually every engineering discipline. The aerospace, automotive, biomedical, chemicals, electronics, energy, geotechnical, manufacturing, and plastics industries routinely apply finite element analysis.

In addition, it is not only used for analyzing classical static structural problems, but also for such diverse areas as mass transport, heat transfer, dynamics, stability, and radiation problems. Finite element analysis is the method of choice for optimizing new designs, verifying the fitness of existing facilities, predictive performance and evaluating new concepts. In addition, it has been used extensively for accident reconstruction and forensic investigations.

Like any other numerical approximation method, solutions produced by finite element analysis contain some error. The magnitude of the error is highly dependent on the type, size, and fineness of the model used. That is why not all finite element models are created equal. Indeed, the educational and industrial experience of the analyst, as well as the use of advanced technologies, is the most critical factors in obtaining accurate results.

Stress Engineering is a leading provider of finite element analysis services to industries worldwide. Our reputation is founded on broad industry experience of our engineers and their ability to expertly apply this sophisticated analysis tool to achieve reliable solutions. The FEA method will be carry on at Final Year Project 2 (FYP II) using ANSYS software.

2.4 Recent work

For this designing and development of vacuum chamber for resin infusion process, currently there is no recent work doing on this same project. Thus, the author needs to start from the beginning to complete this project.

CHAPTER 3

METHODOLOGY/PROJECT WORK

3.1 Designing and Analysis Process

To achieve the objective of this project, there were some steps required to be executed base on the engineering knowledge. The steps were:

1. Define specification
2. Come out with conceptual design and sketches for the early stages
3. Do the design analysis about the thickness of the wall of vacuum chamber and the thickness of the lid that need to be develop
4. Run the material selection and process selection
5. Fabricate the model of the vacuum chamber
6. Run the leak test
7. Do some modify where it needed

Refer to the Figure 10, the general flow chart below to understanding the designing process:

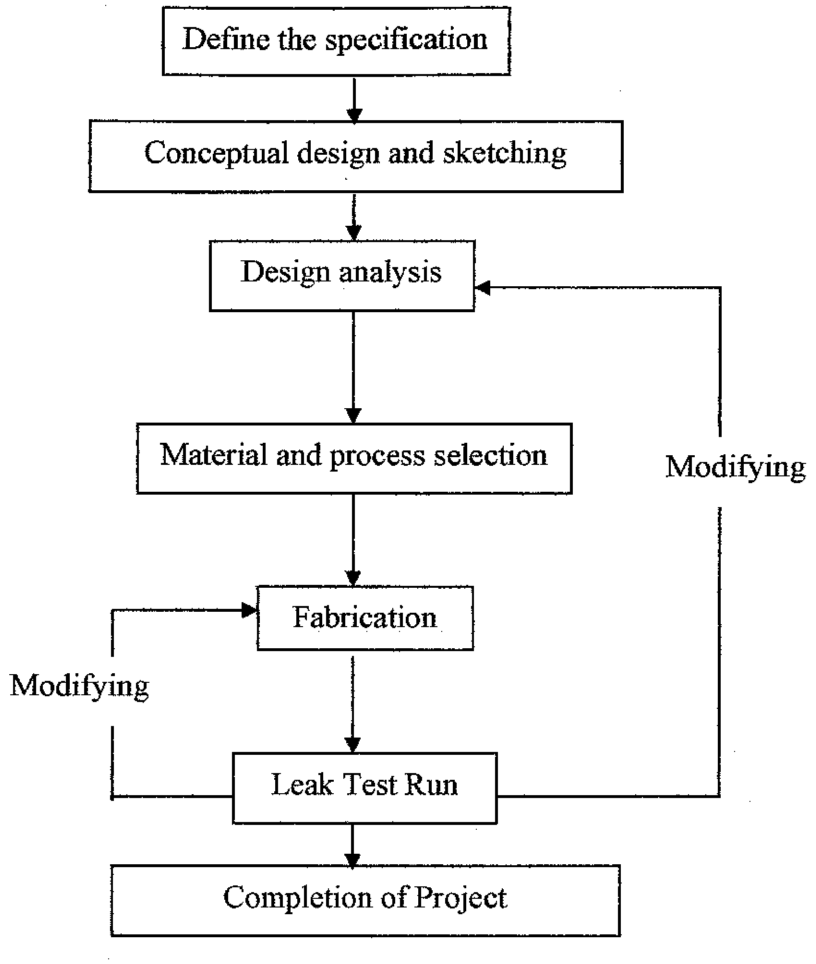

Figure 10: Flow chart of the design and fabrication of developing Vacuum Chamber

Based on the flow charts, the author decided to start the project with find the definition of product need [8]. To define the product needed, the author needs to define the need at the UTP itself. The author decided to prepare the vacuum degassing chamber for learning purpose at UTP due to the expensive cost if want to buy a new one.

The next step was to come out with conceptual design and study [9]. Several conceptual designs should be produced and be analyzing in order to study about it. The author needed to study all about thing that related to this vacuum degassing chamber. Some of the matter that needed to study was the designing process. This could help the author to make a good decision in order to complete this project. The conceptual design could be in any form for example conceptual drawings or models. By come out with several designs, the author could identify the different in each one of them. After identify all the different, the author could use it for next step in this designing process which was designing analysis.

The next step which was the most complicated step which is designing analysis [8]. All the model or conceptual drawings needed to analyze in this stage. The analysis could be on the properties, cost, appropriate manufacturing process, and other. During this stage, the author needed to consider everything that relate to this project in other to design the vacuum degassing chamber. This could be the minimum thickness of the wall of the vacuum degassing chamber, the appropriate fittings of the valve to the vacuum chamber, the material selections, and other. Analysis needed to be done in order to decide all the problems. The author had come out with the project specification to guide the author in develop the vacuum chamber. All the design that came out had to design that meet the specification that already has been decide. This could bring to the good quality of the product based on the specification already set earlier.

Next step was the production drawings. All the possible design should be illustrate in drawings. This kind of production could be seen in several aspect and perspective to easily illustrate the design. There was much software that could be used for production drawings for example Autodesk AutoCAD or CATIA. This software could help to produce the production drawing in either in 2D and 3D drawings. Lots of benefits could be obtained by using that software rather than used the conventional method. It will have precise dimension drawings and could save lots of time. In order to draw the design of the vacuum chamber, the author needed to have the entire dimension of the vacuum chamber. The author needed to have the dimension of the pressure gauge, the valve with its fitting, and the vacuum degassing chamber itself. During this stage, all the possible design needed to be come out with its production drawing. The drawings also can be used to do the analysis using ANSYS software to analyze the effect of the

The considerations are:

1. Thickness of the material
2. Cost of the material
3. Weight of the material
4. Fabrication process for the material
5. Corrosive factor for the material

That consideration could be show in a table that would show the details of the consideration that the author needed to justify. The consideration could be compared with applicants of material that the author tends to decide as the material for vacuum chamber. The analysis of all consideration would justify the author choice of materials.

Below was the example of the table of consideration that the author might use to analyze the applicants of material. Please refer to Table 1 and Table 2 to illustrate the tables.

Table 1: The Sample of Details for Material 1

Criteria	Detail
Factor 1	
Factor 2	
Factor 3	
Factor 4	
Factor 5	

Table 2: The Sample of Details of Material 2

Criteria	Detail
Factor 1	
Factor 2	
Factor 3	
Factor 4	
Factor 5	

4. To calculate the minimum thickness of the vacuum chamber, we could assume that the thickness was the minimum thickness that less than the yield strength of the material used. This could avoid from the material to be fractured.

5. By applying Hoop Stress $\sigma_{H,}$ and assume the hoop stress is the yield stress of the material, the thickness of the wall can be obtained.

Factor 2

The second factor was weight. This factor needed to be considered because to calculate the weight of the vacuum chamber. This could determine the suitability selection between the materials candidates. The material that light could reduce the stability of the vacuum chamber. Same went to the material that too heavy which would make it difficult to handle and not portable and uneasy to be used. The steps to calculate the weight shown below:

Use the relation of $\rho=m/V$

Where ρ = Density of the material

m = Mass of the material

V = Volume of the vacuum chamber

1. The volume of the vacuum chamber was calculated.

2. The weight using the above equation was calculated.

Factor 3

The third factor was the cost of the material. The cost would determine the cheap material that might be used in order to optimize the cost of this project. The author used the market price to estimate the cost of the material.

Factor 4

The forth factor was fabrication process. This factor would determine the availability process that available at the UTP laboratory to simplify the fabrication process. This factor could be determined by several fabrication processes that depend on the materials.

Factor 5

The fifth factor was the corrosive factor. The author needed to choose the material that will not easily corrode. This could help to have a long lifetime of the vacuum chamber. In order to select the material that had these properties, the author needs to check the material properties that have corrosion resistivity.

In order to simplify between candidates of material and the factors, the author needed to construct the decision matrix table to do the material selection. The decision matrix would show the most suitable material to be chosen. The example of decision matrix is shown below in Table 3:

Table 3: The Sample of Decision Matrix

Criteria / Material	Material 1	Material 2
Factor 1		
Factor 2		
Factor 3		
Factor 4		
Factor 5		

The candidate that had better selection criteria would be chosen as the material for the vacuum chamber.

3.3 Testing

To achieve the objective of this project, the author needed to conduct test and experiment to prove the feasibility of the vacuum chamber. The author needed to choose the suitable test for this project. The tests that could be used are hydro test, leak test, or pneumatic test. This test could show that the vacuum chamber achieve the vacuum condition for a certain period. A test run with the vacuum pump also needed to prove that the vacuum chamber is working and the pressure gauge reads the desired pressure without having any leakage and problems.

The author decided to run the leak test in order to verify the vacuum chamber efficiency. The leak test would be run by using vacuum pump that will attach to the valve connected to the vacuum chamber. By closing the other entire valve, such the valve that connected to the resin infusion molding part and open the vacuum pump valve, the vacuum pump will be switch on. The reading from the pressure gauge would be taken. In order to verify the test run was success is to gain the nearly -1atm or nearly -76cmHg (-30"Hg) reading from the pressure gauge [14]. The test run success can confirm that the condition of the pressure camber is safe. And the vacuum chamber meets the specification that 100% air tight and in vacuum condition [15]. If the test run failed to gain the reading of -1atm, the author need to modify whether the designing process or the fabrication part. The need of modify the product depends on the problem that been find out during the leak test.

The possibility of the run test failed could be:

- The collapse of the vacuum degassing chamber wall
- The leak at the fitting between valve and vacuum chamber
- The pressure gauge read the readings more than 1atm value

The possibility of the failure that had been identified needed to be fixing and modified the project. Back to the process flow chart, the author needed to modify at the fabrication stage or designing analysis depends on the need of the modification.

CHAPTER 4

DESIGN

4.1 Specifications

Based on the research and finding that the author had done, and the comparison with the available product at the market, the author decides to come out with the design specifications. This specification can help to design the vacuum chamber properly without too much different with the requirement needed.

Below are the specifications that the author set as a guideline to develop the vacuum chamber:

- Vacuum chamber size – 380mm diameter x 350mm deep.
- Withstand pressure so that the wall of the chamber will not collapse.
- The top part of the vacuum chamber should be see-through in order to monitoring process.
- Easily access to the vacuum chamber for degassing the resin
- 100% air tight and in vacuum condition.
- Attach with valve that will control the pressure in and out, and release valve.
- Attach with vacuum pressure gauge.
- All hoses and fittings necessary for vacuum and oil line connections

The author considers all of the aspect to design and develop the vacuum chamber. The aspects would be about the material selection and availability, the equipment that available at the UTP laboratory, the standards that available for designing and other. The author needs to do more research all about the aspects.

