

**FEASIBILITY STUDY OF LNG PRE – COOLING SYSTEM USING CARBON
DIOXIDE AS A REFRIGERANT**

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ABSTRACT

Refrigeration is a process of removing heat from a colder medium. By using the latent heat properties of refrigerant, the heat will be rejecting to a warmer medium. The basic of requirements for the refrigeration are the compressor, chiller, expansion valve and also condenser. In the LNG industry, refrigeration plays a major part. The aims of this research are to compare the difference of refrigerants used in pre-cooling system. The refrigerants that used in this research are propane and carbon dioxide. Another part that must be focused on this research is the refrigerants' parameters which are most important consideration for approving that the carbon dioxide can be replacing the propane as a refrigerant that can be used soon in pre-cooling loop system. A simple model of propane refrigeration loop is used to create a steady state simulation using Aspen HYSYS 7.0 process simulator. By having a valid data from the propane loop, a simulation can be continued by replacing composition from propane to carbon dioxide. The same model constructed in the loop, but the other conditions must be changed to make it suitable and converged with the new refrigerant. The composition of refrigerant in the loop is still same 1, showing the purification of the component. The result shows the coefficient of performance (COP) for propane is 1.73 and carbon dioxide is 4.78. For the value of compressor duty using carbon dioxide is lower than the original loop, which the value is 96.7808 kW and propane duty is at 162.938 kW. Lastly, in terms of the costing of compressor using carbon dioxide is only at \$ 54320 / yr which lower compared to compressor cost for propane is \$ 91280 / yr. At this stage, we can conclude that the low duty, make the cost is low and this project will be more save. So, from this research, it can be conclude that it is successful because the main objective for replacing carbon dioxide as refrigerant has been achieved where the COP of carbon dioxide is higher than COP of propane.

ABSTRAK

Penyejukan ialah satu proses pemindahan haba daripada satu medium yang lebih sejuk. Dengan menggunakan sifat haba terpendam bahan penyejuk, haba tersebut akan ditolak ke medium lebih panas. Asas keperluan penyejukan adalah pemampat, pendingin, pembesaran injap dan pemeluwap. Tujuan kajian ini adalah untuk membandingkan perbezaan bahan penyejuk digunakan dalam sistem separa sejuk. Bahan penyejuk yang digunakan dalam kajian ini adalah propane dan karbon dioksida. Perkara lain yang perlu difokuskan pada kajian ini ialah parameter bahan penyejuk di mana paling penting mempertimbangkan untuk membuktikan propane dapat digantikan dengan karbon dioksida sebagai bahan penyejuk yang dapat digunakan di dalam sistem separa sejuk akan datang. Satu model ringkas gelung propane penyejukan digunakan untuk mencipta satu keadaan kekal simulasi menggunakan program simulasi Aspen HYSYS 7.0. Dengan mempunyai data yang sah daripada gelung propane, simulasi boleh diteruskan dengan menggantikan komposisi daripada propane kepada karbon dioksida. Model yang sama dibina di dalam gelung tersebut, tetapi lain-lain keadaan harus diubahsuai untuk memberikan kesesuaian dan menumpu dengan bahan penyejuk yang baru. Komposisi di dalam gelung adalah sama 1, yang menunjukkan ketulenan komponen. Keputusan menunjukkan tahap kecekapan bagi propane ialah 1.73 dan karbon dioksida ialah 4.78. Untuk nilai duti compressor menggunakan karbon dioksida adalah lebih rendah daripada gelung asal, dimana nilainya adalah 96.7808 kW dan duti propane ialah pada 162.938 kW. Akhir sekali, dalam nilai kos kompressor, menggunakan karbon dioksida, kos ialah hanya pada \$ 54320 / yr iaitu lebih rendah berbanding kos kompressor untuk propane iaitu pada \$ 91280 / yr. Pada tahap ini, kita dapat konklusikan dengan nilai rendah duti, membuatkan kos rendah dan projek ini lebih menjimatkan. Oleh itu, daripada kajian ini, boleh dikonklusikan sebagai berjaya kerana objektif utama untuk menggantikan karbon dioksida sebagai bahan penyejuk

terlaksana apabila nilai tahap kecekapan karbon dioksida lebih tinggi berbanding tahap kecekapan propane.

