SUBMERSIBLE COMPRESSOR TO ENHANCE GAS PRODUCTION AT THE GAS FIELD

By

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FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
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Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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TRONOH, PERAK

December 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.

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(Muhammad Syukri Bin Mokhtar)

ABSTRACT

Over the next 20 years, the role of natural gas in global energy consumption will increase. The speed of transition to natural gas will be driven by environmental issue, market demand and latest technology. This project is about developing a technological solution for the oil and gas industry's recognized problem of maximizing gas extraction from the gas field by trialing the technology which will increase production. The objectives of this study are to identify an option to boost the gas production and to maintain the pressure at the base of the well by means to prevent the problem of liquid loading by developing the submersible compressor. Submersible Compressor helps to maintain the well energy to lift the gas to the surface by maintaining the pressure differential between the well and surface. The submersible compressor is used in multiple stage compression modes. Scope of study includes the drawing of full scale submersible compressor by using CATIA & AUTOCAD then exported to GAMBIT and FLUENT for subsequence analysis. The results of the analysis consist of discharge pressure and velocity of the compressor. The main target is to increase the discharge pressure so that the pressure differential between well and surface increased.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

Over the next 20 years, the role of natural gas in global energy consumption will increase significantly [1]. The speed of the evolution to natural gas will be driven by environmental issues, market demand and latest technology to be used. The emerging importance of natural gas as global energy source means that new technologies will be essential to maximize recovery of this resource.

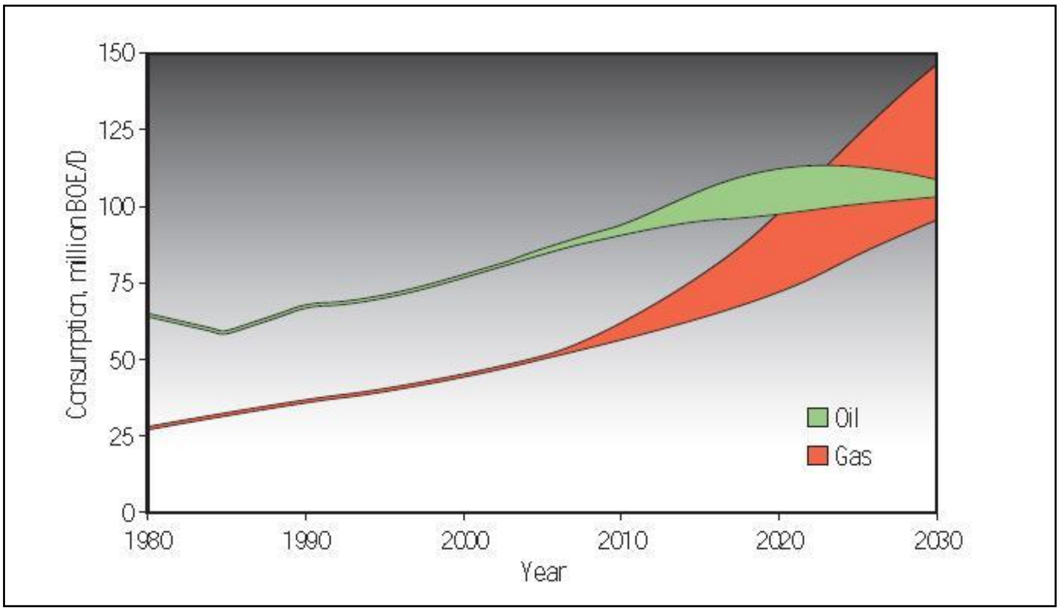

Figure 1: Expected Oil and Gas Consumption

Figure 1 above shows the expected oil and gas consumption. Some experts believe gas consumption will exceed oil by 2025. This prediction has been taken from the Watts P: "Building Bridges-Fulfilling the Potential for Gas In 21st Century".

Although historically, many countries have focused more into oil production but now, they are changing to emphasize more on gas production. Many countries are now using gas to generate power for local consumption and reserving their oil for export. The Oil and Gas Service Provider Companies believes with the expansion of regional market to a global gas market will accelerate the need of improvement in technology and extracting reserves [3].

1.2 Project Problem Statement

Liquid loading is the problem specific to production in gas fields. As pressure drops, fluids fall below its dew point pressure and liquid condenses from the gas as second phase. Since the liquid density is significantly greater than the gas density, the fluids in the wellbore can be more difficult to lift to surface and as a result, creating the liquid-loading problem.

As gas is produced, reservoir pressure in a field declines. Many gas fields around the world are currently facing low pressure problems. These reservoirs still contain significant gas reserves, although the pressure gradient to the surface had dropped. This is due to the natural drive mechanism of the field had decreased. Producing from such low-pressure field is uneconomical as liquid loading can create significant cost for gas production.

This project is focused more on how to increase the production of the gas by using a submersible compressor. Gas flowing from a well drilled into a gas reservoir frequently carries vapor and liquid droplets. The pressure of the gas at the base of the well falls as the gas is extracted. It leads to a decrease of flow velocity of the gas in the production tubing. We can thus state that the problem statements as:

1. How to prevent the problem of liquid loading?
2. How to boost the rate of extraction?
3. How to design a submersible compressor?
4. How to simulate the design of submersible compressor?

1.3 Objectives

The objectives of this project are:

- Suggest an option to boost the gas rate of extraction
- Suggest an option to prevent the problem of liquid loading
- Design a submersible compressor
- Simulating the submersible compressor design using GAMBIT and FLUENT
- Fabrication process
- Run physical test of the submersible compressor

1.4 Scope of Study

In order to achieve these objectives, a few tasks and research need to be carried out by collecting all technical details regarding the existing compressor which is currently used by the gas operator by studying the fundamental behavioral aspects of the compressor. This project will cover:

- Determine design idea and concept
- To develop a detail design of the submersible compressor by using CATIA / AUTOCAD.
- Conduct simulation using GAMBIT and FLUENT to determine the result of gas flow along the model by showing the colour contour.
- Fabrication
- And testing

CHAPTER 2
LITERATURE REVIEW

2.1 General Information

Generally, lowering the surface pressure of a well will result in increased production [4]. This is true for flowing wells and near depleted well. A well's production can be increased over a range from only a few percent to several times the current production of the well depending on the individual well. An artificial lift such as a pump, compressor and gas lift will help to increase production. The concept that been is used is that the pump or compressor will respond to the lower surface pressure with more production as tubing stretch is reduced and lower casing pressure allows a higher fluid level in the annulus for the same rate [5]. This situation will result in more production.

2.2 Effect of Compression

For flowing gas wells, lowering the surface pressure will drastically increase the production, the life of the well and actual reserves. Lowering the surface pressure has two effects [6] and both of it are useful for liquid loading. The effects are:

1. The flowing bottomhole pressure decreases, results in increasing the production rate and gas velocity.
2. The necessary critical rate to remove liquids decreases because of reduced pressures.

Compression provides economic alternatives to tubing changes for offshore wells [7] where the work over costs can be unreasonable. Compressor system can be designed base on the critical velocity. The critical velocity is directly proportional to surface pressure [8]. The compression station can be designed based on surface pressure that maintains the tubing production velocity at some percentage above the minimum critical velocity. The installation design can be optimized to produce the most gas for long term period.

2.3 Compressor Design

2.3.1 Compression Methods

There are many types of compressors and the design is based on the application. The compressor can be divided into two big groups based on compression mode. The two basic modes are intermittent and continuous. The intermittent mode of compression is repeated in nature; a specific quantity of gas ingested by the compressor, compressed and discharged before cycle is repeated while for the continuous compression mode, the gas is moved into the compressor, compressed, move through compressor and discharged without disturbance of the flow at any point.