4.2 Standard

There some standard that needs to apply in order to design and develop the vacuum chamber. The standard could be American Society for Testing and Materials (ASTM), American National Standards Institute (ANSI), American Petroleum Institute (API), American Society of Mechanical Engineers (ASME) and other standard that need to consider while designing this project.

The author had found the standard that might need to apply for this project [6]. Below is the standard that relates to this project:

- ASTM D4991-94(1999) Standard Test Method for Leakage Testing of Empty Rigid Containers by Vacuum Method
- ASTM E515-95(2000) Standard Test Method for Leaks Using Bubble Emission Techniques

The standard listed is the active ASTM standard. The author needs to go for a deep research to apply this entire standard to this project. There must be some that can or cannot been use and suitable for this project. And the author also need to find out is there any standard required to do the leak test (test run). If the standard exists, the author needs to follow the standard to conduct the leak test.

4.3 Analysis

In order for the author to come out with the best selection material, he needs to do the design analysis to obtain the thickness of the vacuum chamber. Thickness of the vacuum chamber wall can be calculated by applying the Hoop Stress and analyze with the yield strength of the materials that he compared. The author also considering the best material to used by other aspect such as the price or cost, weight, strength of the materials and other.

The author chooses to make the comparison between these two materials which are aluminum and steel as the material for the vacuum chamber. The reason for the author to choose those materials is because the availability of the materials at the lab and the fabrication process is easily to handle. All the data and the properties of these two materials need to be taken account.

4.3.1 Thickness

For Aluminum

Determine that the thickness of the material of the vacuum chamber wall that can withstand the vacuum condition. By applying the hoop stress that act at the vacuum chamber and the relationship of the material properties which is yield strength the thick ness can be determined by the calculation below:

Where σ_H = Hoop Stress
P = Internal Pressure
r = Radius of the vacuum chamber
t = Thickness of the vacuum chamber wall

Assume that the thickness of the wall using aluminum is 2mm;

$$\begin{aligned}\sigma_H &= Pr / t \\ &= (0.1\ N/mm^2)(200\ mm) / (2\ mm) \\ &= 10\ N/mm^2 \\ &= 10\ MPa\end{aligned}$$

The Hoop Stress, σ_H should less then the yield stress of the material σ_Y in order for the thin wall to withstand the vacuum condition from fracture.

$\sigma_H = 10$ MPa

❖ $\sigma_H < \sigma_Y$

10 MPa < 50 MPa.

If we use safety factor of 3 we can see that σ_H is still less than σ_Y.

$\sigma_H = 3Pr / t$

$= (3)(0.1 \text{ N/mm}^2) (200 \text{ mm}) / (2 \text{ mm})$

$= 30 \text{ N/mm}^2$

$= 30 \text{ MPa}$

- $\sigma_H < \sigma_Y$

30 MPa < 50 MPa.

To calculate the minimum thickness of the vacuum chamber, we can assume that the thickness is the minimum thickness that less than the yield strength of the material used. This could avoid from the material to be fractured.

By applying Hoop Stress σ_H, and assume the hoop stress is the yield stress of the material, the thickness of the wall can be obtained.

$\sigma_H = Pr / t$

$50 \text{ MPa} = (0.1 \text{ N/mm}^2) (200 \text{ mm}) / t$

$t = (0.1 \text{ N/mm}^2) (200 \text{ mm}) / 50 \text{ MPa}$

$= 0.4 \text{ mm}$

By using safety factor of 3 we will get,

$\sigma_H = 3Pr / t$

$50 \text{ MPa} = (3) (0.1 \text{ N/mm}^2) (200 \text{ mm}) / t$

$t = (3) (0.1 \text{ N/mm}^2) (200 \text{ mm}) / 50 \text{ MPa}$

$= 1.20 \text{ mm}$

<u>For Steel</u>

For steel material, the method to analyze the thickness is the same except for the different value used. The Hoop Stress, σ_H should also less then the yield stress of the material σ_Y in order for the thin wall to withstand the vacuum condition from fracture.

$\sigma_H = 10$ MPa

$\sigma_H < \sigma_Y$

10 MPa < 250 MPa.

If we use safety factor of 3 we can see that σ_H for steel is still less than σ_Y.

σ_H (steel) = 30 MPa

$\sigma_H < \sigma_Y$

30 MPa < 250 MPa.

The minimum thickness without using safety factor:

t = 0.08 mm

By using safety factor of 3 we will get,

t = 0.24 mm

Due to the thickness of Steel is too thin, so the author decides to use 1mm of steel due to the availability of the steel plate.

The summary of the result above are as the Table 4 below:

Table 4: Summary Result

Value / Material	Aluminum	Steel
σ_H	10 MPa	10 MPa
σ_H with Safety factor	30 MPa	30 MPa
Min thickness	0.4 mm	0.08 mm
Min Thickness with Safety factor	1.20 mm	0.24 mm

For Lid

The author needs to analyze the thickness of the lid that can withstand pressure as mention at the design specification. The material for the lid is prespex or scientifically named as Acrylic Glass. This is due to the properties of the prespex which is transparent and the strength compared to the others. The author used software ANSYS to analyze the thickness of the prespex. Using the same dimension of prespex but in different in thickness to analyzed. The result of the analysis shown in Figure 11 and 12 below:

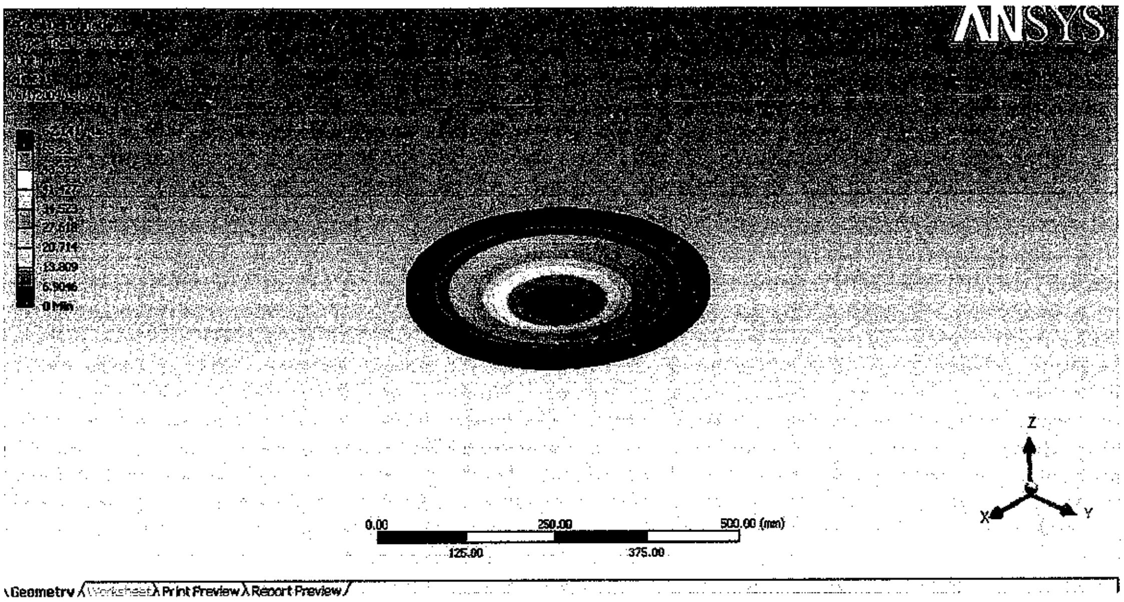

Figure 11: Prespex with 420mm diameter and 12mm thickness

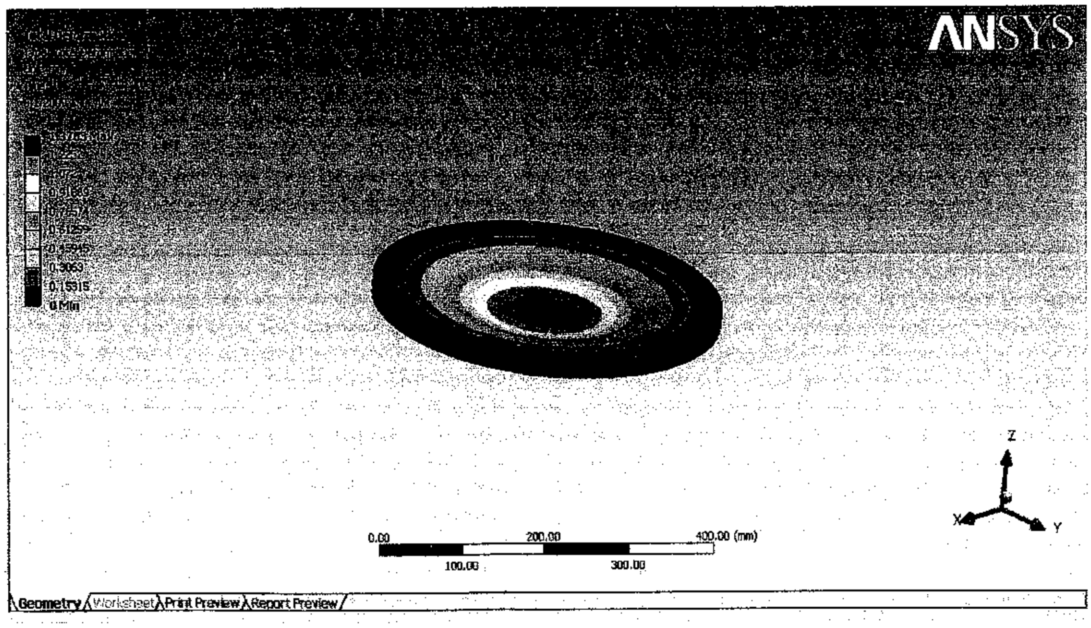

Figure 12: Prespex with 420mm diameter and 20mm thickness

Based on the figure above, the author can conclude that the prespex that has thicker thickness would have the minimum deflection. The Figure 11 shows that the prespex with 12mm thickness has the maximum deflection of 63mm which is high. The Figure 12 shows that the prespex with 20mm thickness has 1.3mm maximum deflection. As a result the author used the lid of prespex with the thickness of 20mm.

4.3.2 Weight

For Aluminum and Steel

The weight of the material can be determined from the density of the material. By using the relation of ρ=m/V, where ρ is the density, m is the weigh and V is the volume, we could achieve the weigh of the materials by using the formula. Due to the attitude of the UTP student that sometime not behave properly, the author need to have the heavy material to retain the stability of the vacuum chamber. The weight analysis is shown below:

For Steel,

$V = 1 * h$

$V = 1 \text{ m}^2 * 0.002 \text{ m}$

$= 0.002 \text{ m}^3$

$\rho = m / V$

$9000 \text{ kg/m}^3 = m / 0.002 \text{ m}^3$

$m = 18 \text{ kg}$

For Aluminum,

The method to determine the weigh is the same with the method above.

$m = 15 \text{ kg}$

For Lid

The weight for the lid was shown in the analysis using ANSY software. The weight was depending on the thickness of the prespex which has the same dimension. The prespex has the diameter of 420mm. The thicknesses were 12mm and 20mm. The weight is 2.3kg and 3.4kg respectively.

Decision Matrix

The author needs to make the decision based on these two materials as the wall of the vacuum chamber.

