MILITARY INSTITUTE OF SCIENCE & TECHNOLOGY (MIST)

DETERMINATION OF CO-EFFICIENT OF PERFORMANCE (COP) OF A VAPOR COMPRESSION REFRIGERATION CYCLE USING DIFFERENT REFRIGERENTS

A thesis submitted to the Department of Mechanical Engineering, Military Institute of Science and Technology, Dhaka, on December 2012 in partial fulfilment of the requirements for the degree of B.Sc in Mechanical Engineering.

SUBMITTED BY

SM Sabahat Hossain	ID: 200918028
Md. Tanjirul Islam	ID: 200918039
Md. Abir Mahmud	ID: 200918064

SUPERVISED BY

Dr. Engr. Md. Shafiqul Islam
Principal Engineer & Project Director
Bangladesh Atomic Energy Commission,
E-12/A Agargaon, Sher-e-Bangla Nagar,
Dhaka-1207, Bangladesh.

SUPERVISOR'S DECLARATION

I hereby declare to the Department of Mechanical Engineering, Military Institute of Science & Technology, Dhaka, Bangladesh that I have checked this thesis "DETERMINATION OF CO-EFFICIENT OF PERFORMANCE (COP) OF A VAPOR COMPRESSION REFRIGERATION CYCLE USING DIFFERENT REFRIGERENTS" and in my opinion this project is satisfactory in terms of scope and quality for the partial achievement of the degree of Bachelor of science in Mechanical Engineering.

Signature:

....

Dr. Engr. Md. Shafiqul Islam
Principal Engineer & Project Director
Bangladesh Atomic Energy Commission,
E-12/A Agargaon, Sher-e-Bangla Nagar,
Dhaka-1207, Bangladesh.

Date:

....

STUDENT'S DECLARATION

This is to certify that the work presented in this thesis titled "DETERMINATION OF CO-EFFICIENT OF PERFORMANCE (COP) OF A VAPOR COMPRESSION REFRIGERATION CYCLE USING DIFFERENT REFRIGERENTS" is an outcome of the investigation carried out by the authors under the supervision of **Dr. Engr. Md. Shafiqul Islam**, Principal Engineer & Project Director, Bangladesh Atomic Energy Commission, Dhaka, Bangladesh. This thesis or any part of it has not been submitted elsewhere for the award of any other degree or other similar title.

Submitted By

Signature: ....
Name: SM Sabahat Hossain
ID Number: 200918028

Signature: ....
Name: Md. Tanjirul Islam
ID Number: 200918039

Signature: ....
Name: Md. Abir Mahmud
ID Number: 200918064

ACKNOWLEDGEMENT

First of all, praise is due to almighty ALLAH with his compassion and mercifulness to allow us finalizing this undergraduate thesis. We express sincerest gratitude to our supervisor, **Dr. Engr. Md. Shafiqul Islam**, Principal Engineer & Project Director, Bangladesh Atomic Energy Commission, Dhaka, Bangladesh, who has supported us throughout our thesis with his patience and knowledge. We attribute the level of our Bachelor degree to his encouragement and effort and without him this thesis would not have been completed and written.

Our special thanks to all the lab assistants of Heat Transfer Lab of MIST who participated in maintenance related to experimental setup. We are grateful to MIST for funding. It would not be possible to complete this thesis without the financial co-operation of this organization. Finally, we thank our parents for supporting us throughout all our studies at University. We are also grateful to our friends for inspiring us in different stages of the thesis work.

The Authors
Department of Mechanical Engineering,
Military Institute of Science & Technology,
Mirpur Cantonment, Dhaka-1216, Bangladesh.
December, 2012.

ABSTRACT

Vapor compression refrigeration system was studied as it is the most widely used refrigeration system especially in small scale of refrigeration application such as in domestic application. Performance of the system becomes main issue and many researches are still ongoing to evaluate and improve efficiency of the system. By learning and understanding the basic vapor-compression refrigeration systems, the performance of refrigeration system can be determined using refrigerator test rig. This thesis deals with coefficient of performance testing under a vapor compression refrigerator using experimental setup for three different refrigerants. The main objective in this thesis was to obtain performance of the refrigeration system in term of refrigeration capacity, compressor work and coefficient of performance (COP) by determining three important parameters during operating mode which are temperature, pressure and refrigerant flowrate. The performance of the refrigerator test rig was analyzed using the actual pressure-enthalpy diagram of refrigeration cycle and by using the mathematical equation. This study may help the readers to analyze the performance of the refrigerator. Performance increases as the evaporating temperature increases, but reduces as the condensing temperature increases. We have found from the experiment that the average actual COP of R-12, R-22 and R-134a are 4.07, 3.97 and 3.80 respectively. Considering the overall assessment of the results and global warming potentials (GWPs) we can say that R134a will be a better alternative than other two refrigerants in the refrigeration system.

TABLE OF CONTENTS

Chapter VI: Conclusions and Recommendations

References

Appendixes

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

NOTATION	DEFINATION
COP	Coefficient of Performance
VCRC	Vapor Compression Refrigeration Cycle
GWP	Global Warming Potential
ODP	Ozone Depletion Potential
CFC	Chlorofluorocarbon
FC	Fluorocarbon
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
NBP	Normal Boiling Point
LED	Light Emitting Diode
Q	Flowrate
$\dot{m}$	Mass Flowrate
d	Density of Refrigerant
RE	Refrigeration Effect
CW	Compressor Work
h	Enthalpy
T	Temperature
P	Pressure
s	Entropy
v	Specific Volume

SUBSCRIPT

l	Liquid
v	Vapor
sat	Saturated

th	Theoritical
act	Actual
g	Gaseous
inl	Inlet
con	Condenser
eva	Evaporator
dis	Discharge

CHAPTER I

INTRODUCTION

1.1Background

Refrigeration may be defined as the process to achieve and keep an enclosed space at a temperature lower than its surrounding temperature. This is done by continuous extraction of heat from the enclosed space whereas the temperature is below than that of the surrounding temperature.

Now-a-days refrigeration is something that is indispensable in our daily life. One of the most important applications is the preservation of perishable foods and keeps the food in fresh condition. There is no doubt that food, is just like air and water are necessities for livings. People often utilize refrigeration to chill their drinks, making it more scrumptious. In additional, refrigeration also being used in providing thermal comfort to people by means of air conditioning process.

Historically, it is generally agreed that the first refrigeration machine was introduced in 1755 which was made by Scottish professor William Cullen. However, he did not use his discovery for any practical purpose. In the following 50 years, an American inventor, Oliver Evans, designed the first refrigeration machine. An American physician, John Gorrie, built a refrigerator based on Oliver Evans' design in 1844 to make ice to cool the air for his yellow fever patients. A German engineer named Carl von Linden patented not a refrigerator but the process of liquefying gas in 1876 that is part of basic refrigeration technology.

Generally refrigeration systems can be classified in 3 main cycle systems which are vapor compression refrigeration system, vapor absorption refrigeration system, and gas cycle refrigeration system. However the vapor compression refrigeration system is the most widely used in the refrigeration process. It is adequate for most refrigeration applications. The ordinary vapor compression refrigeration systems are simple, inexpensive, reliable and practically maintenance free.

However for large industrial applications, other refrigeration systems will be used to fulfill the effectiveness need. Jacob Perkins, an American living in London actually had designed the vapor compression refrigeration system and was built by Jacob Perkins in 1835 and had received his patent in 1834. The first practical vapor compression refrigeration system was made by James Harrison who took a patent in 1856 for vapor compression refrigeration system using ether, alcohol or ammonia as refrigerant.

Most of the domestic refrigerators today are running based on the vapor compression refrigeration system. It is somewhat analogous to a reverse Rankin cycle. The vapor compression refrigeration system contains four main components which are compressor, condenser, expansion device, and evaporator. Compressor is used to compress the low pressure and low temperature of refrigerant from the evaporator to high pressure and high temperature. After the compression process the refrigerant is then discharge into condenser. In the condenser, the condensation process requires heat rejection to the surroundings. The refrigerant can be condensed at atmospheric temperature by increasing the refrigerant's pressure and temperature above the atmospheric temperature.

After the condensation process, the condensed refrigerant will flow into the expansion device, where the temperature of refrigerant will be dropped lower than the surrounding temperature caused by the reducing pressure inside the expansion device. When the pressure drops, the refrigerant vapor will expand. As the vapor expands, it draws the energy from its surroundings or the medium in contact with it and thus produces refrigeration effect to its surroundings. After this process, the refrigerant is ready to absorb heat from the space to be refrigerated. The heat absorption process is to be done in the evaporator. The heat absorption process is normally being called as evaporation process. The cycle is completed when the refrigerant returns to the suction line of the compressor after the evaporation process.

The performance of the domestic refrigerator is to be analyzed by using experimental method and attempt to improve and achieve the maximum performance for a unit of domestic refrigerator. In order to have more accurate results for analyzing the performance of the domestic refrigerator, the suitable locations of parameters to be recorded down to determine the performance of the domestic refrigerator is crucial to be identified. The experiment is carried out by making a new test rig. The test rig is improved and modified when necessary.

We have used different types of refrigerant that are tested in the system and its effect on the performance of the refrigeration system is observed. This report is to give the understanding of how the coefficient of performance (COP) changes for different refrigerants.

1.2 Problem Statement

Now-a-days, refrigeration system is important because it is widely used for domestic application. However, the actual performance of the refrigerator is still unknown. So, we need some research to analyze the actual performance of refrigerator. At the same time we need to analyze the coefficient of performance using different refrigerants under same condition and power. For this we have to construct a test rig to find the coefficient of performance. We have taken three different refrigerants R-12, R-22, R-134a to analyze and compare their performances.

1.3 Objectives of Research

The main objectives of this thesis are given below:

- To develop an experimental rig for vapor compression refrigeration system.
- To determine the coefficient of performance (COP) of the refrigeration system using different refrigerants.
- To learn and understand the basic vapor compression refrigeration systems.
- To identify correctly the exact locations of points where the data for temperature and pressure should be collected.
- To improve the configuration of the refrigerator test rig to a simpler form based on previous development and research on basic vapor compression cycle.
- To identify the scope to improvise the cycle performance for the future.

CHAPTER II

LITERATURE REVIEW

2.1 History of Refrigerant

In general a refrigerant may be defined as "anybody or substance that acts as a cooling medium by extracting heat from another body or substance". Under this general definition, many bodies or substances may be called as refrigerants, e.g. ice, cold water, cold air etc. In closed cycle vapor compression cycle refrigeration system the refrigerant is a working fluid that undergoes cyclic changes. However, normally by refrigerants we mean the working fluids that undergo condensation and evaporation as in compression systems. The history that we are talking about essentially refers to these substances. Since these substances have to evaporate and condense at required temperatures (which may broadly lie in the range of $-100^{o}C$ to $+100^{o}C$) at reasonable pressures, they have to be essentially volatile. Hence, the development of refrigerants started with the search for suitable, volatile substances. Historically the development of these refrigerants can be divided into three distinct phases, namely:

i. Refrigerants prior to the development of CFCs

ii. The synthetic fluorocarbon (FC) based refrigerants

iii. Refrigerants in the aftermath of stratospheric ozone layer depletion

i. Refrigerants Prior to the Development of CFCs

W*ater* was the first refrigerant to be used in a continuous refrigeration system by William Cullen (1710-1790) in 1755. William Cullen is also the first man to have scientifically observed the production of low temperatures by evaporation of ethyl ether in 1748. Oliver Evans (1755-1819) proposed the use of a volatile fluid in a closed cycle to produce ice from water. He described a practical system that uses ethyl ether as the refrigerant. As already mentioned the credit for building the first vapor compression refrigeration system goes to Jacob Perkins (1766-1849). Perkins used sulphuric (ethyl) ethe*r* obtained from India rubber as refrigerant. Early commercial refrigerating machines developed by James Harrison (1816-1893) also used ethyl ether as refrigerant. Alexander Twining (1801-1884) also developed refrigerating machines using ethyl ether. After these developments, ethyl ether was used as refrigerant for several years for ice making, in breweries etc. Ether machines were gradually replaced by ammonia and carbon dioxide based machines, even though they were used for a longer time in tropical countries such as India. Ethyl ether appeared to be a good refrigerant in the beginning, as it was easier to handle it since it exists as a liquid at ordinary temperatures and atmospheric pressure. Ethyl ether has a normal boiling point (NBP) of 34.5^{o}C; this indicates that in order to obtain low temperatures, the evaporator pressure must be lower than one atmosphere, i.e., operation in vacuum. Operation of a system in vacuum may lead to the danger of outside air leaking into the system resulting in the formation of a potentially explosive mixture. On the other hand a relatively high normal boiling point indicates lower pressures in the condenser, or for a given pressure the condenser can be operated at higher condensing temperatures. This is the reason behind the longer use of ether in tropical countries with high ambient temperatures. Eventually due to the high NBP, toxicity and flammability problems ethyl ether was replaced by other refrigerants.