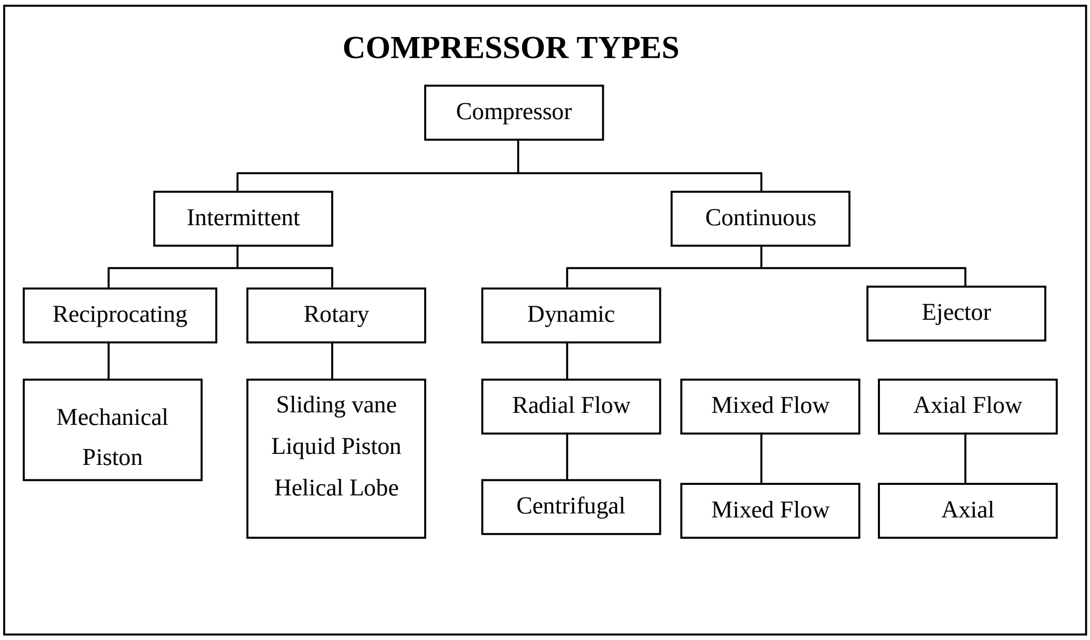

Figure 2: Compressor Types

Figure 2 shows the various types of compressor while Figure 3 below shows the typical application range of each compressor. Figure 4 shows the comparison of the characteristic curve of dynamic compressor, axial and centrifugal with positive displacement.

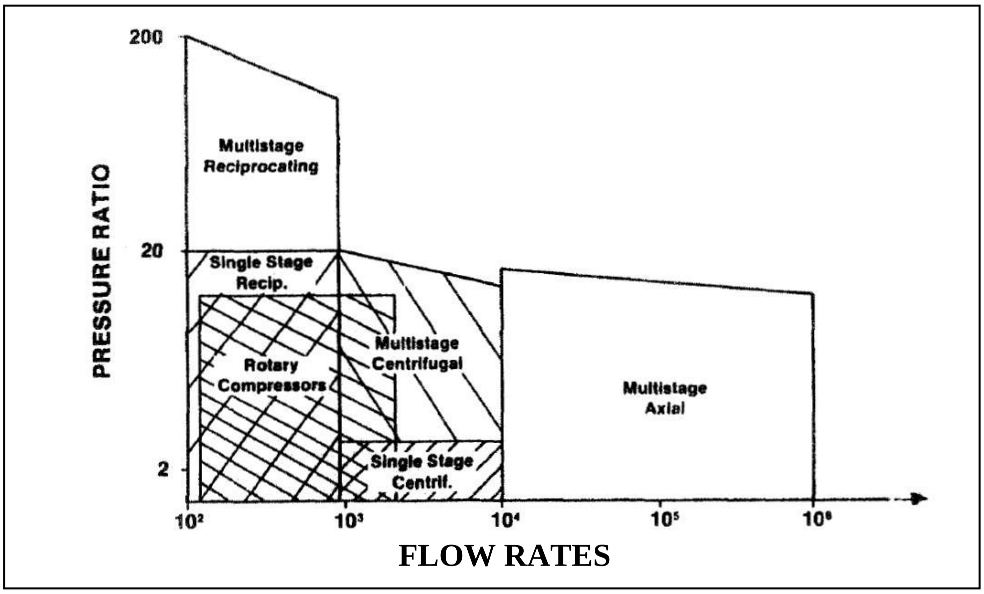

Figure 3: Typical Application Ranges of Compressor Types

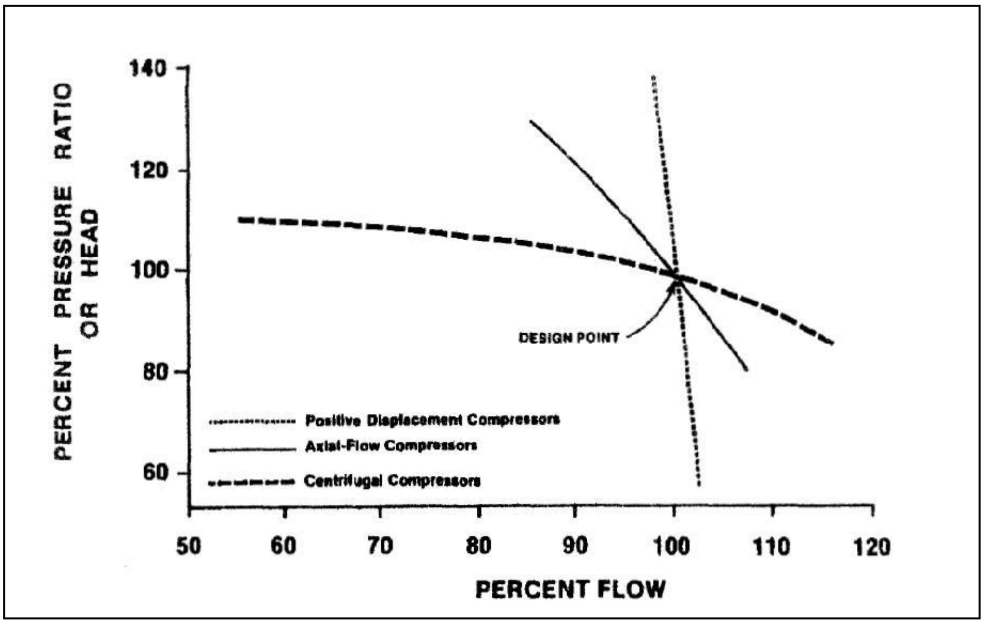

Figure 4: General Performance for Axial Flow, Centrifugal and Positive Displacement

From the characteristics shows above, it will give some ideas which type of compressor will be chosen as the basis of design for the submersible compressor. The suitable compressor type that meets the criteria of the submersible compressor design is centrifugal compressor which put under dynamic compressor. Centrifugal compressor was chosen because of design flexibility (single stage or multistage) and meets the operation requirements. It’s also had fewer rubbing parts, is relatively energy efficient, and gives higher airflow. Centrifugal flow compressors offer the advantages of simplicity of manufacture and relatively low cost. This is due to require less stages to achieve the same pressure rise. The basic reason for this stems from a centrifugal compressor's large change in radius. It is the change in radius that allows the centrifugal compressor to generate large increases in fluid energy over a short distance.

2.3.2 Centrifugal Compressor

The radial flow or centrifugal compressor is commonly used compressor in the process industries. Example for multistage centrifugal compressor can be seen in Figure 5 below.

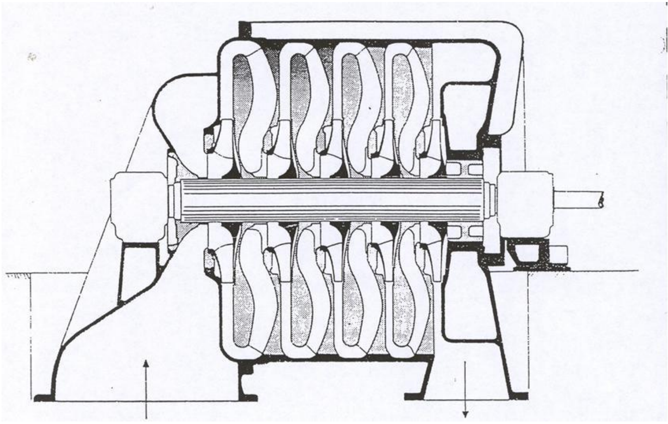

Figure 5: Typical Multistage Centrifugal Compressor

The compressor uses an impeller consisting of radial blades and a front and rear cover. The front cover is optimally rotating or stationary depending on the specific design. As the impeller rotates, gas is moved between the rotating blades from the area near the shaft and radially outward to discharge into the diffuser as shows in Figure 6. Energy is transferred to the gas while it is travelling through the impeller. Part of the energy change to pressure along the blade path while the balance maintain as velocity at the impeller tip where it is slowed in the diffuser and changed to pressure.