Table 5: Decision Matrix

Criteria \ Material	Aluminum	Steel
Thickness (min) (4)	Thickness is important to withstand pressure 1 X 4 = 4	Thickness is important to withstand pressure 2 X 4 = 8
Cost (2)	The minimum cost 3 X 2 = 6	The minimum cost 1 X 2 = 2
Weight (1)	The minimum weight 3 X 1 = 3	The minimum weight 1 X 1 = 1
Fabrication (2)	Method to fabricate 2 X 2 = 4	Method to fabricate 3 X 2 = 6
Corrosive (1)	Corrosive resistivity 3 X 1 = 3	Corrosive resistivity 1 X 1 = 1
Total	20	18

By using decision matrix, the author set some of the criteria in order for the author to choose the best material to be the suitable material for the vacuum chamber. Based on the decision matrix above, there are five (5) criteria that the author chooses to be compared. The author also chooses two (2) different candidate of material that might be use as the vacuum chamber wall. The decision matrix use weightage depend on the need of the criteria towards this project. The rates for the weightage of the criteria were 1: poor, 2: normal, 3: best. The table is shown at Table 5 above.

The first criterion is the minimum thickness. The author tends to choose the material that has the most minimum thickness from the candidates. But due to the available product in the market, the author tends to choose the material that has the thickness that can be easily to be found. The minimum thickness different between the two candidates is about a few of mm. There will be not much different between these two candidates.

For the second criterion, this is cost. The author decides to choose the material that will have low cost rather than the expensive one. Between the candidates, the Aluminum is the material that has a lower cost. From the survey from the internet and some of the hardware shop, the author notices that the price for Aluminum is cheaper than the steel.

The weight is one of the criterions that the author needs to identify. The author tends to choose the material that has heavier weight than the lighter one to gain stability of the vacuum chamber. In order to withstand all the loads such as valve, pressure gauge and others, the vacuum chamber should not to light to gain stability. The author decides to choose Aluminum as the material for the chamber because the suitability weight of the material to the vacuum chamber.

Next criterion is fabrication process. The author need to choose the material that has the easier fabrication process in order to fabricate the vacuum chamber. Because of the Aluminum need some special fitting process, so it could bring some difficulty for the author to fabricate the vacuum chamber using Aluminum instead using the steel as the material for the wall of the vacuum chamber.

For the last criterion, the author chooses to consider the corrosive factor. The material that has high possibility to corrode will not be chosen. The steel tend to be the material that can easily corrode than the Aluminum so the author chooses to select the Aluminum as the material. Due to some prevention method to prevent material from corrosion, the author can still select steel. One of the methods is by applying paint at the wall of the vacuum chamber.

From the decision matrix above, we can see that the Aluminum satisfy some of the criterions and has the weightage of 20 which is higher than steel. As a result the author tends to choose the Aluminum as the material for the vacuum chamber.

4.4 Schematic Drawing

Although the decision has been made, the author still makes further study about the materials selection. There are other criterions might be more important that might need to be considered or other aspect needs to be taking into account.

The author made some sketch of the vacuum chamber during FYP I. The further production drawing had be produced next semester during the FYP II. The sketch of the vacuum chamber is shown at Figure 13 below:

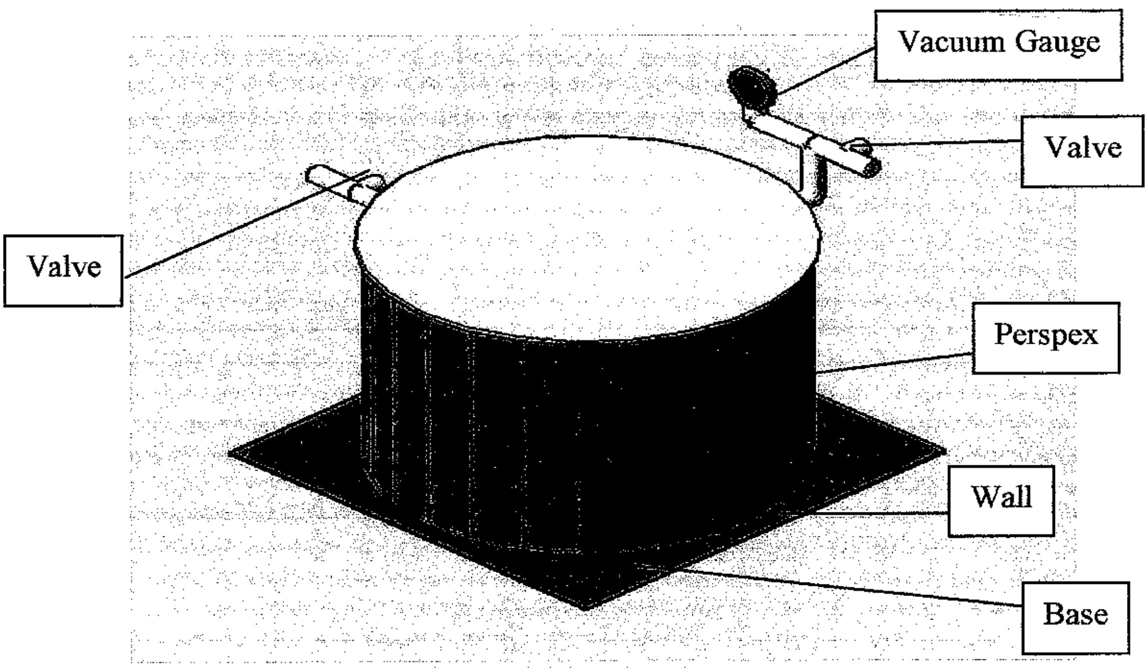

Figure 13: The sketching of the vacuum chamber

During FYP I, the author starts to produce schematic drawings. The drawing contains information about the dimension of the vacuum chamber. For the time being, the author produced the orthographic drawing and oblique drawing. For the future, the author will continue to produce the detail drawings. All the parts that have been bought and involved in this project will come out with schematics drawings.

During FYP II, the author produced the drawings using AutoCAD software. The drawings will include all the part of the vacuum chamber and its fittings. It also included the information of the dimension of the equipment and the schematics of the fittings. The author will produce several drawings which include 3D Model Drawing, Assembly Drawing, and Detailed Drawings

All of the drawings can be seen at the appendixes.

CHAPTER 5

FABRICATION

5.1 Fabrication Process Selection

After the analysis done and the material had been selected, the author needed to do the fabrication process selection. The fabrication process would be divided into several parts which were:

1. Body
2. Fittings
3. Fabrication Process

5.1.1 Body

The vacuum chamber needed to be fabricated using processes that the author needs to choose. Some of the processes are:

1. Welding between sheet
2. Cutting the sheet
3. Rolling the sheet
4. Drilling holes
5. Using silicon

The processes above needed to choose either one or needed to be combined in order to fabricate the sheet into the body of the vacuum chamber. The author used Gas Tungsten Arc Weld (GTAW) to weld the aluminum sheet and seal any leak using silicon.

5.1.2 Fittings

The body of the vacuum chamber needed to be fit with some fittings in order to connect with pressure gauge, open valve, release valve, pump, and other. The author needed to select to fittings process in order to connect them. There were fittings that used in this project to connect them. The fittings were:

1. Using hose connector
2. Using 4 ways Cross Connector
3. Using ball valve
4. Using rubber hose
5. Using P.T.F.E. Tape (poly tetra floro ethaline tape)
6. Using rubber sealant

5.2 Fabrication Process

During this stage, the author needed to plan the fabrication process to fabricate the vacuum chamber. The fabrication process will cover all the aspect on build the body of the vacuum chamber itself and install all the fittings to the vacuum chamber.

The first stage was to prepare the vacuum chamber body which is made from aluminum or steel sheet. The aluminum or steel sheet that available at the UTP Laboratory was not in the same dimension of the aluminum or steel sheet that the author desired. It needed to be cut into the same dimension as the author needed to prepare the body of the vacuum chamber. The aluminum or steel sheet needed to be cut using automatic hydraulic cutter that can easily cut the aluminum or steel sheet into the square sheet that the author desired. Refer to the Figure 14 to see the example of aluminum sheet, Figure 15 to see the example of steel sheet and refer to Figure 16 to see the hydraulic shearing machine.

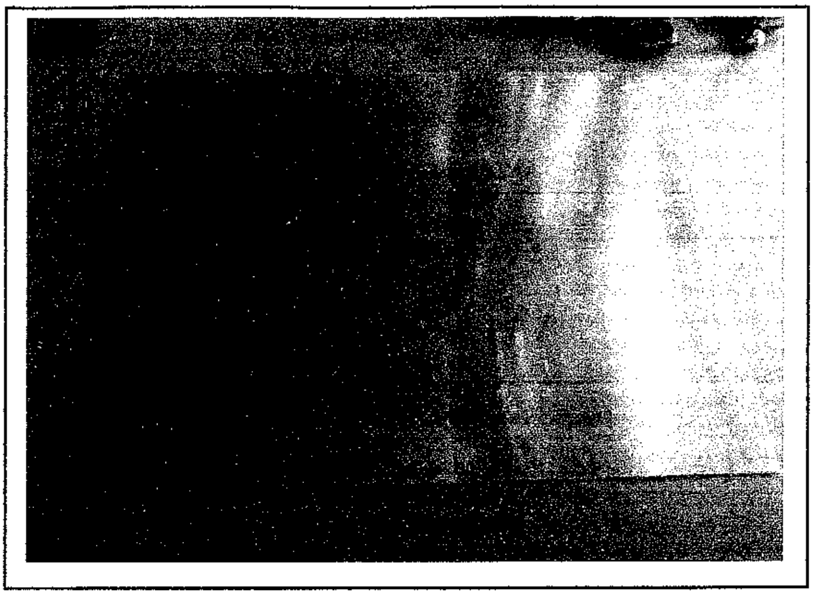

Figure 14: Aluminum Sheet

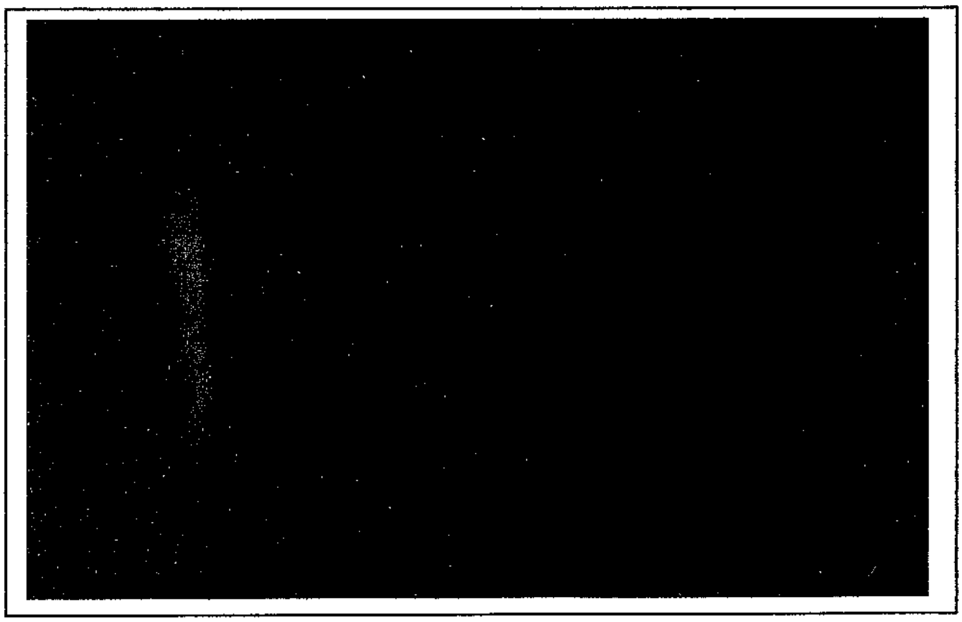

Figure 15: Steel Sheet

Figure 16: Hydraulic Shearing Machine

After the aluminum or steel was cut into the desired dimension, it needed to be rolled using rolling machine that available at the UTP Laboratory. The aluminum or steel sheet needed to be rolled because it needs to be jointed at the end of both part of the aluminum or steel sheet using the welding techniques. Refer to Figure 17 to illustrate the rolling machine that the author used. The aluminum or steel sheet needed to be rolled several times in a certain degree in order to obtain the desired cylinder shape of the body of the vacuum chamber.