In 1866, the American T.S.C. Lowe (1832-1913) introduced carbon dioxide compressor. However, it enjoyed commercial success only in 1880s due largely to the efforts of German scientists Franz Windhausen (1829-1904) and Carl von Linde (1842-1934). Carbon dioxide has excellent thermodynamic and thermo physical properties; however, it has a low critical temperature (31.7^{o}C) and very high operating pressures. Since it is non-flammable and non-toxic it found wide applications principally for marine refrigeration. It was also used for refrigeration applications on land. Carbon dioxide was used successfully for about sixty years however, it was completely replaced by CFCs. It is ironic to note that ever since the problem of ozone layer depletion was found, carbon dioxide is steadily making a comeback by replacing the synthetic CFCs/HCFCs/HFCs etc.

One of the landmark events in the history of refrigerants is the introduction of ammonia. The American David Boyle (1837-1891) was granted the first patent for ammonia compressor in 1872. He made the first single acting vertical compressor in 1873. However, the credit for successfully commercializing ammonia systems goes to Carl von Linde (1842-1934) of Germany, who introduced these compressors in Munich in 1876. Linde is credited with perfecting the ammonia refrigeration technology and owing to his pioneering efforts; ammonia has become one of the most important refrigerants to be developed. Ammonia has a NBP of -33.3 ^{o}C; hence, the operating pressures are much higher than atmospheric. Ammonia has excellent thermodynamic and thermo physical properties. It is easily available and inexpensive. However, ammonia is toxic and has a strong smell and slight flammability. In addition, it is not compatible with some of the common materials of construction such as copper. Though these are considered to be some of its disadvantages, ammonia has stood the test of time and the onslaught of CFCs due to its excellent properties. At present ammonia is used in large refrigeration systems (both vapor compression and vapor absorption) and also in small absorption refrigerators (triple fluid vapor absorption).

Sulphur dioxide has the advantage of being an auto-lubricant. In addition it is not only non-flammable, but actually acts as a flame extinguisher. However, in the presence of water vapor it produces sulphuric acid, which is highly corrosive. The problem of corrosion was overcome by an airtight sealed compressor (both motor and compressor are mounted in the same outer casing). However, after about sixty years of use in appliances such as domestic refrigerators, sulphur dioxide was replaced by CFCs. In addition to the above, other fluids such as methyl chloride, ethyl chloride, iso-butane, propane, ethyl alcohol, methyl and ethyl amines, carbon tetra chloride, methylene chloride, gasoline etc. were tried but discarded due to one reason or other.

ii. The Synthetic CFCs/HCFCs

Almost all the refrigerants used in the early stages of refrigeration suffered from one problem or other. Most of these problems were linked to safety issues such as toxicity, flammability, high operating pressures etc. As a result large-scale commercialization of refrigeration systems was hampered. Hence it was felt that “refrigeration industry needs a new refrigerant if they expect to get anywhere”. The task of finding a “safe” refrigerant was taken up by the American Thomas Midgley, Jr., in 1928. Midgley was already famous for the invention of tetra ethyl lead, an important anti-knock agent for petrol engines. Midgley along with his associates Albert L. Henne and Robert R. McNary at the Frigidaire Laboratories (Dayton, Ohio, USA) began a systematic study of the periodic table. From the periodic table they quickly eliminated all those substances yielding insufficient volatility. They then eliminated those elements resulting in unstable and toxic gases as well as the inert gases, based on their very low boiling points. They were finally left with eight elements: carbon, nitrogen, oxygen, sulphur, hydrogen, fluorine, chlorine and bromine. These eight elements clustered at an intersecting row and column of the periodic table, with fluorine at the intersection.

A look at the refrigerants discussed above shows that all of them are made up of seven out of the eight elements identified by Midgley (fluorine was not used till then). Other researchers have repeated Midgley's search with more modern search methods and databases, but arrived at the same conclusions. Based on their study, Midgely and his colleagues have developed a whole range of new refrigerants, which are obtained by partial replacement of hydrogen atoms in hydrocarbons by fluorine and chlorine. They have shown how fluorination and chlorination of hydrocarbons can be varied to obtain desired boiling points (volatility) and also how properties such as toxicity, flammability are influenced by the composition. The first commercial refrigerant to come out of Midgley's study is Freon-12 in 1931. Freon-12 with a chemical formulaCCl_2F_2, is obtained by replacing the four atoms of hydrogen in methane (CH_4) by two atoms of chlorine and two atoms of fluorine. Freon-12 has a normal boiling point of -29.8^{o}C, and is one of the most famous and popular synthetic refrigerants. It was exclusively used in small domestic refrigerators, air conditioners, water coolers etc. for almost sixty years. Freon-11 (CCl_3F) used in large centrifugal air conditioning systems was introduced in 1932. This is followed by Freon-22 ($CHClF_2$) and a whole series of synthetic refrigerants to suit a wide variety of applications. Due to the emergence of a large number of refrigerants in addition to the existence of the older refrigerants, it has become essential to work out a numbering system for refrigerants. Thus all refrigerants were indicated with 'R' followed by a unique number (thus Freon-12 is changed to R12 etc.). The numbering of refrigerants was done based on certain guidelines. For all synthetic refrigerants the number (e.g. 11, 12, and 22) denotes the chemical composition.. Refrigerant mixtures begin with the number 4 (zeotropic) or 5 (azeotropic), e.g. R-500, R-502 etc.

The introduction of CFCs and related compounds has revolutionized the field of refrigeration and air conditioning. Most of the problems associated with early refrigerants such as toxicity, flammability, and material incompatibility were eliminated completely. Also, Freons are highly stable compounds. In addition, by cleverly manipulating the composition a whole range of refrigerants best suited for a particular application could be obtained. In addition to all this, a vigorous promotion of these refrigerants as “wonder gases” and “ideal refrigerants” saw rapid growth of Freons and equally rapid exit of conventional refrigerants such as carbon dioxide, sulphur dioxide etc. Only ammonia among the older refrigerants survived the Freon magic. The Freons enjoyed complete domination for about fifty years, until the Ozone Layer Depletion issue was raised by Rowland and Molina in 1974. Rowland and Molina in their now famous theory argued that the highly stable chlorofluorocarbons cause the depletion of stratospheric ozone layer. Subsequent studies and observations confirmed Rowland and Molina theory on stratospheric ozone depletion by chlorine containing CFCs. In view of the seriousness of the problem on global scale, several countries have agreed to ban the harmful Ozone Depleting Substances, ODS (CFCs and others) in a phase-wise manner under Montreal Protocol. Subsequently almost all countries of the world have agreed to the plan of CFC phase-out. In addition to the ozone layer depletion, the CFCs and related substances were also found to contribute significantly to the problem of “global warming”. This once again brought the scientists back to the search for “safe” refrigerants. The “safety” now refers to not only the immediate personal safety issues such as flammability, toxicity etc., but also the long-term environmental issues such as ozone layer depletion and global warming.

iii. Refrigerants in the aftermath of Ozone Layer Depletion

The most important requirement for refrigerants in the aftermath of ozone layer depletion is that it should be a non-Ozone Depleting Substance (non-ODS). Out of this requirement two alternatives have emerged. The first one is to look for zero ODP synthetic refrigerants and the second one is to look for “natural” substances. Introduction of hydro fluorocarbons (HFCs) and their mixtures belong to the first route, while the re-introduction of carbon dioxide (in a supercritical cycle), water and various hydrocarbons and their mixtures belong to the second route. The increased use of ammonia and use of other refrigeration cycles such as air cycle refrigeration systems and absorption systems also come under the second route. Both these routes have found their proponents and opponents. HFC-134a (synthetic substance) and hydrocarbons (natural substances) have emerged as alternatives to Freon-12. No clear pure fluid alternative has been found as yet for the other popular refrigerant HCFC-22. However several mixtures consisting of synthetic and natural refrigerants are being used and suggested for future use. Table shows the list of refrigerants being replaced and their alternatives. Mention must be made here about the other environmental problem, global warming. In general the non-ODS synthetic refrigerants such as HFC-134a have high global warming potential (GWP), hence they face an uncertain future. Since the global warming impact of a refrigerant also depends on the energy efficiency of the system using the refrigerant (indirect effect), the efficiency issue has become important in the design of new refrigeration systems. Though the issues of ozone layer depletion and global warming has led to several problems, they have also had beneficial effects of making people realize the importance of environmental friendliness of technologies. It is expected that with the greater awareness more responsible designs will emerge which will ultimately benefit the whole mankind.

2.2 History of Vapor Compression Refrigeration Systems

The basis of modern refrigeration is the ability of liquids to absorb enormous quantities of heat as they boil and evaporate. Professor William Cullen of the University of Edinburgh demonstrated this in 1755 by placing some water in thermal contact with ether under a receiver of a vacuum pump. The evaporation rate of ether increased due to the vacuum pump and water could be frozen. This process involves two thermodynamic concepts, the vapor pressure and the latent heat. A liquid is in thermal equilibrium with its own vapor at a pressure called the saturation pressure, which depends on the temperature alone. If the pressure is increased for example in a pressure cooker, the water boils at higher temperature. The second concept is that the evaporation of liquid requires latent heat during evaporation. If latent heat is extracted from the liquid, the liquid gets cooled. The temperature of ether will remain constant as long as the vacuum pump maintains a pressure equal to saturation pressure at the desired temperature. This requires the removal of all the vapors formed due to vaporization. If a lower temperature is desired, then a lower saturation pressure will have to be maintained by the vacuum pump. The component of the modern day refrigeration system where cooling is produced by this method is called evaporator. If this process of cooling is to be made continuous the vapors have to be recycled by condensation to the liquid state. The condensation process requires heat rejection to the surroundings. It can be condensed at atmospheric temperature by increasing its pressure. The process of condensation was learned in the second half of eighteenth century. U.F. Clouet and G. Monge liquefied SO_2 in 1780 while van Marum and Van Troostwijk liquefied NH_3in 1787. Hence, a compressor is required to maintain a high pressure so that the evaporating vapors can condense at a temperature greater than that of the surroundings. The man responsible for making a practical vapor compression refrigeration system was James Harrison who took a patent in 1856 for a vapor compression system using ether, alcohol or ammonia. Charles Tellierof France patented in 1864, refrigeration system using diethyl ether which has a normal boiling point of −23.6°C.Carl von Linde in Munich introduced double acting ammonia compressor. It required pressures of more than 10 atmospheres in the condenser. Since the normal boiling point of ammonia is -33.3°C, vacuum was not required on the low pressure side. Since then ammonia is used widely in large refrigeration plants. David Boyle, in fact made the first NH_3system in 1871 in San Francisco. John Enright had also developed a similar system in 1876 in Buffalo N.Y. Franz Windhausen developed carbon dioxide(CO_2) based vapor compression system in Germany in 1886. The carbon dioxide compressor requires a pressure of about 80 atmospheres and therefore a very heavy construction. Its lowest pressure was high enough to prevent the leakage of air into the system. Palmer used C_2H_5Clin 1890 in a rotary compressor. He mixed it with C_2H_5Br to reduce its flammability. Edmund Copeland and Harry Edwards used iso-butane in 1920 in small refrigerators. It disappeared by 1930 when it was replaced by CH_3Cl. Dichloroethylene (Dielene) was used by Carrier in centrifugal compressors in 1922-26.