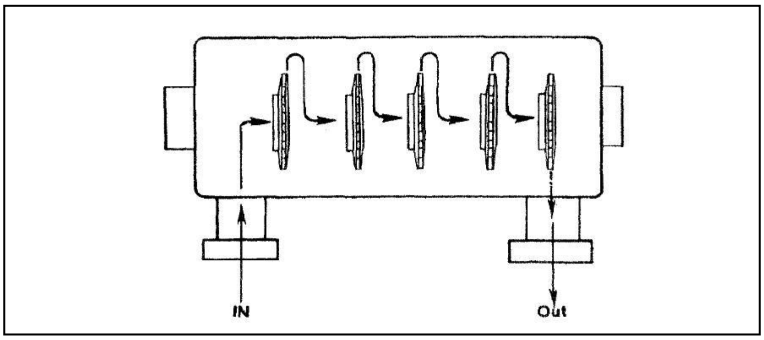

Figure 6: Centrifugal Diagram with the Straight Flow Path

Centrifugal compressors are quite often built in multi-stage configuration, where multiple impellers are installed in one frame and operate in series. In single wheel configuration, the pressure varies considerably. A common low pressure compressor may only be capable of 10 to 12 psi discharge pressure. In higher-head model, pressure ratios of 3 are available, which on air is a 30 psi discharge pressure when the inlet is at atmospheric pressure.

Another characteristic of a centrifugal compressor is its capability to admit or extract flow to or from the main flow stream, at relatively close pressure intervals. These flows are referred to as side streams. Pressure of a multistage machine is quite different and hard to simplify because of many factors that control pressure.

2.3.3 Gas Equation

Many common gases used in compressor for plant process in reality are in vapor condition. In many cases, the material may transform state during a portion of the compression cycle. To have a clear view on compression effect on gas, we need to know the gas equation and characteristic.

2.3.3.1 Ideal Gas Equation

Gas pressure varies with absolute temperature. If volume is constant, pressure will vary in proportion to absolute temperature [9]. Using proportionality constant R, the relationships can be combined to form the equation of state for a ideal gas, known as ideal gas law.

$$Pv = RT$$

Where,
P= Absolute Pressure
v= Specific Volume
R= Constant Proportionality
T= Absolute Temperature

If the specific volume v is multiply by mass m, the volume becomes a total volume V. Therefore multiplying both side of the equation with m, will produce:

$$PV = mRT$$

In an engineering process, moles are used in performing the calculations. A mole is defined as the mass of a substance that is numerically equal to its molecular weight. Avogadro's Law states that identical volumes of gas at the same temperature and pressure contain equal number of molecules for each gas. These identical volumes will have a weight proportional to a molecular weight of the gas. If the mass is expressed as:

$$m = n \times mw$$

Where
n = number of moles, mw = molecular weight
Then

$$PV = nwRT$$

If the value nwR is the same for all gasses, the universal gas constant (ugc) is defined and R becomes specific gas constant

$$R = \frac{ugc}{mw}$$

Another useful relationship:

$$\frac{P1V1}{T1} = mR = \frac{P2V2}{T2}$$

If both sides are divided by time the term V becomes Q, volumetric flow per unit time and mass flow per unit time become w.

$$PQ = wRT$$

2.3.3.2 Compressibility

An expression may now be added to equation $Pv = RT$ to correct it for deviation from the ideal gas law.

$$Pv = ZRT$$

Solving for Z,

$$Z = \frac{Pv}{RT}$$

Equation $PQ = wRT$ may be modified in similar manner by addition of compressibility term Z as follows:

$$PQ = wZRT$$

CHAPTER 3
METHODOLOGY

3.1 Procedure Identification

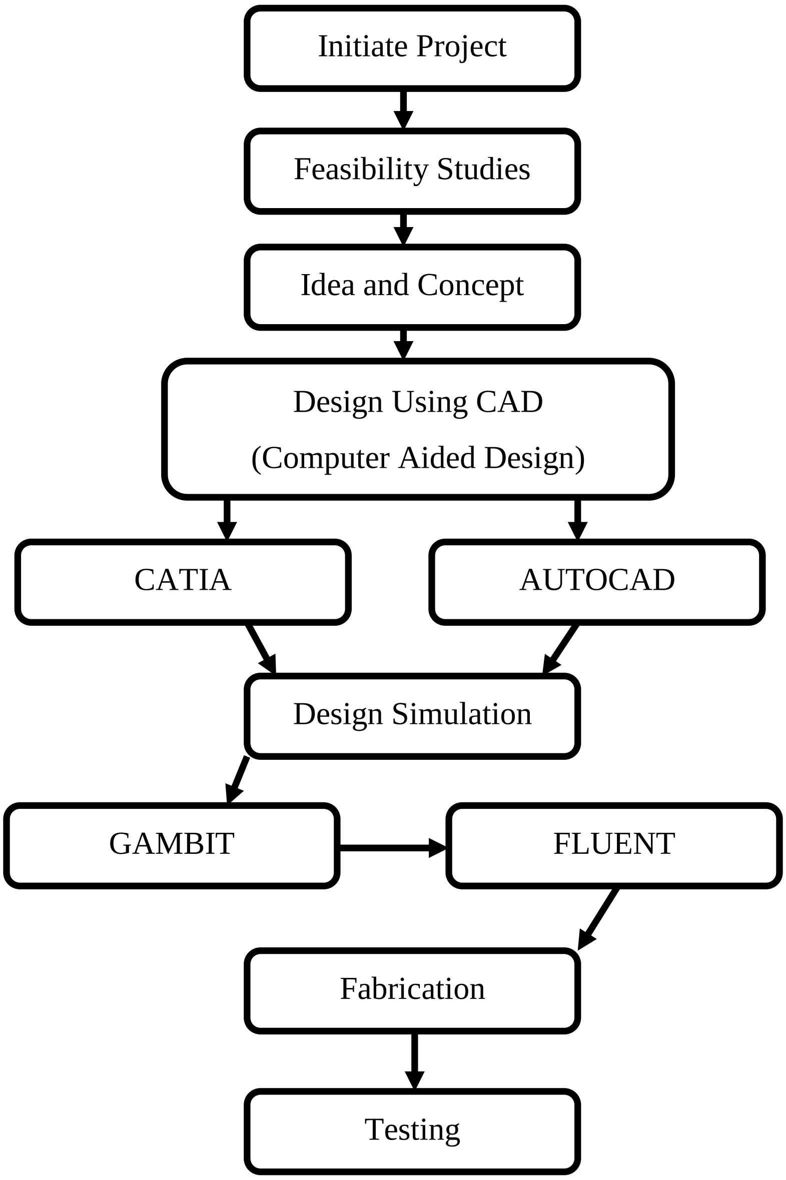

Figure 7: Flow Chart of Project

3.1.1 Design and Concept

Centrifugal compressor sometimes referred to as radial compressors is a special class of radial-flow work-absorbing machinery that includes pumps, fans, blowers and compressors. Modern centrifugal compressors are higher in speed and analysis must deal with compressible flow. In an idealized sense, the dynamic compressor achieves a pressure rise by adding kinetic-energy or velocity to a continuous flow of fluid through the rotor or impeller. This kinetic energy is then converted to an increase in static pressure by slowing the flow through a diffuser.

The design need to consider how to manipulate gas pressure and velocity in a continuous flow and how to achieve the main target which is to increase the discharge pressure. For design purpose, the constraints need to be considered are the size of the tubing, running mode (continuous or intermittent), and inlet pressure as well as discharge pressure. As mentioned earlier, the centrifugal compressor has its own way to get the better discharge pressure so the design should include diffuser, multi-stage impeller and variation on the tubing size or volume. Figure 8 shows the sketch of the designed submersible compressor.