Figure 17: Rolling Machine

After the aluminum or steel sheet had been rolled, the author needed to weld between the two joint. Due to the possibility that the author might choose between two materials, the welding process that needed to be applied will be different. If the material is steel, the author could weld it at UTP Laboratory using Gas Tungsten Arc Welding (GTAW) method. The details of GTAW welding techniques could be found in [11]. The GTAW welding process also could be done for aluminum sheet, but due to the availability of some items at UTP Laboratory, it could only be done by outsourcing the welding process work at outside of UTP. The author needed to find the workshop that can do the engineering works which located at Pusing which is not far away from UTP. Refer to Figure 18 to illustrate the GTAW welding equipments.

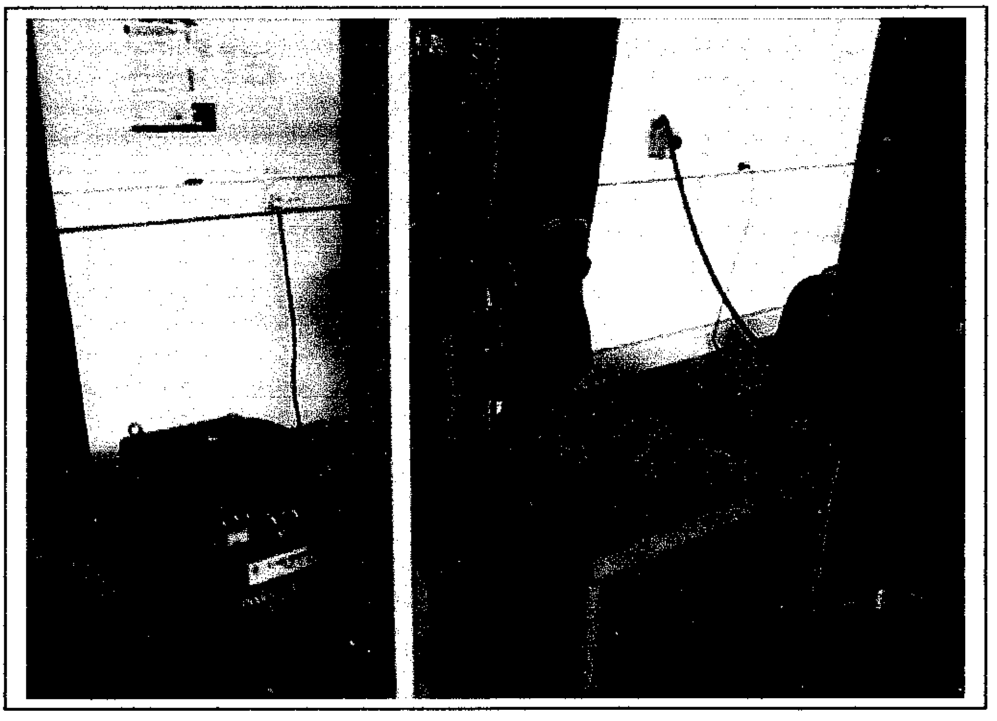

Figure 18: GTAW Equipment

The material needed to be welded with the sheet that has a round shape which is act as its base. The author needed to prepare the round aluminum or steel sheet. After cut the sheet into the desired dimension, the author needed to cut the sheet into round shape and refine the shape using Leaver Shear [12]. The rounded sheet then could be sent to the workshop that the author has outsourced the welding work to be welded with the body of the vacuum chamber. Refer to Figure 19 to illustrate the leaver shear that available at UTP Laboratory and the one that the author used.

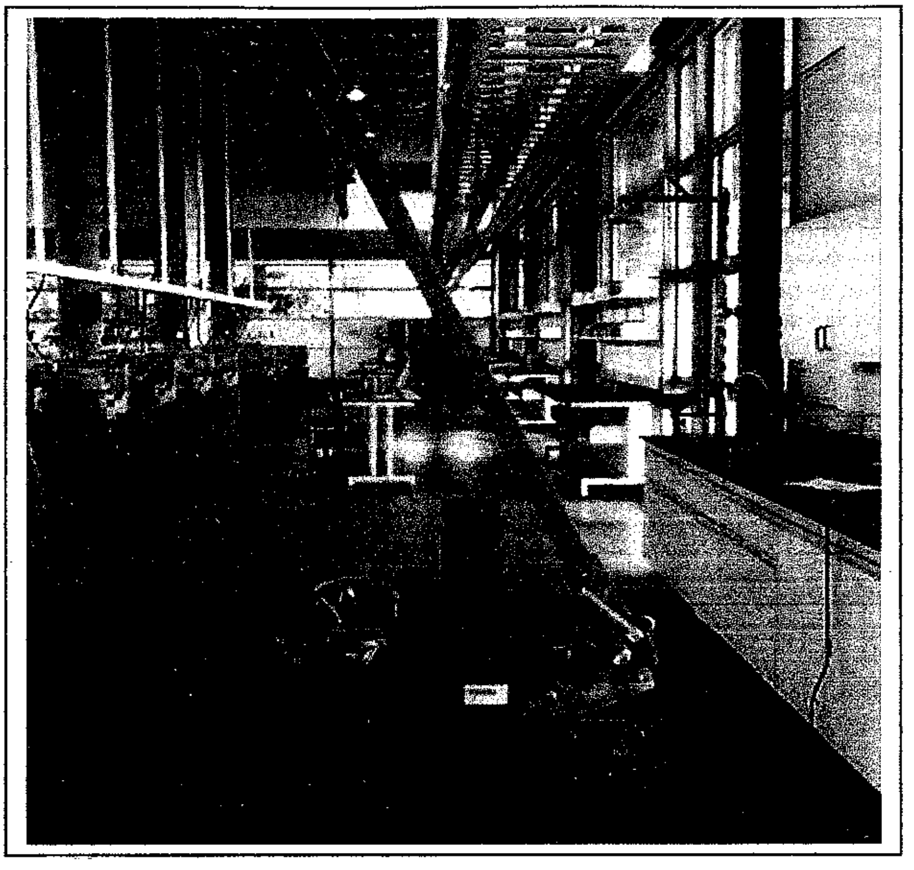

Figure 19: Leaver Shear

Next, after complete the fabrication of the vacuum chamber body, the author had to make some modification in order to install all the fittings. Basically, there would be two holes that the author had to drill. The two holes would be used for the connection to the resin infusion mold and the other one holes would be connect to the fittings that would combine the release valve, pressure gauge and to the pump connection. Due to the size of the vacuum chamber, the author had to use power drill tool to drill the holes [13 and 14]. The figure of the power drill toll was show at Figure 20.

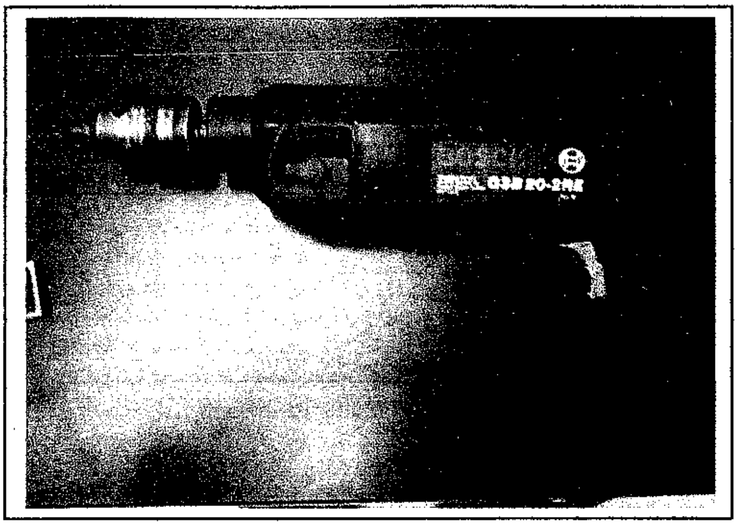

Figure 20: Power Drill Tool

The next step after finished drill the holes were to install all the fittings at the required holes. All the fittings such as ball valve, vacuum gauge, reducer and T-connector can be installing easily. They would be fit with aid of P.T.F.E tape (poly tetra floro ethaline tape) which would help to reduce the leak factor among the fittings. In order to make sure that there was no leak, the author added some rubber sealant at every possible leak location to prevent to leak factor problem. Please refer to Figure 21 for the illustrate the P.T.F.E Tape.

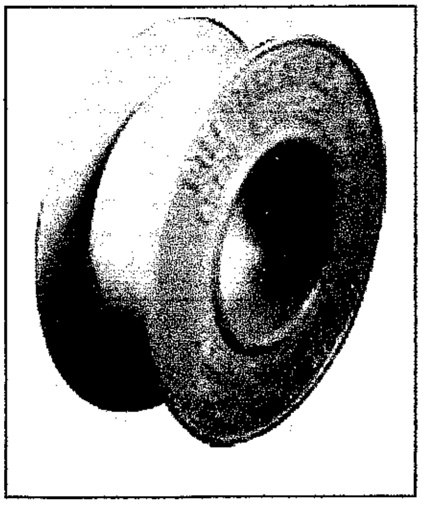

Figure 21: P.T.F.E tape

5.3 Testing

To achieve the objective of this project, the author needed to conduct test and experiment to prove the feasibility of the vacuum chamber after the completion of fabrication processes. The author decided to run the leak test in order to verify the vacuum chamber efficiency. The leak test would be run by using vacuum pump that will attach to the valve connected to the vacuum chamber. By closing the other entire valve, such the valve that connected to the resin infusion molding part and open the vacuum pump valve, the vacuum pump will be switch on. The reading from the pressure gauge would be taken. In order to verify the test run was success is to gain the nearly -1atm or nearly -76cmHg (-30"Hg) reading from the pressure gauge. After several minutes, the pressure reading is taken again to see the efficiency of the chamber.

The possibility of the failure that had been identified needed to be fixing and modified the project. Back to the process flow chart, the author needed to modify at the fabrication stage or designing analysis depends on the need of the modification.

CHAPTER 6

CONCLUSION AND RECOMENDATION

In conclusion, based on the available literature on Resin Infusion Process, the author set a guideline to develop a new vacuum chamber that also acts as resin trap and degassing chamber. In this study, there are three (3) major stages of concern which are the designing of the vacuum chamber, the fabrication of the chamber and the type of testing on the performance of the vacuum chamber. The author managed to analyze the minimum thickness which is 3mm Aluminum plate use as the wall of the vacuum chamber. The author also analyzed of the finite element on the loads affects at the vacuum chamber and determined the thickness of the lid which was 20mm Prespex. The author also manages to do the fabrication of the vacuum chamber and analyze the performance of the vacuum chamber using leak test. The author manages to achieve the objective that he already set at the beginning of this project. For recommendation, there are other analyses that need to be done to get a better and accurate result of the vacuum chamber. Some of the analysis that needed was the analysis of how much it affected the fittings when the chamber was running, and which the most critical part was affect by the vacuum condition and others.

