# 3-D MODELING AND RAPID PROTOTYPING OF A CRYOGENIC LIQUEFIER

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

**Bachelor of Technology**

**In**

**Mechanical Engineering**

By


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Under the guidance of

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**National Institute of Technology**

**Rourkela**


**2010**

**National Institute of Technology**
**Rourkela**

# CERTIFICATE

This is to certify that the thesis entitled, **"3-D Modeling and Rapid Prototyping of a Cryogenic Liquefier"** submitted by **Mr. Nikhilesh Bishoyee** in partial fulfillment of the requirements for the award of Bachelor of Technology Degree in **Mechanical Engineering** at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/ Institute for the award of any degree or diploma.

Place: Rourkela
Date:

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# ACKNOWLEDGEMENT

I am extremely fortunate to be involved in such an exciting and challenging research project like "**3-D modeling and Rapid Prototyping".** This project increased my thinking and understanding capability in the field of cryogenics.

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I would like to express my thanks to all my classmates, all staffs and faculty members of mechanical engineering department for making my stay in N.I.T. Rourkela a pleasant and memorable experience and also giving me absolute working environment.


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# ABSRACT

Our country is still dependent on imports for most of its needs in cryogenic refrigerators and liquefiers. These products are proprietary in nature which makes it very expensive for its cost and maintenance. With support from the Department of Atomic Energy, our institute has initiated a program on development and study of a nitrogen liquefier of intermediate capacity in the range of 10-50 liters/hr by using technologies already developed in our country. The process is based on a suitable modified Claude cycle which minimizes the number of heat exchangers and also takes care to accommodate the in house developed turbo expander. The thermodynamic parameters (temperature, pressure, pinch point temperature) and rate of mass flow are evaluated to obtain the required designing specifications for each component. The main objective of this report is to model all the components that are to be placed inside the vessel using CAD software and make an assembly so that all the components are placed properly inside the vessel and then connect pipes between components according to the design specifications.

# *Chapter 1*

## Introduction

# 1. INTRODUCTION

## 1.1 Cryogenic Liquefier

### 1.1.1 Principle behind Liquefaction

Liquefaction of gases is always done by refrigerating the gas to a temperature below its critical temperature so that liquid can be formed at some suitable pressure below the critical pressure. Thus gas liquefaction is a special case of gas refrigeration and cannot be separated from it. In both cases of liquefaction and refrigeration the gas is first compressed to an elevated pressure in an ambient temperature inside a compressor. This high-pressure gas is passed through a countercurrent recuperative heat exchanger to a throttling valve or expansion engine. Upon expanding to the lower pressure, cooling may take place, and some liquid may be formed. The cool, low-pressure gas returns to the compressor inlet to repeat the cycle. The purpose of the countercurrent heat exchanger is to warm the low-pressure gas prior to recompression and simultaneously to cool the high-pressure gas to the lowest temperature possible prior to expansion. Both refrigerators and liquefiers operate on this basic principle.

In a gas liquefying system the liquid is constantly accumulates and it is withdrawn and stored in other places but in case of a continuous refrigeration system there is no accumulation or withdrawal of refrigerant needed. Thus the total mass of the gas in a liquefying system that gets warmed in the countercurrent heat exchanger is less than the mass of gas that is to be cooled by an amount of the gas that got liquefied. Thus there is an imbalanced mass flow in the heat exchanger. But in case of a refrigeration system the mass of the gas getting cooled and warmed are equal. This is called balanced flow condition. Though the thermodynamic principles behind both refrigeration and liquefaction are same, the analysis and design of these two systems are different because of the condition of balanced mass flow in refrigeration and unbalanced flow in liquefying system.

Low temperature can be produced by throttling process but it depends upon the Joule-Thompson coefficient. J-T coefficient is a property of each gas that depends upon pressure and temperature and it can have a positive, negative or zero value. For instance gases like hydrogen, helium, and neon have negative J-T coefficients at ambient temperature. So, to be used as refrigerants in a throttling process they should first be cooled by a separate pre-coolant liquid. Then throttling process can be applied for further cooling otherwise it will heat these gases.

There is another method for producing low temperature which is the isentropic expansion of the gas through as an expansion engine. In the ideal case, the expansion is generally reversible and adiabatic and therefore the process is isentropic. In this case, the isentropic expansion can be defined as the coefficient which expresses the temperature change due to a pressure change at constant entropy. The isentropic expansion through an expander always results in a decrease of temperature, whereas an expansion through an expansion valve may not always result in a temperature decrease. In the isentropic expansion process energy is removed from the gas in the form of external work, so this method of low-temperature production is sometimes called the external work method.

### 1.1.2 Requirement of nitrogen liquefier

Nitrogen liquefier is used to produce liquid nitrogen. Liquid nitrogen is the commonly used cooling medium because of its low production cost and relatively higher levels of safety. The various application areas of liquid nitrogen are:

- As a pre coolant in production of liquid helium and other low temperature refrigerators.
- Cryotreatment of critical metallic components such as, milling cutters, rollers, needles, dies and punches, knives, bearings and other precision measuring equipments.
- Preservation of live biological material as blood, animal and human sperms, embryos, human parts etc.
- Miscellaneous industrial and laboratory applications.

### 1.1.3 Production of Liquid Nitrogen

Liquid nitrogen can be bought from bulk suppliers or it can be produced in laboratory depending on the requirement. In some parts of India, it is possible to buy liquid nitrogen at low cost from bulk suppliers. There are three major international suppliers of nitrogen liquefiers in our country:

- Consolidated Pacific Industries, USA

- Linde AG, Germany, and
- Stirling Cryogenics of Netherlands.

The liquefier from Stirling Cryogenics is based on the integral Philips-Stirling Cycle, while the latter two use turbine for cold production.

**1.2 Three dimensional modeling**

3D modeling is the process of developing a mathematical representation of any three-dimensional surface of object by the use of specialized software. The product is called a 3D model. It can be displayed as a two-dimensional image through a process called *3D rendering* or used in a computer simulation of physical phenomena. The model can also be physically created using 3D Printing devices.

Almost all 3D models can be divided into two categories.

- Solid - These models define the volume of the object they represent (like a rock). These are more realistic, but more difficult to build. They appear to be the same as a surface model but have additional properties, such as weight, density and center of gravity, just like that of a physical object. These models are commonly used as prototypes to study engineering designs. Solid models are mostly used for non-visual simulations such as medical and engineering simulations, for CAD and specialized visual applications such as ray tracing and constructive solid geometry

- Shell/boundary - these models represent the surface, e.g. the boundary of the object, not its volume (like an infinitesimally thin eggshell). A 3D surface is like a piece of paper that can have any dimension and can be placed at any angle to define a shape. Just like a paper model, different surfaces can be joined to form a surface model. These are easier to work with than solid models. Almost all visual models used in games and film are shell models.

## 1.3 Rapid Prototyping

Rapid prototyping is a process that can be used to produce solid models from Computer Aided Design data. It is a method that uses new manufacturing technologies to produce parts on a layer by layer method. Using this method complex parts can be manufactured quickly and will be cost effective. As the time taken is less compared to other methods it is called rapid. Rapid Prototyping Technologies and Rapid Manufacturing Technologies offer great potential for producing models and unique parts for manufacturing industry. Use of rapid prototyping increases the reliability of the product, saves time and money.

## 1.4 Objectives of the work

Prior to the making of the turboexpander based nitrogen liquefier, the thermodynamic processes have been designed and each equipment specifications have been determined. From the specifications determined for all the components used in the nitrogen liquefier, the modeling of these components is to be done in a solid modeling software and then the components are to be assembled for proper positioning and to be joined with tubes. Then in a 3-d printer the rapid prototyping is to be done.

Requirement of 3-d modeling:

- Proper placing of components inside the vessel.
- To reduce the length of pipes connected to different components.
- To know existing problem with the size of components so that a solution can be made.
- To get a proper understanding of different components and thei requirement.

# *Chapter 2*

# Literature Review

# 2. LITERATURE REVIEW

## 2.1 History of Liquefaction

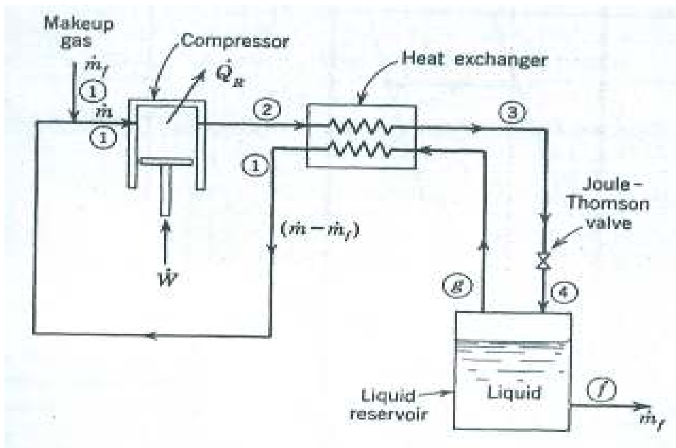
Before 1877, it was believed that the permanent gases, including hydrogen, oxygen, nitrogen and carbon monoxide could not be liquefied at pressures as high as 400 atm. At first in 1877 oxygen gas was liquefied by Cailletet. It was the first permanent gas to be liquefied. Simultaneously Pictet also liquefied oxygen in the same year 1877, in which oxygen was first cooled by sulphur dioxide and then by liquid carbon dioxide in heat exchangers, before being expanded into the atmosphere by opening a valve. The expansion yielded a transitory jet of liquid oxygen, but no liquid could be collected from the high velocity jet.

In 1883, the Polish scientists Olzewski and Wroblewski, at Cracow, had improved Cailletet's apparatus by:

1. Adding an inverted U to the glass tube; and
2. Rreducing the ethylene temperature to - 136°C by pumping it below atmospheric pressure.

These improvements enabled them to produce small quantities of liquid oxygen in the U tube and to liquefy carbon monoxide and nitrogen for a few seconds.

In 1895, Hampson in London and Linde in Munich simultaneously patented compact and efficient air liquefiers which used self-intensive or regenerative cooling of the high pressure air by the colder low pressure expanded air in long lengths of coiled heat exchanger. In this simple way, the complications of cascade precoolers employing liquid ethylene and other liquid cryogens were removed. A further advantage of this simple liquefier was the absence of moving parts at low temperature, the cooling being produced by Joule-Thomson expansion through a nozzle or valve. Carl von Linde made rapid progress in developing this technological breakthrough. He was a professor and research worker at the University of Munich, and he had his own company constructing refrigeration plant.



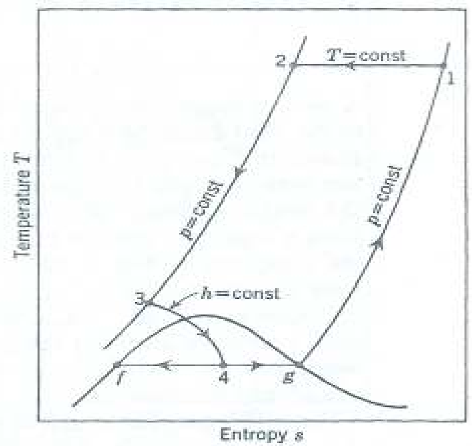
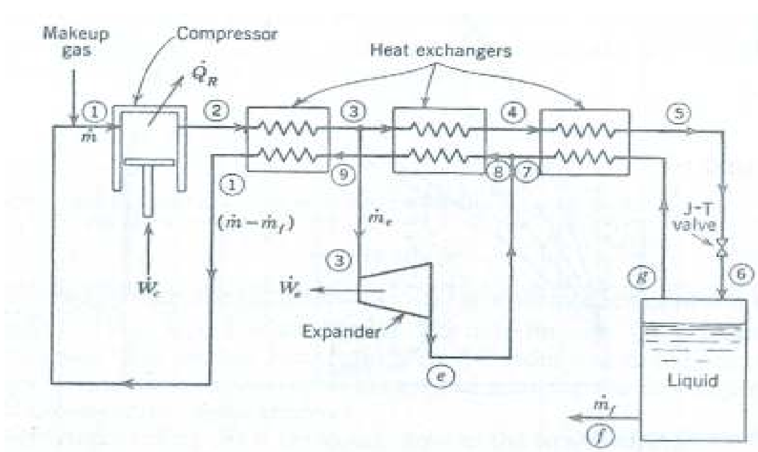




**Fig. 2.1 Linde air liquefaction system** **Fig. 2.2 T-S Diagram of Linde cycle**

Figures have been taken from the book "Cryogenic Systems", Randall F. Barron, 1985.

By 1898, Charles Tripler, an engineer in New York, had constructed a similar but much larger air liquefier, driven by a 75 kW steam engine, which produced gallons of liquid air per hour..

In the year, 1902, a young French innovative engineer Georges Claude, with wide connections in the scientific world of Paris, had succeeded in producing a piston expansion engine working at the low temperatures required for the liquefaction of air. The increase in cooling effect over the Joule-Thomson nozzle expansion of the Linde, Tripler, and Hampson designs was so large as to constitute a second technological breakthrough. Claude developed air liquefiers with piston expanders.



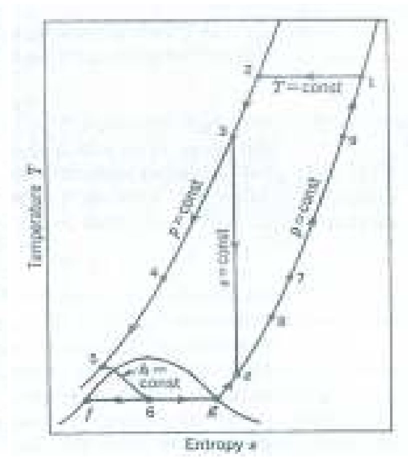




**Fig. 2.3 Claude air liquefaction system** **Fig. 2.4 T-S Diagram of Claude Cycle**

Figures have been taken from the book "Cryogenic Systems", Randall F. Barron, 1985.

In 1882, Kamerlingh Onnes embarked on building up a cryogenic laboratory at the University of Leiden in the Netherlands. Onnes was the first person to develop the triangle of interaction between research, training and industry. He operated an open door policy, encouraging visitors from many countries to visit, learn and discuss.