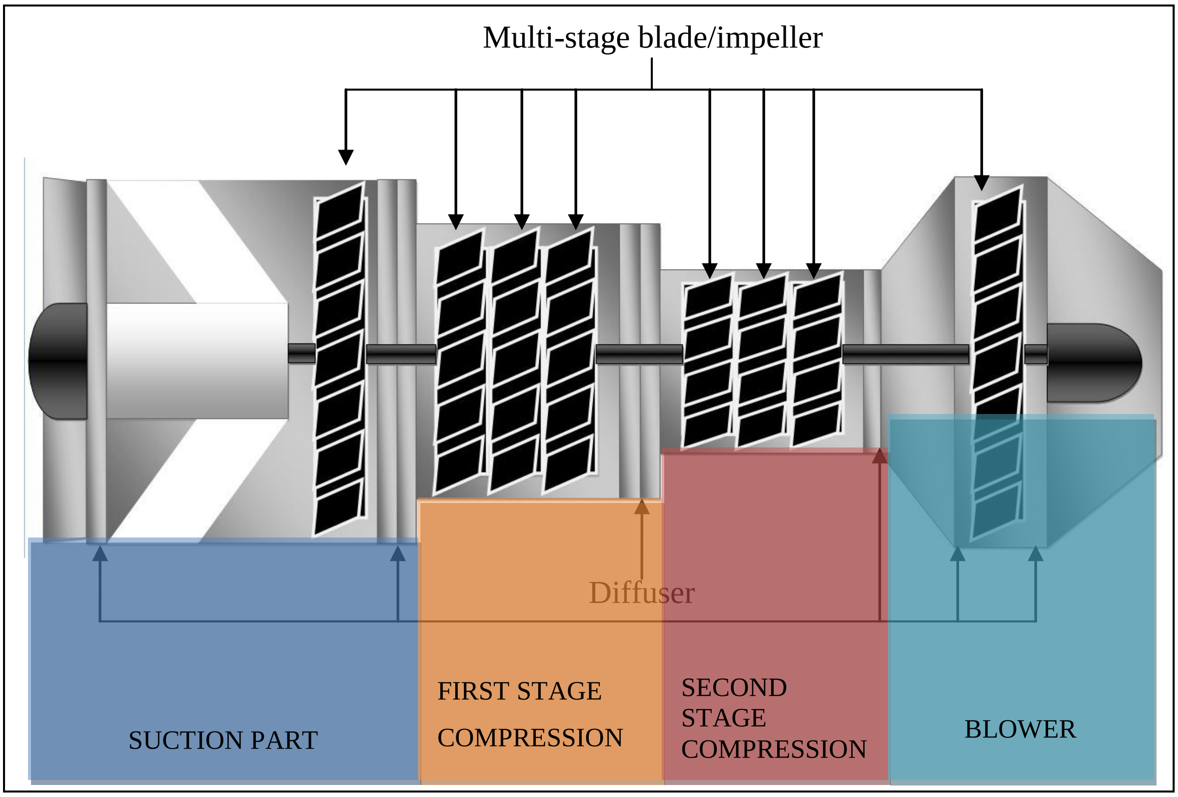

Figure 8: Sketch of the Designed Submersible Compressor

3.1.2 Design Using Computer Aided Design Software

CATIA P3 V5R12 has been used to develop the design. The design was develop base on the characteristics of the centrifugal compressor and constraints that already stated before (the design should include diffuser, multi-stage impeller and variation on the tubing size or volume). The parts that need to be constructed are:

- **Inlet/suction part** – It consist of a DC motor as a driver and one rotating impeller or blade. It will receive gas as much as it can and blow to the next stage.

- **Low Compression Part** – also known as first stage compression. It consists of two rotating blades and a single stationary blade. At this part, gas starts to be compressed because the size of the tubing has been reduced.

- **High Compression Part** – also known as second stage compression. It consists of two rotating blades and a single stationary blade. In this part, gas will be compressed for the second stage. The tubing size will be reduced than the high compression part to increase pressure.

- **Discharge Part** – act like a vessel. It will gather as much as it can and blow it through the exhaust. At the beginning of the discharge part, pressure is high but after the gas enters the discharge part, it’s experienced a high velocity and low pressure because the size of the tubing has been increased. Pressure from the high compression part gives the kinetic energy to gas and results the gas flows in high velocity. At the end of this part, the velocity of gas will decrease because gas needs to discharge from the compressor through the exhaust.

- **Exhaust** – Exhaust will increase the pressure and push the gas to the surface. The smaller the exhaust, the greater the pressure and the greater the flow.

- **Rotating blades and stationary blades** – The use of rotating and a stationary blade is to increase the velocity and pressure of the gas. The figure below shows how it works:

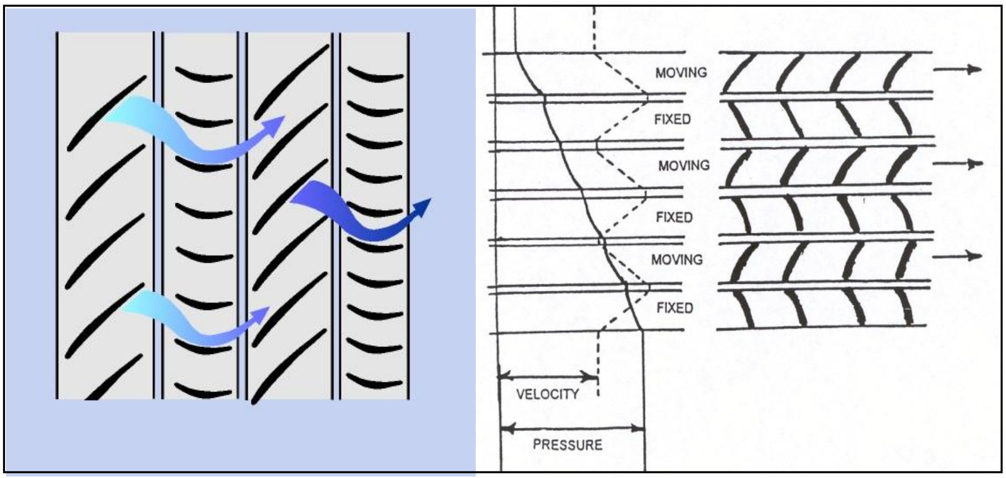

Figure 9: Configuration of Rotating and Stationary Blades

The rotating blade and the stationary blade will help to increase the pressure and velocity so it can push the gas in fastest time. The combination of pressure and velocity will produce greater flow.

- Diffuser – Slowing the flow and convert kinetic energy to static pressure.

All parts are constructed and assembled using CATIA. The design started by selecting the design part menu under mechanical design. Parts that have been built is assemble by using the assemble part menu under mechanical design as well. The important thing in assembling the design is to put the right constraint because if the constraint is wrong, we cannot proceed to the next step which is complete meshing and set boundary condition using GAMBIT. The overall design is shown in Figure 11.

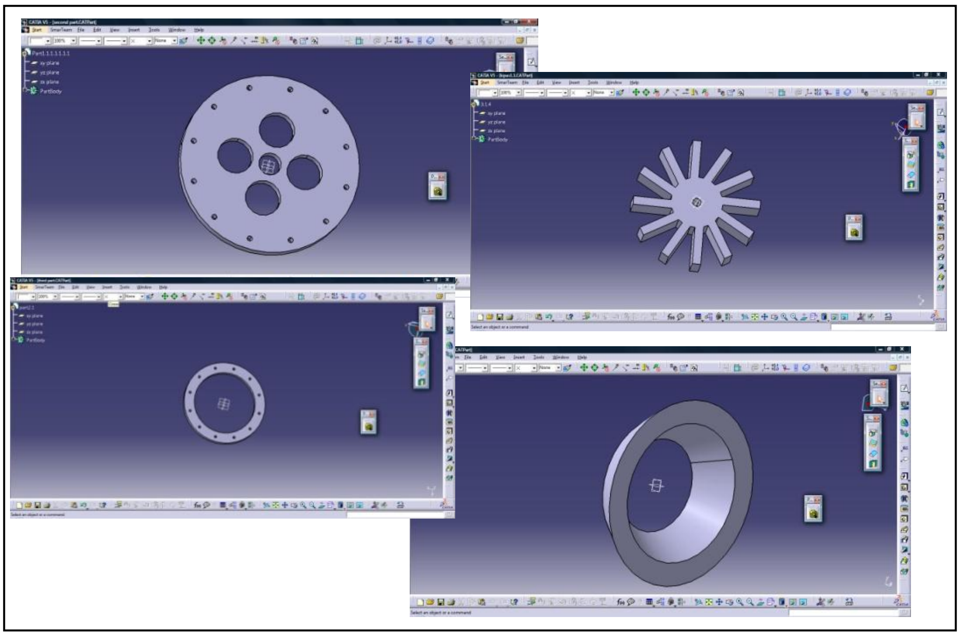

Figure 10: Part Design

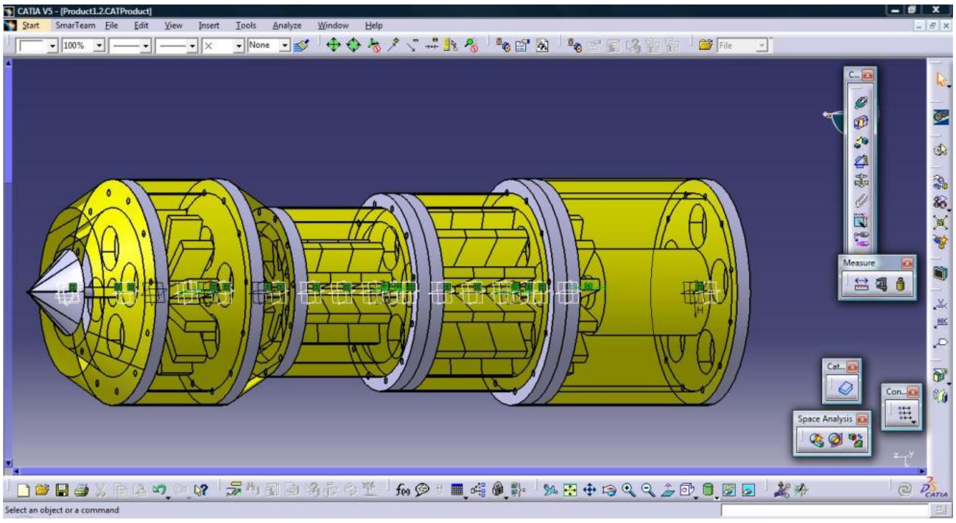

Figure 11: Design of the Submersible compressor

The completed design is now ready to be exported to GAMBIT for meshing and setting the boundary condition. The file must save in “.stp” or “.igs” format. So that it easily can be imported from GAMBIT

3.1.3 *Simulation using GAMBIT and FLUENT*

3.1.3.1 *GAMBIT*

The purpose of using GAMBIT is to set boundary condition and mesh design volume. This step must be completed first before it can be simulated in FLUENT. Firstly, file from CATIA must be imported. The file is in ".stp" or ".igs" format. After that, we need to define the solver. In this case the fluent 5/6 is used. Figure 12 shows the meshing diagram of submersible compressor.