2.3 History of Domestic Refrigeration Systems

The domestic refrigerator using natural ice (domestic ice box) was invented in 1803 and was used for almost 150 years without much alteration. The domestic ice box used to be made of wood with suitable insulation. Ice used to be kept at the top of the box, and low temperatures are produced in the box due to heat transfer from ice by natural convection. A drip pan is used to collect the water formed due to the melting of ice. The box has to be replenished with fresh ice once all the ice melts. Though the concept is quite simple, the domestic ice box suffered from several disadvantages. The user has to replenish the ice as soon as it is consumed, and the lowest temperatures that could be produced inside the compartment are limited. In addition, it appears that warm winters caused severe shortage of natural ice in USA. Hence, efforts, starting from 1887 have been made to develop domestic refrigerators using mechanical systems. The initial domestic mechanical refrigerators were costly, not completely automatic and were not very reliable. However, the development of mechanical household refrigerators on a large scale was made possible by the development of small compressors, automatic refrigerant controls, better shaft seals, developments in electrical power systems and induction motors. General Electric Company introduced the first domestic refrigerator in 1911, followed by Frigidaire in 1915. Kelvinator launched the domestic mechanical refrigerator in 1918 in USA. In 1925, USA had about 25 million domestic refrigerators of which only 75000 were mechanical. However, the manufacture of domestic refrigerators grew very rapidly, and by 1949 about 7 million domestic refrigerators were produced annually. With the production volumes increasing the price fell sharply (the price was 600 dollars in 1920 and 155 dollars in 1940). The initial domestic refrigerators used mainly sulphur dioxide as refrigerant. Some units used methyl chloride and methylene chloride. These refrigerants were replaced by Freon-12 in 1930s. In the beginning these refrigerators were equipped with open type compressors driven by belt drive. General Electric Company introduced the first refrigerator with a hermetic compressor in 1926. Soon the open type compressors were completely replaced by the hermetic compressors. First refrigerators used water-cooled condensers, which were soon replaced by air cooled-condensers. Though the development of mechanical domestic refrigerators was very rapid in USA, it was still rarely used in other countries. In 1930 only rich families used domestic refrigerators in Europe. The domestic refrigerator based on absorption principle as proposed by Platen and Munters, was first made by Electrolux Company in 1931 in Sweden. In Japan the first mechanical domestic refrigerator was made in 1924. The first dual temperature (freezer-refrigerator) domestic refrigerator was introduced in 1939. The use of mechanical domestic refrigerators grew rapidly all over the world after the Second World War. Today, a domestic refrigerator has become an essential kitchen appliance not only in highly developed countries but also in countries such as India. Except very few almost all the present day domestic refrigerators are mechanical refrigerators that use a hermetic compressor and an air cooled condenser. The modern refrigerators use either HFC-134a (hydro-fluoro-carbon) or iso-butane as refrigerant.

CHAPTER III

DESIGN AND CONSTRUCTION

While designing a vapor compression test rig it should be kept in mind that it is compact and represent the whole vapor compression refrigeration cycle. The condenser is naturally air cooled. So we have designed the test rig in such a way that the condenser can easily dissipate the heat to the environment. We have attached four wheels at the bottom of test rig frame, so that it can be moved easily from one place to another.

3.1 Design Requirements

To design a vapor compression test rig the following requirements should be fulfilled:

- Simple construction and components
- Capital cost should be low
- Environmental Friendly
- Quite enough to operate in a room
- Annual usage, life expectancy & reliability – comparable to other existing refrigerator
- User friendly to operate and maintain
- Safe
- Compact and light weight
- Proper insulation of evaporator

Considering the above requirements we have developed a test rig which is described in 3.2.

3.2 Test Rig Design

The schematic diagram of our test rig is shown in Fig 3.1.The main frame and basement is made of steel. The length, breadth and height of the frame are 0.76m, 0.61m and 1.37m respectively. We have used a board at the back of the frame which is made of plywood. We have mounted four temperature gauges, two pressure gauges, flowmeter and dryer on the board. The cooling chamber is placed on angle bar at a height of 0.46m above the basement. The evaporator is welded inside the cooling chamber. We have used 0.05m insulation for the cooling chamber. The dimension of the cooling chamber is 0.63m×0.51m×0.45m.

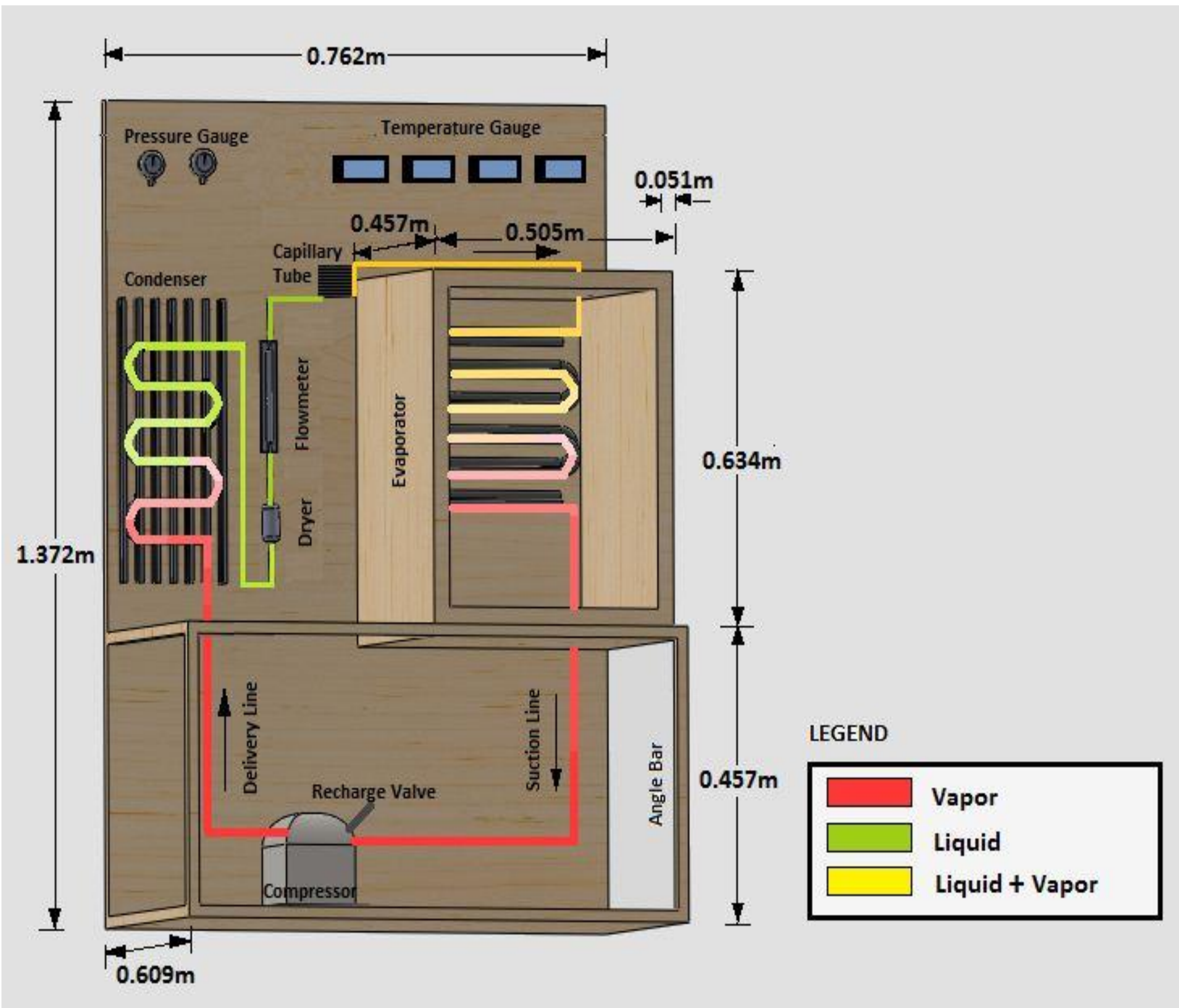


Fig 3.1: Schematic diagram of vapor compression refrigeration test rig.

A vapor refrigeration cycle is composed of several components. The main components are evaporator, compressor, condenser and capillary tube. The refrigerant has gone through three phases in this VCRC. In figure 3.1 red, green and yellow shows three phases of refrigerant which are vapor, liquid and liquid-vapor respectively. In our design we have used four digital temperature meters for measuring temperature of delivery line, condenser, evaporator and surrounding. To measure the pressure of delivery line we have used high pressure gauge .Besides to measure the pressure of suction line we have used low pressure gauge.

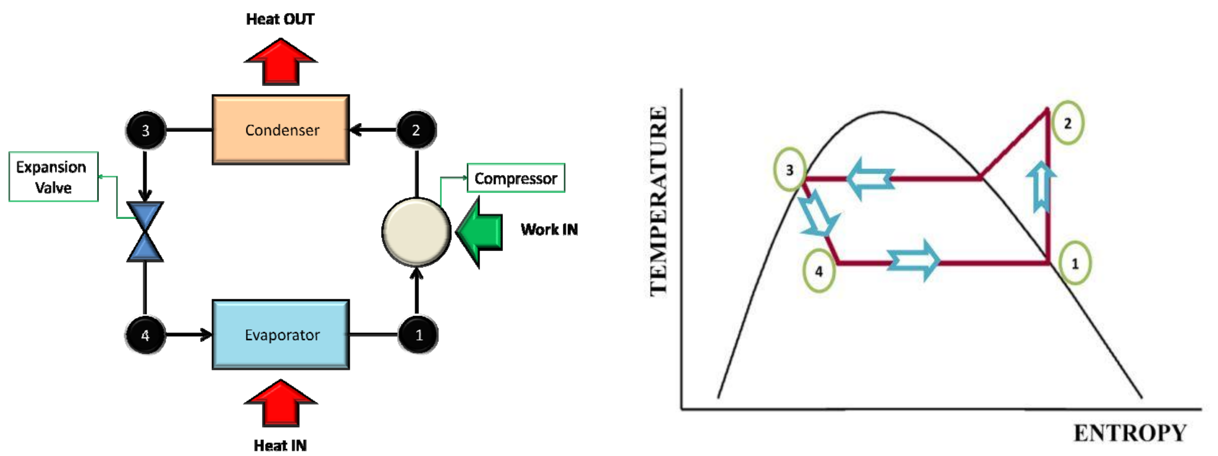


Figure 3.2: Schematic and T-S diagram of VCRC.

Referring to Figure 3.2, the functions of the four main components of an ideal VCRC may be summarized as follows:

1-2 Compressors: The low pressure saturated vapor is compressed to a high pressure superheated vapor under constant entropy value.

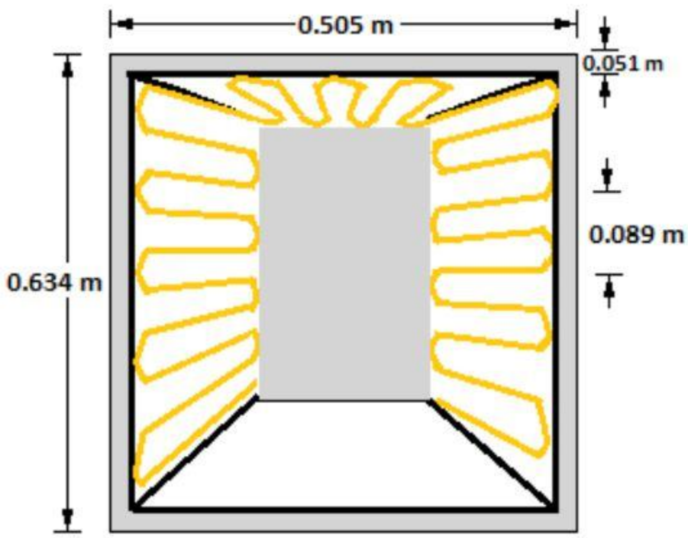
2-3 Condensers: The high pressure superheated vapor is sub-cooled to s saturated vapor state and then condenses into a saturated liquid state under constant pressure.

3 -4 Capillary Tubes: The high-pressure saturated liquid is expanded to a low pressure and temperature liquid-vapor mixture at constant enthalpy.

4-1 Evaporator: The low-pressure two-phase mixture boils to saturated vapor under constant pressure.

Evaporator Design

Evaporator cooling chamber of the test rig is mainly a rectangular box made of steel sheet which is shown in Fig 3.3. We have attached a door at the front side of the compartment which is made of aluminum frame and glass. Outer dimension of the cooling chamber is 0.63m×0.51m×0.45m. The insulation thickness of the cooling chamber is 0.05m.The evaporator coil is welded inside the cooling chamber. The diameter of the coil is 0.003m with a total length of 10.795m. Loop to loop distance of the evaporator coil is 0.09m.