Kapitza (1939) modified the basic Claude system by eliminating the third or low-temperature heat exchanger. Several notable practical modifications were also introduced in this system. A rotary expansion engine was used instead of a reciprocating expander.

Around 1942 Samuel C. Collins of the department of mechanical Engineering at Massachusetts Institute of technology developed an efficient liquid helium laboratory facility. He developed Collins helium cryostat results economical and safe production of liquid helium.

Helandt (Davies 1949) noted that for a high pressure of approximately 20 MPa (200 atm) and an expansion-engine flow-rate ratio of appro ximately 0.60, the optimum value of temperature before expansion through the expander was near ambient temperature. Thus, one could eliminate the first heat exchanger in the Claude system by compressing the gas to 20 MPa.

**2.2 Solid Modeling using CAD software**

CAD software, also referred to as Computer Aided Design software and in the past as computer aided drafting software, refers to software programs that assist engineers and designers in a wide variety of industries to design and manufacture physical products.

In web we can find out the history of CAD software development. From the website *www.cadazz.com/cad-software-history.htm* the history of CAD software can be known. Here it has been discussed.

"***The Elements***" proposed by the mathematician Euclid of Alexanderia around 350 B.C. is the foundation of Euclidian geometry and today's CAD software are built upon that.

In the early 1960s sketchpad was developed by Ivan Sutherland which was very innovative and useful at that time. He was pursuing his PhD thesis in MIT at that time.

The first generation of CAD software were 2D drafting applications which was developed by some manufacturer's internal IT team with collaboration of university researchers. Dr. Hanratty had co-designed such a CAD system, which was named DAC (Design Automated by Computer) in the mid 1960s at General Motors Research Laboratories.

In 1965, Charles Lang's group including A.R.Forres and Donald Welbourn, began research into 3D modeling using CAD software at Cambridge University's Computing Laboratory. The co In mid 1960s in Europe, French researchers were doing research work into complex 3D curve and surface geometry computation. Citroen's de Casteljau made some useful research in computing complex 3D curve geometry and Bezier incorporated some algorithm proposed by de Casteljau to publish his breakthrough research, in the late 1960s.

Until 1970 CAD software was used only for research purpose but in 1970s it was commercialized. Different manufactyuring companies in automotive and aerospace sector used their teams to develop CAD software and university researchers were working with them too. Different automotive companies like Ford, Mercedes-Benz, General Motors. Nissan, Toyota and aerospace manufacturers like McDonnell-Douglas, Lockheed and Northrop had their own CAD development teams.

Avions Marcel Dassault, a French aerospace company bought a source-code license of CADAM from Lockheed and in 1977 it developed a CAD software called CATIA known as Computer Aided Three Dimensional Interactive Application which is used now-a-days too with modifications.

After that many research work has been done in the field of 3-D modeling using CAD software and many software have been developed. Time to time these software have been modified to make them more user friendly. Different 3-D modeling software used now-a-days are AUTODESK INVENTOR, CATIA, PRO-E etc.

## 2.3 History of Rapid Prototyping

Rapid prototyping is a useful technology in which a model done using CAD is taken as input and then by layer by layer construction a solid part similar to the model can be produced. It helps for analysis and development of different components of a system. It has minimum production risk and it is a time saving process in case of complex designs.

From the web search the history of Rapid Prototyping can be known. Here below the history of Rapid Prototyping has been discussed which has been taken from the website *www.prototypezone.com/prototype/prototyping-history-and-prototype-development-information.*

In the late sixties Herbert Voelcker, an engineering professor thought about computer controlled automatic machine tools. He was trying find a method to control the automatic machine tools using a program in the computer.

Carl Deckard, a researcher form the University of Texas, proposed the layer based manufacturing method in 1987. He thought of building a model layer by layer. He used laser beam to fuse metal powder to form solid prototypes, making only one layer at a time. This technique was developed into Selective Laser Sintering.

Voelcker's and Deckard's useful findings, innovative thoughts and researches have given new approaches to the rapid prototyping industry. Rapid prototyping techniques have been developed and revolutionized.

Though there are many people who have done significant work in the field of rapid prototyping, Charles Hull's patent of Apparatus for Production of 3D Objects by Stereo lithography has been recognized the most. He is known as the father of Rapid Prototyping.

Today a design in any CAD software can be prototyped without much hard work and it has made manufacturing not only simple and quick but also cost effective.

# *Chapter 3*

# Process Design and Components of Nitrogen Liquefier

### 3.1 Modified Claude Cycle for Nitrogen Liquefier

A modified Claude cycle is taken into consideration to design nitrogen liquefier to take the advantage of both the turboexpander and JT valve. Instead of three heat exchangers as in the Claude cycle, two numbers of heat exchangers are used in this liquefier. Last two heat exchangers of the Claude cycle are combined to a single heat exchanger to reduce the cost of the liquefier.

A turbo expander based nitrogen liquefier consists of following parts:

- Compressor
- Heat exchangers
- Turboexpander
- JT Valve
- Phase separator
- Cold box
- Piping
- Instrumentation

A screw compressor will be installed to provide the compressed nitrogen gas. Heat exchangers are vital components of any cryogenic refrigerator. To exchange high heat in small area plate fin compact heat exchanger are used. The turboexpander is the heart of the liquefier and it can used lowering the temperature to expectable amount adiabatically. JT valve is used for isenthalpic expansion. Phase separator is used to separate liquid and gas. Piping and other instrumentations are required to connect and control the systems. Whole thing is kept inside the cold box.

Fig.3.1 shows the process diagram of the nitrogen liquefier. At atmospheric temperature and pressure at 1.1 bar the pure nitrogen gas is feed into the screw compressor and compressed up to 8 bars. The compressed gas is passed through the first heat exchanger i.e. HX1. Then some mass is diverted through the turboexpander and remain passes through the second heat exchanger i.e.HX2 for liquefaction. For easy calculation HX2 split into two parts i.e. HX2a and HX2b. From the HX2, isenthalpic expansion takes place by using JT valve which results liquid nitrogen.

Liquid nitrogen taken out and remain vapor nitrogen meet with the isentropic expanded nitrogen by the turboexpander and feed again to the compressor by passing through the HX2 and HX1.

From the study of the thesis "*Process Design of Terboexpander based Nitrogen Liquefier", 2009, by Mr. Balaji Kumar Chouwdhury*, the process design and the T-S diagram of modified Claude cycle has been given here.

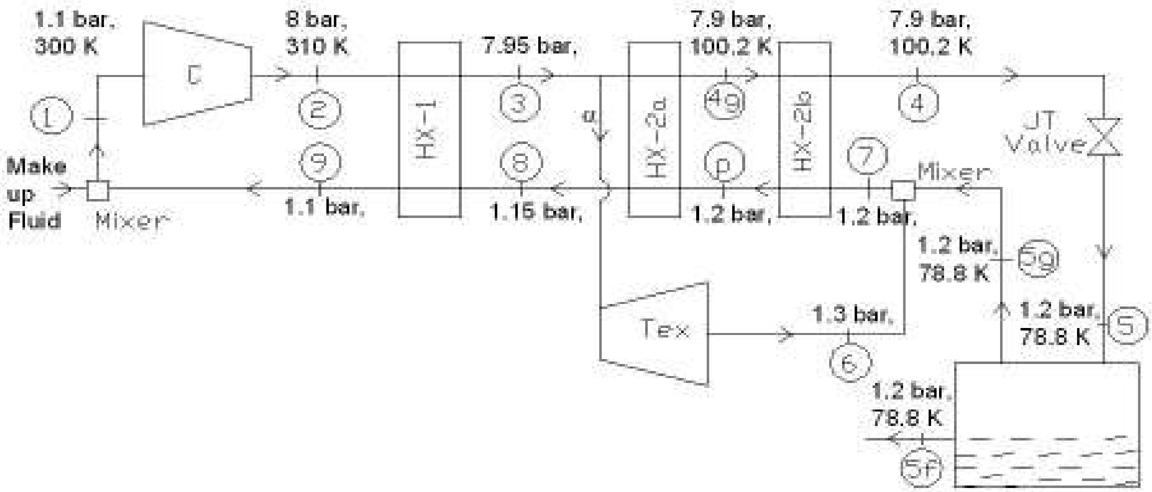



**Fig. 3.1 Process Diagram Nitrogen Liquefier**

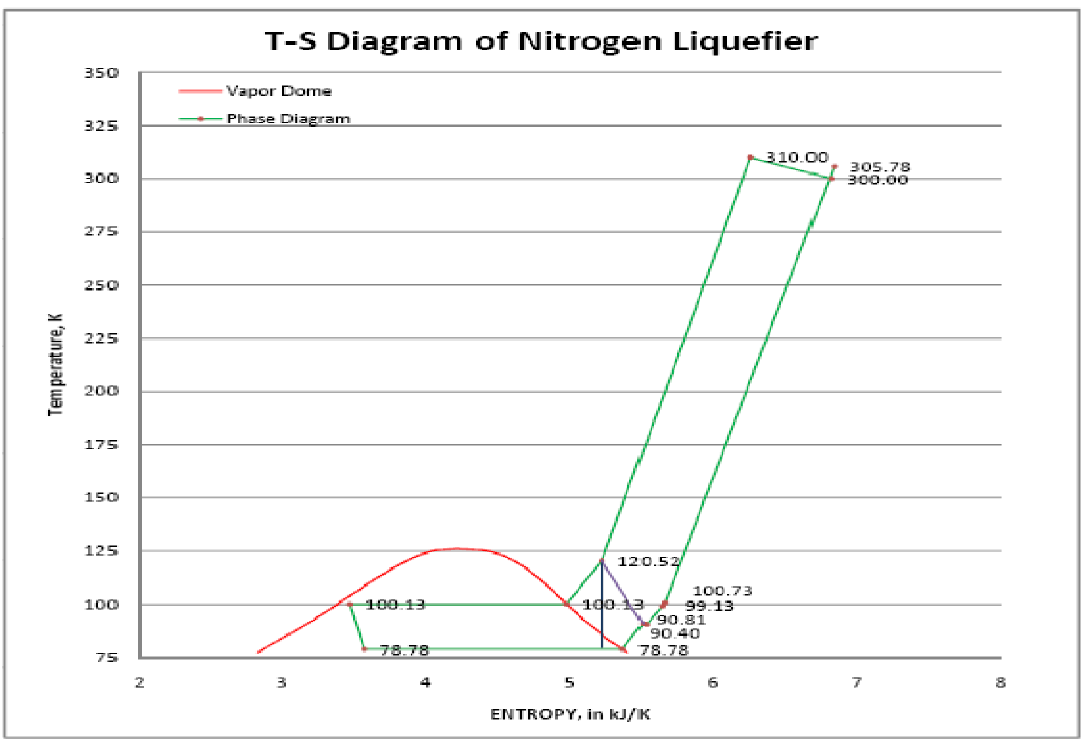



**Fig. 3.2 T-S Diagram of Nitrogen Liquefier**

# *Chapter 4*

# 3-D Modeling using CAD

### 4.1 Autodesk Inventor

Different types of engineering drawings, construction of solid models, assemblies of solid parts can be done using inventor.

Different types of files used are:

1. Part files: .ipt
2. Assembly files: .iam
3. Drawing files: .idw
4. Presentation files: .ipn

**Part Modeling**

Autodesk inventor is a parametric feature based solid modeling application.

**2-D Sketch Panel**

- Line,spline
- Center point circle, Tangent circle, Ellipse
- Three point arc, Tangent arc, Center point arc
- Fillet, Chamfer
- Point , Center point
- Polygon
- Two point rectangle, Three point rectangle
- Mirror
- Rectangular pattern
- Circular pattern
- Offset

Dimensioning:

- General dimension
- Auto dimension
- Constraints (perpendicular, parallel, tangent, smooth, coincident, concentric, collinear, equal, horizontal, vertical, fix, symmetric)

Other features:

- Trim
- Split

- Move
- Copy
- Scale
- Rotate

**3-D Modeling Features:**

Extrude: To make a sketch thick in any perpendicular direction or to cut material

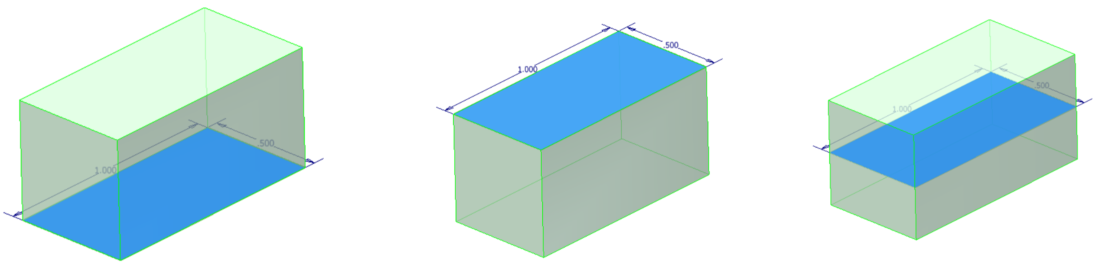


**Fig. 4.1 Extrusion feature in Autodesk Inventor**

Revolve: a sketch can be revolved about an axis or line to get a solid feature

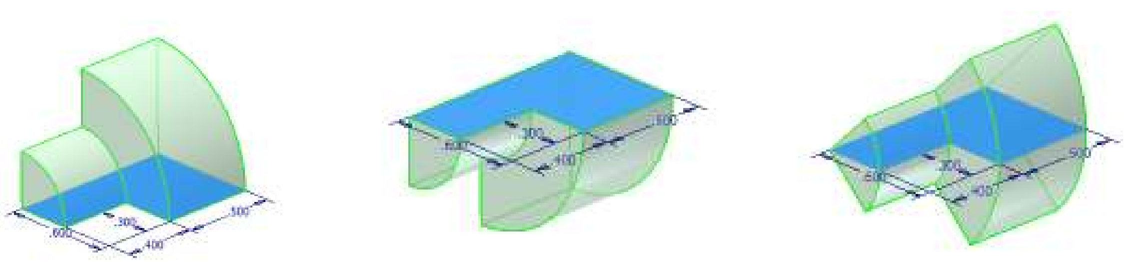


**Fig. 4.2 Revolve feature in Autodesk Inventor**

Hole: To make a hole in the solid.