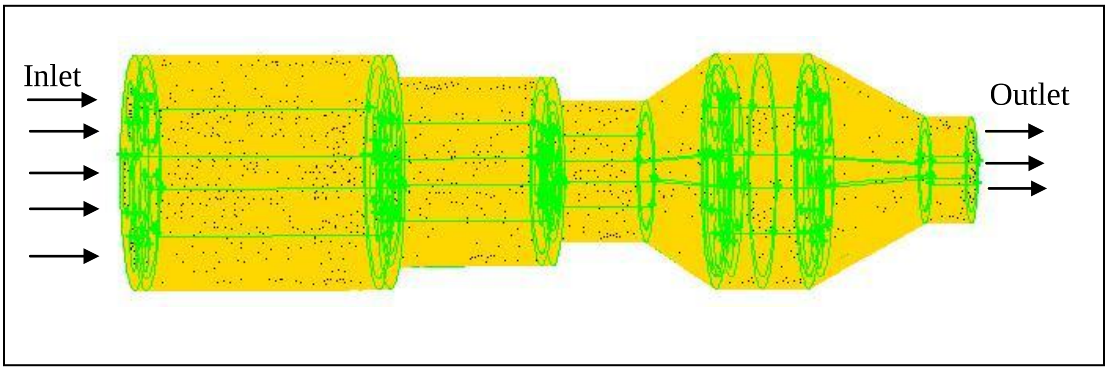

Figure 12: Meshing Diagram of Submersible Compressor

Next step is to set the boundary condition. In this step, the point of inlet, outlet needs to be identified. Inlet is set to be pressure inlet while the outlet is set as pressure outlet. This boundary condition is important because all the iteration and calculation that we need from FLUENT must follow this boundary condition.

After completing the meshing and set the boundary condition, the meshing file is export to the FLUENT file. Fluent is the important part to show the results. It's actually represented by colour contour, the output velocity and pressure as well as quantitative reports. This mode we call as examine the flow. Under this mode we actually can complete a lot of calculation and iteration.

3.1.3.2 FLUENT

FLUENT is more complicated compared to GAMBIT because in FLUENT we have to set a lot of boundary condition. Firstly, Run FLUENT in 3D simulations and import file from GAMBIT. Check the mesh by using grid menu. Then choose the model that we need first is for the solver frame work, energy equation and viscosity model. Set all parameter and proceed to the next setting which is material boundaries. All the specification of methane can be found in the FLUENT libraries. Next, set up the operating condition and solver control. Then move to the initialization and monitors mode. Here we have to set which point we want to start to compute. Finally, we can iterate solution to steady state. We can have a few set of result by trialing another type of model such as static pressure, dynamic pressure and turbulence model.

3.1.4 Fabrication

After completing with detailed design, we need to proceed to the fabrication stage. For the fabrication method, we have two options which are in-house fabrication or outsource. For in-house fabrication, we will gain a lot of experience but the constraints are time and money. Outsourcing fabrication will be the better option. It will save money to buy part by part and save time.

3.1.5 Prototype Testing

The testing objective is to find the input pressure and the output pressure. The testing will be done in the lab by injecting pressure to the inlet and measure the outlet pressure by using the pressure gauge.

Figure 13: Submersible Compressor Prototype

3.2 Specification Sheet

The following points need to be considered when preparing a specification sheet (process datasheet) for the submersible compressor:

- Application: (service application of unit should be described if possible.
- Fluid stream
- Fluid composition (volume percentage)
- Entrained Particles:

    - Size range
    - Size percentage distribution
    - True relative Density (specific gravity) of particle, in this case referred to water – 1.0
    - Source of entrainment, (boiling liquid)
    - Composition

- Operating condition (minimum, maximum and normal):

    - Gas flow rate
    - Entrained flow rate
    - Temperature (^{o}c)
    - Pressure ,(kPa)
    - Moisture content
    - Dew point (^{o}c)

- Installation Altitude
- Nature of entrainment liquid

    - Description (e.g. Oily or corrosive)
    - Surface tension at operating conditions
    - Viscosity at operating conditions

- Insulation required and reason
- Construction features
- Special condition (if any)

3.3 Data Analysis for Design Parameters

Below are the tables of data analysis of the design parameters. This data encompasses of external specification and operating condition which are required in designing this submersible compressor.

Table 1: Process Data Sheet

Item	**Unit**	
content	-	Gas/Liquid
Operating Temperature	^{o}c	300
Operating Pressure	psig	300
Dimensions		
Compressor size		
Max Width	mm	100
Max length	mm	45
Design Pressure	psig	385
Design Temperature	^{o}c	300
Insulation		
Material		Stainless Steel
Orientation		vertical

Design flow includes a 10% design margins of leakage and 20% of capacity design margins. All the parameters are declared during the simulation. The purpose is to have the actual condition simulation. Table 2 shows the gas composition of the gas that we want to compress using the submersible compressor.

Table 2: Inlet Gas Composition

Component	**Mol %**
Carbon Dioxide	2.5700
Nitrogen	0.0700
Methane	88.8900
Ethane	4.1200
Propane	2.0900
I-Butane	0.4800
N-Butane	0.5300
N-Pentane	0.1300
I-Pentane	0.2000
N-Hexane	0.1791
N-Heptane	0.4910
N-Octane	0.2498
N-Nonane	0.0029
N-Decane	0.0016
N-Undecane	0.0002
N-Dodecane	0.0001
Total	100.000

This gas composition will be used to be put into the fluent simulation to analyze the compressor performance. As methane appears to be major composition, its data is used for simulation.

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 Results and Discussion

4.1.1 Static Pressure

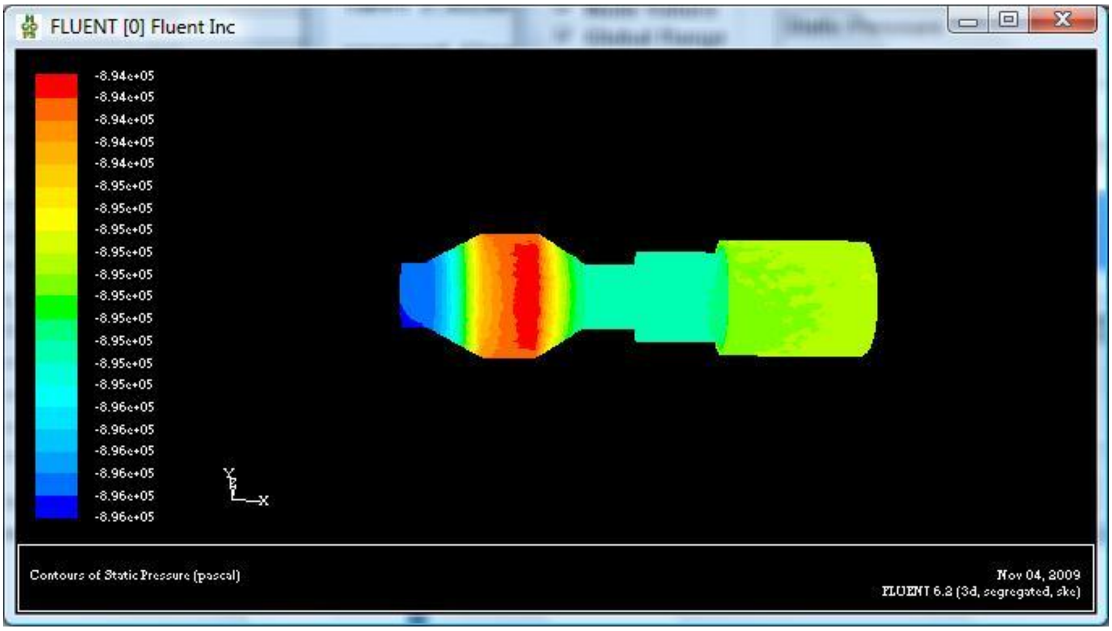

Figure 14: Contours of Static Pressure inside the compressor

Static pressure is the condition where no flowing fluid or gas inside the compressor. Pressure will increase with increasing in area; A. Figure 14 shows that the pressure at the throat is lower than the bigger section. The things happen because of the various in tubing size. Static pressure always refers as atmospheric pressure.