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LIST OF NOMENCLATURES

P- R	: Peng – Robingson
CO ₂	: Carbon Dioxide
H	: Hydrogen
C	: Carbon
HCFCs	: Hydrochlorofluorocarbons
CFCs	: Chlorofluorocarbons
HCS	: Hydrocarbons
LNG	: Liquefied Natural Gas
MR	: Mixed Refrigerant
COP	: Coefficient of Performance
GWP	: Global Warming Potential
P	: Pressure
H	: Enthalpy
KW	: Kilo Watt
E	: 10 ⁵
US DOE	: United State Department of Energy
KG	: Kilo Gram
h	: Hour

J – T : Joule – Thompson

kPa : Kilo Pascal

°C : Degree Celcius

CHAPTER 1

INTRODUCTION

1.1 Refrigeration

Industrial refrigeration systems are widely used for gas liquefaction, food processing, food preservation chemical production and numerous other special applications in the construction and manufacturing industries (by K.A Manske, 2001). A process which removing heat form a substance is called as a refrigeration process. It will reject the heat and will remove to the atmosphere at a high temperature level. Heat flows from a body at a high temperature to another at a low temperature level. An external energy is required and important which is for the heat flow from the lower to higher energy level. While refrigerant is the medium for carrying heat. It is needed during their cycle in the refrigeration system. Heat will be absorbed at low temperature level and removed at a higher level. Refrigerants are come from two molecules, methane and ethane. These two molecules simply contain hydrogen (H) and carbon (C) is referred to as pure hydrocarbons (HCs).

1.1.1 History of Refrigeration

In 1850, the word of refrigerate was introduced when a method was found as the addition of chemicals, such as sodium nitrate or potassium nitrate into water causes that the temperature to fall. The American physician, John Gorrie, had designed and built a tool for air – cooling, which the aim for this invention is for treating yellow – fever patients. The basic of his invention is same like the basic principle of refrigerators that often used in nowadays. By using compression level, the gas was cooling by sending through the radiating coils and expanding process will take part which is functioned for lowering temperature level. He was granted the first U.S Patent for mechanical refrigeration in 1851. After that, the starting of refrigeration was taken part in refrigerated cars which were used to transport milk and butter in 1840.

In 1850, brewing was the initial activity that using mechanical refrigeration. The process was used the basic of absorption and which firstly used by S. Liebmann's Song Brewing Company in 1870 that placed Brooklyn, New York. "Good sources were harder and harder to find. By the 1890 's natural ice became a problem because of pollution and sewage dumping." This stated by co – author of Heat and Cold: Mastering the Great Indoors, Bern Nagengast. (Published by the American Society of Heating, Refrigeration and Air – conditioning Engineers). This was referred to the ice, which was used as the refrigeration agent, which at the end becoming as a health problem. The first signed was proved in the brewing industry.

1.1.2 Refrigeration System

There are several different of refrigeration systems which are being used for the production of LNG (Liquefied Natural Gas). These include mixed refrigerant processes such as mixed refrigerant (MR). In the pre-cooling cycle, the treated natural gas and mixed refrigerant (MR) of the main liquefaction cycle are cooled to a temperature of about -50°C . The pre cool refrigerant is primarily mixture of ethane and propane. The pre-cooling cycle is two stages and uses spool wound heat exchangers, since the liquid pre-cool MR evaporates over a temperature range rather than at one temperature, similarly like case of propane. The pre-cool MR is compressed in a two stage air-cooled centrifugal compressor.