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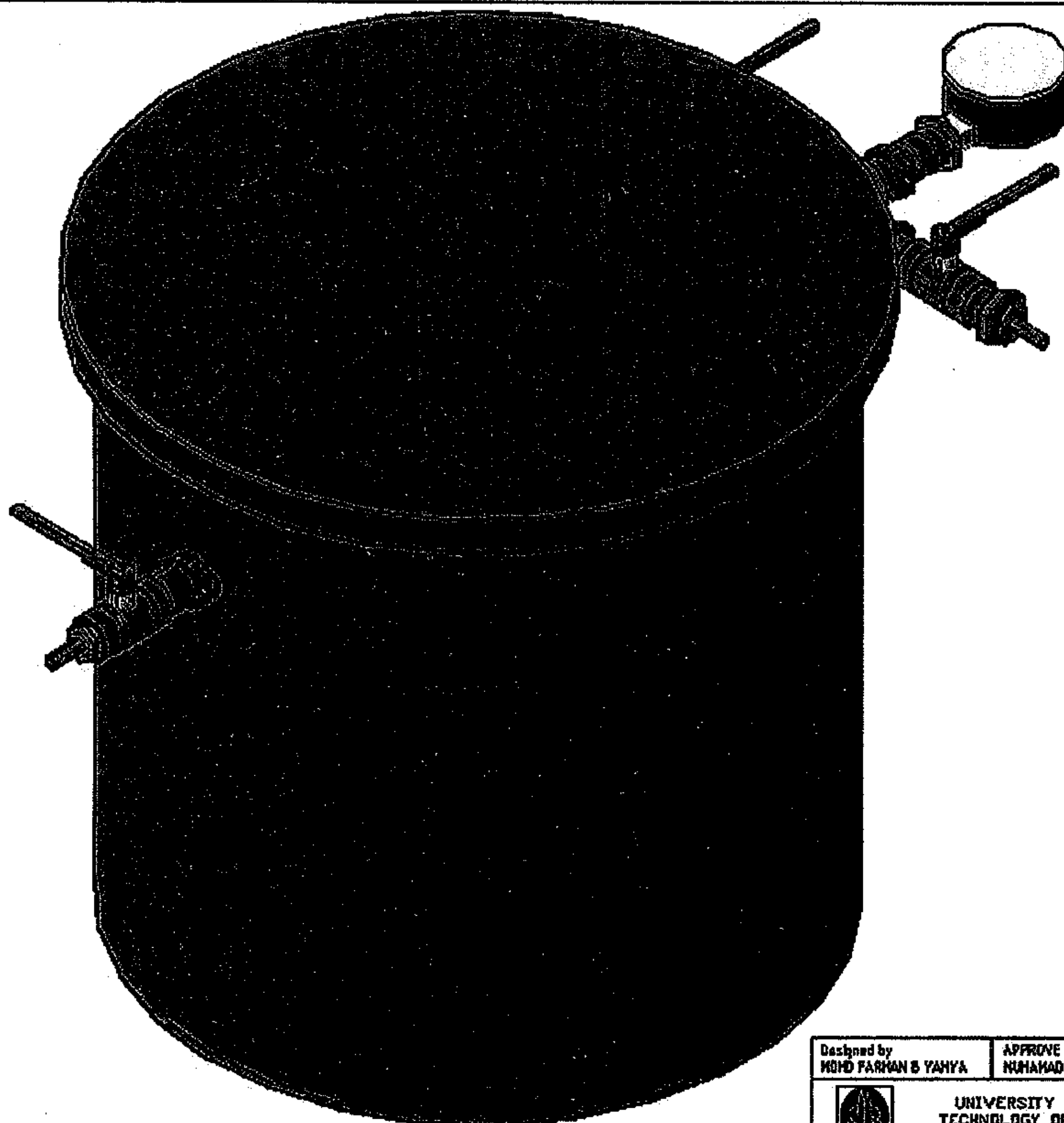
APPENDIX

Mechanical properties of Perspex

Property	Test Method	Units	PERSPEX GS Cast Sheet	PERSPEX XT Extruded Sheet
Tensile Strength	ISO 527 (1)	MPa	75	70
Elongation at Break	ISO 527 (1)	%	4	4
Flexural Strength Flexural	ISO 178 (2)	MPa	116	107
Modulus Charpy	ISO 178 (2)	MPa	3210	3030
Impact Strength	ISO 179 (3)	kJ.m -2	12	10
Vicat Softening Point	ISO 306 (4)	Degrees C	ca 110	>105
Rockwell Hardness	ISO 2039-2	M Scale	102	101
Light Transmission	ASTM D1003	% (5)	>92	>92
Refractive Index	ISO 489/A	-	1.49	1.49
Water Absorption	ISO 62	%	0.2	0.2
Relative Density	ISO 1183	-	1.19	0.19

NB: (1) 5 mm/min
(2) 2 mm/min
(3) un-notched
(4) Method A
(5) in 3 mm thickness



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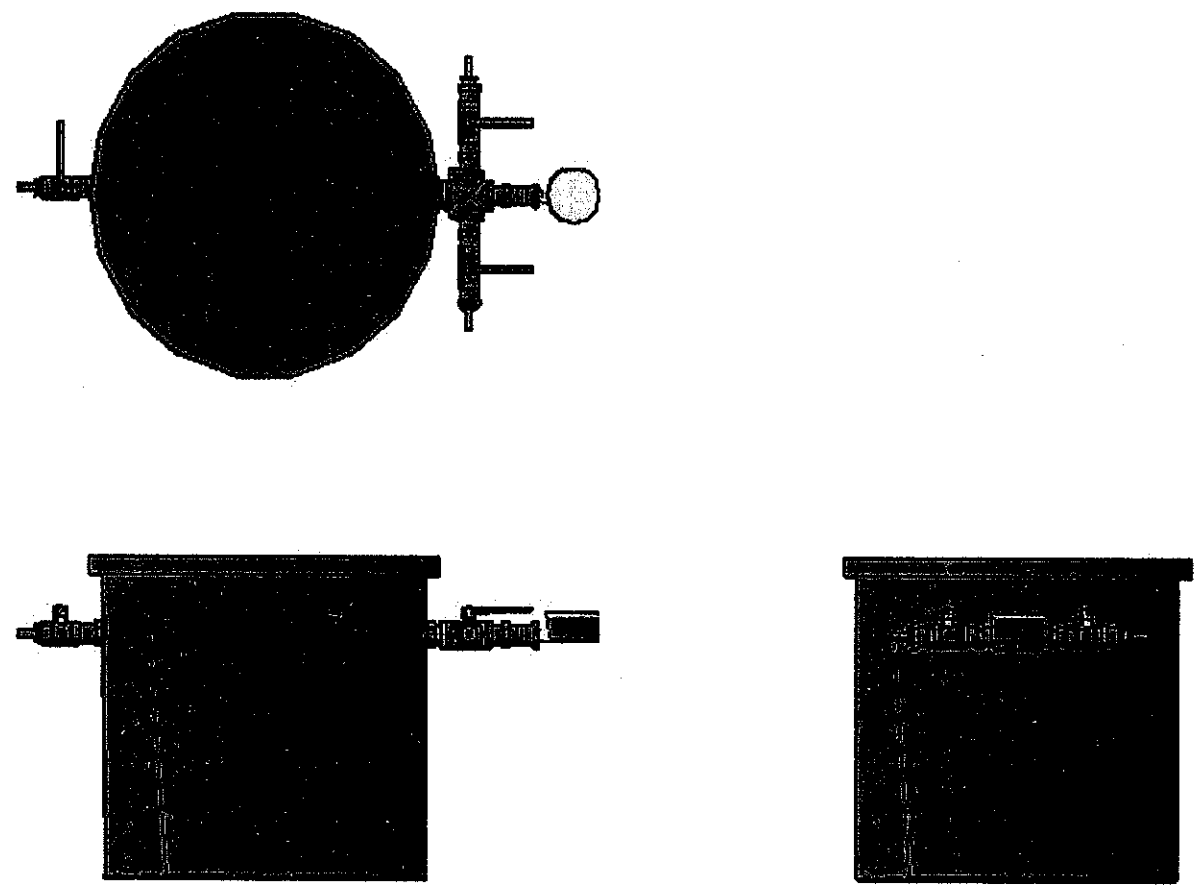
		3D Model Vacuum Chamber	REV 0	SHEET 1/1



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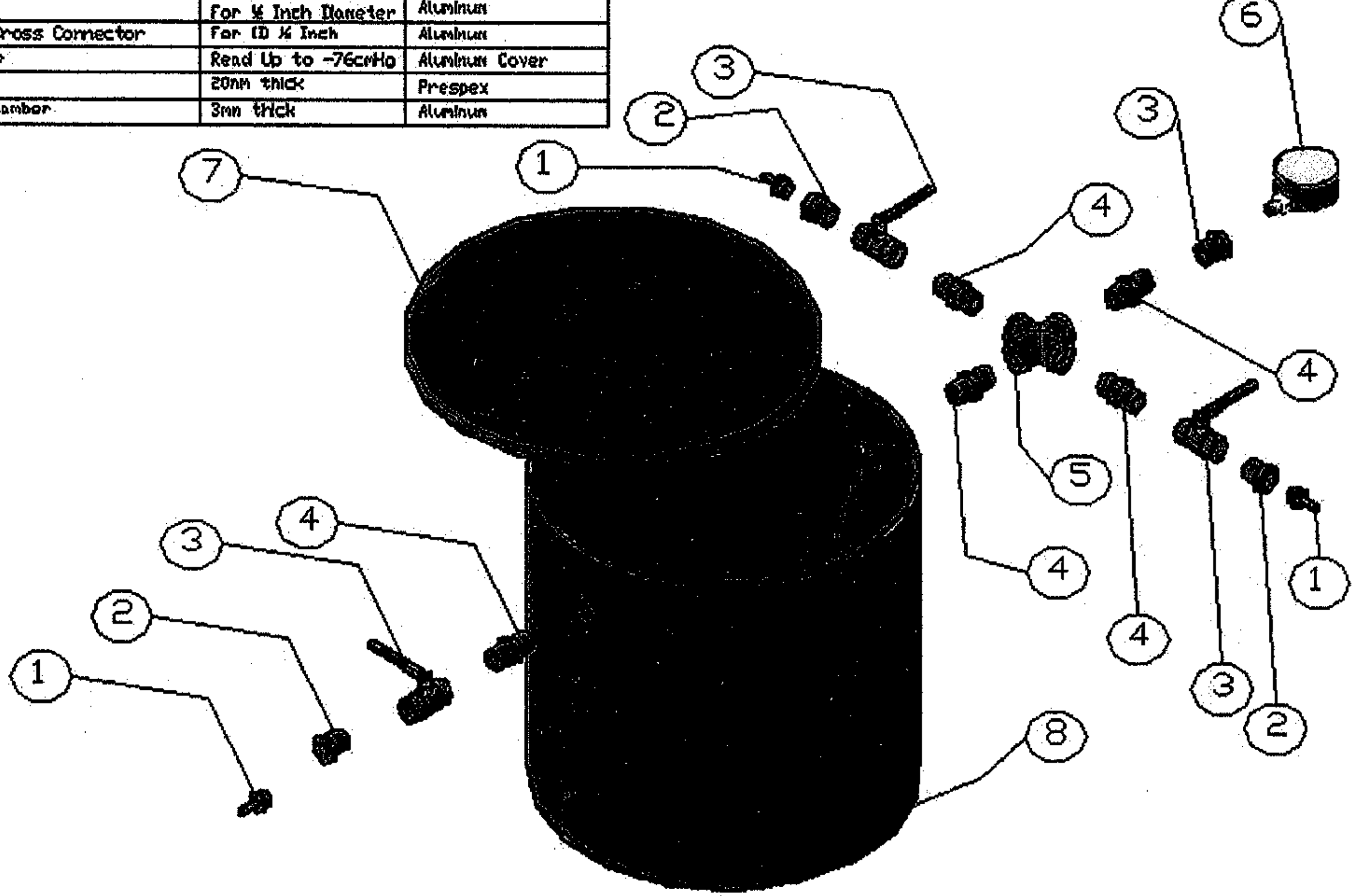
	Vacuum Chamber Orthographic		REV 0	SHEET 1/1