4.1.2 Dynamic Pressure

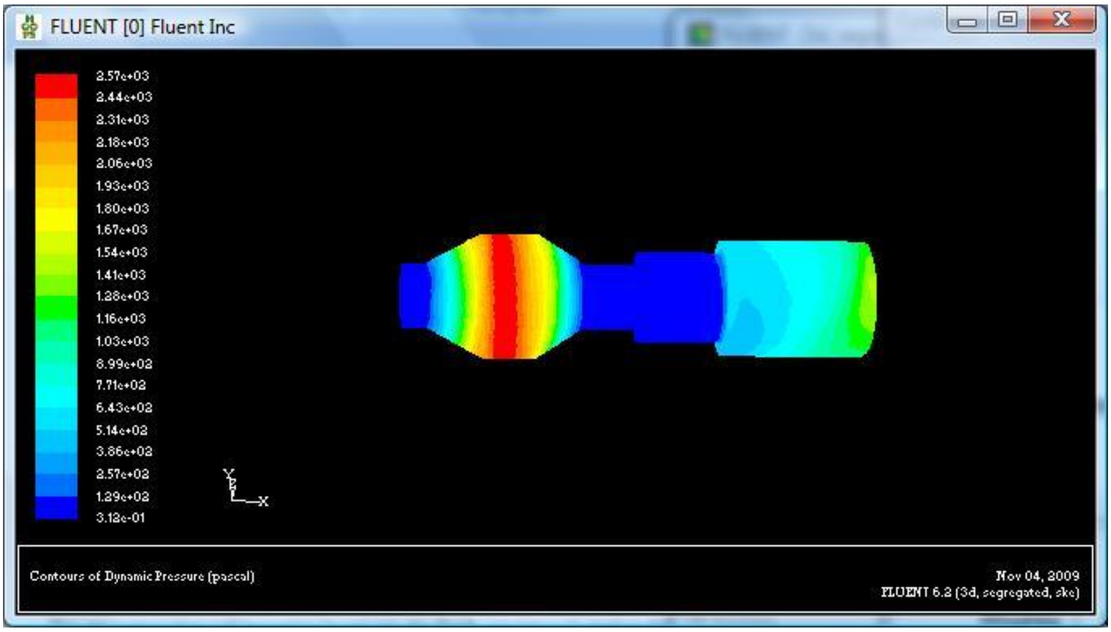

Figure 15: Contours of Dynamic Pressure inside the Compressor

There is steady state and constant pressure at the initial and last part of the compressor but at the second stage inside, the pressure increase. This occurrence due to the centrifugal forces of flowing gas exists as the flow hit the compressor wall and creates the swirling movement. The blue area shows the low pressure area where at this point the velocity can reach supersonic. For this simulation, the 2^{nd} stage compression and 3^{rd} stage compression become stern because the pressure at the 4^{th} part is too high.

4.1.3 Turbulence

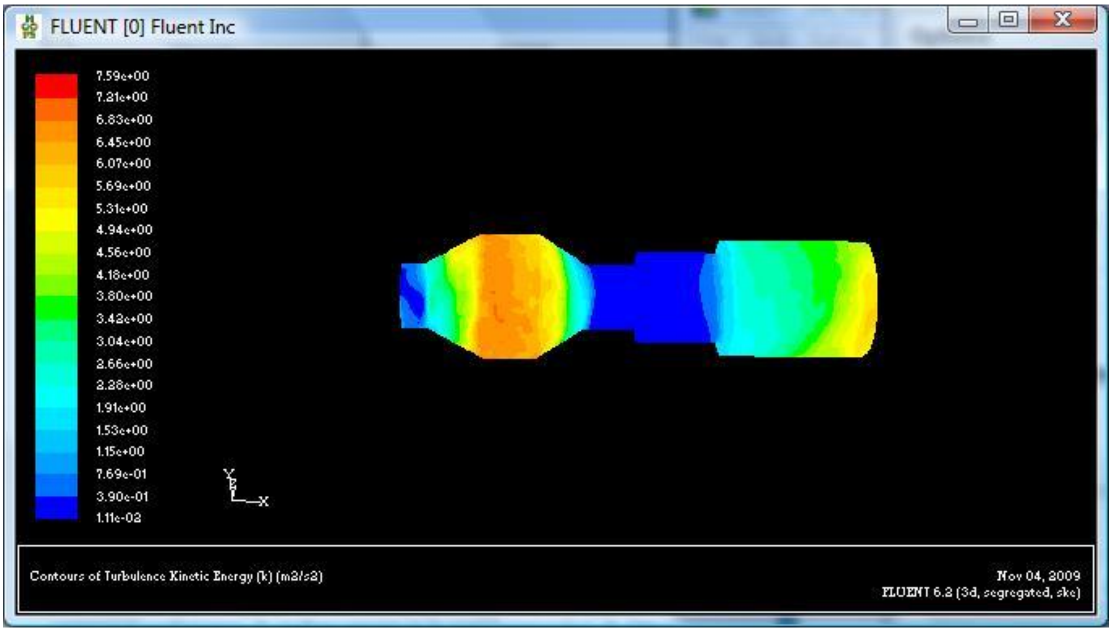

Figure 16: Contours of Turbulence Kinetic Energy inside the Compressor

For turbulence kinetic energy analysis, the picture depicts laminar flow occurs at the inlet and outlet of the compressor. This is due to steady movement of the gas without undergoing any process. The higher energy is supplied at the blower part because the pressure at the part before is enough to make gas move faster.

4.1.4 *Velocity*

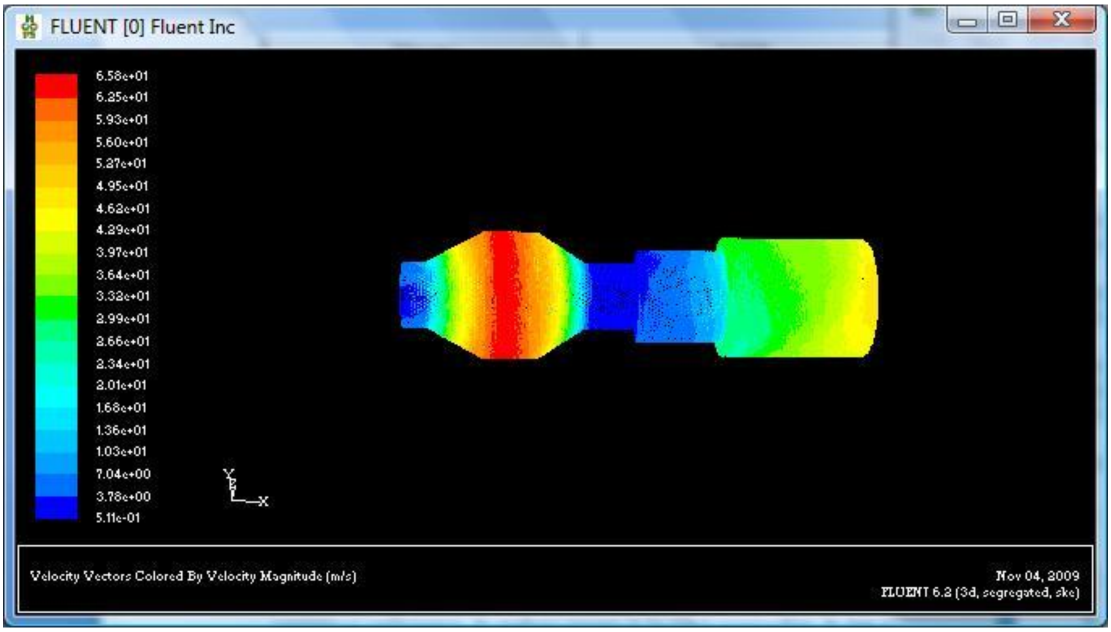

Figure 17: Contours of Velocity inside the Compressor

Velocity is base on the pressure intensity. If the pressure increase the velocity is reduce. At the suction part the velocity is slightly high but after that it's reduce and then increase back. It's because pressure changing will resulting in change of velocity. At the exhaust part, the velocity should increase but in this case it's not happen because the mach number selection in the designing stage. According to the fluid mechanic concept, at the throat, the velocity can reach mach 1 which is same as speed of sound. In this case, mach 0.3 have been chosen so gas flows in subsonic condition. To get the supersonic condition (higher than speed of sound), the 3^{rd} part and the exhaust part should have the same sectional area. In this case the 3^{rd} part is slightly bigger than the exhaust part, that's why the fluid flows in subsonic condition.