1.1.3 Refrigeration Process Loop

In a refrigeration process loop, there are five basic things that must be involved. The four important things are the unit operations. The rest is the refrigerant that will be used in the process. The first unit operation as an initial for processing the refrigeration process is chiller or evaporator. This is very important to remove the unwanted heat that coming from the product through the liquid refrigerant. The second is by putting the compressor which the role of this equipment for transforming the vapor form from the lower temperature to the higher temperature and at the same time, the pressure level also will be increasing. After the compressor, the condenser will be continue its

process by extracting the heat that having in refrigerant to the air. The last part of the loop is by continuing the process with an expansion valve. The function of that valve is to send back the liquid refrigerant to the chiller.

1.2 Problem Statement

The use of CO₂ as a refrigerant dates back more than a century, but it fell out of favor in the air-conditioning and refrigeration industry with the development of chlorofluorocarbons (CFCs) in the 1930s. However, when concerns about the depletion of the stratospheric ozone layer emerged in the 1970's national and international agreements were enacted to phase out CFCs and HCFCs (hydrochlorofluorocarbons). Carbon dioxide is non-flammable and non-toxic in contrast to other natural refrigerants.

Centralized refrigeration systems used in supermarkets are prone to leakage due to the large number of refrigerant line joints, long runs of refrigerant piping, and frequent thermal cycling. Carbon dioxide can be used efficiently in these systems, and some leakage can be tolerated. However there is a downside to using CO₂ as a refrigerant. Many studies, both theoretical and experimental, have demonstrated that the thermodynamic efficiency of CO₂ cycles is lower than that of conventional fluorocarbon-based vapor compression systems, particularly at high ambient temperatures.

In this research, feasibility study is done whether the carbon dioxide can be used as refrigerant while at the same time CO₂ emission can be reduced. The other focus is by trying to make it more environmental friendly in refrigeration system. In the refrigeration requirement, one of the most important things that must be focused carefully is the value of its coefficient of performance (COP) that must be in higher level which can be the best refrigerant. This COP is important which will show its efficiency in the process.

The next part of that is by having low duty in compressor unit. By lowering the duty, the cost of compressor also will be decreasing as what like the formula of calculation for compressor cost is taking the duty value from compressor. Therefore, when the lower duty, the process will be more save because of decreasing its cost.

1.3 Objectives

Objective of this study is to perform simulation study in using carbon dioxide as a suitable pre-cooling refrigerant for LNG production by using Aspen HYSYS. This simulation will be trying with two different of refrigerants that starting with propane and next is using carbon dioxide. After that the comparison between these two refrigerants will be done.

1.4 Scopes of Study

In this research, there are several parts or characteristics of best refrigerant will be in consideration to compare which refrigerant is the best by comparing its coefficient of performance (COP), the value of compressor duty and its compressor cost that will be one of the main requirements in choosing refrigerant in industry which will give the best efficiency and low cost to make the industrial operation more save.

1.5 Significance of Study

Through this study, there are several of advantages by having this research which the characteristics of refrigerant can be understand completely, the requirements that must be considered in choosing refrigerant and also the basic of refrigeration cycle can be known by knowing its basic components that every process in refrigeration has their own function through the certain condition that effecting the flow of liquid refrigerant in refrigeration loop. Another part of this research is to reduce the emission of carbon dioxide where by replacing the carbon dioxide as a refrigerant.

CHAPTER 2

LITERATURE REVIEW

2.1 The Discovery of Carbon Dioxide

In the vapor compression, carbon dioxide has been used as refrigerant for over 130 years. The new techniques that involving this refrigerant just be found last decade which to exploit the uniquely advantages properties of carbon dioxide. In the 18th century the initial steps were found by two Scots physicians, Dr William Cullen and Dr James Black. From the experiment by Black, led him to the exploration of carbon dioxide which had been given called as “fixed air“. The further experiment showed that this carbon dioxide had involved in burning and breathing processes. The prediction of that “fixed air” present only in small portion in atmosphere was correct which the level was 0.03 %. Neither Cullen nor Black was primarily interested in thermodynamics or refrigeration, and their ideas not developed for nearly a century (Thevenot, 1979).