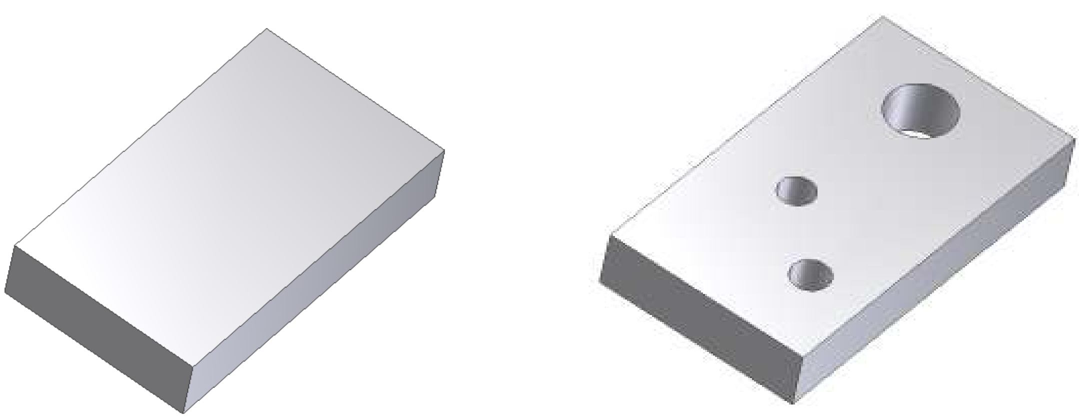


**Fig. 4.3 Hole feature in Autodesk Inventor**

Shell: To make a solid hollow shell feature is applied and thickness is mentioned.

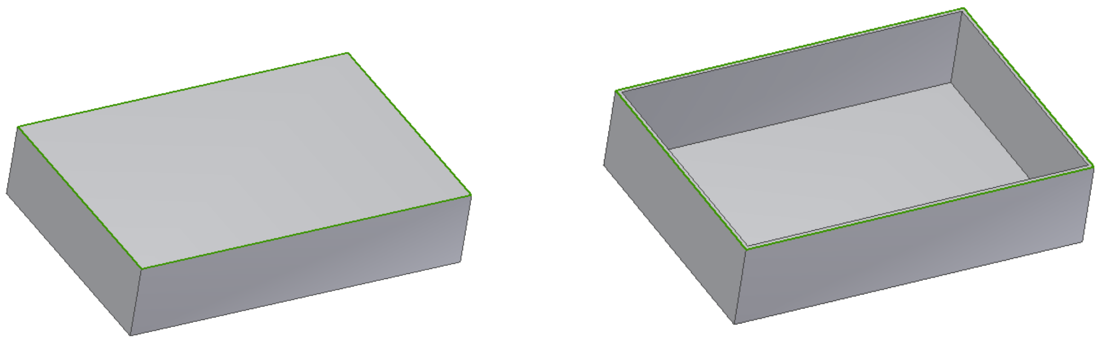


**Fig. 4.4 Shell feature in Autodesk Inventor**

Rib: A rib is a triangular or rectangular solid object to add extra strength

Loft: it is a solid feature build on multiple sketches. It has a variable cross section defined by two or more sketches residing on different sketch planes. Different sketch planes are taken and closed profiles are made to guide the solid.

Sweep: it can be 2-d or 3-D sweeping. In 2-D the path in which profile will be guided is in a plane and in 3-D it is in space (not in one plane).

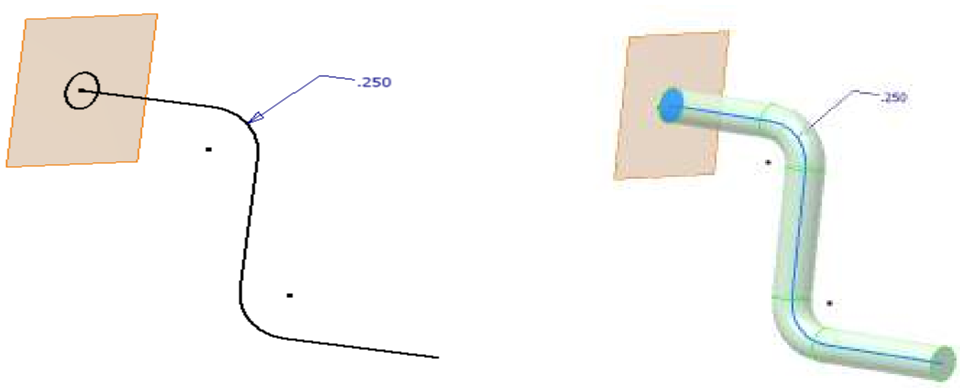



**Fig. 4.5 2-D Sweep feature in Autodesk Inventor**

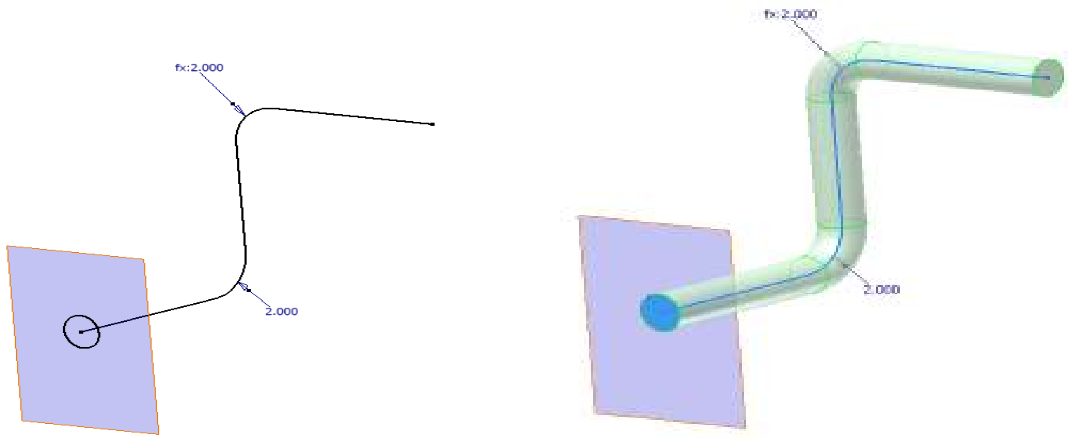



**Fig. 4.6 3-D Sweep feature in Autodesk Inventor**

Join: New sketched solid features and existing solids can be joined by using this feature.

Cut: To cut the newly sketched solid feature from the existing one.

Intersect: after making a new sketched solid, intersection option is choosen to make a resultant solid which contains the common solid part of both new sketched and existing solid.

Coil: It is special kind of 3-D sweep solid in which the profile sketch is swept along a helical path.

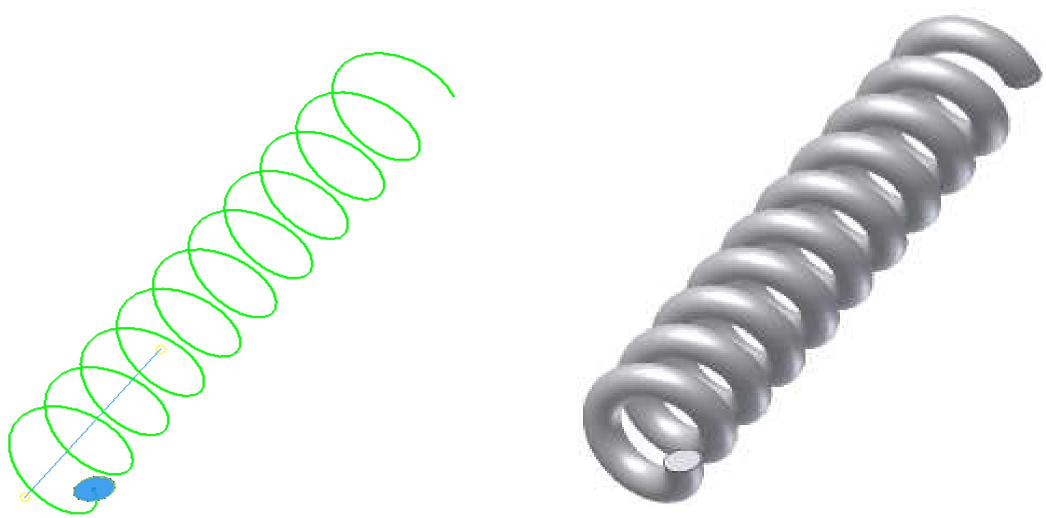


**Fig. 4.7 Coil feature in Autodesk Inventor**

Thread: To create threading. A circulate object is selected and the pith and length of thread is defined for threading.

**Fig. 4.8 Thread feature in Autodesk Inventor**

Fillet: The fillet feature is used to round off the edges of a solid. Edge is selected and fillet radius is specified.

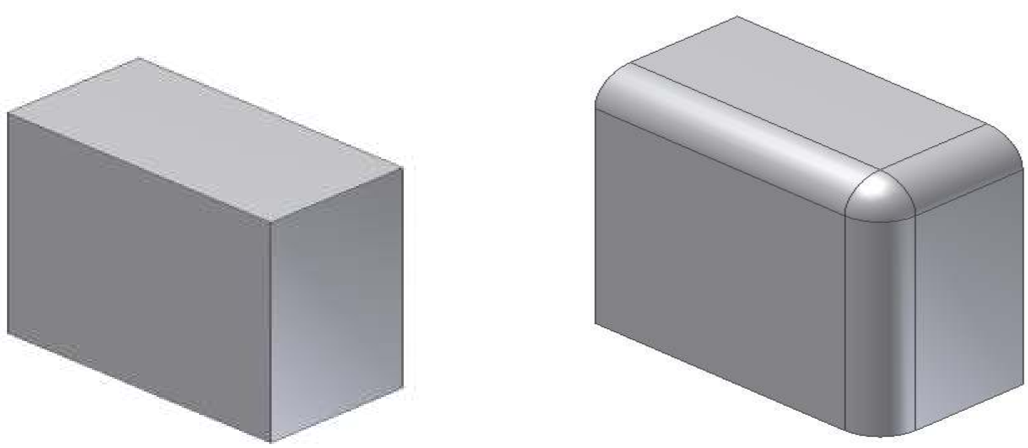


**Fig. 4.9 Fillet feature in Autodesk Inventor**

Chamfer: It bevels the edges of a solid. Bevel distance or angle is specified after selecting the edge.

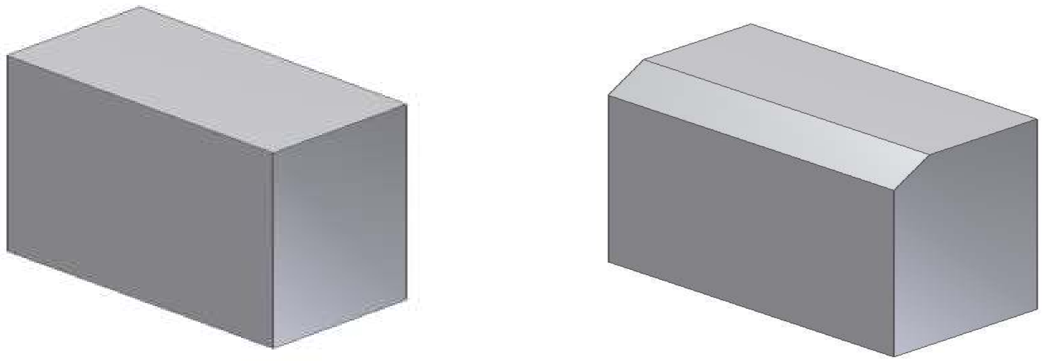


**Fig. 4.10 Chamfer feature in Autodesk Inventor**

Rectangular and Circular pattern: To repeat some feature in a solid rectangular pattern or circular pattern is used.

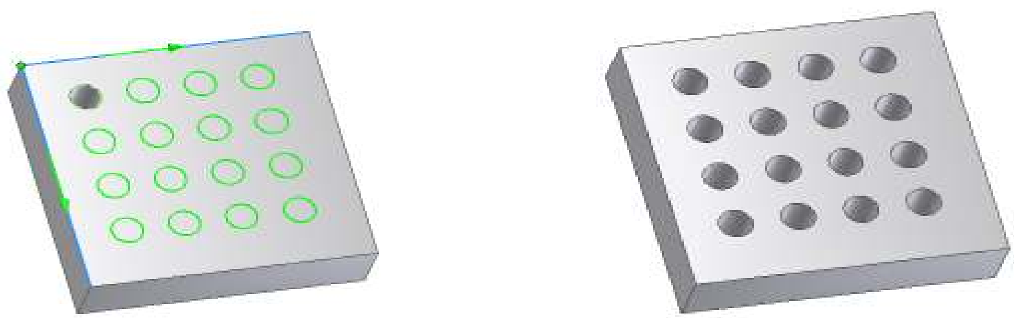


**Fig. 4.11 Rectangular Pattern feature in Autodesk Inventor**

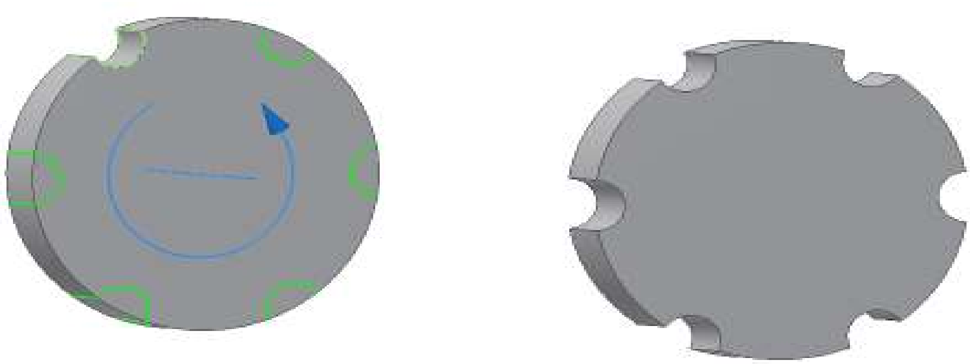


**Fig. 4.12 Circular Pattern feature in Autodesk Inventor**

### 4.2 Modeling of components of Nitrogen Liquefier

Different components modeled using Autodesk Inventor are

- Single Heat exchanger
- Double Heat Exchanger
- Turbo Expander
- Top plate
- Vessel
- Phase separator
- Valve

The components listed above have been modeled using the features like extrude, revolve,rib, sweep, shell, fillet, hole etc. The images of the modeled components have been shown below.