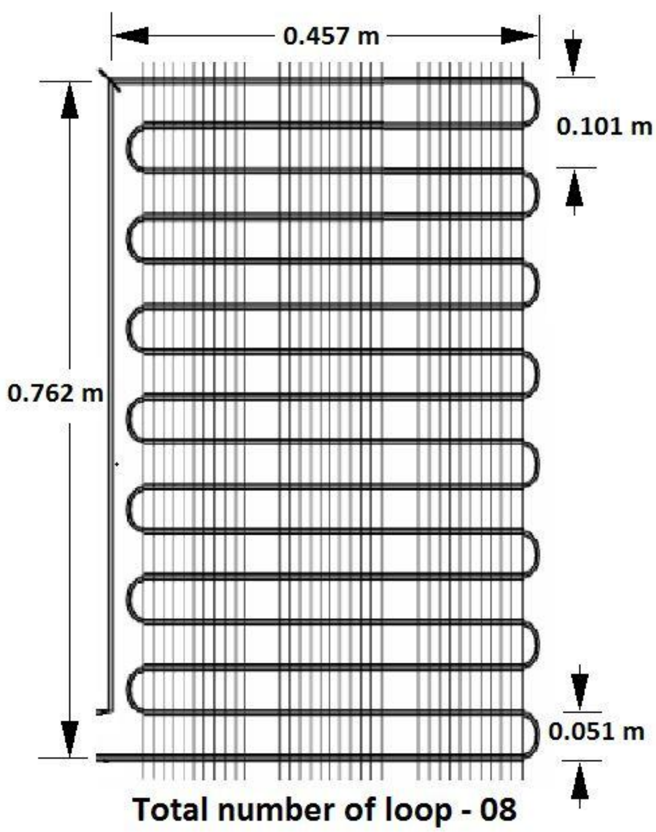


Description	Dimention
Width	0.505 m
Length	0.634 m
Loop to loop distance	0.089 m
Pipe diameter	0.003 m
Total pipe length	10.795 m

Fig 3.3: Design of evaporator of vapor compression refrigeration system.

Condenser Design

The design of condenser of vapor compression refrigeration system is shown in Fig 3.4. We have used naturally air cooled condenser in the test rig. The length and width of the condenser is 0.76m and 0.46m respectively. There are 08 loops in this condenser. Loop to loop distance of the condenser is 0.10m.Total length of the pipe is 8.63m.



Description	Dimension
Width	0.457 m
Length	0.762 m
Loop to loop distance	0.101 m
Pipe diameter	0.005 m
Total pipe length	8.635 m

Fig 3.4: Design of condenser of vapor compression refrigeration system.

3.3 Different Components

Different components of the vapor compression test rig are given below:

Compressor

In a refrigeration cycle, the compressor has two main functions within the refrigeration cycle. The function of the compressor is to pump the refrigerant vapor from the evaporator so that the desired temperature and pressure of the system. The second function is to increase the pressure of the refrigerant vapor through the process of compression, and simultaneously increase the temperature of refrigerant vapor. The compressor is shown in Fig 3.5.

Fig 3.5: Compressor.

Condenser

The heat extracted from the substance to be cooled by the refrigerant in the evaporator is rejected to the atmosphere through the condenser. The refrigerant is forced through the condenser In order to remove as much heat as possible with the tubes arranged to provide maximize surface area. In the condenser, the temperature of the superheated vapor has to be brought down to its saturation temperature before condensed into a liquid. The condenser is shown in Fig 3.6.

Fig 3.6: Condenser.

Capillary tube

The capillary tube is the simplest type of refrigerant flow control device and may be used in place of an expansion valve. The capillary tube is small-diameter tubes through which the refrigerant flows into the evaporator. It reduce the condensing pressure to the evaporating pressure in a copper tube of small internal diameter, maintaining a constant evaporating pressure independently of the refrigeration load range. The capillary tube is shown in Fig 3.7.

Fig 3.7: Capillary tube.

Evaporator

Evaporator can be considered the point of heat capture in refrigeration system and provides the cooling effect required for any particular application. During the same process, the high pressure liquid is lowered to what is called the evaporator pressure, or suction pressure. During evaporation, the refrigerant remains the same temperature throughout the coil until all droplets of liquid are vaporized, or totally saturated. The evaporator is shown in Fig 3.8.

Fig 3.8: Evaporator.

Pressure gauge

There are two types of pressure gauge used in refrigeration system. One is high pressure gauge and other is low pressure gauge. High pressure gauge is connected to the delivery line and low pressure gauge is connected to the sanction line. The pressure gauge is shown in Fig 3.9.

Fig 3.9: Pressure gauge.

Temperature meter

Temperature meter gives the temperature reading of different point of the refrigeration system. Digital temperature meter gives more accurate value than analog temperature meter. It shows reading in degree Celsius. The temperature meter is shown in Fig 3.10.

Fig 3.10: Digital temperature meter.

Ammeter

An ammeter is a measuring instrument used to measure the electric current in a circuit. Electric currents are measured in amperes (A), hence the name. It is connected in series in the circuit. Improved instruments were designed which could be mounted in any position and allowed accurate measurements in electric power systems. There are generally two types of ammeter called analog and digital ammeter. The ammeter is shown in Fig 3.11.

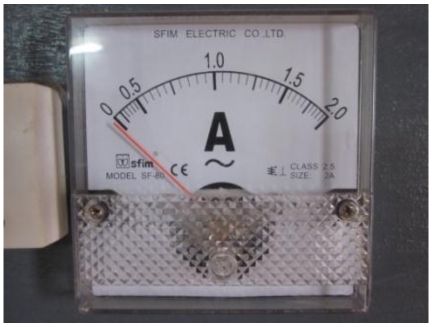


Fig 3.11: Ammeter.

Voltmeter

A voltmeter is a measuring instrument used to measure the voltage in a circuit. Electric voltages are measured in volts (V). It is connected parallel in the circuit. Improved instruments were designed which could be mounted in any position and allowed accurate measurements in electric power systems. The voltmeter is shown in Fig 3.12.

Fig 3.12: Voltmeter.

Dryer

Filter-dryer is a device used to trap the moisture, small metal chips, and dirt, in the refrigerant from entering the system which can restrict the free flow of refrigerant into the expansion valve. Every time a repair work is carried out in your refrigerator or freezer, it must be replaced with a new one. The dryer is shown in Fig 3.13.

Fig 3.13: Dryer.

Cooling fan

The cooling fan motor for compressor is used to force the air into its surface in order to dissipate the heat into the atmosphere and to bring down its temperature rapidly; and it sucks in the cool air from the surroundings and forces its way through the compressor surface where the heat is being removed. The cooling fan is shown in Fig 3.14.

Fig 3.14: Cooling fan.

Thermostat

Refrigerator thermostats are usually located inside the refrigerator and have a knob that allows users to adjust them. Once a user sets the desired temperature, the thermostat maintains that temperature by sensing internal fluctuations and prompting the compressor to turn on or off in response to those changes. When the refrigerator is appropriately adjusted to the designated temperature, the thermostat stops the flow of electricity to the compressor, stopping it from cooling the appliance. The thermostat is shown in Fig 3.15.

Fig 3.15: Thermostat.

Liquid line indicator

Moisture liquid indicators ensure a fast and safe inspection of the conditions of the refrigerant fluid in the circuit concerning regular flow and moisture. Liquid indicators also ensure inspection of the regular return of oil to the compressor crankcase. The liquid indicators consist of a sensitive element as a ring, which changes color passing from blue to pink according to the percentage of moisture in the system. The liquid line indicator is shown in Fig 3.16.

Fig 3.16: Liquid line indicator.

We have ensured proper insulation of the evaporator compartment with polystyrene and foam to prevent heat loss from the compartment. We attached a cooling fan near the compressor to avoid the overheating of the compressor. It increases the pumping effort of the compressor and gives better performance to the overall system. The condenser is placed in the system such a way that it can dissipate heat to the environment efficiently.

We have used digital temperature meter to get more accurate temperature reading of different points of the system during the experiment. To calculate the total power consumed by the system we must know the voltage and current reading, so we have attached an ammeter and a voltmeter in the system. To measure the flow rate of the refrigerant directly a liquid flowmeter is attached.

To construct the test rig at first the main steel frame is made and then we have colored it. Then we have made the cooling chamber and welded the evaporator coil inside it. We have also added a booster line to the cooling chamber. A door has been attached in front of the cooling chamber which is made of aluminum bar and glass. Then the cooling chamber is placed on the main steel frame. The condenser is placed at the back of the test rig. The sequence of the working process is shown in Fig 3.5.

We have collected all necessary equipment’s like pressure gauges, dryer, liquid line indicator, cooling fan etc. Then we have attached a ply wood board in the test rig. All the equipment’s are mounted on the board and then we have conned them sequentially. Then we have attached a light inside the cooling chamber. After that we have vacuumed the test rig to check any leakage. Finally we have recharged the required refrigerant in exact amount. The working sequence is shown in Fig 3.6.

3.4 Some Snapshots of Test Rig during Construction

(i)

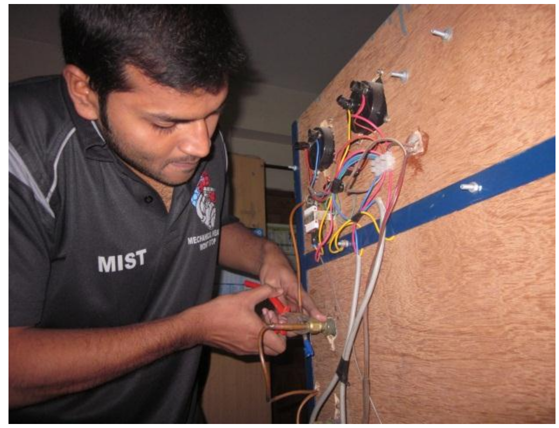
(ii)

(iii)

(iv)

Fig 3.5**:** (i) Main frame (ii) Cooling chamber (iii) Cooling chamber with door (iv) Condenser setting.

(v)



(vi)

(vii)

(viii)

Fig 3.6**:** (v) Test rig equipment's (vi) Flowmeter setting (vii) Cooling chamber light setting (viii) Recharge valve closing.

CHAPTER IV

EXPERIMENT

4.1 Experimental Setup

A vapor compression refrigerator is designed and fabricated in figure the detailed description of experimental apparatus experimental procedure are illustrated in the following section of this chapter.

Experimental Apparatus

The experimental setup of a vapor compression refrigerator is shown in Fig 4.1 consists of:

- Compressor
- Condenser
- Evaporator
- High pressure gauge(500 psi)
- Low pressure gauge(250 psi)
- Digital temperature meter
- Compartment light switch
- Ammeter
- Voltmeter
- Thermostat
- Flowmeter
- Bypass valve
- Dryer
- Liquid line indicator
- Capillary tube