2.2 Adaption Compressor for Carbon Dioxide

From the work of Thaddeus Lowe in Texas, carbon dioxide was the next to make breakthrough. He was a scientist that responsible for founding of Union Army's Observation Corps in 1861. In 1860, he developed a compressor which then adapted for Carbon Dioxide in 1866. It was then used for the manufacture of artificial ice. In 20 years then, a suggestion was made that his system which to produce "dry ice" was in an open system. However there is no doubt that his British Patent, number 952, of 1867 (Newton, 1867) discloses a closed vapor compression cycle.

2.3 The Decline and Fall of Carbon Dioxide

In the 1880's carbon dioxide became a well – known refrigerant because of its efficiency that more efficient than the open – circuit air cycle system and reliable. There are some listed of advantages of 'liquid carbonic acid' which including "being already much cheaper than nearly all chemicals used as yet in ice – machines" (H. Lake, 1884) and also stated that "cold, of almost any low degree can be produced" and "in case of leakage, no more or less unpleasant gases which are deleterious to health enter the work room" (F. Windhausen, 1886). This only contemporary early carbon dioxide systems report was not 'unparalleled' quality level. Carbon dioxide ever been used for ships because it was safer, and reduced the seawater temperature level to 20 °C. In 1932, the Frick Company in response to ongoing safety concerns about large ammonia charges,

started installing a hybrid system which used carbon dioxide for the low temperature stage, with a much smaller ammonia plant providing the necessary refrigeration to condense the carbon dioxide at moderate temperature and pressures (F. Kitzmiller, 1932).

2.4 Carbon Dioxide Future Possibilities

Some of the factor that fixing carbon dioxide is currently pressure. The requirement in developing for an industrial system is should have a compressor that able to operate at 50 bar g. This development in industrial field need not only for large systems, but it will be able for engineer to comprise the carbon dioxide compressor. As an additional, the system also must be updated by using the reverse cycle defrosting of reduce temperature carbon dioxide evaporators, that will cause it suitable and can be used for small freezers and low temperature cold stores.

One of the conclusion can be done during the 19th century, carbon dioxide was probably the cheapest that a good refrigerant. In that time, the manufacturing was easy to cope with the requirements, and an increased level of safety and the legislation which can be one of the medium that helping to make carbon dioxide a preferred choice in industrial systems in the near future.

2.5 Refrigeration Cycle

The refrigeration is simplified as the process of removing heat from the cold medium and the heat will be rejected at the hot medium. During this removing and rejection of heat, the temperature level of refrigerant will be different. In the process of removing heat, refrigerant must have lower temperature level compared to the medium to be cooled. While for the rejection part, the temperature for refrigerant must be higher than its medium for rejecting heat. In the refrigeration cycle, there are five basic components that must have in this cycle. The components are the evaporator or chiller, compressor, condenser and also an expansion valve. The last is refrigerant that will be used in the cycle.

A chart is an important part to understanding the cycle completely. The Figure 2.1 below shows the cycle involved in refrigeration cycle. In this P – H chart, comparison is done between the pressure and enthalpy. From the P – H chart, the horizontal line shows the constant in pressure and while the vertical line is shows the constant in enthalpy. There are three regions or division in this chart. The sub cooled region is at the left, the superheated region is at the right and lastly the wet region is at the middle. The mixture region indicated for the constant temperature which the process for changing phases will be done and the pressure also in constant. The regions which stated “saturated vapor line” and “saturated liquid line” are for the saturated states for refrigerant.