CHAPTER 5
CONCLUSION & RECOMMENDATION

5.1 Conclusion

Submersible compressor is one of the option to increase the differential pressure between well and surface. The problem of liquid loading can also be avoided because the possibilities of gas changed to liquid droplet are low at the high pressure condition. These conclusion is depends on the simulation results which shows the pressure is increased at the discharge/outlet after flowing through the compressor. The results also prove that centrifugal compressor is the suitable design to be the design basis because its efficiency and the size constraint as well as the design meet operation range.

5.2 Recommendation

The efficiency of this design must be verified at the actual condition. The practical ways is to do the test in the simulated well. Field test will determine whether the designed submersible compressor can work or not at the real condition which is high pressure and temperature well.

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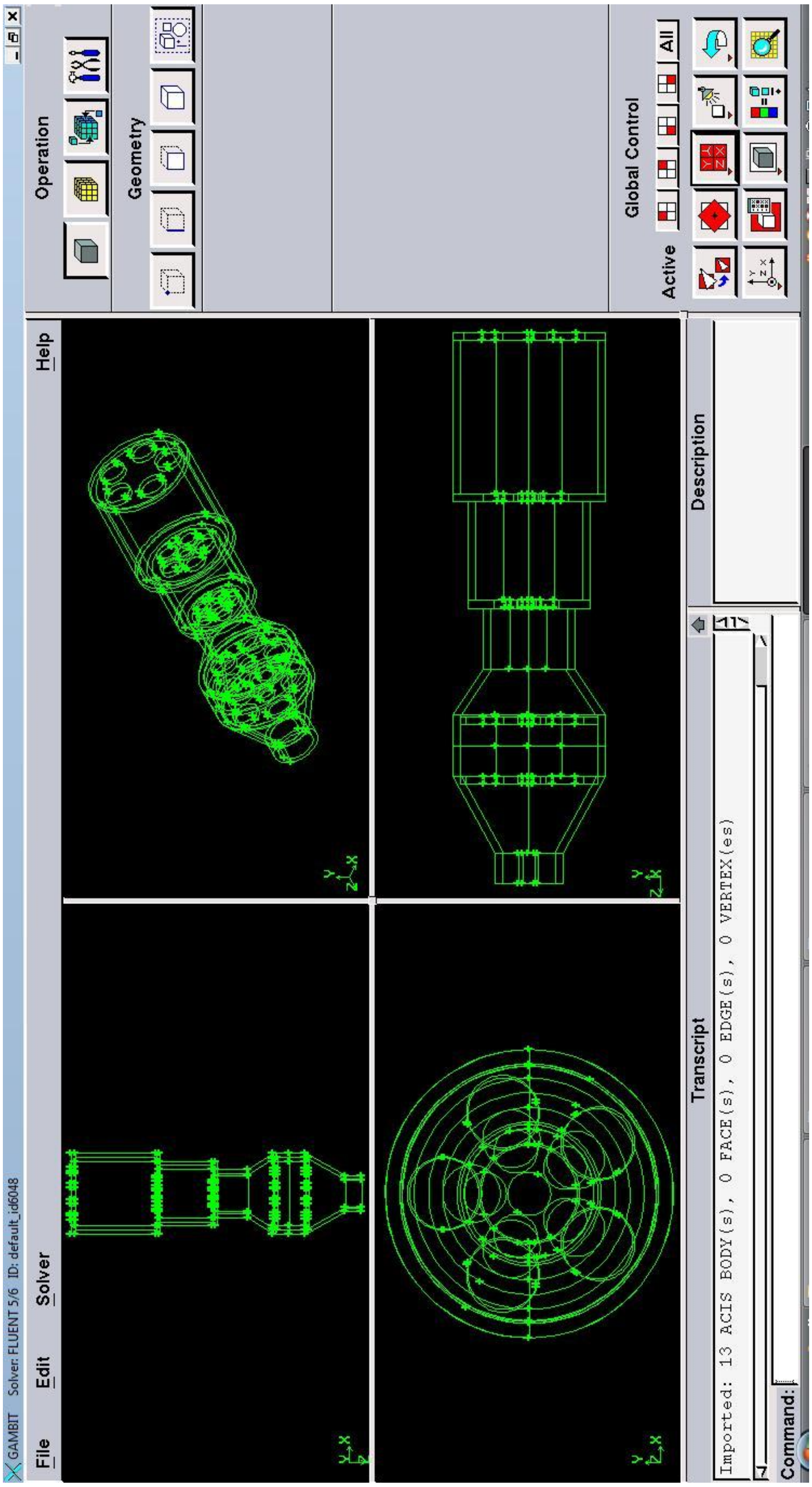
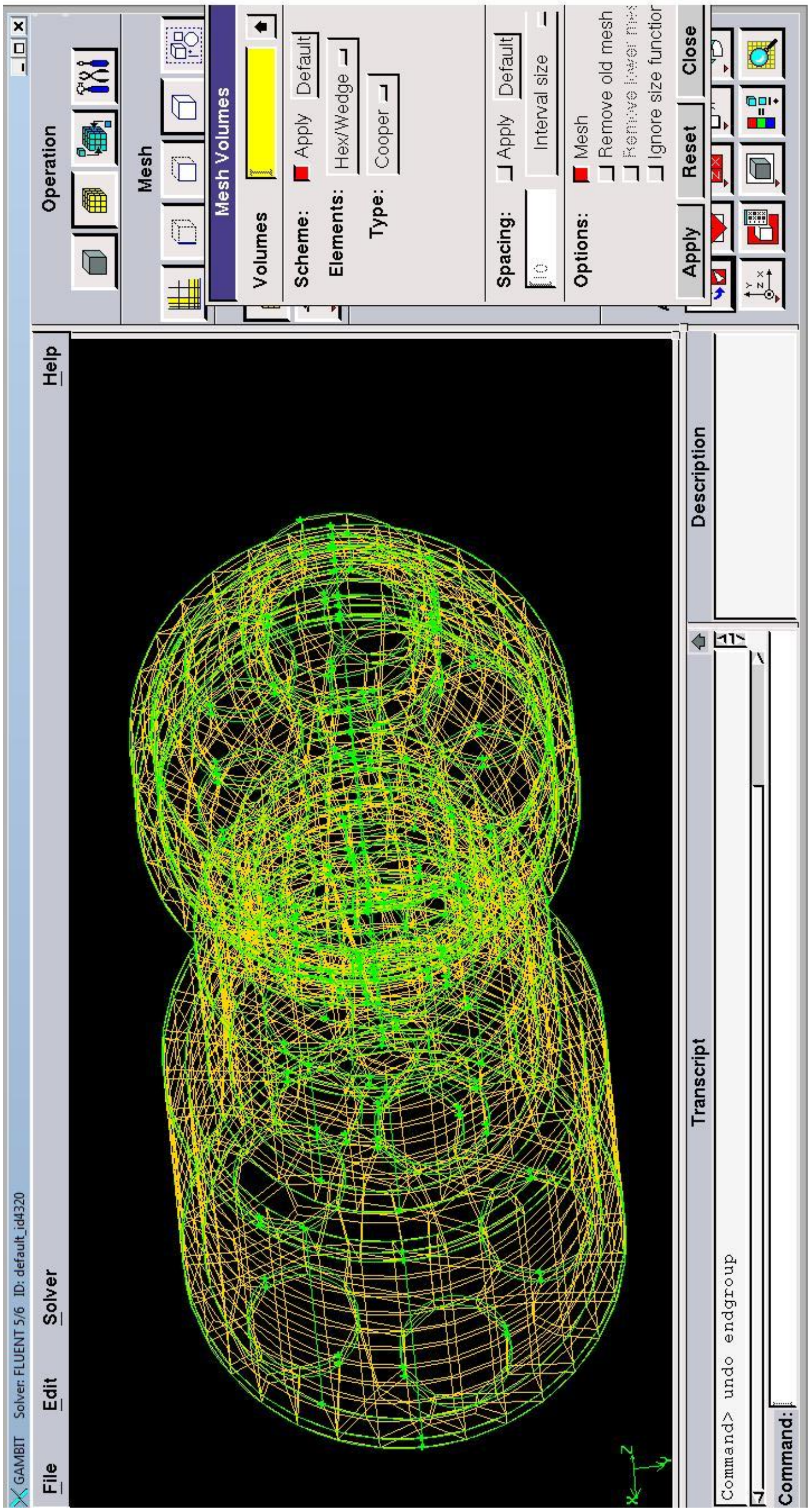
APPENDICES