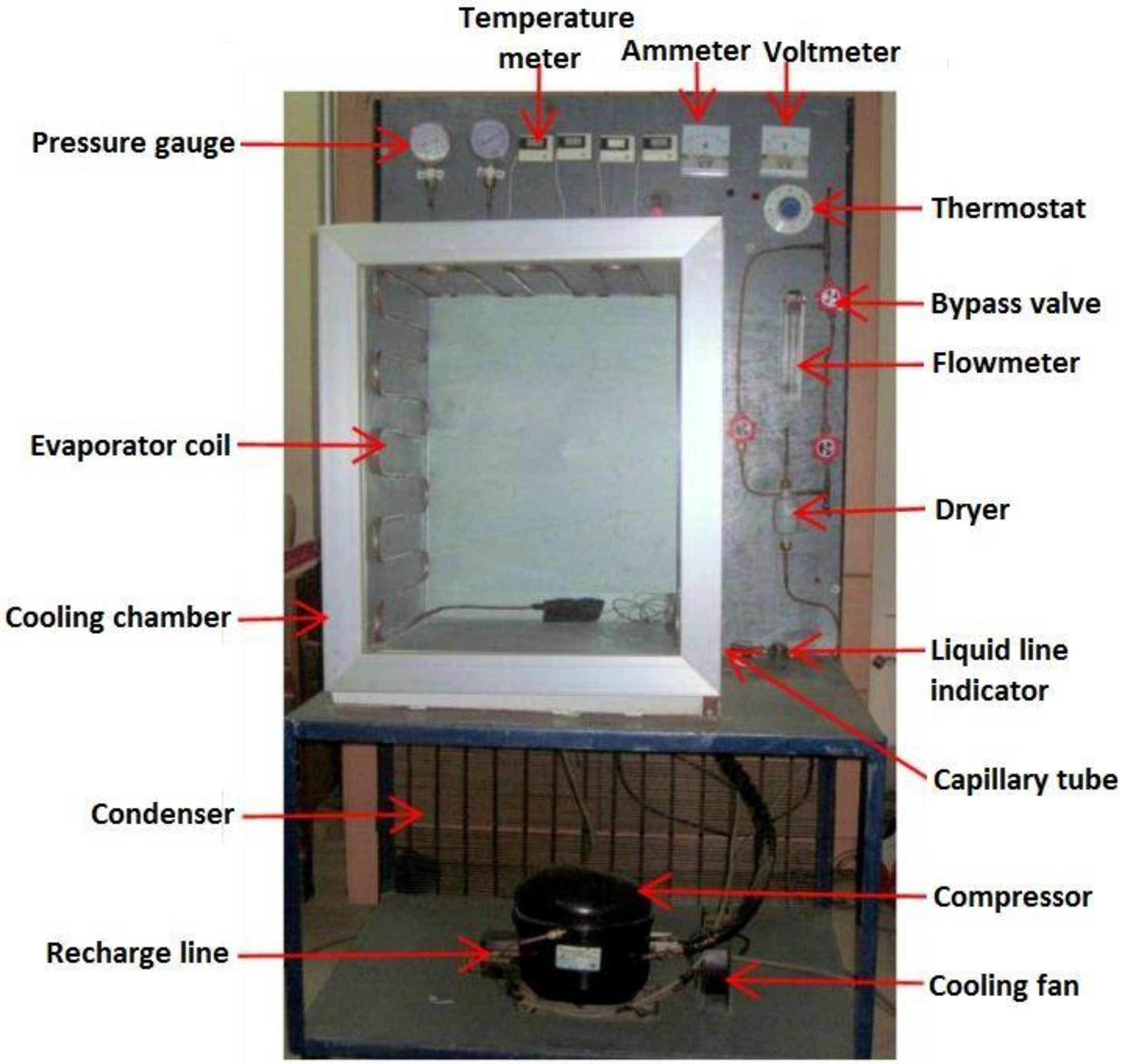


Fig 4.1: Different components of vapor compression test rig.

This vapor compression refrigeration test rig is built with condenser which is naturally air cooled. The evaporator is made of copper tube which is placed inside the cooling chamber. Dimension of the cooling chamber is 0.63m×0.51m×0.45m. A hermitically sealed compressor is used to compress the refrigerant. To measure pressure and temperature at different point of the system we have used two analog pressure gauges and four digital temperature meters. To measure the flowrate of the refrigerant a liquid flowmeter is attached to the system. We have used voltmeter and ammeter to measure the power consumed by the system. The components of the test rig are shown in Fig 4.1.

4.2 Experimental Procedure

The experimental procedure is described below:

- When the experimental setup was ready and inspected visually we first vacuum the whole system for 30 minutes.
- By observing the pressure gauge reading we have ensured that the system is totally leak proof.
- Then we have charged right amount refrigerant in the system.
- The tests are conducted under room condition, ranging temperature from 29 to 32 ℃.
- Then we turned the power supply on and ensure that all the electrical instruments are working properly.
- After that we have waited until the system reached the steady state condition.
- Then by closing the bypass valve we have taken the flowrate of the refrigerant from the liquid flowmeter.
- After taking the value we gradually open the bypass valve to reduce the pressure on the flowmeter.
- When the bypass valve is fully open there is no refrigerant flow through the flowmeter which keep it safe.
- Then in steady state condition we have taken the reading from pressure gauge and temperature meter carefully.
- Then we have repeated the same procedure for other two refrigerants.

4.3 Data Collection

We have taken data's for the three refrigerants in three different days. We could not take the data in a single day as it takes time to vacuum and to recharge the refrigerant in the system. To find out the theoretical COP we need to know the enthalpy of the system. For different temperature and pressure the enthalpy of the system is different. We have mainly used the condenser and evaporator temperatures for calculating the COP. At the same time we have noted down the high and low pressure from pressure gauges. Then we have used related chart and table to find the corresponding enthalpy. Finally the theoretical COP is calculated by putting these values in the mathematical formula.

Table 4.1(a): Theoretical & Actual COP for R-12 Date: 05/09/20012

Ambient temp: 31.4℃

Obs. no	T_{dis} (°C)	T_{inl} (°C)	T_{con} (°C)	T_{eva} (°C)	P_{inl} (KPa)	P_{dis} (KPa)	$\dot{m}$ (Kg/s)	h(kJ/kg)				COP	
								h_1	h_2	h_3	h_4	th	act
1	53.6	-11.3	34.6	-12.6	34.47	965.3	.01238	233.68	347.09	363	233.68	7.13	4.09
2	53.8	-13.2	35.5	-12.2	34.47	965.3	.01238	234.60	347.27	365	234.60	6.28	4.06
3	53.2	-14.4	35.4	-12.3	34.47	965.3	.01238	234.50	347.22	364	234.50	6.72	4.07
4	55.4	-14.4	35.5	-12.8	34.47	965.3	.01238	234.60	346.99	365	234.60	6.24	4.05

Table 4.1(b): Determination of enthalpy (h_3) by using pressure & entropy

T_{con} (°C)	P (Kpa)	S_g (KJ/Kg.K)	h_3 (KJ/kg)
34.6	837.64	1.54	363
35.5	857.00	1.54	365
35.4	854.84	1.54	364
35.5	857.00	1.54	365

Table 4.2(a): Theoretical & Actual COP for R-22 Date: 11/09/2012

Ambient temp: 31.1℃

Obs. no	T_{dis} (°C)	T_{inl} (°C)	T_{con} (°C)	T_{eva} (°C)	P_{inl} (KPa)	P_{dis} (KPa)	$\dot{m}$ (Kg/s)	h(kJ/kg)				COP	
								h_1	h_2	h_3	h_4	th	act
1	54.9	-1.4	39.8	-13.5	62.05	1526.1	.0214	249.38	399.78	418	249.38	8.25	3.99
2	55.3	-1.7	40.1	-13.9	62.15	1537.2	.0214	249.78	399.62	419	249.78	7.73	3.97
3	55.7	-0.8	40.3	-13.1	68.60	1544.8	.0214	250.31	399.86	420.2	250.31	7.55	3.97
4	56.3	-1.2	40.5	-13.3	68.95	1552.1	.0214	250.05	399.94	419.8	250.05	7.35	3.96

Table 4.2(b): Determination of enthalpy (h_3) by using pressure & entropy

T_{con} (°C)	P (Kpa)	S_g (KJ/Kg.K)	h_3 (KJ/kg)
39.8	1526.1	1.7	418
40.1	1537.2	1.7	419
40.3	1544.8	1.7	420.2
40.5	1552.1	1.7	419.8

Table 4.3(a): Theoretical & Actual COP for R-134a

Date: 20/09/2012

Ambient temp: 30.5℃

Obs. no	T_{dis} (°C)	T_{inl} (°C)	T_{con} (°C)	T_{eva} (°C)	P_{inl} (KPa)	P_{dis} (KPa)	$\dot{m}$ (Kg/s)	h(kJ/kg)				COP	
								h_1	h_2	h_3	h_4	th	act
1	54.9	-1.4	34.2	-12	41.05	867	.0121	247.83	391.46	414	247.83	6.37	3.81
2	55.1	-1.7	34.5	-11.8	41.15	874	.0121	248.27	391.70	417	248.27	5.68	3.80
3	55.3	-0.8	34.6	-11.6	41.60	877	.0121	248.42	391.70	415	248.42	6.15	3.80
4	55.8	-1.2	34.8	-11.2	41.95	882	.0121	248.71	391.94	418	248.71	5.49	3.80

Table 4.3(b): Determination of enthalpy (h_3) by using pressure & entropy

T_{con} (°C)	P (Kpa)	S_g (KJ/Kg.K)	h_3 (KJ/kg)
34.2	867	1.71	414
34.5	874	1.71	417
34.6	877	1.71	415
34.8	882	1.71	418

CHAPTER V

RESULTS AND DISCUSSIONS

The experiment is carried out with recording the evaporator temperature and condenser temperature for three different working refrigerants (R-12, R-22 and R-134a). Both theoretical and actual COP of these refrigerants is calculated by using the collected data and graph which shown in Appendix-B and Appendix-C. Using this data for various evaporator temperatures, condenser temperature and working refrigerants various curves are plotted. All graphs are clearly explained and analyzed in this chapter.

5.1 Effect of Condenser Temperature on COP for Different Refrigerants

Fig 5.1, 5.2 and 5.3 are illustrated the relation between condenser temperature and COP of R-22, R-12 and R-134a respectively. The experimental data is shown in table 4.1(a), 4.2(a) and 4.3(a).

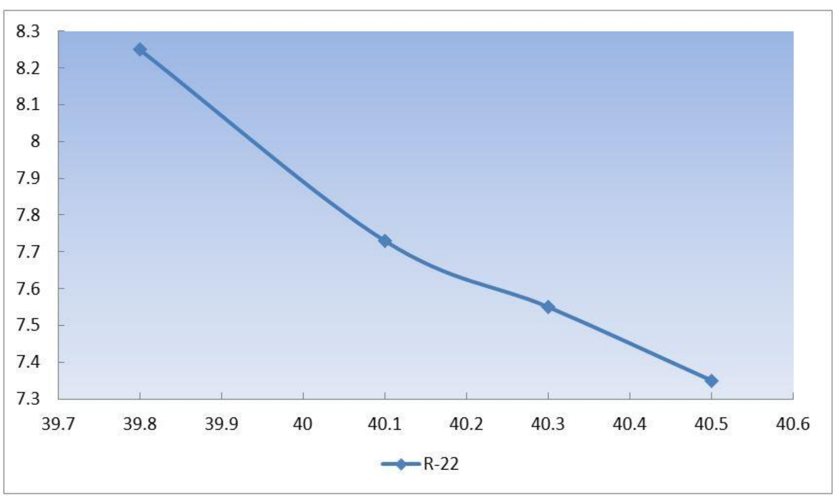


Fig 5.1: Effect of Condenser Temperature on COP for R-22

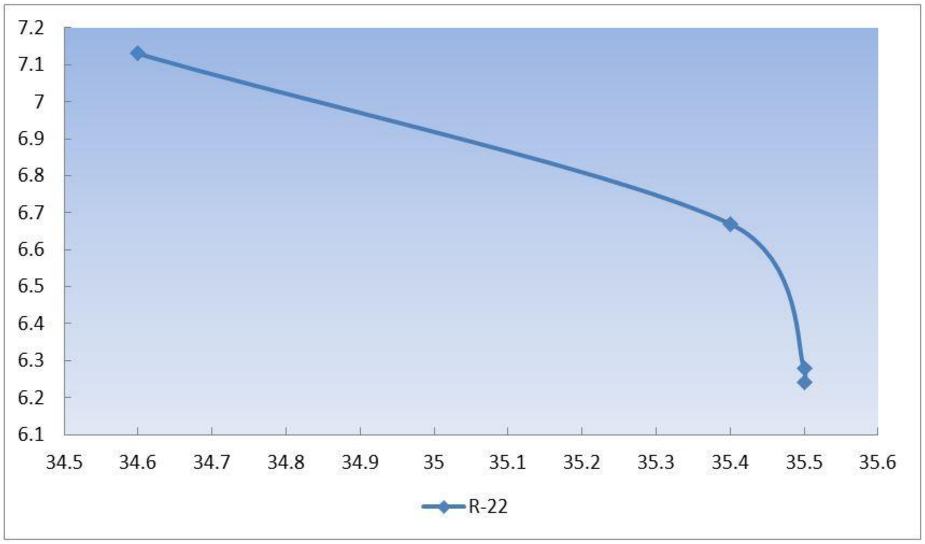


Fig 5.2: Effect of Condenser Temperature on COP for R-12

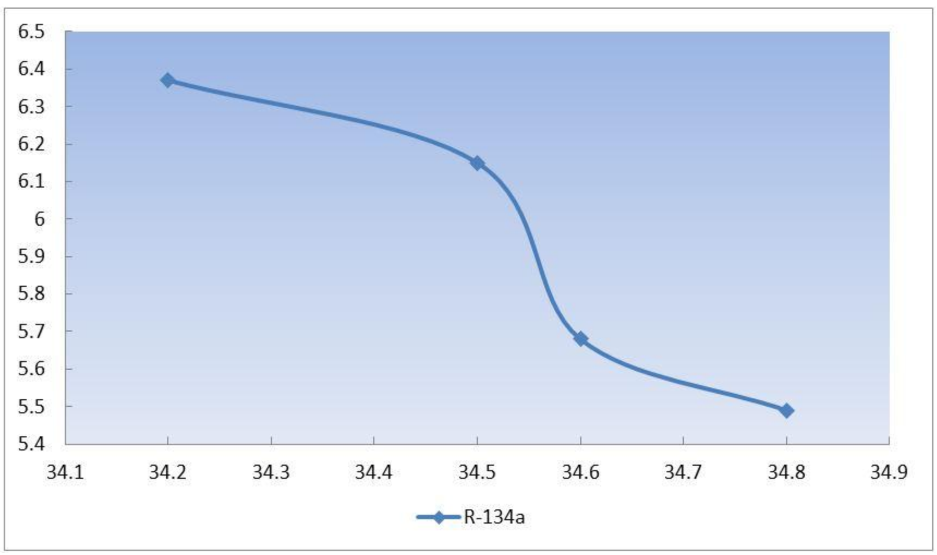


Fig 5.3: Effect of Condenser Temperature on COP for R-134a

In Fig 5.1 we can see that COP of refrigerant R-22 decreases with the increase of condenser temperature almost linearly. We can see that COP changes linearly for temperature 39.8℃ to 40.1℃ and 40.3℃ to 40.5℃.But the curve is slightly deflected from its linear position in between 40.1℃ to 40.3℃. This slight deflection might be happened for system loss.