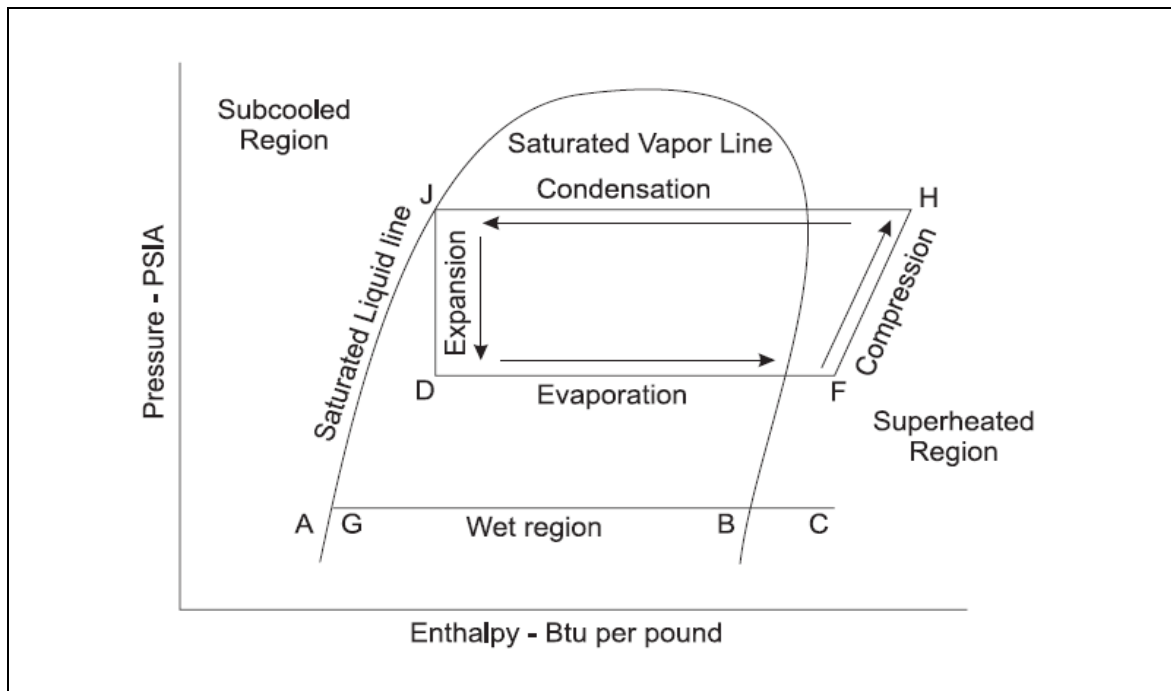


Figure 2.1 P – H chart

Based on the chart, it's explaining if the refrigerant starts to absorb heat at point A, it will start to boil and the pressure is in constant. After that, an evaporation will be taken place and temperature no changes at this state. The value of enthalpy will be higher when the heat is increased. For this time, it will be entering into the wet region which is the mixture between two phases, vapor and liquid.

Point B is the region where the mixture of vapor and liquid will be changed to be saturated vapor. For any additional of heat that applying during this cycle, refrigerant will be in the superheat region which the same thing happened is pressure is also

constant. This region is indicated by point C. In the evaporation, the refrigerant will be entering into evaporator as the mixture of vapor and liquid phases which then absorbing heat. At this stage, process changing of liquid to gas phase happened. Then the gas is compressed from the low pressure to the high pressure.

On the compression process, the points of F and H showed the process happened. Now, the condition is hot with high pressure then sending into condenser for entering new process of “Total Heat of Rejection”. The heats that rejected are from the compression and evaporation processes. From the chart, the condensation can be seen through the constant of pressure. At the points H and J, heat transfer will be happened because of the difference between the enthalpy. Lastly, at the point of J, this showing that the refrigerant has totally condensed to liquid and the pressure is still constant.

2.6. Types of Compressor

There are several types of compressor that can be used. Industrial plants used the compressor in their product operations. The U.S. Department of Energy (2003) has reported that compressor and compressed air systems are very important in improving the energies efficiency at industrial plant. System in the compressed air is containing of compressor and treatment.

There are two basic compressor types, positive displacement and dynamic. In the positive displacement type, a given quantity of air or gas is trapped in a compression chamber and the volume it occupies is mechanically reduced, causing a corresponding rise in pressure prior to discharge, in addition, the air flow remains essentially constant at constant speed.(United States Department Of Energy, 2003).