After modeling of components to be placed inside the vessel, the assembly was done for proper positioning and to create pipes between them. the inlet and outlet of the pipes were made exactly according to the actual nitrogen liquefier and positioning of components was done so that the pipe length will be minimum.

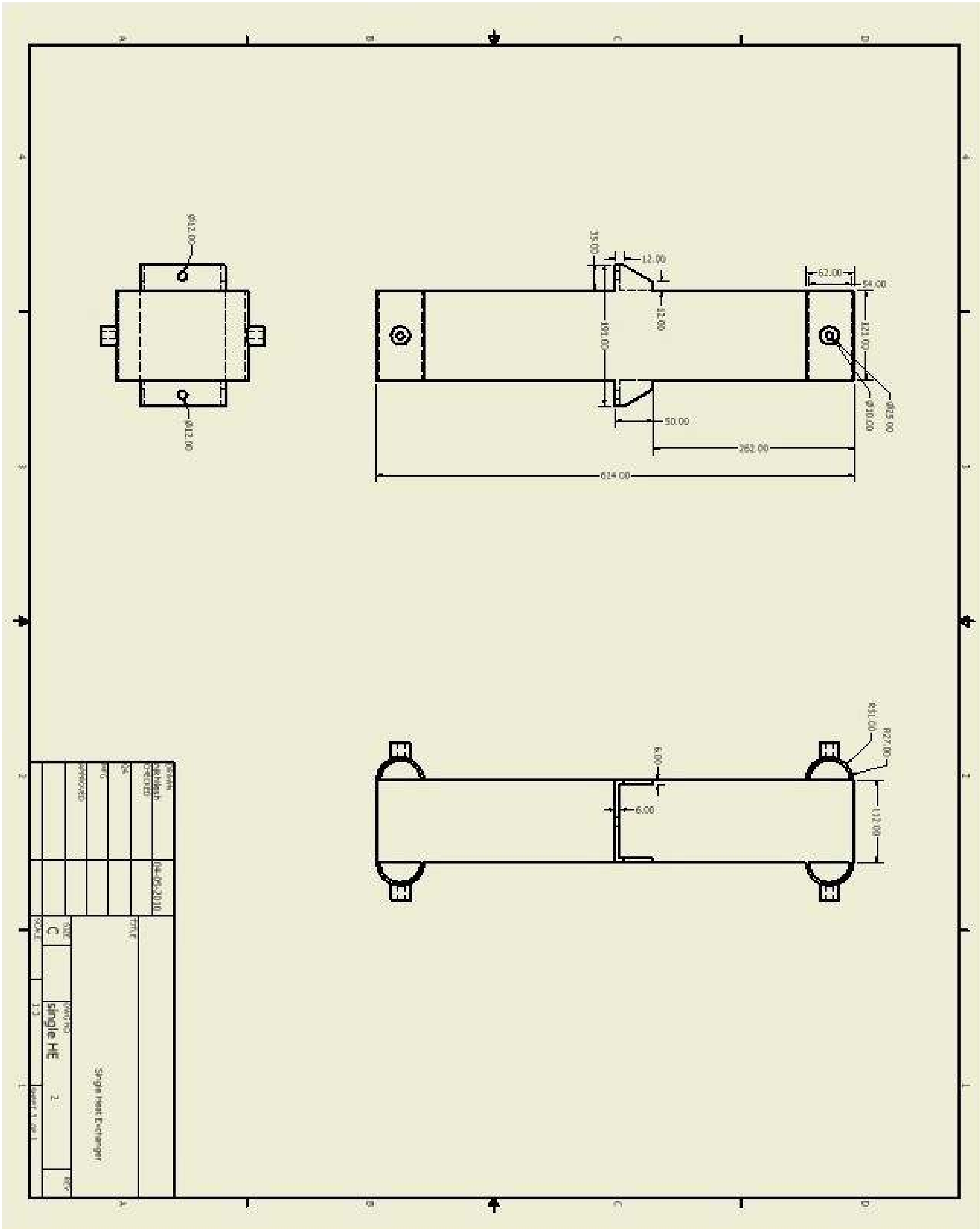


**Fig. 4.13 Single Heat Exchanger Draft Sheet**

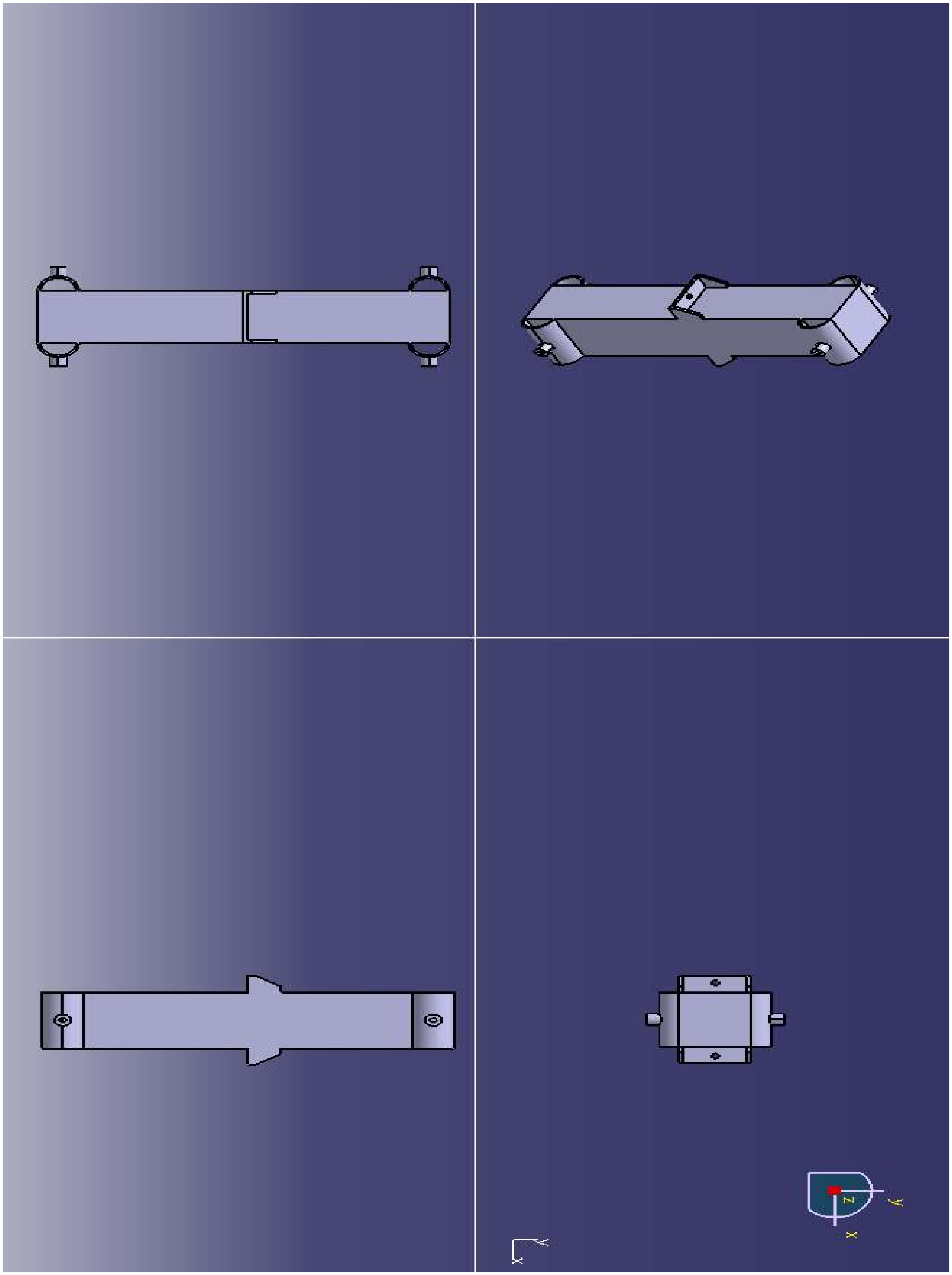



**Fig. 4.14 Single Heat Exchanger 3-D Model**

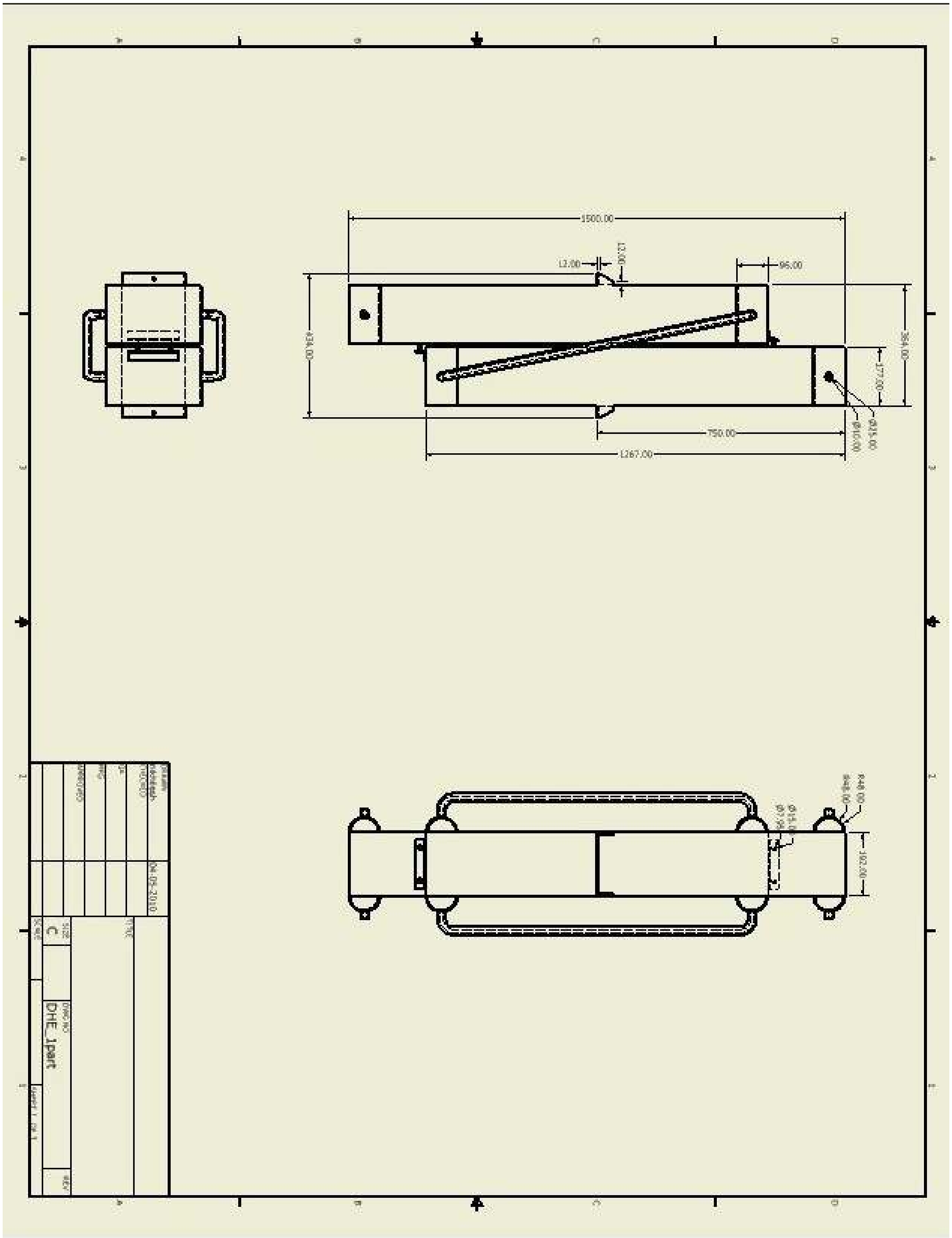


Fig. 4.15 Double Heat Exchanger Draft Sheet

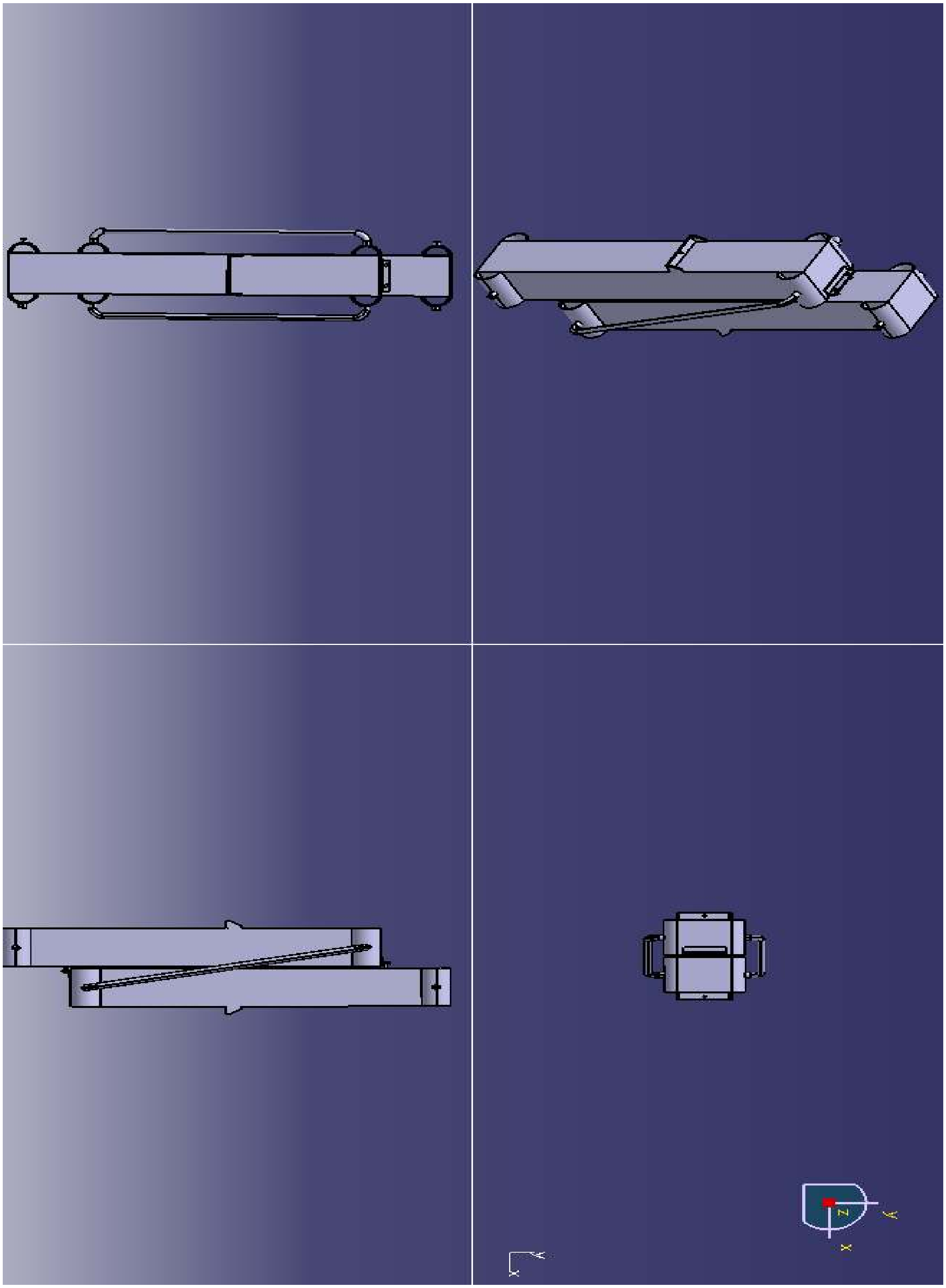


Fig. 4.16 Double Heat Exchanger 3-D Model

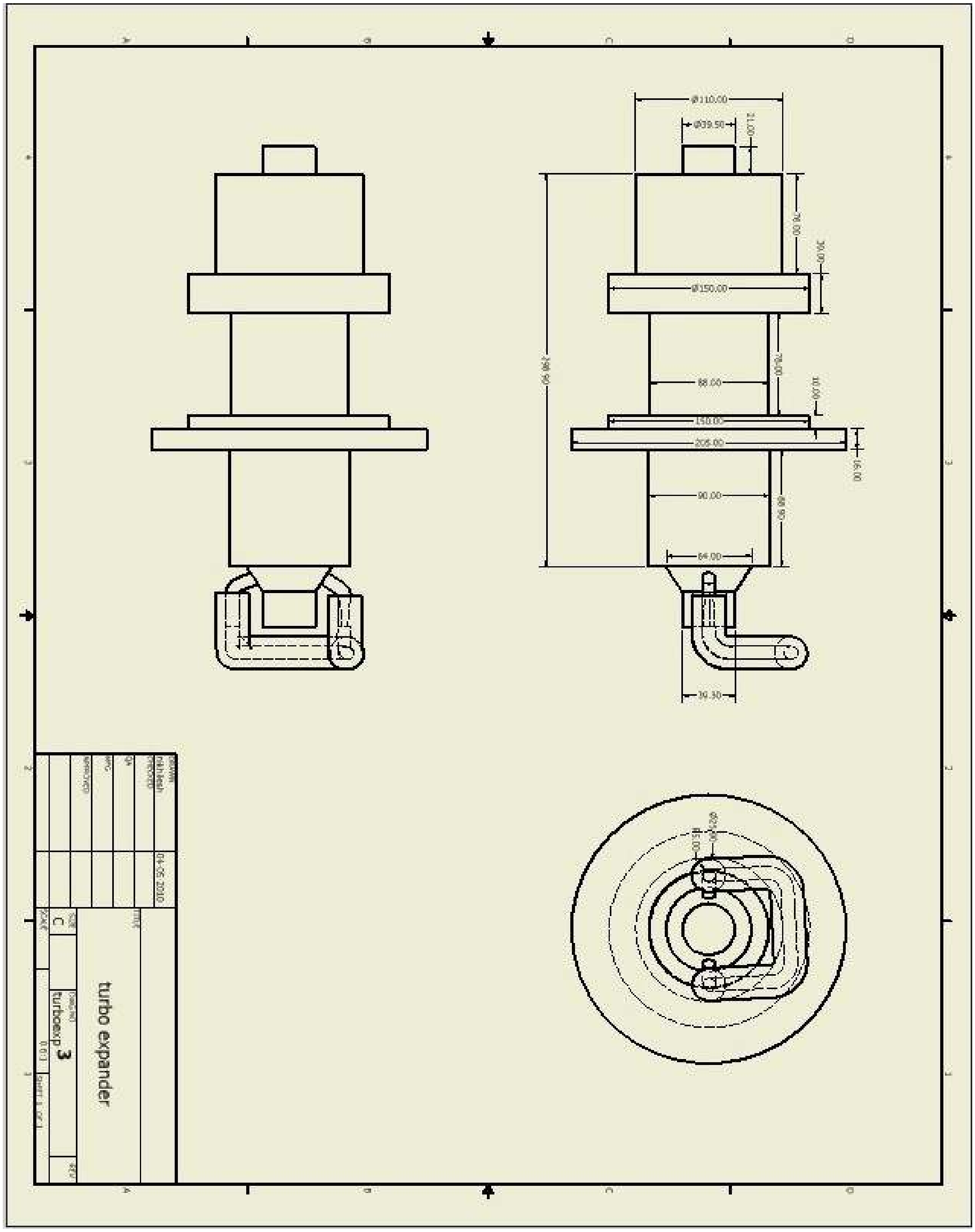


**Fig. 4.17 Turbo Expander Draft Sheet**

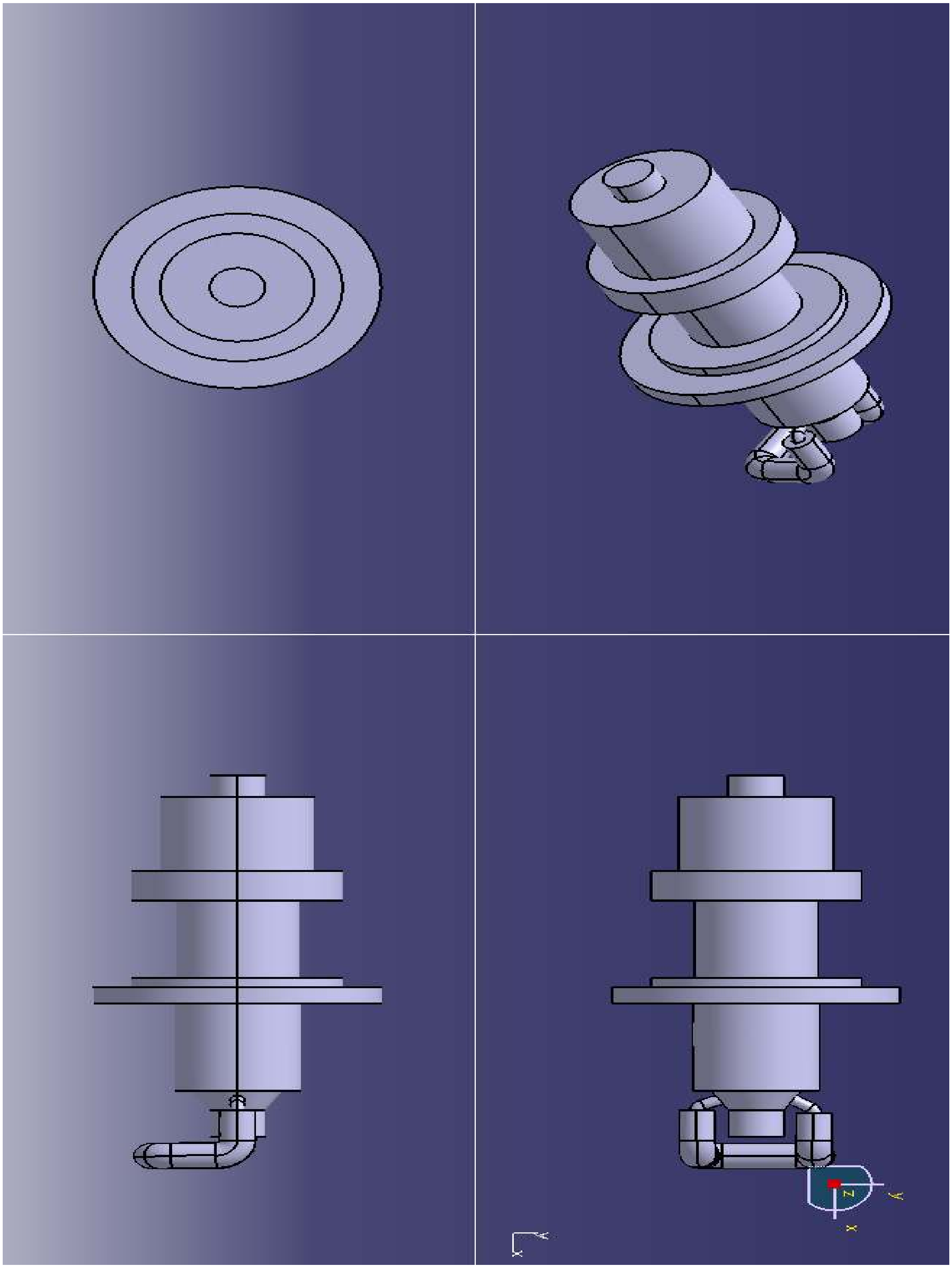


Fig. 4.18 Turbo Expander 3-D Model

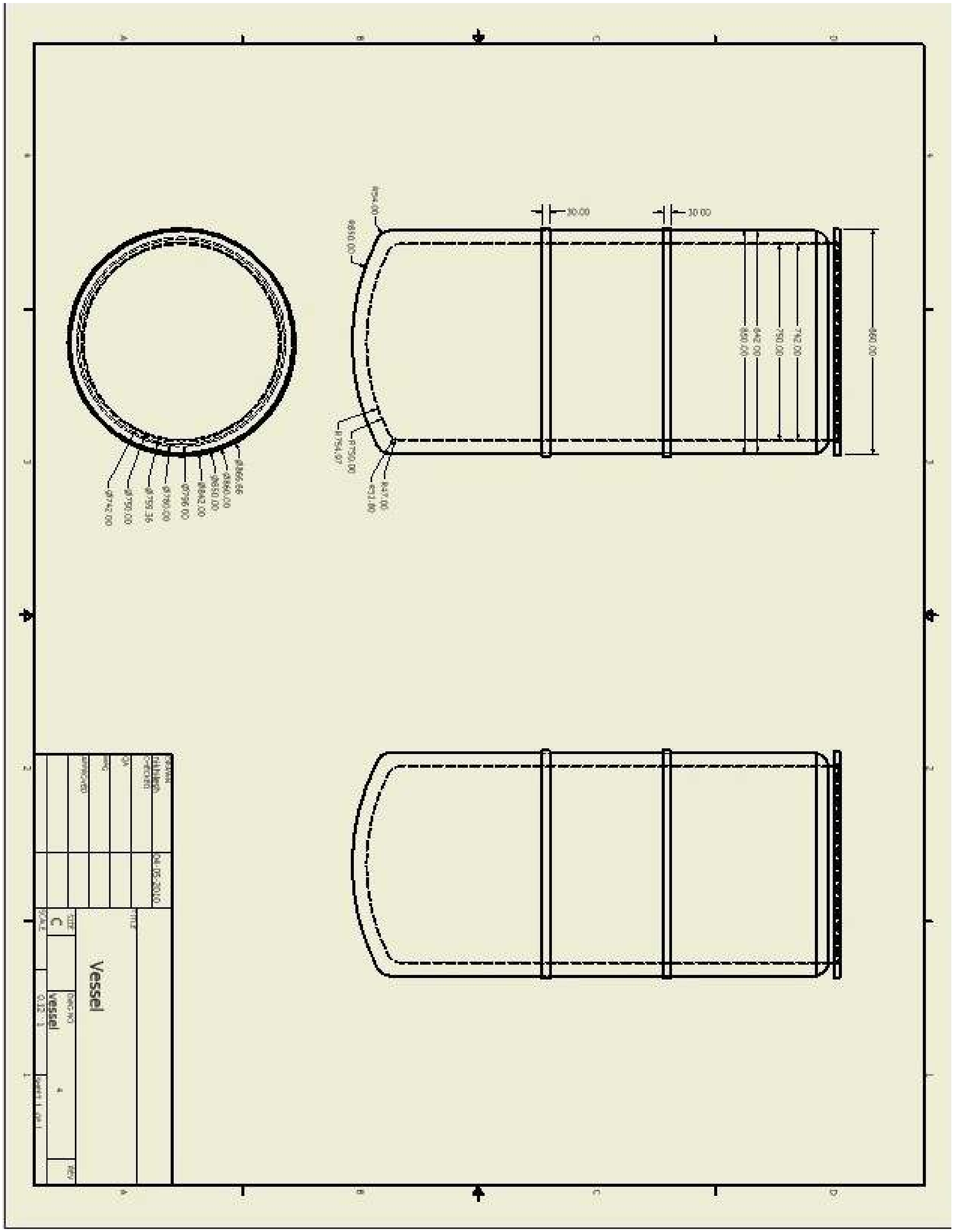



Fig. 4.19 Vessel Draft Sheet

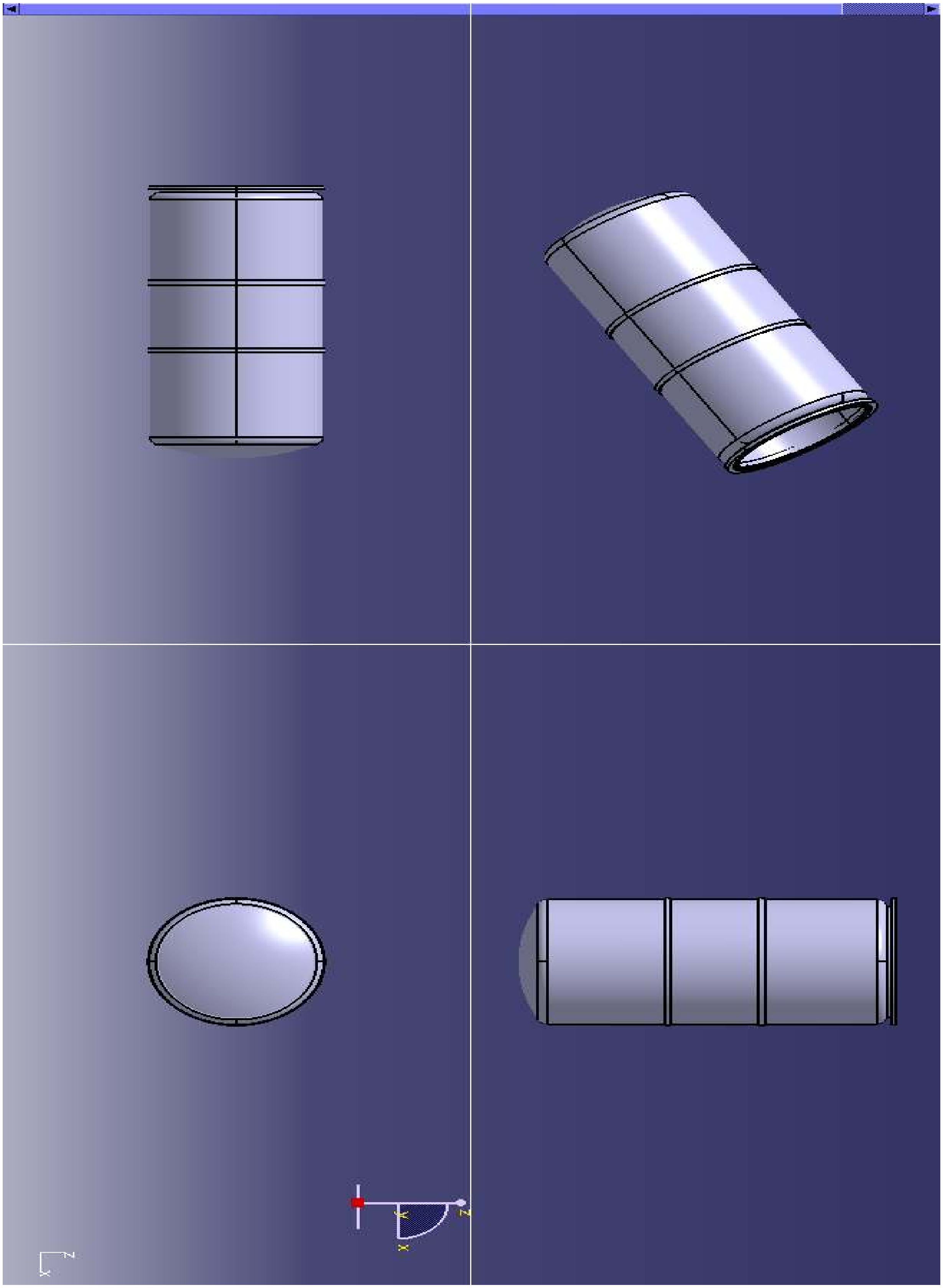


**Fig. 4.20 Vessel 3-D Model**

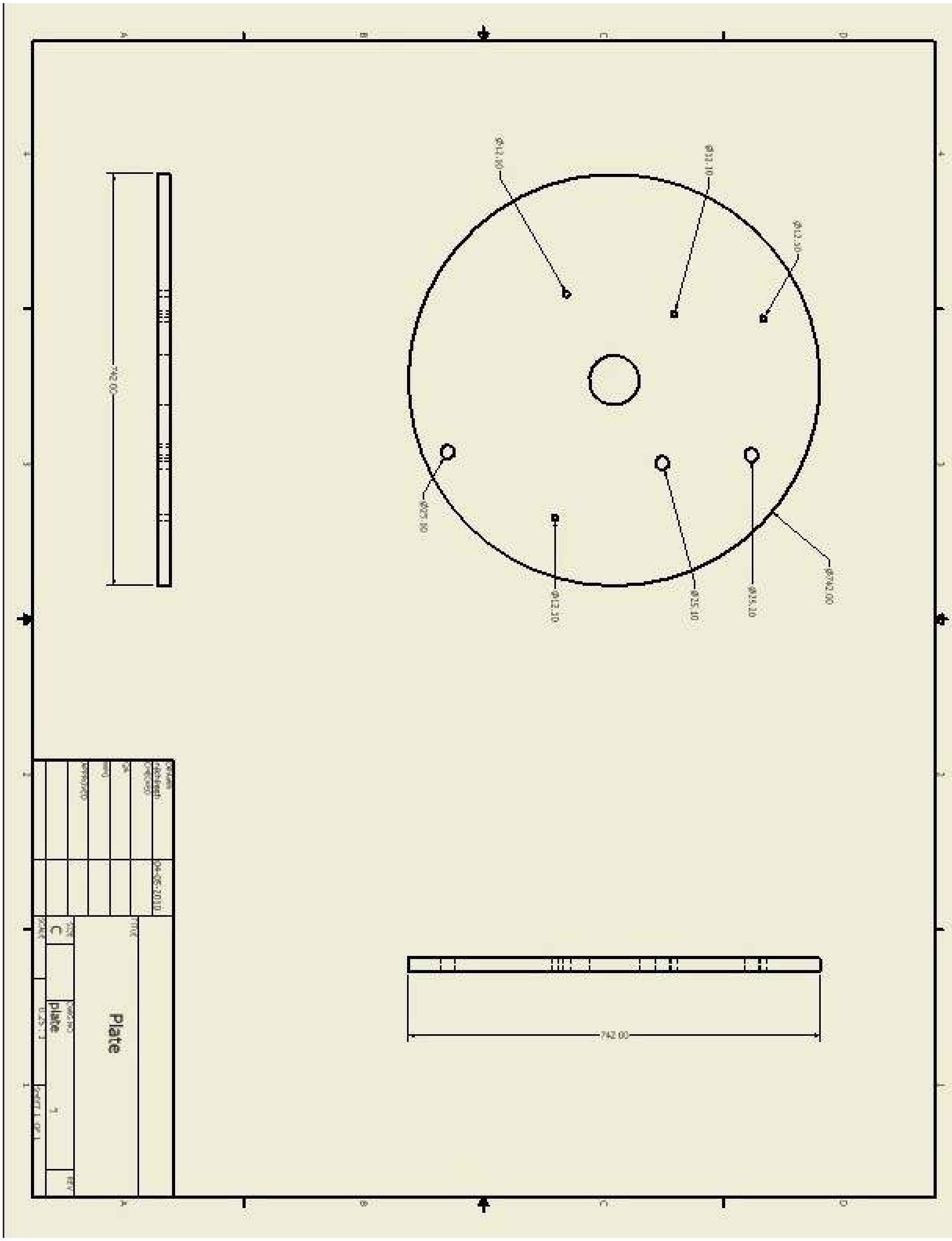


**Fig. 4.21 Top Plate Draft Sheet**

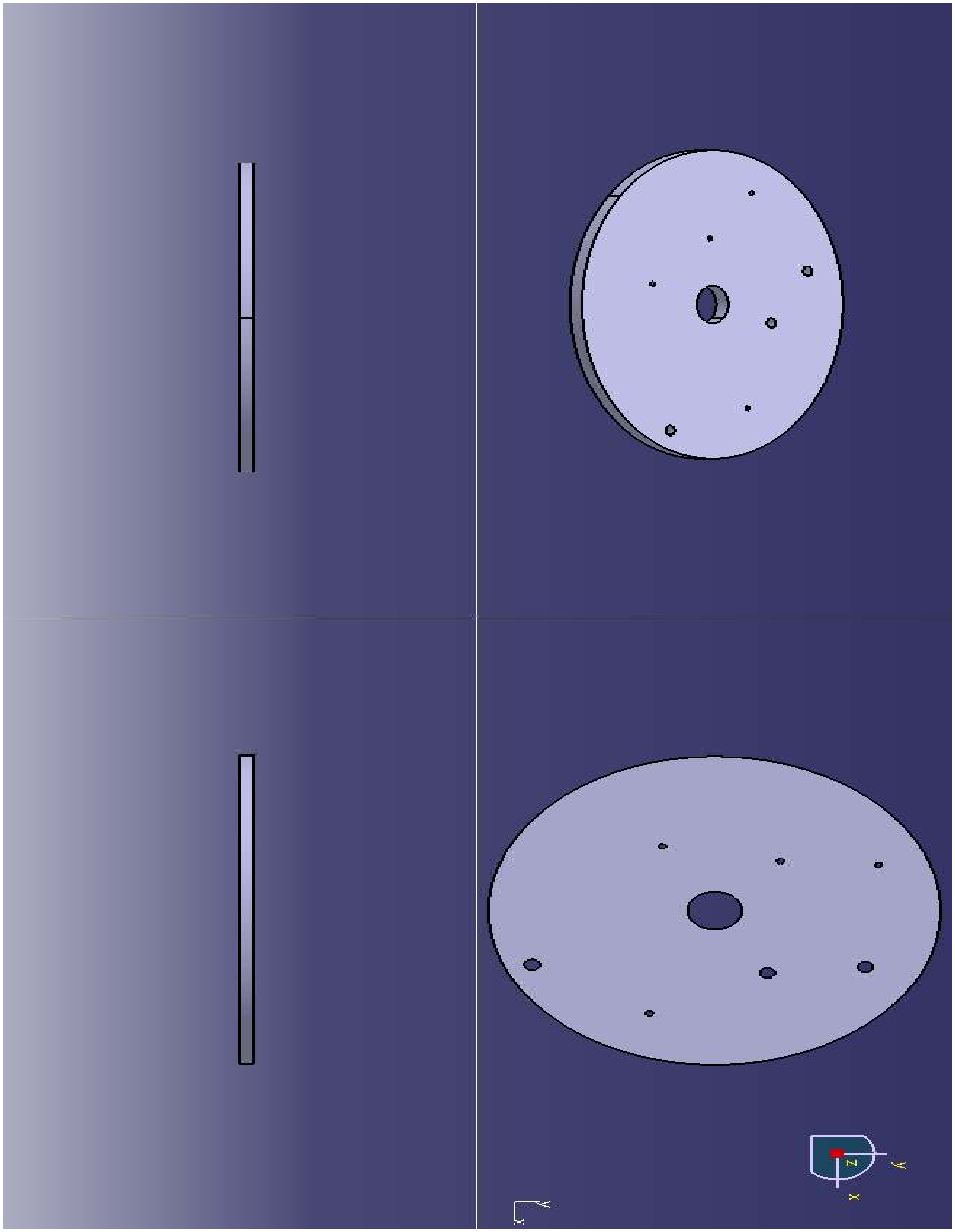



Fig. 4.22 Top Plate 3-D Model

# *Chapter 5*

# Rapid prototyping

### 5.1 Rapid Prototyping

*Rapid prototyping* (RP) refers to a class of technologies that can automatically produce solid models from Computer-Aided Design (CAD) data. It is a freeform fabrication technique in which the object of prescribed shape, size, dimension and finish can be directly constructed from the CAD based geometrical model stored in a computer, with little human intervention.