Bil Of Material				
No.	QTY	NAME/DESCRIPTION	DETAILS	MATERIAL
1	3	Hose Connector	For ID ¼ Inch	Carbon Steel
2	4	Female Reducer	For ID ¼ Inch	Aluminum
3	3	Ball Valve	For ¼ Inch Diameter	Brass
4	5	Male Connector	For ¼ Inch Diameter	Aluminum
5	1	4 Way Female Cross Connector	For ID ¼ Inch	Aluminum
6	1	Pressure Gauge	Read Up to -76cmHg	Aluminum Cover
7	1	Lid Prespex	20mm thick	Prespex
8	1	Wall Vacuum Chamber	3mm thick	Aluminum



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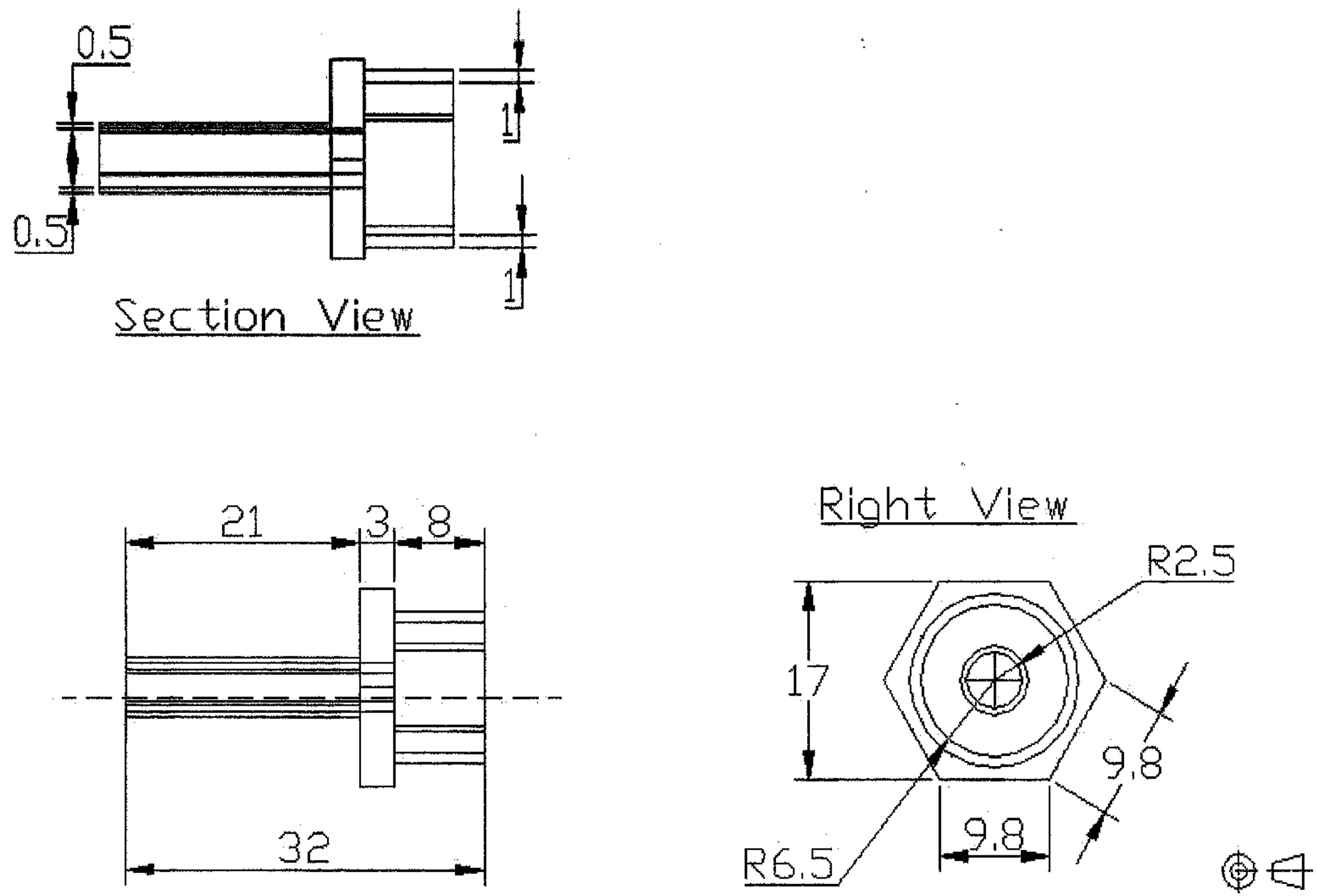

Front View

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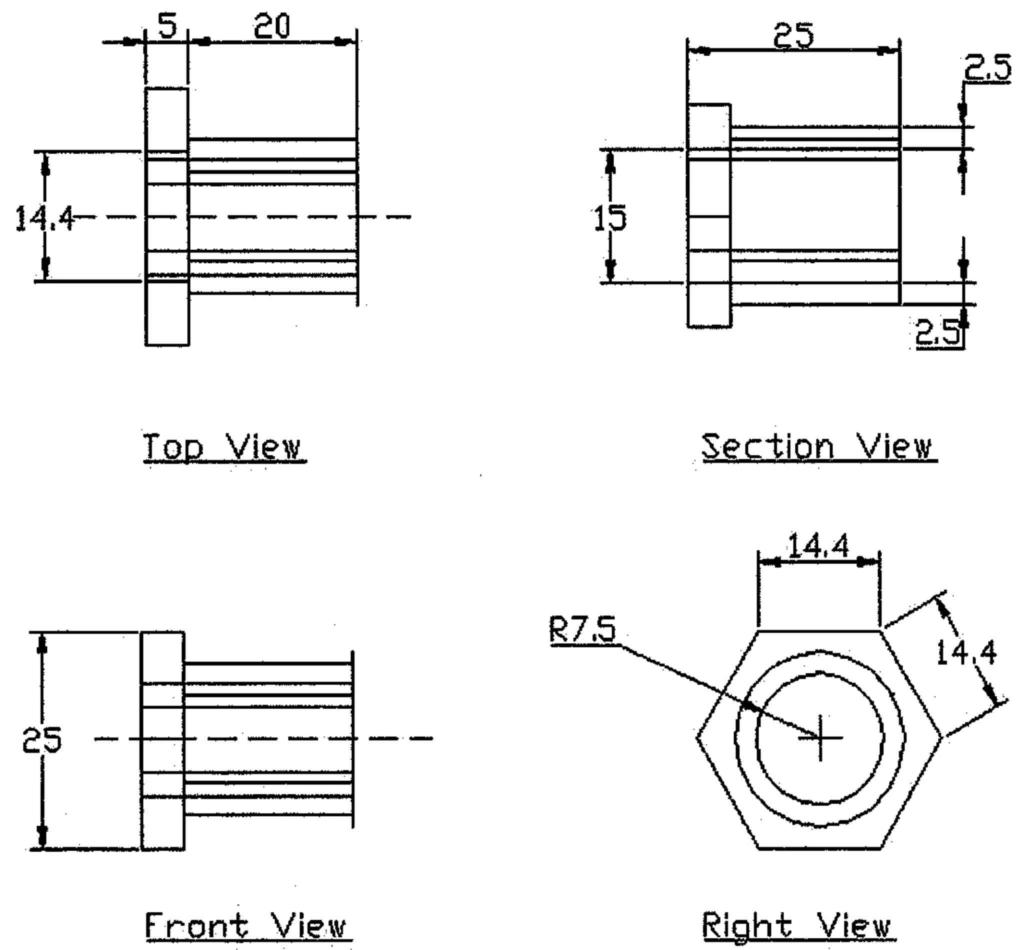
	Hose Connector Detail Drawing		REV 0	SHEET 1/1



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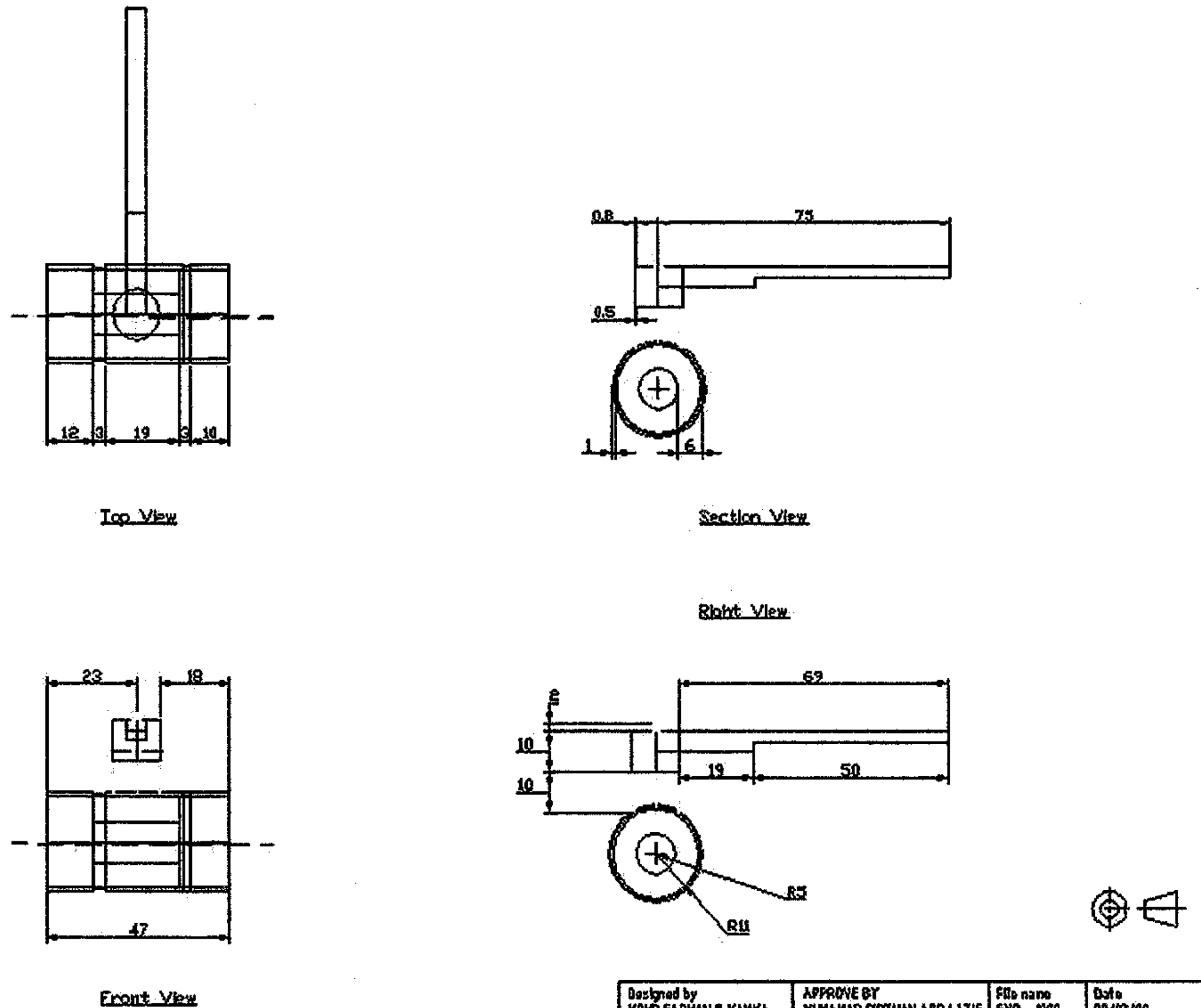