For dynamic compressor, it is usually used for the continuous flowing air which also used in gas by changing its velocity energy into pressure energy both by the impellers and the eliminating of diffusers. In the centrifugal – type dynamic compressors, the shape of the impeller blades determines the relationship between air flow and the pressure (or head) generated (United State Department of Energy, 2003).

2.6.1 Positive Displacement Compressor

In the positive displacement compressor, there are two types that available, the compressors are reciprocating and rotary. From the figure 2.2 below shows the reciprocating compressor which is available for many configurations which are widely used in horizontal, vertical, horizontal balance – opposed and tandem.

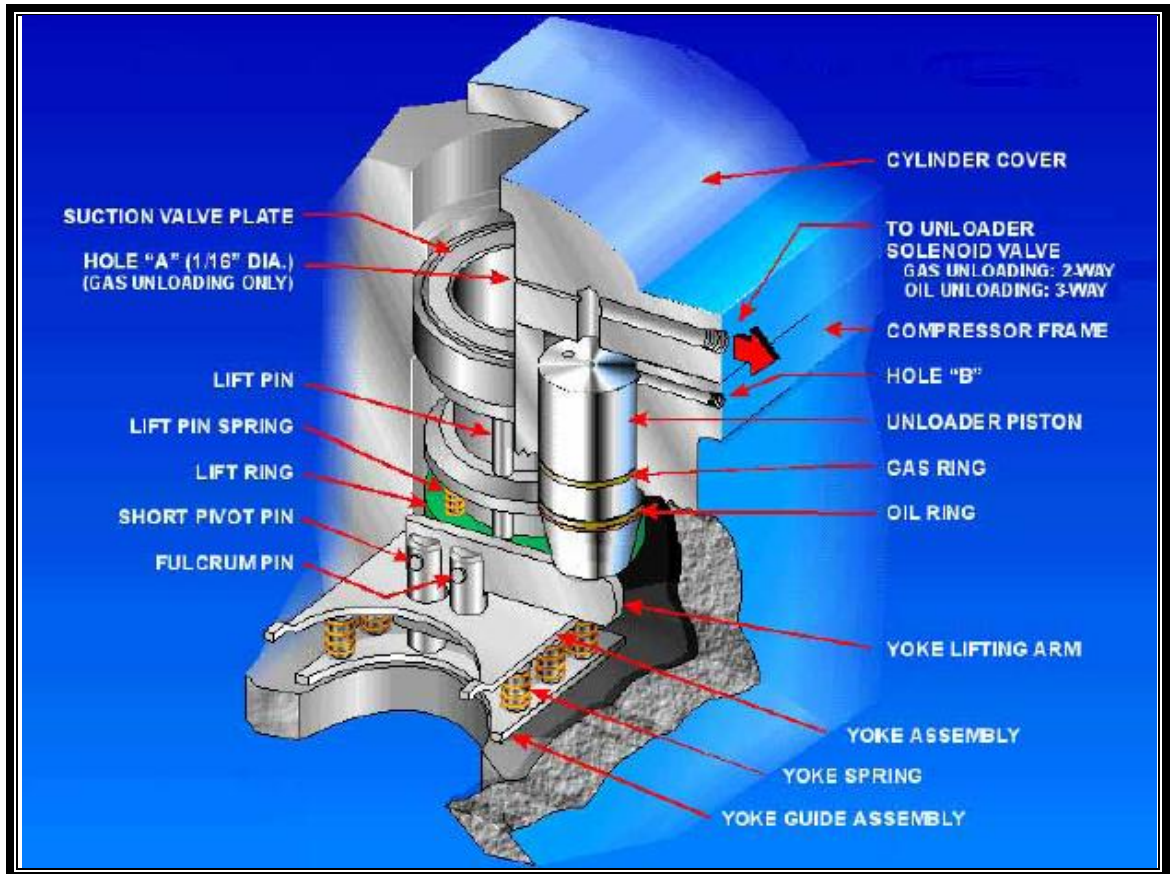


Figure 2.2 Reciprocating Compressor

Vertical type reciprocating compressors are used in the capacity range of 50 – 150 cfm while the horizontal balance opposed compressors are used in the capacity range of 200 – 5000 cfm in multi – stage design and up to 10, 000 cfm in single stage designs (National Productivity Council, 1993). Air compressor reciprocating is considered as the single acting when the compressing is accomplished using only the one side of the piston while the double acting is when compressor uses both side of the piston.