The fabrication processes in a rapid prototyping can basically be divided into three categories which are additive, subtractive and formative[3]. In the additive or incremental processes, the object is divided into thin layers with distinct shape and then they are stacked one upon other to produce the model. The shaping method of each layer varies for different processes. Most of the commercial Rapid Prototyping systems belong to this category. Such processes can also be called layered manufacturing (LM) or solid freeform fabrication (SFF). Layer by layer construction method in LM greatly simplifies the processes and enables their automation. An important feature in LM is the raw material, which can be either one-dimensional (e.g. liquid and particles) or two-dimensional (e.g. paper sheet) stocks. Whereas in case of subtractive RP processes three-dimensional raw material stocks are used. Stereolithography apparatus (SLA), three dimensional printing, selective laser sintering (SLS), contour crafting (CC), fused deposition modeling (FDM), etc. are few examples of LM. Subtractive or material removal (MR) processes uses the method of cutting of excessive material from the raw material stocks. There are not as many subtractive prototyping processes as that of additive processes. A commercially available system is DeskProto[5], which is a three-dimensional computer aided manufacture (CAM) software package for Rapid Prototyping and manufacturing. As in case of pure subtractive RP processes the model is made from a single stock, fully compact parts of the same material as per actually required for end use is possible. The other advantages like accuracy of the part dimensions and better surface quality can be achieved by the subtractive machining approach. However if we compare geometric complexity the MR processes are limited than the LM processes. Different types of cutting methods used are computer numerical control (CNC) milling, water-jet cutting, laser cutting etc. In formative or deforming processes, a part is shaped by the deforming ability of materials. At present there is no commercial forming-based RP system in the market. In case of LM process the geometric complexity of objects is relaxed upto a significant extent due to the layer by layer manufacturing. Some features which are difficult to obtain using MR process can be achieved using LM process. Raw material is one of the limitation in case of LM process. Both the LM and MR processes can be integrated to obtain more benefits. This integration creates a hybrid RP system which can produce better surface quality without tempering the manufacturability in case of complex features.