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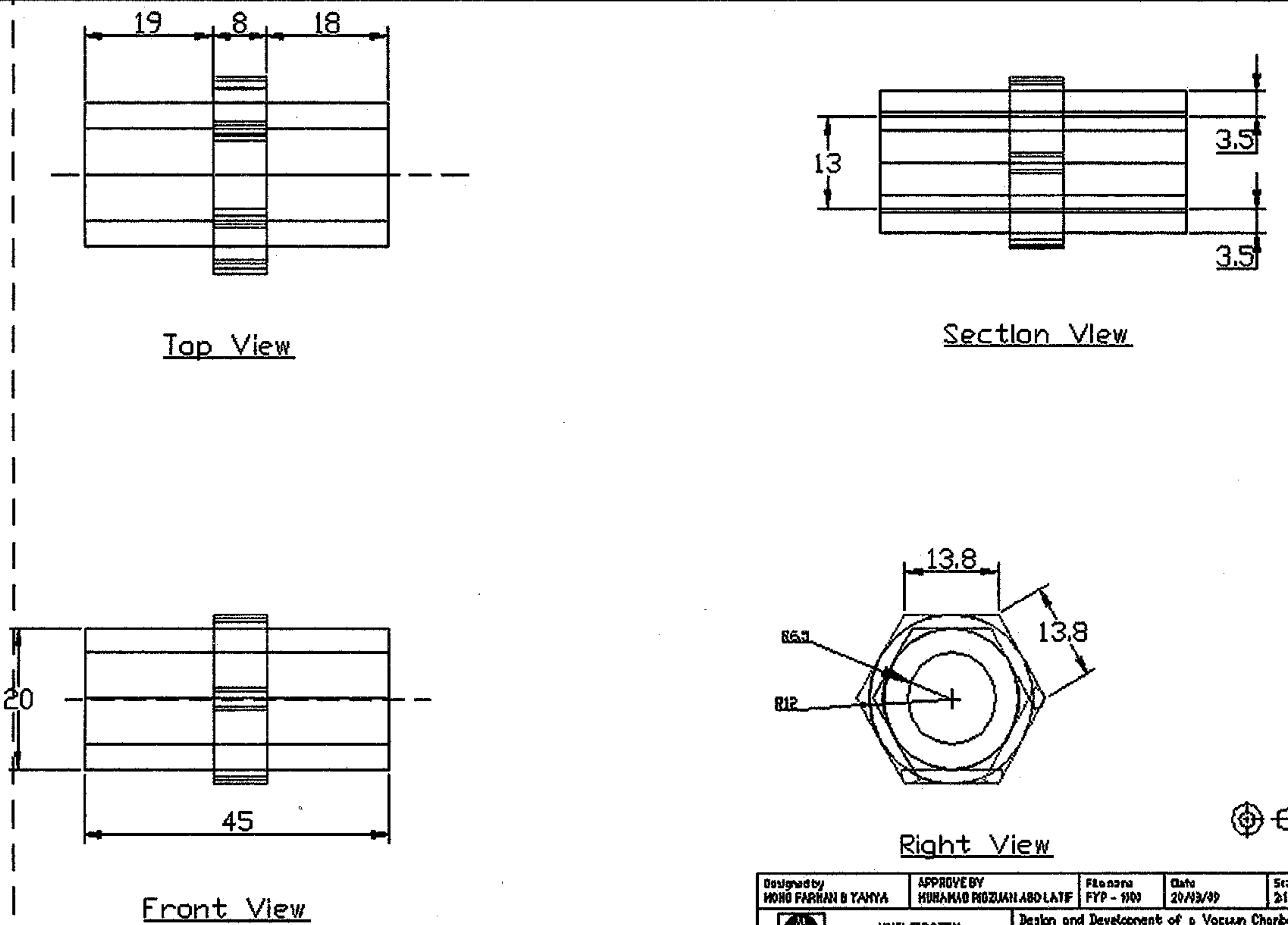
	Ball Valve Detailed Drawing		REV 0	SHEET 1/1



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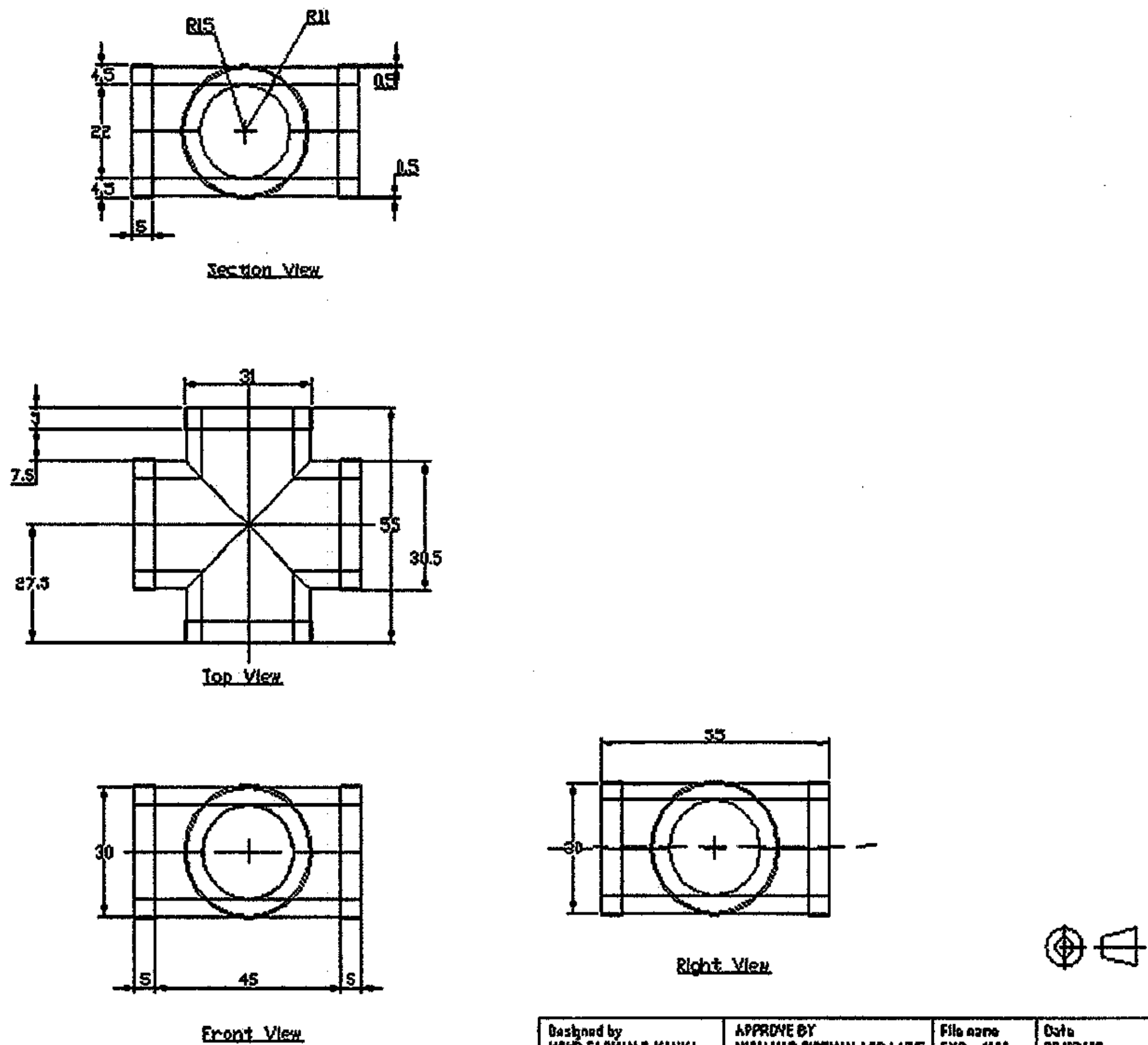

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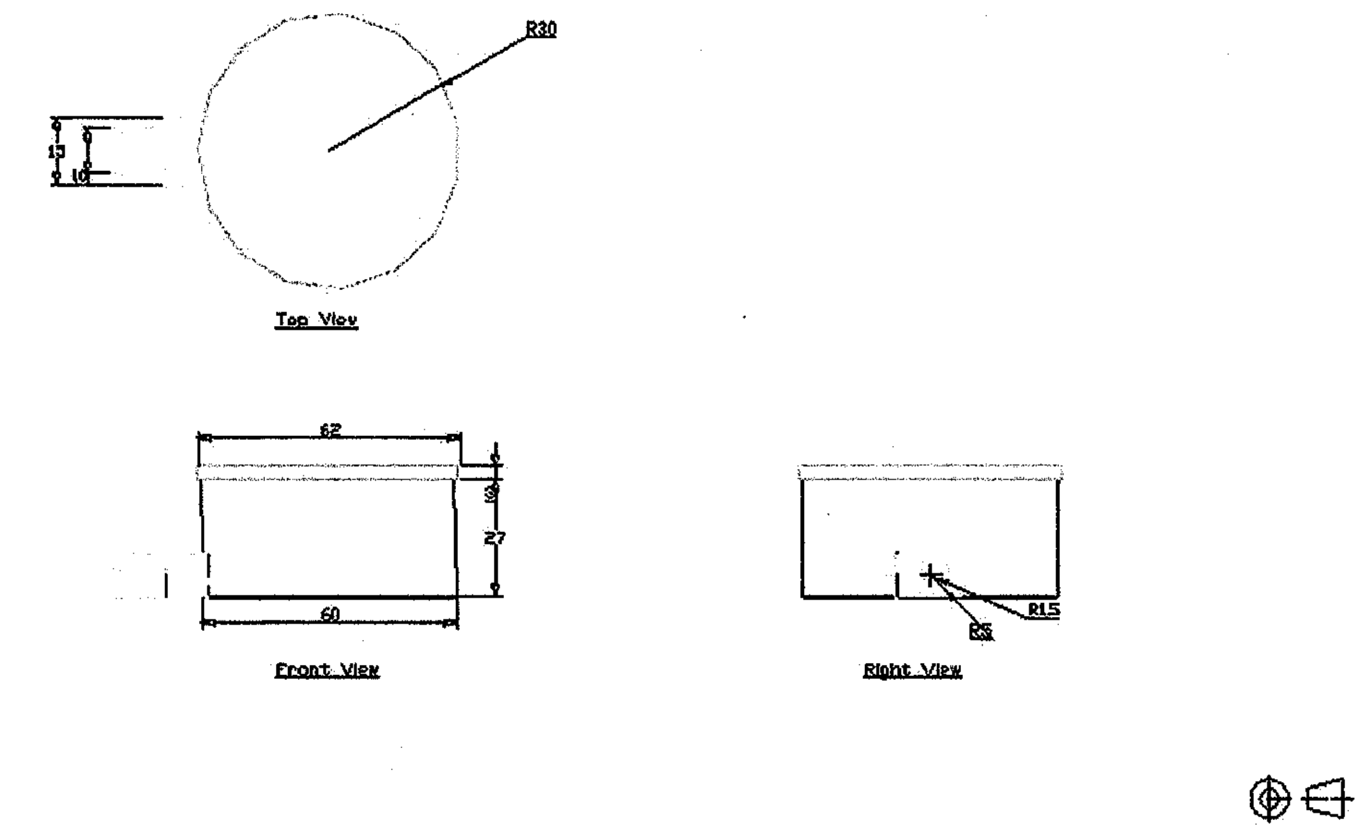
	4 Way Cross Connector Drawing		REV 0	SHEET 1/1