For the next type of positive displacement compressor is the rotary type. In the Figure 2.3 below shows the rotary compressor which can be operated at high speed and provided more throughput if compared to reciprocating compressor.

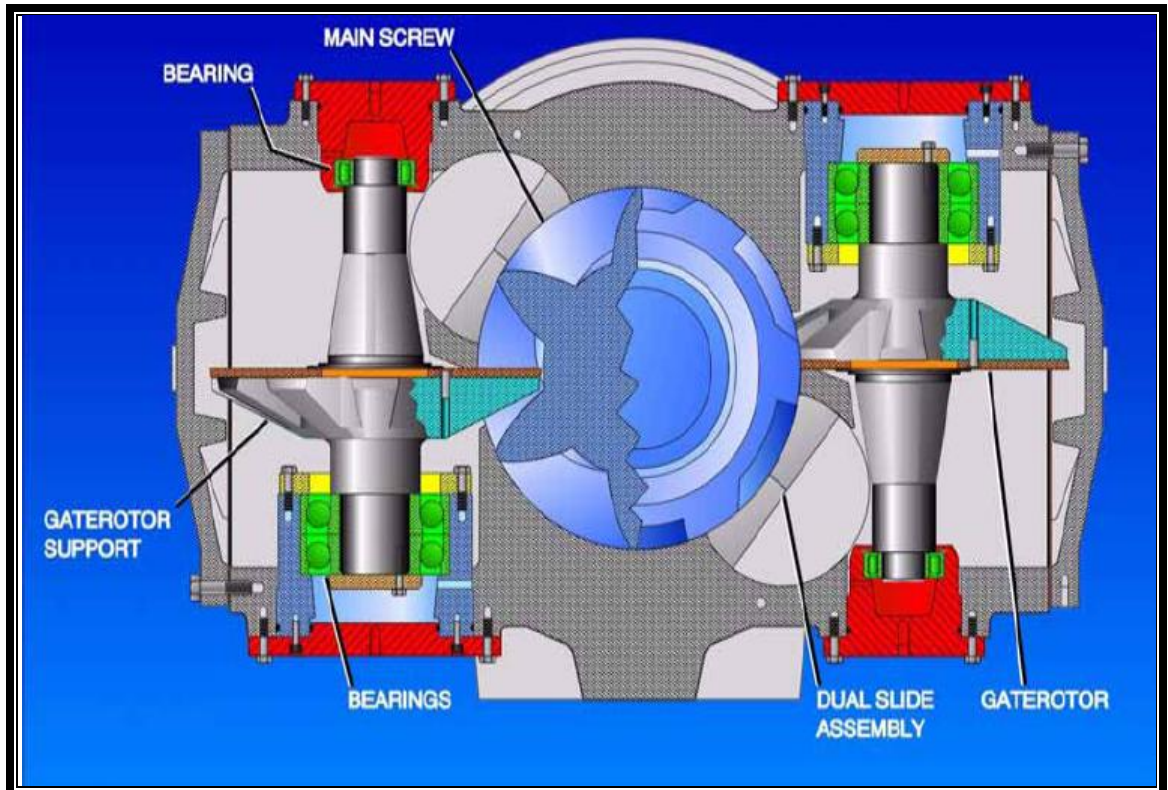


Figure 2.3 Rotary Compressor

This kind of compressor having rotors in place of pistons and it also will give the continuous for pulsation free discharge. In terms of cost and its weight, it is low and very compact in the scope of size, and the most important part is easy to maintain. By having these characteristics, it is the reason why rotary compressor is much known in industry field. Usually it is used in the range between 22 to 150 kW.