APPENDIX A

GAMBIT APPLICATION

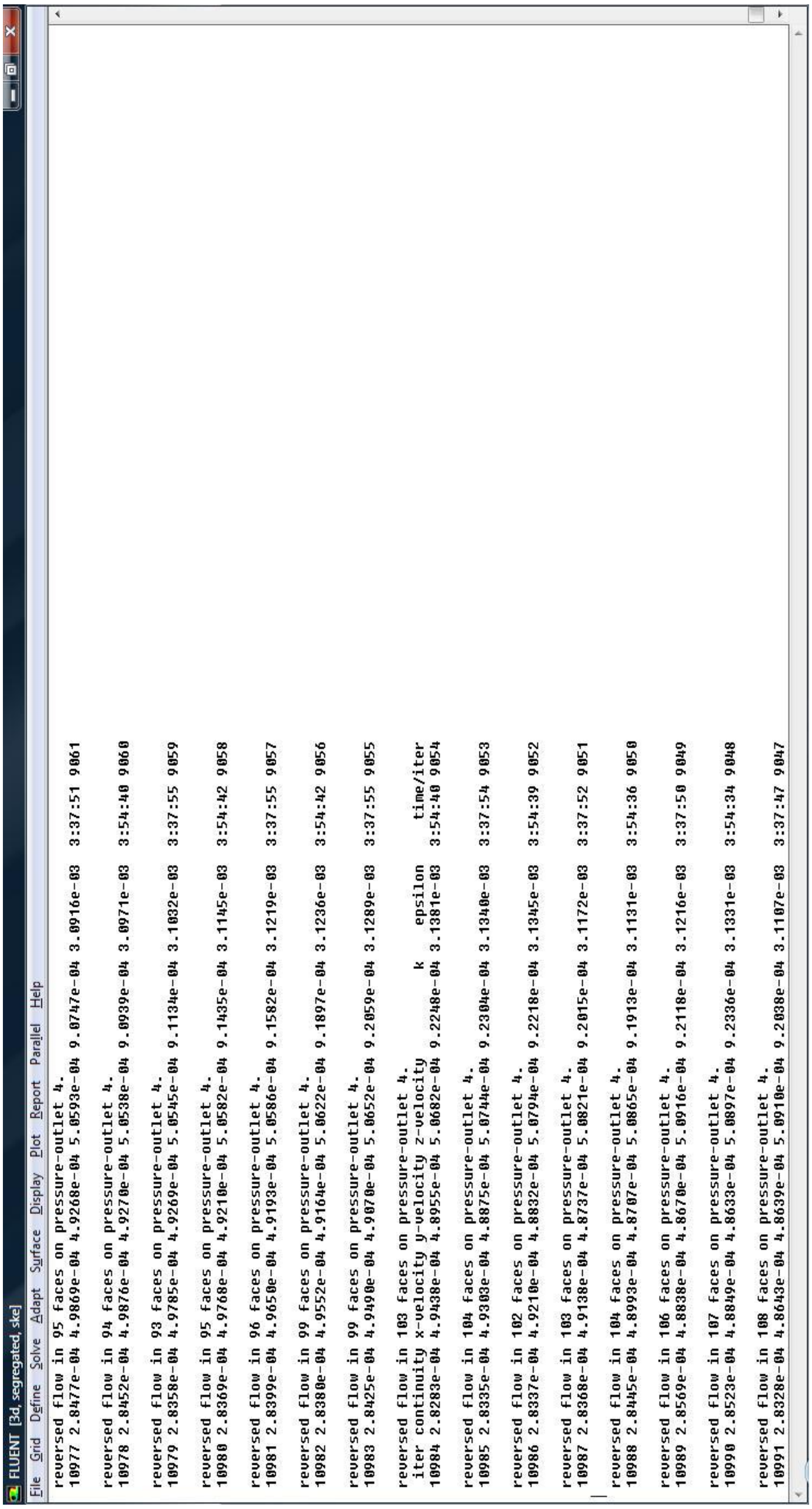


Prototype Drawing

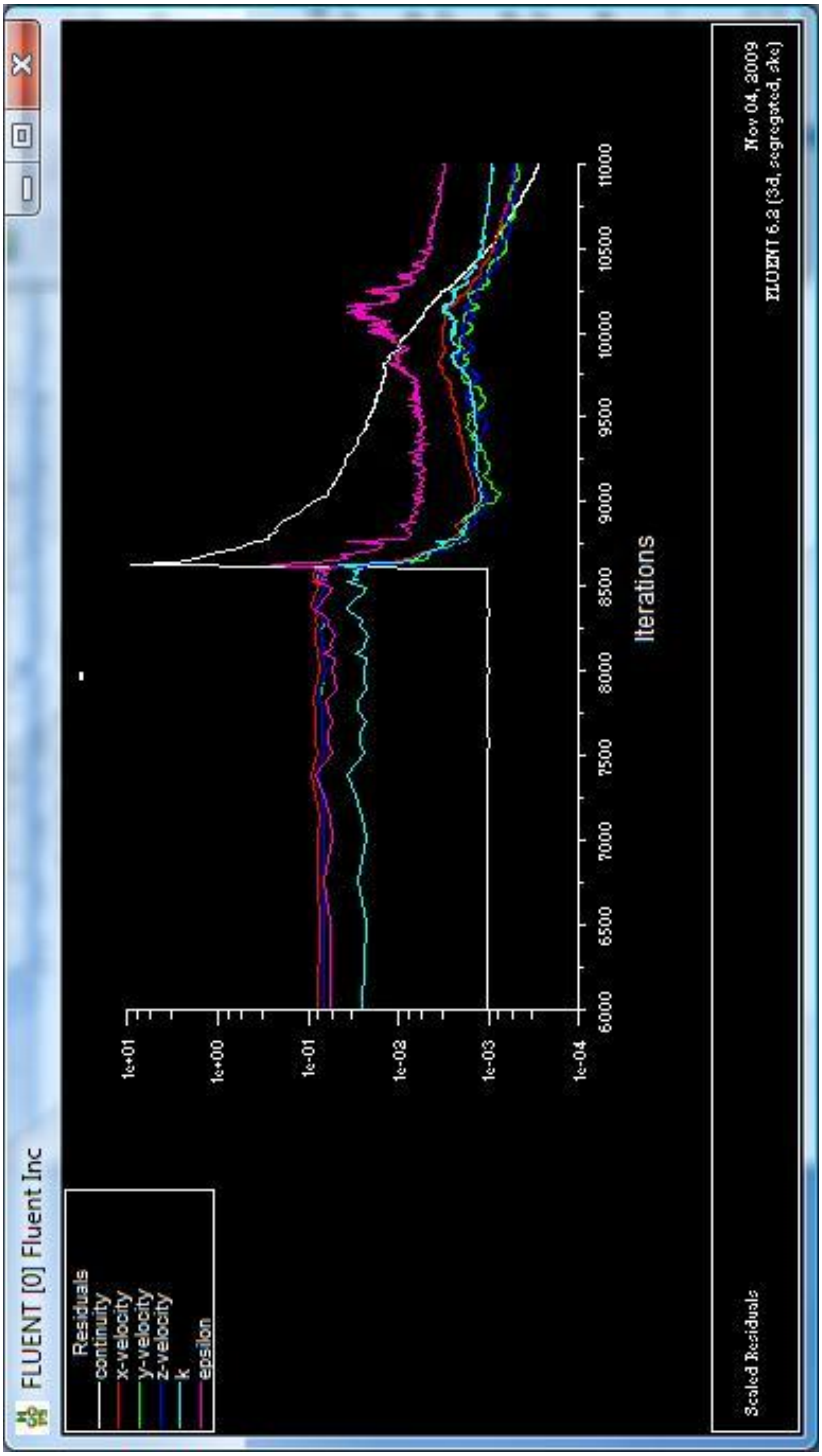


Prototype Meshing

APPENDIX B
FLUENT APPLICATION



Iteration Process



Iteration Process

APPENDIX C
PROTOTYPE PICTURE

Prototype Testing

Prototype view