COP of refrigerant R-12 also decreases with the increase of condenser temperature in Fig 5.2.The curve remain linear between temperatures 34.6℃ to 35.4℃ . After that the curve started to fall suddenly. This happened when the refrigerant effect remains same but the compressor work increase suddenly.

For refrigerant R-134a the curve changes non-linearly when COP decrease with the increase of condenser temperature shown in Fig 5.3. We can see that the COP decrease more rapidly between temperatures 34.5℃ to 34.6℃. It might be happened due to decrease of heat transfer rate of condenser.

5.2 Theoretical and Actual COP of Different Refrigerants

Fig.5.4, 5.5 and 5.6 are plots of theoretical and actual COP for three different refrigerants (R-12, R-22 and R-134a).The experimental data are shown in data table 4.1(a), 4.2(a) and 4.3(a)

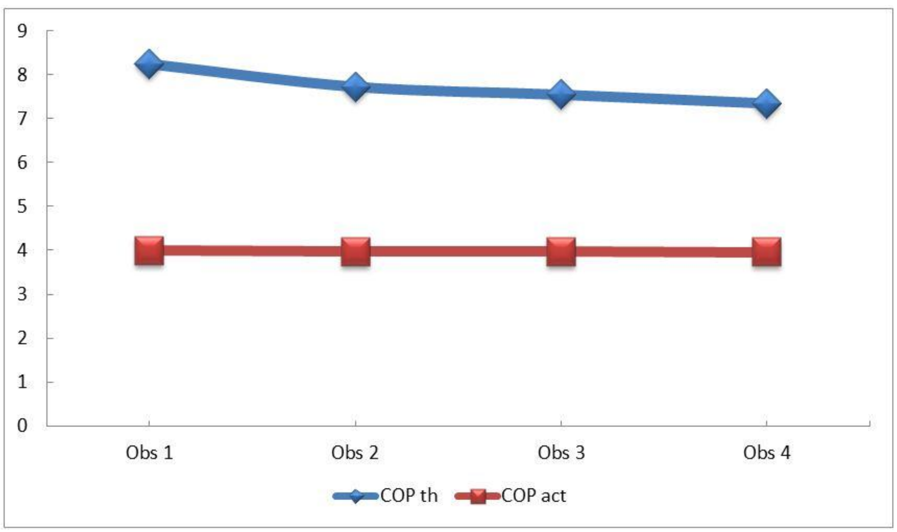


Fig 5.4: Theoretical and Actual COP of R-22.

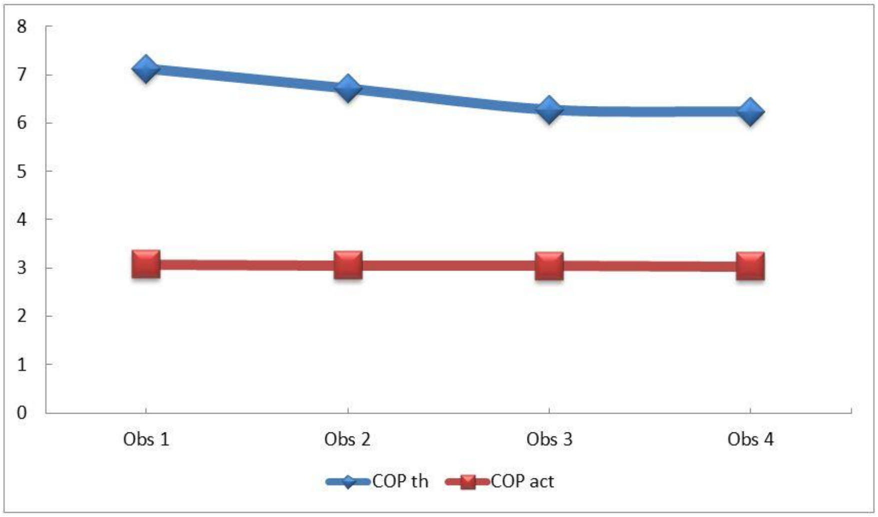


Fig 5.5: Theoretical and Actual COP of R-12.

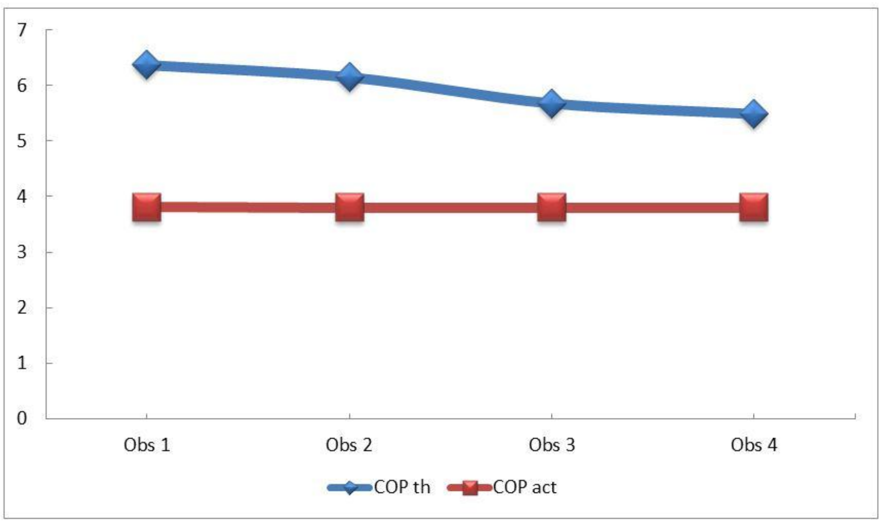


Fig 5.6: Theoretical and Actual COP of R-134a.

From Fig 5.4, 5.5 and 5.6 we can see that there is difference between theoretical and actual value of COP for the all three refrigerants. For R-22 the average actual COP is 3.97 and the average theoretical COP 7.72. For refrigerant R-12 the average actual and theoretical value of COP is 4.07 and 6.59 respectively. The average actual and theoretical value of R-134a is 3.8 and 5.92. The graphical representation of actual and theoretical COP for four observations of refrigerant R-22, R-12 and R-134a are given below.

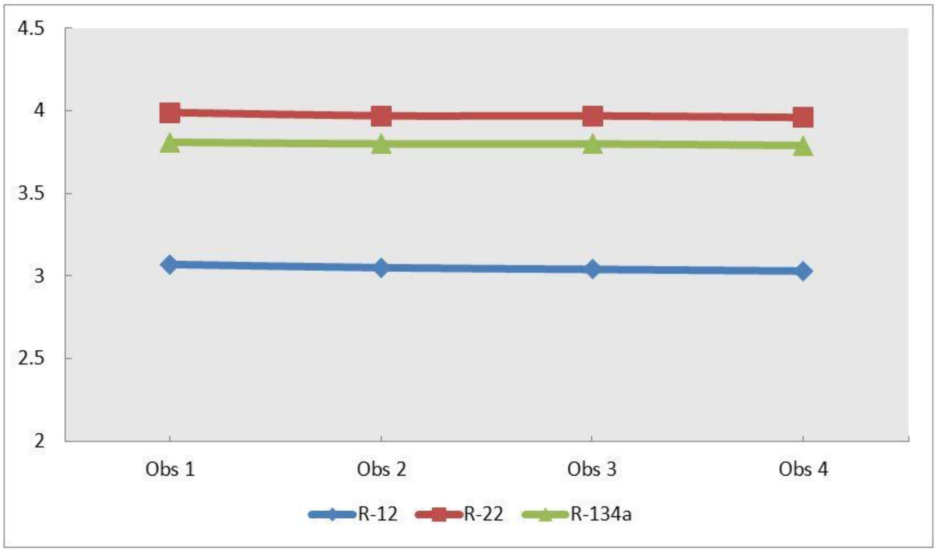


Fig 5.7: Actual COP of R-12, R-22 and R-134a

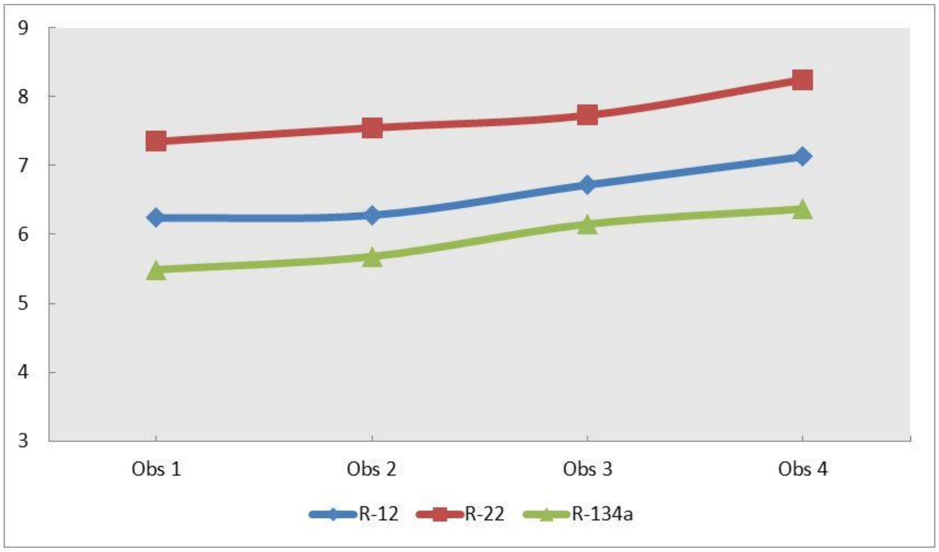


Fig 5.8: Theoretical COP of R-12, R-22 and R-134a

It was seen that the refrigerant enters the evaporator as a two phase liquid vapor mixture. Ideally this two-phase liquid is turned to steam with the heat addition received in the evaporator heat exchanger. Had it been the case where droplets of liquid refrigerant entered the compressor could significantly hinder the performance of this component. This wet compression of the refrigerant could potentially damage this component via cavitation. Ideally this compression is done isentropically with no heat addition from its surroundings and internally reversible. Unfortunately this is not the case of a real vapor compression cycle and due to this issue the efficiency of the system is lowered. Once the compressor has increased the pressure of the refrigerant it is passed through the condenser, it is here that heat is rejected to the surroundings. In this component the refrigerant entered in both conditions as a superheated vapor and should leave as a saturated liquid. The next step for the vapor compression refrigeration cycle is the isenthalpic throttling valve. This expansion cooled the refrigerant and lowers its pressure to the pressure inside the evaporator. This cooled two-phase liquid vapor mixture is then returned to the evaporator to close the loop. It was found that compressor did more work when fans were off than when fan was on. This can be explained with the fact that the cycle was operating with a variable orifice expansion valve.

Recently, the ozone depleting potential (ODP) and global warming potential (GWP) have become the most important criteria in the development of new refrigerants apart from the refrigerant CFCs and HCFCs, both of which have high ODP and GWP, due to the their contribution to ozone layer depletion and global warming. In spite of their high GWP, alternatives to refrigerant CFCs and HCFCs such as hydro fluorocarbon (HFC) refrigerants with their zero ODP have been preferred for use in many industrial and domestic applications intensively for a decade. HFC refrigerants also have suitable specifications such as non-flammability, stability, and similar vapor pressure to the refrigerant CFCs and HCFCs. The problems of the depletion of ozone layer and increase in global warming caused scientists to investigate more environmentally friendly refrigerants than HFC refrigerants for the protection of the environment.