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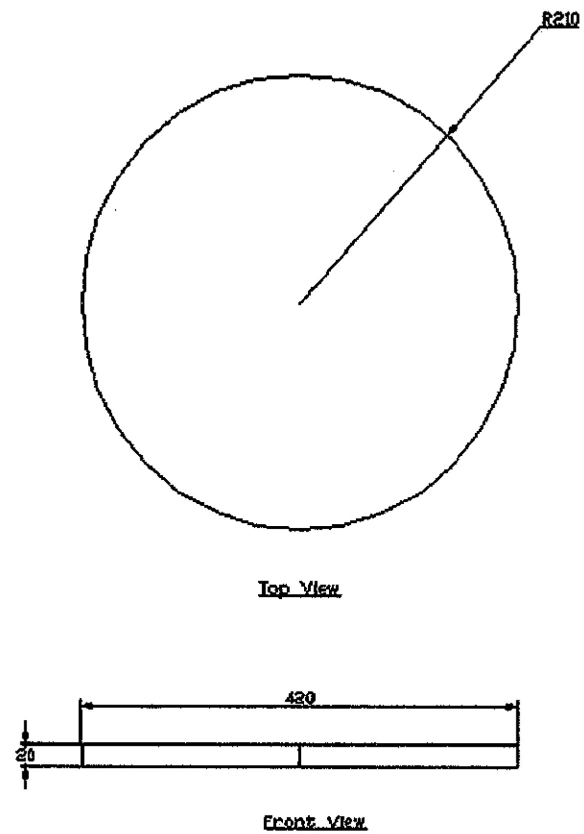

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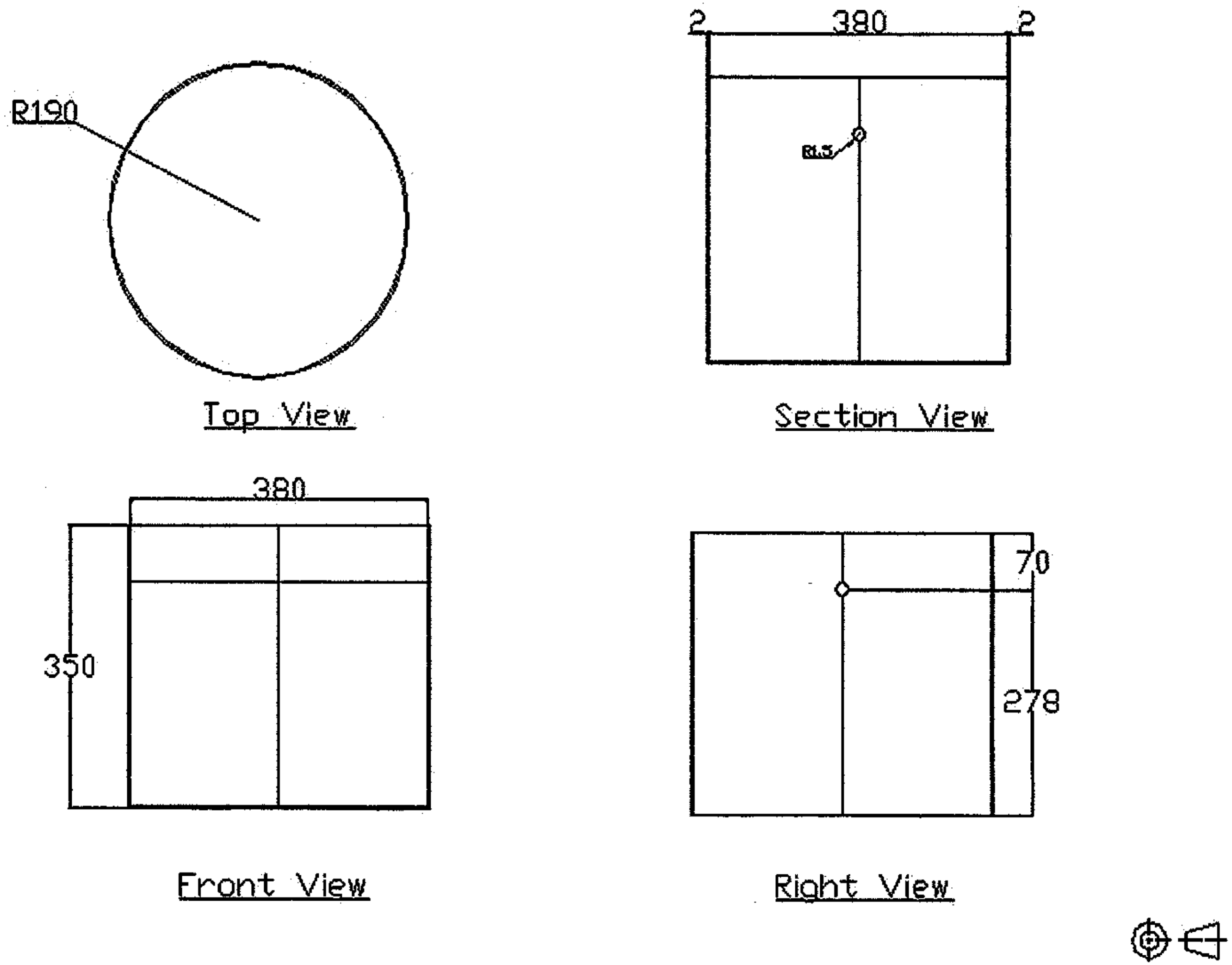
		Lid Prespex Detail Drawing	REV 0	SHEET 1/1



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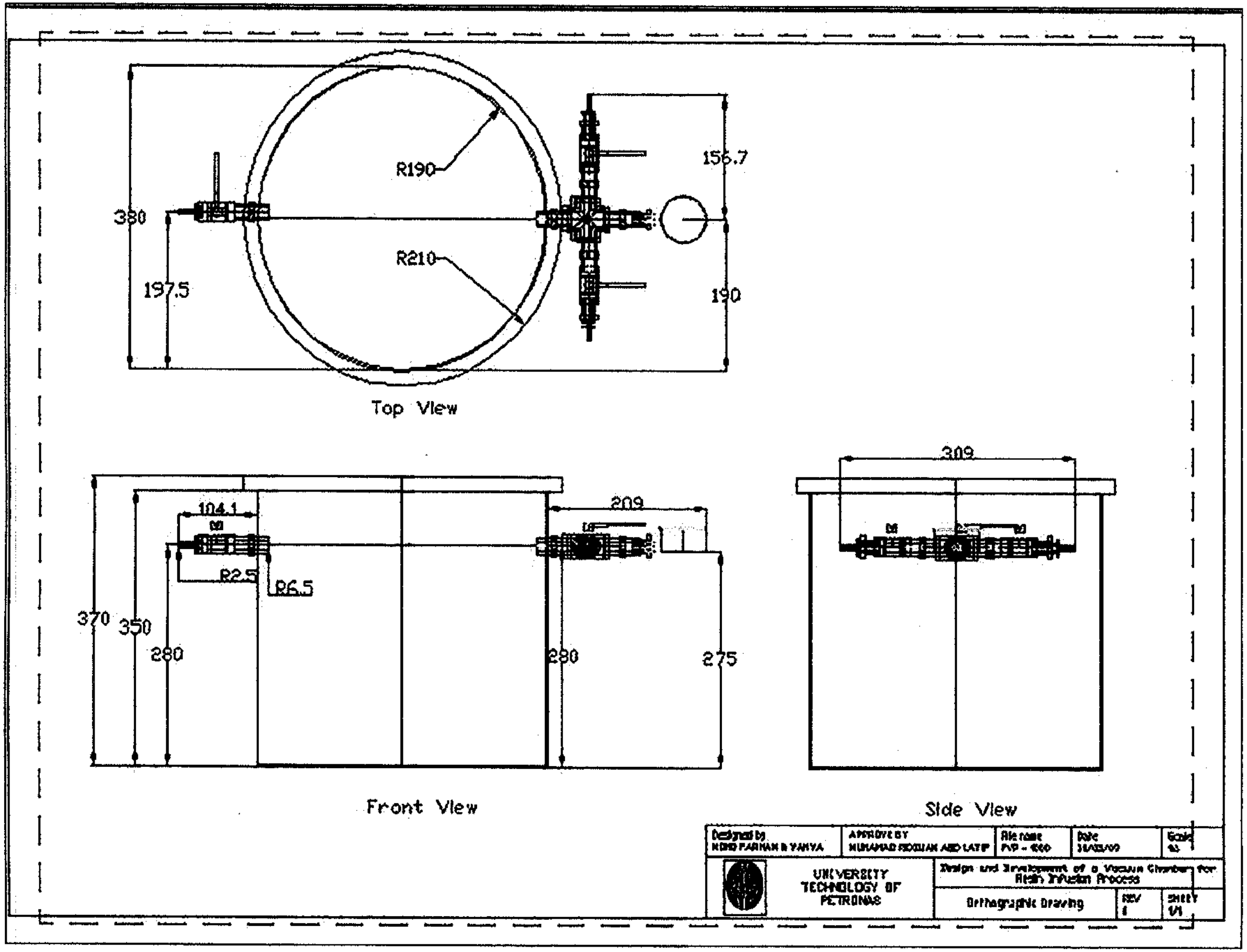
	Wall Vacuum Chamber Drawing		REV 0	SHEET 1/1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197.5
R190
R210
156.7
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Top View
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350
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104.1
R2.5
R6.5
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Front View
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Side View
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UNIVERSITY
TECHNOLOGY OF
PETRONAS
Design and Development of a Vacuum Chamber for
Resin Infusion Process
Orthographic Drawing
REV
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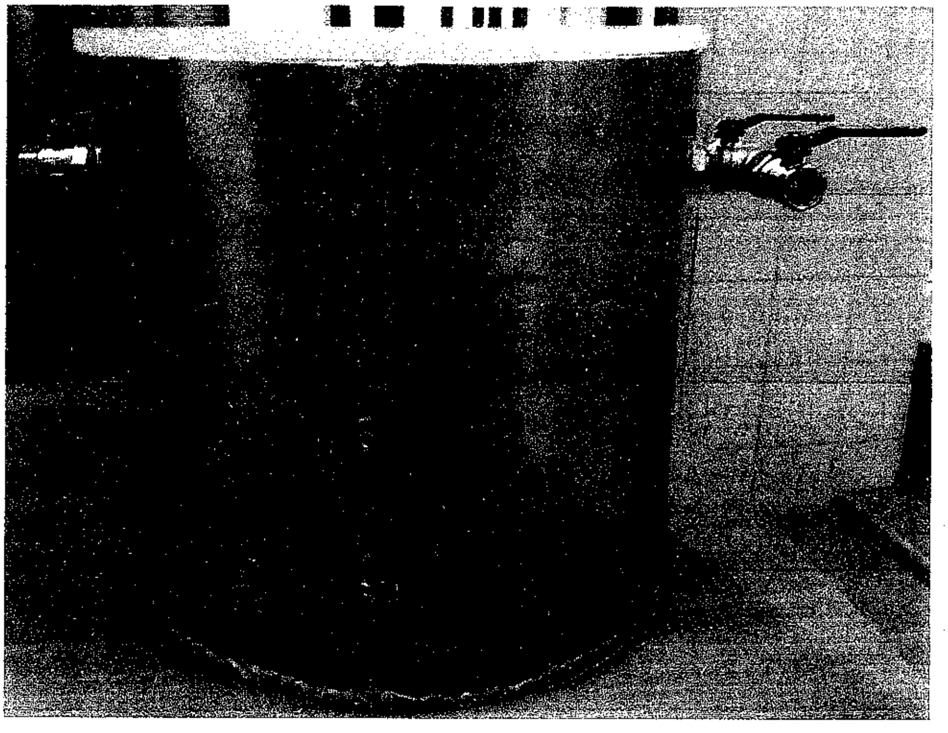

The final product