**5.2 Working Principle behind Rapid prototyping**:

Although several rapid prototyping techniques exist, all employ the same basic five-step process. The steps are:

1. Creation of the CAD model of the design
2. Conversion of the CAD model to STL format
3. Slicing the STL file into thin cross-sectional layers
4. Layer by layer construction
5. Cleaning and finishing the model

**Creation of CAD Model:**

First, the object to be built is modeled using a Computer-Aided Design (CAD) software. Solid modelers, such as Pro-E, CATIA and Autodesk Inventor tend to represent 3-D objects more accurately than wire-frame modelers such as AutoCAD, and will therefore yield better results. A pre-existing CAD file or a newly created CAD file for prototyping purpose can also be used. This process is identical for all of the RP build techniques.

**Conversion of CAD model to STL Format:**

Different CAD software save the modeled files in different formats. To establish consistency, a standard format has been adopted which is known as STL (stereolithography, the first RP technique) format for rapid prototyping industry. The second step, therefore, is to convert the CAD file into STL format. This format represents a three-dimensional surface as an assembly of planar triangles. Increasing the number of triangles improves the approximation and result, but the file size gets bigger. As the large and complicated files take more time for construction the designer should consider for both accuracy and manageability while creating the STL file. Since the STL format is universal, this process is identical for all of the RP build techniques.

**Slicing of the STL File into layers:**

In the third step, a pre-processing program is used to prepare the STL file for construction. For this purpose several programs are available and the size, location and orientation of the model can also be adjusted by the user. Build orientation is important for several reasons. As the layers are formed in x-y plane, the properties of the prototyped model are weaker and less accurate along z-direction. So part orientation is used to make the orientation of the model such that the minimum dimension lies along z-direction which not only improves the quality and accuracy, also reduces the time due to decrease in number of layers. The STL model is sliced into a number of layers from 0.01 mm to 0.7 mm thick using the pre-processor software and it also depends on the building technique. pre-processor software is supplied by the manufacture of the rapid prototyping machine.

**Layer by Layer Construction:**

In the fourth step the actual construction of the part is done. Layers can be produced by different methods. Therefore several types of techniques are available for the production of layers. One of these techniques can be used to produce the part.

**Cleaning and Finishing:**

The final step is post-processing. In this step the prototyped model is taken out of the machine and supports are detached. Prototypes may also require minor cleaning and surface treatment. Sanding, sealing, and/or painting the model will improve its appearance and durability.

## 5.3 Rapid Prototyping Techniques

Most commercially available rapid prototyping machines use one of six techniques[3].

### 5.3.1 Stereolithography

This technique works on the principle that when liquid photosensitive polymers are exposed to ultraviolet light they get solidified. In this process the platform is situated in liquid epoxy or acrylate resin. When the UV light falls on the liquid layer, the part that is to be constructed gets solidified and remaining part stays liquid. An elevator is used to lower the platform to form successive layers. In this way the process is repeated to finally get the final model. After that the model is taken out and excess liquid is removed and then placed in a UV oven for complete curing.

### 5.3.2 Laminated Object Manufacturing

This technique was developed by Helisys of Torrance, CA. in this method layers of adhesive-coated sheet material are bonded together to make the prototype. Here a feeder mechanism is used to prepare the sheet over the build platform. A heated roller is used to apply pressure for bonding of paper to the base. Laser cutting is used to cut the outline of the layers. After each layer is prepared and cut, the platform lowers and fresh material is used for another layer. As the model is prepared from paper, after completion of the prototyping the model must be sealed and finished with paint to prevent it from moisture damage.

### 5.3.3 Selective Laser Sintering

This technique has been developed by Carl Deckard and was patented in 1989. A laser beam is used to fuse powdered materials such as elastomer, nylon into a solid object. Here the platform is situated just below the surface in bin containing heat-fusible powder. After fusing of the first layer by the laser beam, the platform is lowered by the height of a layer and powder is applied again. This process is repeated until the completion of the model. Excess powder helps in supporting the model during the process.

### 5.3.4 Fused Deposition Modeling

In this method some thermoplastic material is heated and extruded from a tip. The tip moves in x-y plane and very thin beads are deposited on the platform to build the first layer. Low temperature is maintained at the platform so that the thermoplastic will get hard quickly. Then the platform is lowered and the second layer is formed over the first one. In this way the model is prototyped.

### 5.3.5 Solid Ground Curing

In this method ultraviolet light is used to harden photosensitive polymers. It is a bit similar to stereolithography method but here the curing of the entire layer is done at a time. A photomask is developed according to the layer and placed above a glass plate, which is over the platform containing photosensitive resin. The mask is then exposed to UV light, which only passes through the transparent portion and hardens the required shape of the layer. After completion of each layer vacuum is used to remove excess liquid resin and wax is applied for support. This process is repeated till model is complete.

### 5.3.6 3-D Ink-Jet Printing

Ink-jet printers employ ink-jet technology. Z Corporation uses this technology in its 3-D printers. Here a printing head deposits a binder over the powder material to fuse them together in the required areas according to the model. Unbounded powder is used as support. After completion of one layer the platform is lowered and excess powder is blown off. Then the next layer is printed and this process is repeated till the model is complete. This process is very fast and the parts produced have a bit grainy surface.

### 5.4 Advantages of RP

The main benefits[3] of RP are:

- Production of parts is faster and less expensively.
- Material savings in comparison to other methods.
- Product testing is quickly possible.
- Design improvements can be achieved.
- Error elimination from design can be fast.
- Experiments can be done on physical objects of any complexity in a relatively short period of time..
- Using a prototype development of a system can be done with less effort in comparison to development without prototype.
- Labor cost due to manufacturing, machining, inspection and assembly is reduced.

- Reduction in material cost waste disposal cost, inventory cost, material transportation cost.
- Design misinterpretations can be avoided.
- Quick design modification is possible.
- Better communication between the designer and user because of 3-d presentation of the model to be prototyped.

**5.5 Disadvantages of RP**

Some of the disadvantages[3] of rapid prototyping are described below.

- According to some people rapid prototyping is not an effective model of instructional design because it does not replicate the real thing.
- Many problems may be overlooked that results in endless rectification and revision.
- Rushing in to develop a prototype may exclude other design ideas.
- Design features may get limited because of the limitation of the prototyping tool.
- Sometimes the prototyping machine may not deliver product up to expectation.
- The system could be left unfinished due to various reasons or the system may be implemented before it is completely ready.
- The producer may produce an inadequate system that is unable to meet the overall demands of the organization.

**5.6 Applications of Rapid Prototyping**

Rapid prototyping is widely used in the automotive, aerospace, medical, and consumer products industries.

**Engineering**

In aerospace industries rapid prototype method is used for production of complex parts. For space shuttle and space stations also parts are manufactured using RP. Boeing's Rocketdyne has used RP technology to produce hundreds of parts of space shuttle and international space station.

To manufacture parts for fighter jets also RP technology is used. In labs for testing of a new concept rapid prototyping is done and experiments are executed.

**Architecture**

In the field of architecture, new designs and ideas can be shown using rapid prototyped models. It helps for better understanding and analysis.

**Medical Applications**

RPT has created a new market in the world of orthodontics. Instead of using metal teeth straighter rapid prototyped teeth can be used for better appearance. The stereolithography technology can be used to produce custom-fit, clear plastic aligners in a customized mass process. The RP technique is also used to make hearing instruments. The instrument shells produced are stronger, fit better and are biocompatible to a very high degree. The ear impression is scanned and then digitized with the help of an extremely accurate 3-D scanner. Then using the software developed the digital image is converted into a virtual hearing instrument shell .Thanks to the accuracy of the Rapid Prototyping process, instrument shells are produced with high precision and reproducibility. In the case of repairs, an absolutely identical shell can be manufactured quickly, since the digital data are stored in the system.

**Arts and Archeology**

Selective Laser Sintering with marble powders can be used to restore or duplicate ancient statues and ornaments, which suffer from environmental influences. The originals are scanned to derive the 3D data, damages can be corrected within the software and the duplicates can be created easily. One application is duplicating a statue. The original statue was digitized and a smaller model was produced to serve a base for a bronze casting process.

# *Chapter 6*

## Result and Discussion

- All the components of the nitrogen liquefier were modeled according to their given design specifications.
- The modeled components were assembled in the assembly section of Autodesk Inventor.
- Hit and trial method was used for proper positioning of the components so that all components remain inside the vessel.
- After that the components were connected with tubes as specified in the process design.
- While modeling the tubes, every attempt has been made to make the tube length as minimum as possible.
- Rapid prototyping could not be done because of some technical problems in the ZPrinter®310 (rapid prototyping machine from Z-corporation).
- From the assembly it can be observed that all the components have been placed inside the vessel and the tubes connected are properly.