Considering the above discussion we can see that CFC and HCFC refrigerants have negative impact on environments. We have analyzed the COP of three refrigerants R-12(CFC), R-22(HCFC) and R-134a (HFC).Among them R-134a has zero ODP though its COP is little bit lesser than other two refrigerants. So considering environmental safety issue and availability of refrigerant we should use R-134a in vapor compression refrigeration system.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This experiment was carried out in order to observe and find COP of simple vapor compression refrigeration cycle with three different refrigerants. Temperature and pressure measurements were taken with special care with gages critical points of the system. With the properties of the refrigerants at all the stages of the refrigeration cycle known, the COP of refrigeration system was calculated. The conclusions that could be taken from this experiment are as follows:

- With the increase of compressor work COP decrease while change of refrigeration effect is negligible.
- Theoretical COP decrease with the increase of condenser temperature.
- As the condensing temperature is lowered, the compressor power input decreases.
- As evaporating temperature increases, so too does the compressor power input; however, this power increase is less than the capacity increase.
- As the temperature lift is reduced, the refrigeration compressor capacity increases.
- Both high pressure and low pressure reading of pressure gauge changes due to ambient temperature during the experiment.

6.2 Recommendations

- May contain sensor based doors for auto open or close like lift door.
- Brighter and more efficient chamber LED lights can be added.
- Electronic touch controls may be incorporated in the system.
- More efficient chilling technology.
- Out looking can be developed by using proper tools and architectural designs.
- Models with three doors and a freezer on the bottom may be introduced.
- Thinner, more effective insulation.
- Radio devices that make them Internet and smart-grid ready to take advantage of future improvements in convenience and efficiency.
- Identifying cooling load automatically and serve properly based on that.
- Advanced defrost sensor may be added which minimize frost build-up to maintain evaporator coil efficiency.
- Battery backup can be attached to assure control panel function during power failure.

References

[1] **Ahmadul Ameen**, "*Refrigeration and Air Conditioning*". PHI Learning Private Limited, 2005.

[2] **Wilbert F. Stoecker, J. W. Jones**, *"Refrigeration and Air Conditioning".* Tata Mcgraw-Hill Publishing Company LTD., Second Edition, 1983.

[3] **M. Y. Taieb, A. A Aziz, "***Refrigeration and Air Conditioning".* 3rd Edition. Prentice Hall, USA, 1998.

[4] **Dossat R. J.** , "*Principles of Refrigeration*". John Wiley & Sons, New York, 2002.

[5] **Whitman, C. W., Johnson, W. M**, "*Refrigeration and Air Conditioning Technology*". 4th edition. Delmar Thomson Learning, USA, 2000.

[6] **Jordan, R. C. and Priester, G. B**., "*Refrigeration and Air Conditioning systems*". 2nd edition. Prentice-Hall of India Private Limited, New Delhi, 1985.

[7] **McKellar, M. G. and Tree, D. R.,** "*Steady State Characteristics of Failures of a Household Refrigerator*". West Lafayette, Indiana, 1988.

[8] **Philipp, J., Kraus, E. and Meyer, "***A Presentation of a Test Rig to Record Mass Flow Rate, Pressures and Temperatures of a Household Refriherator During On/Off Cycling Mode*". West Lafayette, Indiana, 1996.

[9] **Refrigeration volume,** ASHRAE Handbook, ASHRAE, Inc., Atlanta, GA

[10] **Anderson, Oscar Edward** . *"Refrigeration in America: A history of a new technology and its impact".* Kennikat Press, 1972.

[11] **Woolrich, Willis Raymond**. "*The men who created cold: A history of refrigeration",* (1st ed.). Exposition Press, (1967).

[12] **William C. Whitman, William M. Johnson and John Tomczyk**. "*Refrigeration & Air Conditioning Technology"* (5th ed.). Thomson Delmar Learning, 2005.

Appendix-A

Sample Calculation

1. Determination of COP for refrigerant R-12

We know, $Q = \frac{\dot{m}}{d}$

Or, $\dot{m} = Q.d$

Here, $Q = 0.5$ L/min

$= \frac{0.5}{1000\times60}\ m^3/s$

$= 8.33\times 10^{-6} m^3/s$

So, $\dot{m} = (8.33\times 10^{-6} \times 1486)\ Kg/s$

$= 0.01238\ \ Kg/s$

For observation no 1:

T_{eva} = -12.6℃

T_{cond} = 34.6℃

From table we have got,

Enthalpy, $h_1 = h_4 = 233.68$ KJ/ Kg

$h_2 = 347.09$ KJ/ Kg

$h_3 = 363$ KJ/ Kg

Refrigeration effect, RE $= \dot{m}(h_2 - h_1)$

$= 0.01238\ (347.09 - 233.68)$ KW

$= 1.404$ KW

Compressor work, CW $= \dot{m}(h_3 - h_2)$

$= 0.01238(363 - 347.09)$

$= 0.1969$ KW

Now Coefficient of performance, $COP_{th} = \frac{(h_2 - h_1)}{(h_3 - h_2)}$

$$= \frac{(347.09 - 233.68)}{(363 - 347.09)}$$

$= 7.13$

Again, Coefficient of performance, $COP_{act} = \frac{\text{Refrigerant effect}}{\text{Compressor work}}$

$$= \frac{\dot{m}(h_2 - h_1)}{\sqrt{3}VICos\emptyset}$$

$$= \frac{0.01238\ (347.09 - 233.68)}{\sqrt{3} \times 220 \times 1.5 \times 0.6}$$

$= 4.09$

2. Determination of COP for refrigerant R-22

We know, $Q = \frac{\dot{m}}{d}$

Or, $\dot{m} = Q\, d$

Here, Q = 0.4 L/min

$= \frac{0.4}{1000\times60}\ m^3/s$

$= 6.67\times 10^{-6}\ m^3/s$

So, $\dot{m} = (6.67\times 10^{-6} \times 3660)\ Kg/s$

$= 0.0214\ Kg/s$

For observation no 1:

T_{eva} = -13.5℃

T_{cond} = 39.8℃

From table we have got,

Enthalpy, $h_1 = h_4$ = 249.38 KJ/ Kg

h_2 = 399.78 KJ/ Kg

h_3=418 KJ/ Kg

Refrigeration effect, RE= $\dot{m}(h_2 - h_1)$

$= 0.0214\ (399.78 - 249.38)$ KW

= 3.218 KW

Compressor work, CW = $\dot{m}(h_3 - h_2)$

$= 0.0214(418 - 399.78)$

= 0.389 KW

Now Coefficient of performance, $COP_{th} = \frac{(h_2 - h_1)}{(h_3 - h_2)}$

$= \frac{(399.78 - 249.38)}{(418 - 399.78)} = 8.25$

Again, Coefficient of performance, $COP_{act} = \frac{\text{Refrigerant effect}}{\text{Compressor work}}$

$$= \frac{\dot{m}(h_2 - h_1)}{\sqrt{3}VICos\emptyset}$$

$$= \frac{0.0214\ (399.78 - 249.38)}{\sqrt{3} \times 220 \times 1.5 \times 0.8}$$

$= 3.99$

3. Determination of COP for refrigerant R-134a

We know, $Q = \frac{\dot{m}}{d}$

Or, $\dot{m} = Q.d$

Here, Q = 0.6 L/min

$= \frac{0.6}{1000 \times 60}\ m^3/s$

$= 6.67 \times 10^{-6}\ m^3/s$

So, $\dot{m} = (6.67 \times 10^{-6} \times 508)$ Kg/s

$= 0.0121$ Kg/s

For observation no 1:

T_{eva} = -12℃

T_{cond} = 34.2℃

From table we have got,

Enthalpy, $h_1 = h_4 = 247.83$ KJ/ Kg

$h_2 = 391.46$ KJ/ Kg

$h_3 = 414$ KJ/ Kg

Refrigeration effect, RE = $\dot{m}(h_2 - h_1)$

$= 0.0121\ (391.46 - 247.83)$ KW

$= 1.738$ KW

Compressor work, CW = $\dot{m}(h_3 - h_2)$

$= 0.0121(414 - 391.46)$kW

$= 0.273$ KW

Now Coefficient of performance, $COP_{th} = \frac{(h_2 - h_1)}{(h_3 - h_2)}$

$$= \frac{(391.46-247.83)}{(414-391.46)}$$

$= 6.37$

Again, Coefficient of performance, $COP_{act} = \frac{\text{Refrigerant effect}}{\text{Compressor work}}$

$$= \frac{\dot{m}(h_2-h_1)}{\sqrt{3}VICos\emptyset}$$

$$= \frac{0.0121\ (391.46-247.83)}{\sqrt{3}\times 220\times 1.5\times 0.8}$$

$= 3.81$

Appendix-B

Table 5: Thermodynamic properties of refrigerants

Refrigerants	Chemical formula	Molecular mass (g/mol)	Boiling point (℃)	Ozone depletion potential (ODP)	Global warming potential (GWP)
R-12	CF_2Cl_2	121	-26.1	1	10900
R-134a	$C_2H_2F_4$	102	-29.8	0	1430
R-22	$CHClF_2$	86.47	-40.7	0.032	1800

Appendix-C

Table 6: Properties of saturated liquid and saturated vapor of R-12

t [°C]	p_l [bar]	p_g [bar]	h_l [kJ/kg]	h_g [kJ/kg]	s_l [kJ/kgK]	s_g [kJ/kgK]	v_l [dm3/kg]	v_g [dm3/kg]
-25	1.234932	1.234932	177.1224	341.3049	0.912686	1.574312	0.67887	132.2204
-24	1.28603	1.28603	178.0182	341.776	0.916275	1.573541	0.680238	127.3108
-23	1.338752	1.338752	178.9155	342.2465	0.919854	1.572787	0.681616	122.6233
-22	1.393131	1.393131	179.8143	342.7162	0.923426	1.57205	0.683003	118.146
-21	1.449202	1.449202	180.7146	343.1852	0.926988	1.571329	0.6844	113.8678
-20	1.507	1.507	181.6165	343.6534	0.930542	1.570625	0.685807	109.7784
-19	1.566561	1.566561	182.52	344.1208	0.934088	1.569936	0.687225	105.8679
-18	1.627918	1.627918	183.425	344.5874	0.937625	1.569263	0.688652	102.1272
-17	1.691109	1.691109	184.3315	345.0531	0.941154	1.568605	0.69009	98.54758
-16	1.756168	1.756168	185.2397	345.5179	0.944675	1.567962	0.691538	95.12087
-15	1.823132	1.823132	186.1495	345.9818	0.948188	1.567334	0.692997	91.83936
-14	1.892037	1.892037	187.0609	346.4448	0.951694	1.566719	0.694467	88.69582
-13	1.96292	1.96292	187.974	346.9067	0.955191	1.566118	0.695948	85.68341
-12	2.035818	2.035818	188.8887	347.3676	0.958681	1.565531	0.69744	82.79566
-11	2.110768	2.110768	189.8051	347.8274	0.962163	1.564957	0.698944	80.02649
-10	2.187807	2.187807	190.7231	348.2862	0.965638	1.564396	0.70046	77.37014
-9	2.266972	2.266972	191.6429	348.7438	0.969106	1.563847	0.701987	74.82118
-8	2.348302	2.348302	192.5644	349.2003	0.972566	1.56331	0.703526	72.37448
-7	2.431834	2.431834	193.4876	349.6555	0.976019	1.562786	0.705078	70.02518
-6	2.517606	2.517606	194.4126	350.1096	0.979465	1.562273	0.706642	67.76869
-5	2.605658	2.605658	195.3393	350.5624	0.982905	1.561771	0.708219	65.60067
-4	2.696027	2.696027	196.2678	351.0138	0.986337	1.56128	0.709808	63.517
-3	2.788753	2.788753	197.1981	351.464	0.989762	1.5608	0.711411	61.5138
-2	2.883874	2.883874	198.1302	351.9128	0.993181	1.560331	0.713027	59.58737
-1	2.981431	2.981431	199.0642	352.3601	0.996594	1.559871	0.714657	57.73422
0	3.081461	3.081461	200	352.8061	1	1.559422	0.716301	55.95105
1	3.184005	3.184005	200.9377	353.2505	1.0034	1.558982	0.717958	54.2347
2	3.289104	3.289104	201.8773	353.6935	1.006793	1.558551	0.71963	52.58221
3	3.396796	3.396796	202.8188	354.1349	1.010181	1.55813	0.721317	50.99074
4	3.507122	3.507122	203.7622	354.5746	1.013562	1.557717	0.723018	49.45761
5	3.620123	3.620123	204.7075	355.0128	1.016937	1.557312	0.724735	47.98027
6	3.735839	3.735839	205.6549	355.4493	1.020307	1.556916	0.726467	46.55631
7	3.854311	3.854311	206.6042	355.8841	1.023671	1.556528	0.728215	45.18342
8	3.97558	3.97558	207.5555	356.3171	1.027029	1.556147	0.729979	43.85941
9	4.099688	4.099688	208.5089	356.7484	1.030382	1.555774	0.731759	42.58221
10	4.226675	4.226675	209.4644	357.1778	1.033729	1.555408	0.733556	41.34985