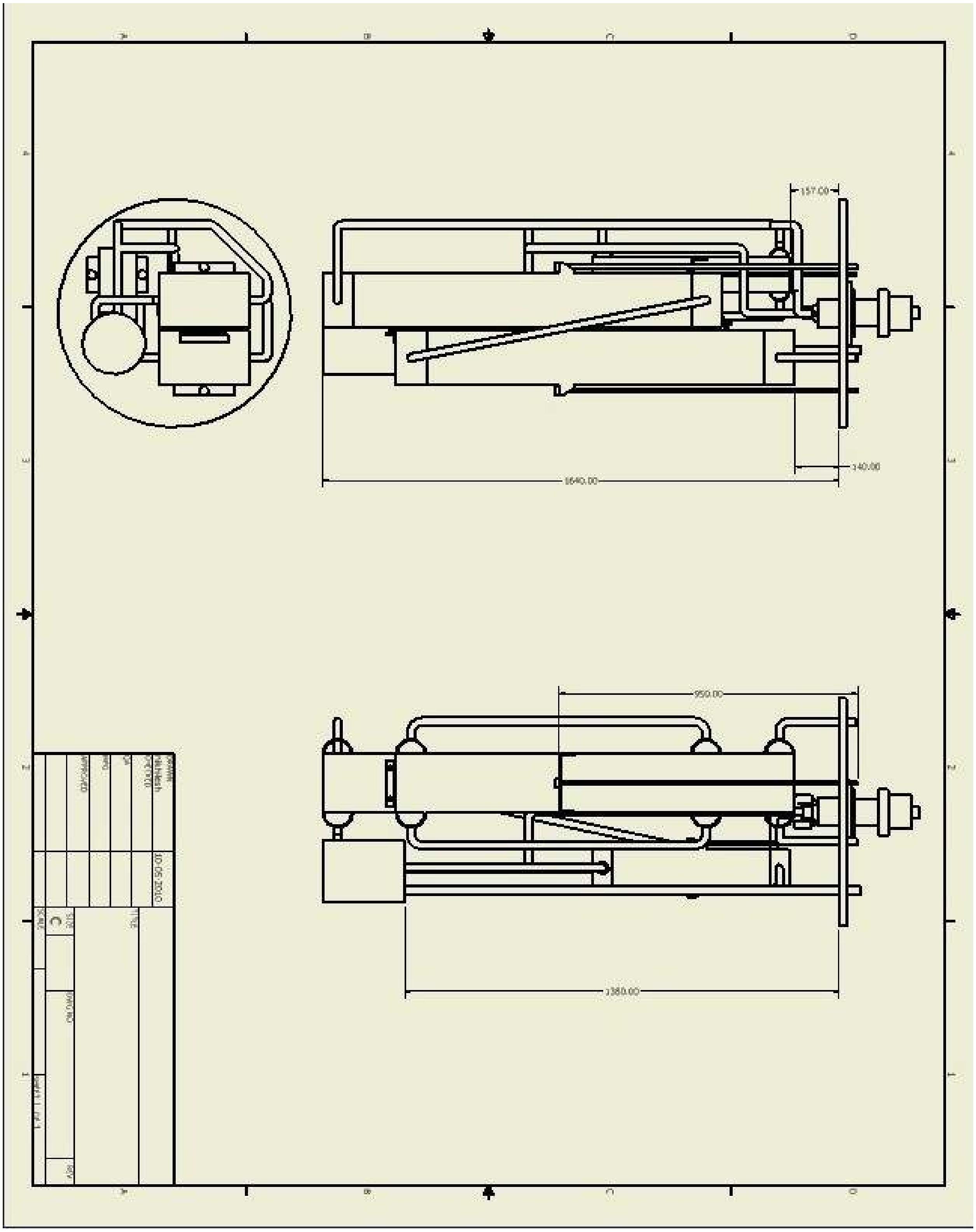



Fig. 6.1 Nitrogen Liquefier Assembly Draft Sheet

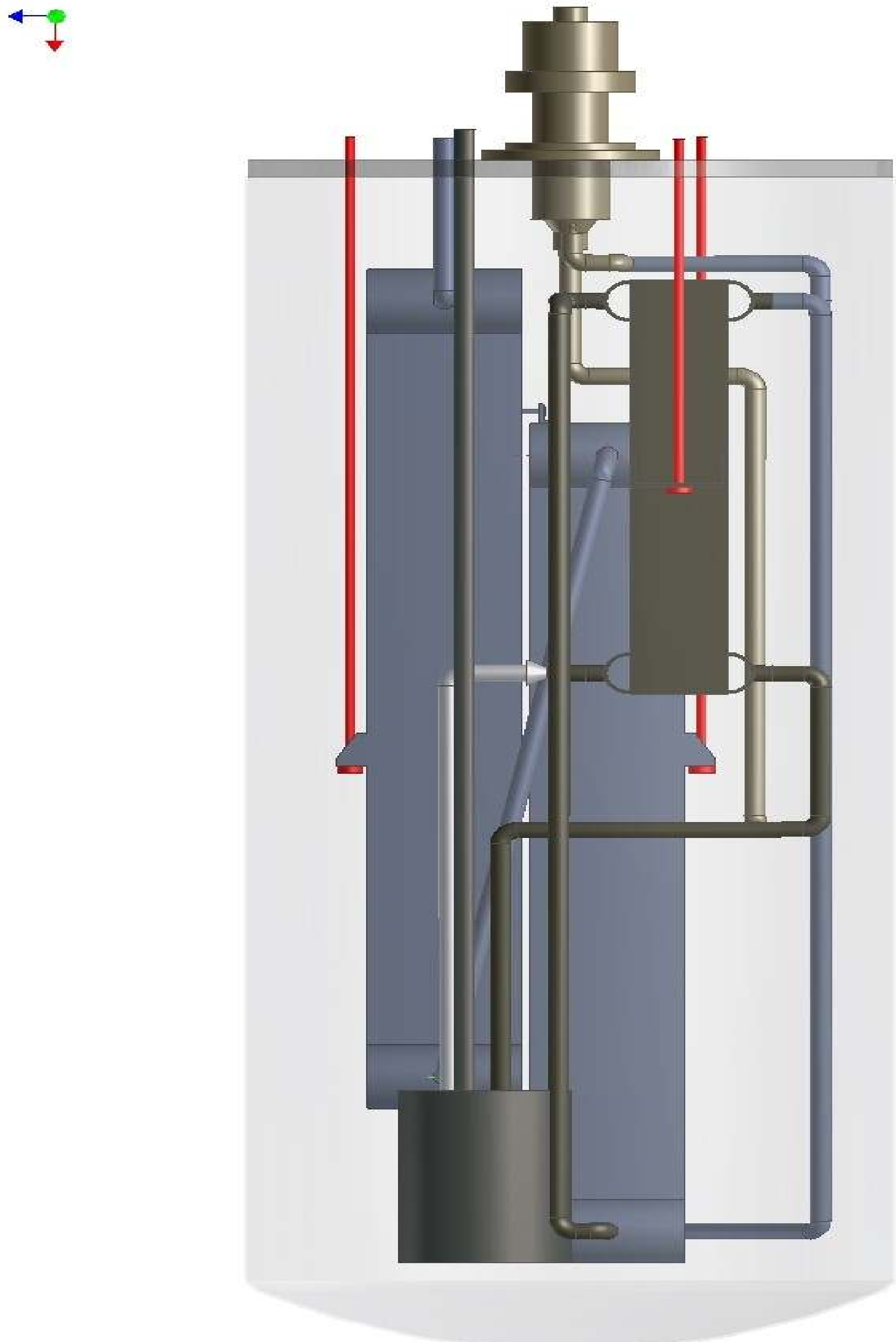


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**Fig. 6.2 Front View of Nitrogen Liquefier Assembly**

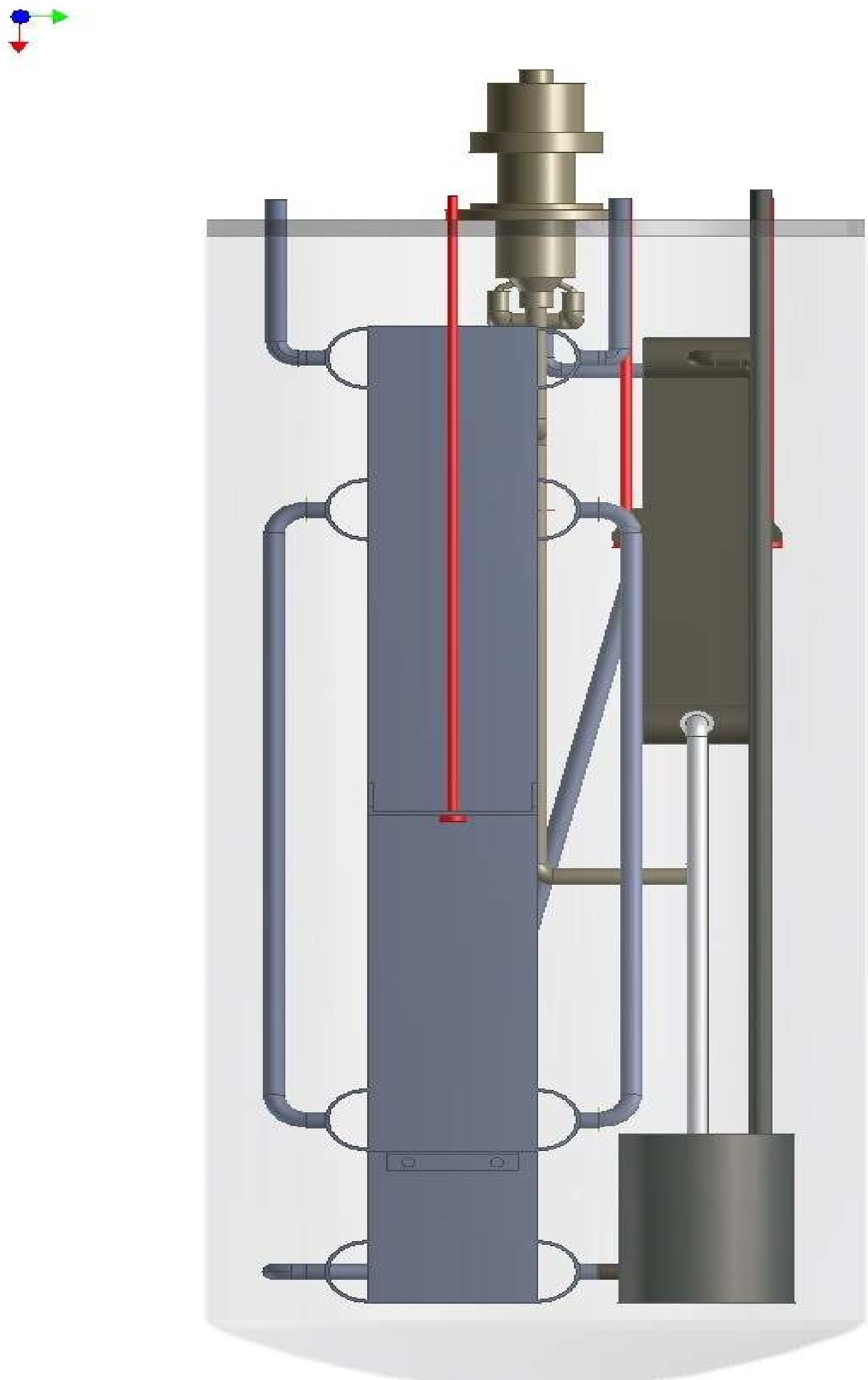

**Fig. 6.3 Side View of Nitrogen Liquefier Assembly**

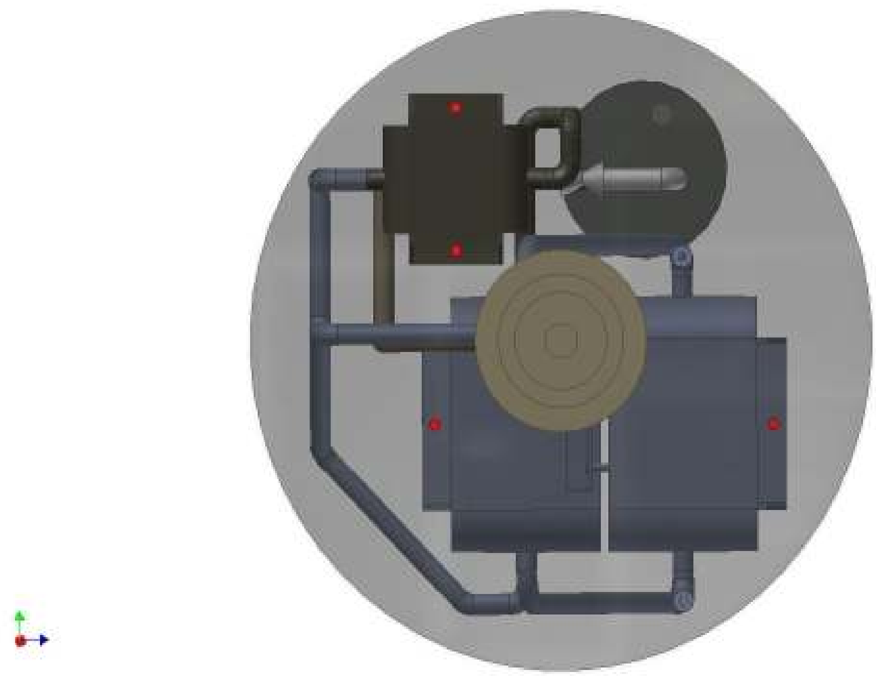

**Fig. 6.4 Top View of Nitrogen Liquefier Assembly**

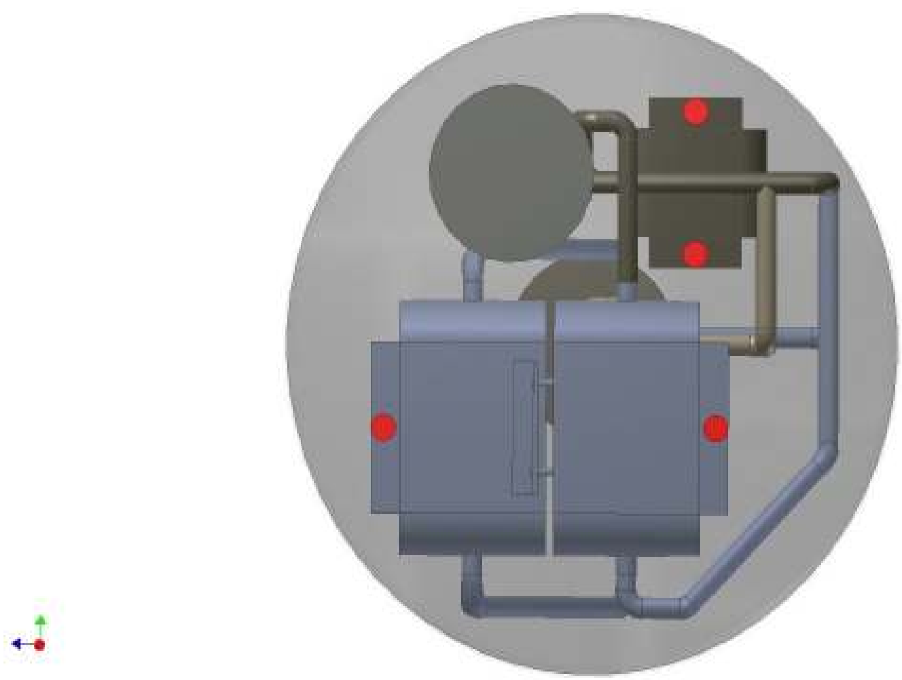

**Fig. 6.5 Bottom View of Nitrogen Liquefier Assembly**

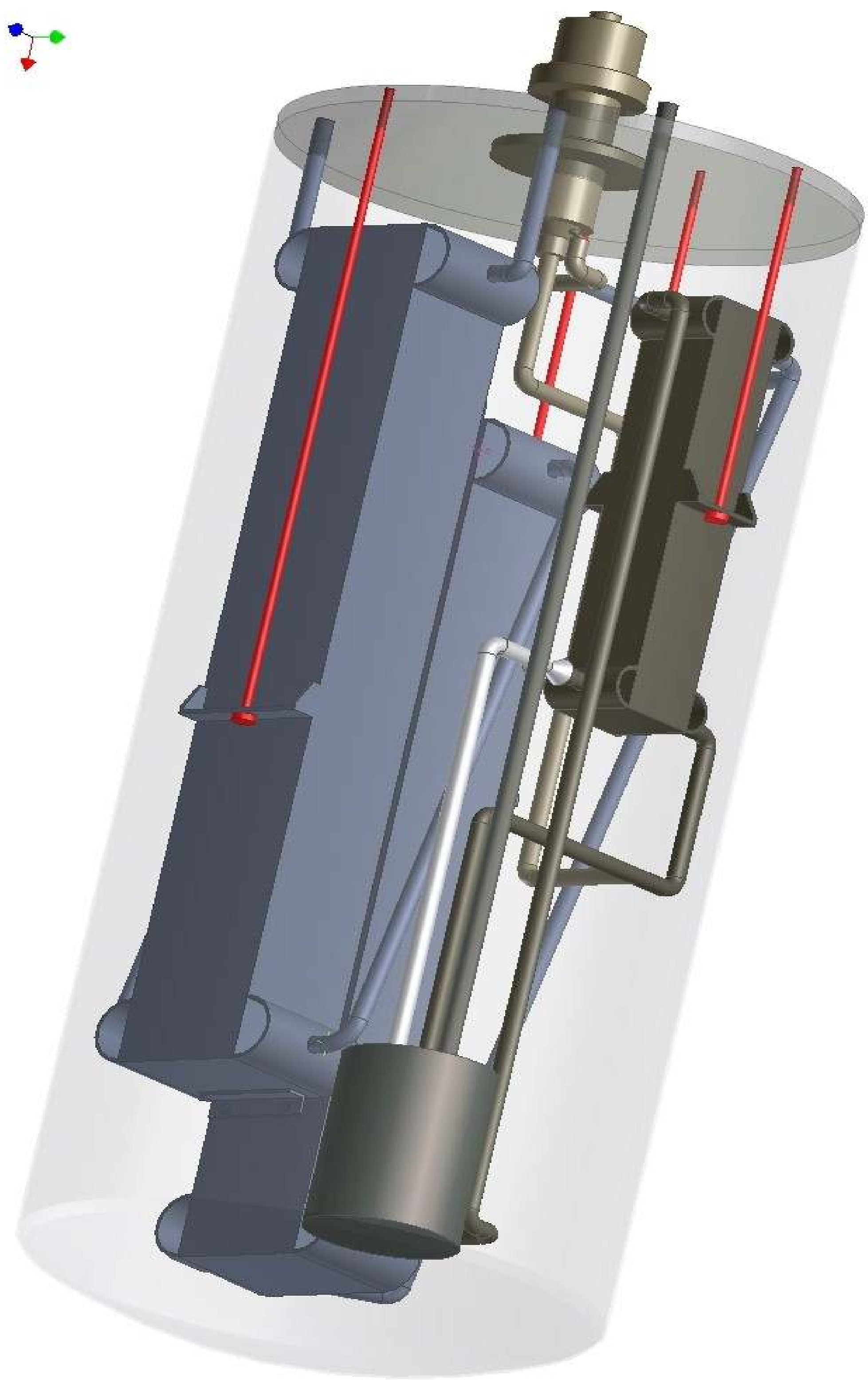

**Fig. 6.6 Nitrogen Liquefier Assembly**

# *Chapter 7*

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