11	4.356583	4.356583	210.4219	357.6053	1.037071	1.555049	0.73537	40.16043
12	4.489454	4.489454	211.3815	358.0309	1.040408	1.554697	0.737202	39.01217
13	4.625331	4.625331	212.3432	358.4545	1.04374	1.554351	0.739051	37.90336
14	4.764254	4.764254	213.3071	358.8762	1.047067	1.554011	0.740918	36.83238
15	4.906267	4.906267	214.2732	359.2957	1.050389	1.553677	0.742803	35.79768
16	5.051412	5.051412	215.2415	359.7132	1.053706	1.553349	0.744707	34.79778
17	5.199731	5.199731	216.212	360.1286	1.057018	1.553026	0.746631	33.83129
18	5.351267	5.351267	217.1848	360.5417	1.060326	1.552708	0.748574	32.89686
19	5.506064	5.506064	218.1598	360.9526	1.063629	1.552395	0.750537	31.99322
20	5.664165	5.664165	219.1372	361.3612	1.066929	1.552086	0.75252	31.11913
21	5.825612	5.825612	220.1168	361.7674	1.070223	1.551782	0.754524	30.27345
22	5.990451	5.990451	221.0989	362.1713	1.073514	1.551482	0.75655	29.45505
23	6.158723	6.158723	222.0834	362.5726	1.076801	1.551186	0.758597	28.66287
24	6.330475	6.330475	223.0703	362.9715	1.080084	1.550894	0.760667	27.89591
25	6.505748	6.505748	224.0596	363.3679	1.083363	1.550605	0.762759	27.15318
26	6.684589	6.684589	225.0515	363.7616	1.086638	1.550319	0.764875	26.43378
27	6.867041	6.867041	226.0459	364.1526	1.08991	1.550035	0.767014	25.7368
28	7.05315	7.05315	227.0429	364.5409	1.093178	1.549755	0.769178	25.06141
29	7.24296	7.24296	228.0424	364.9263	1.096444	1.549477	0.771367	24.40679
30	7.436516	7.436516	229.0446	365.309	1.099706	1.5492	0.773582	23.77216
31	7.633864	7.633864	230.0495	365.6886	1.102965	1.548926	0.775822	23.15679
32	7.835049	7.835049	231.0571	366.0653	1.106221	1.548653	0.778089	22.55997
33	8.040118	8.040118	232.0674	366.439	1.109474	1.548381	0.780384	21.98101
34	8.249116	8.249116	233.0806	366.8095	1.112725	1.548111	0.782707	21.41926
35	8.46209	8.46209	234.0966	367.1767	1.115973	1.547841	0.785059	20.8741
36	8.679086	8.679086	235.1155	367.5408	1.119219	1.547572	0.787441	20.34493
37	8.90015	8.90015	236.1373	367.9014	1.122462	1.547302	0.789853	19.83118
38	9.125331	9.125331	237.1621	368.2586	1.125704	1.547033	0.792296	19.33229
39	9.354674	9.354674	238.1899	368.6123	1.128944	1.546763	0.794771	18.84774
40	9.588228	9.588228	239.2209	368.9624	1.132181	1.546493	0.797278	18.37702
41	9.826041	9.826041	240.2549	369.3088	1.135418	1.546221	0.79982	17.91964
42	10.06816	10.06816	241.2922	369.6515	1.138653	1.545948	0.802396	17.47515
43	10.31463	10.31463	242.3326	369.9902	1.141886	1.545674	0.805008	17.04308
44	10.56551	10.56551	243.3764	370.325	1.145119	1.545398	0.807657	16.62301
45	10.82084	10.82084	244.4236	370.6558	1.14835	1.54512	0.810343	16.21453
46	11.08067	11.08067	245.4742	370.9824	1.151581	1.544839	0.813068	15.81724
47	11.34506	11.34506	246.5282	371.3047	1.154811	1.544555	0.815834	15.43075
48	11.61404	11.61404	247.5859	371.6226	1.158041	1.544268	0.81864	15.05471
49	11.88768	11.88768	248.6471	371.936	1.161271	1.543977	0.821489	14.68875
50	12.16601	12.16601	249.7121	372.2448	1.1645	1.543683	0.824381	14.33254
51	12.4491	12.4491	250.7809	372.5489	1.16773	1.543384	0.827319	13.98574
52	12.737	12.737	251.8535	372.8481	1.170961	1.54308	0.830303	13.64806

Table 7: Properties of saturated liquid and saturated vapor of R-22

t [°C]	p_l [bar]	p_g [bar]	h_l [kJ/kg]	h_g [kJ/kg]	s_l [kJ/kgK]	s_g [kJ/kgK]	v_l [dm3/kg]	v_g [dm3/kg]
-25	2.014341	2.014341	171.4402	394.904	0.891247	1.791766	0.73422	111.629
-24	2.096821	2.096821	172.5571	395.3402	0.895714	1.789887	0.735878	107.4859
-23	2.181886	2.181886	173.6759	395.7742	0.900171	1.788031	0.73755	103.529
-22	2.269589	2.269589	174.7966	396.206	0.904616	1.786198	0.739235	99.74862
-21	2.359984	2.359984	175.9191	396.6355	0.90905	1.784388	0.740934	96.13535
-20	2.453126	2.453126	177.0437	397.0627	0.913474	1.782599	0.742648	92.68057
-19	2.54907	2.54907	178.1702	397.4876	0.917887	1.780832	0.744376	89.37609
-18	2.647871	2.647871	179.2988	397.9101	0.92229	1.779085	0.746118	86.21423
-17	2.749584	2.749584	180.4294	398.3301	0.926683	1.777359	0.747876	83.18774
-16	2.854264	2.854264	181.5621	398.7476	0.931066	1.775652	0.749649	80.2898
-15	2.96197	2.96197	182.697	399.1625	0.935439	1.773965	0.751437	77.51396
-14	3.072756	3.072756	183.834	399.5749	0.939803	1.772297	0.753241	74.85417
-13	3.186681	3.186681	184.9732	399.9847	0.944157	1.770647	0.755061	72.3047
-12	3.303801	3.303801	186.1147	400.3917	0.948502	1.769016	0.756898	69.86016
-11	3.424175	3.424175	187.2584	400.796	0.952839	1.767402	0.758751	67.51543
-10	3.54786	3.54786	188.4044	401.1976	0.957166	1.765805	0.760621	65.26571
-9	3.674915	3.674915	189.5528	401.5963	0.961485	1.764224	0.762508	63.10644
-8	3.805399	3.805399	190.7036	401.9921	0.965796	1.76266	0.764413	61.03332
-7	3.939371	3.939371	191.8568	402.3849	0.970098	1.761112	0.766336	59.04229
-6	4.07689	4.07689	193.0124	402.7748	0.974393	1.759578	0.768277	57.12948
-5	4.218017	4.218017	194.1706	403.1616	0.978679	1.75806	0.770237	55.29127
-4	4.362812	4.362812	195.3312	403.5453	0.982958	1.756557	0.772215	53.5242
-3	4.511334	4.511334	196.4945	403.9258	0.987229	1.755067	0.774213	51.82501
-2	4.663645	4.663645	197.6603	404.3031	0.991493	1.753591	0.77623	50.1906
-1	4.819806	4.819806	198.8288	404.6772	0.99575	1.752129	0.778268	48.61803
0	4.979879	4.979879	200	405.0479	1	1.750679	0.780326	47.10453
1	5.143925	5.143925	201.1739	405.4152	1.004243	1.749241	0.782405	45.64746
2	5.312006	5.312006	202.3506	405.7791	1.008479	1.747816	0.784505	44.2443
3	5.484185	5.484185	203.5301	406.1394	1.012709	1.746402	0.786627	42.8927
4	5.660524	5.660524	204.7125	406.4962	1.016933	1.745	0.788771	41.59038
5	5.841087	5.841087	205.8978	406.8493	1.021151	1.743608	0.790937	40.33522
6	6.025937	6.025937	207.086	407.1987	1.025362	1.742227	0.793127	39.12516
7	6.215137	6.215137	208.2772	407.5443	1.029568	1.740855	0.79534	37.95827
8	6.408752	6.408752	209.4715	407.886	1.033769	1.739494	0.797577	36.83272
9	6.606846	6.606846	210.6688	408.2238	1.037964	1.738141	0.799839	35.74676
10	6.809483	6.809483	211.8693	408.5577	1.042153	1.736797	0.802126	34.69871
11	7.016728	7.016728	213.0729	408.8874	1.046338	1.735462	0.804439	33.68699
12	7.228647	7.228647	214.2798	409.213	1.050518	1.734134	0.806778	32.71009

13	7.445305	7.445305	215.49	409.5344	1.054693	1.732815	0.809143	31.76658
14	7.666768	7.666768	216.7035	409.8514	1.058864	1.731502	0.811537	30.85508
15	7.893103	7.893103	217.9204	410.1641	1.063031	1.730196	0.813958	29.97429
16	8.124375	8.124375	219.1408	410.4723	1.067193	1.728897	0.816408	29.12296
17	8.360652	8.360652	220.3647	410.7759	1.071352	1.727603	0.818887	28.29991
18	8.602	8.602	221.5921	411.0748	1.075507	1.726315	0.821397	27.50401
19	8.848488	8.848488	222.8232	411.369	1.079658	1.725032	0.823938	26.73418
20	9.100184	9.100184	224.0579	411.6584	1.083807	1.723754	0.82651	25.98937
21	9.357155	9.357155	225.2964	411.9428	1.087952	1.72248	0.829115	25.26862
22	9.619471	9.619471	226.5388	412.2221	1.092094	1.721209	0.831752	24.57098
23	9.8872	9.8872	227.785	412.4963	1.096234	1.719943	0.834424	23.89555
24	10.16041	10.16041	229.0352	412.7652	1.100371	1.718679	0.837131	23.24148
25	10.43918	10.43918	230.2894	413.0288	1.104507	1.717417	0.839874	22.60794
26	10.72356	10.72356	231.5477	413.2868	1.10864	1.716158	0.842654	21.99415
27	11.01364	11.01364	232.8102	413.5393	1.112772	1.7149	0.845472	21.39936
28	11.30949	11.30949	234.077	413.786	1.116902	1.713644	0.848329	20.82285
29	11.61117	11.61117	235.3482	414.0268	1.121031	1.712388	0.851226	20.26394
30	11.91876	11.91876	236.6238	414.2616	1.125159	1.711132	0.854164	19.72196
31	12.23233	12.23233	237.9039	414.4903	1.129286	1.709876	0.857144	19.19629
32	12.55196	12.55196	239.1887	414.7127	1.133413	1.708619	0.860168	18.68632
33	12.87771	12.87771	240.4782	414.9286	1.13754	1.707361	0.863238	18.19149
34	13.20966	13.20966	241.7726	415.138	1.141668	1.7061	0.866353	17.71122
35	13.54789	13.54789	243.0718	415.3406	1.145796	1.704838	0.869516	17.245
36	13.89246	13.89246	244.3762	415.5363	1.149924	1.703572	0.872729	16.79231
37	14.24347	14.24347	245.6857	415.7249	1.154054	1.702303	0.875993	16.35267
38	14.60097	14.60097	247.0005	415.9062	1.158186	1.701029	0.879309	15.9256
39	14.96506	14.96506	248.3208	416.0801	1.162319	1.699751	0.88268	15.51066
40	15.3358	15.3358	249.6466	416.2463	1.166455	1.698467	0.886106	15.10741
41	15.71327	15.71327	250.9781	416.4046	1.170593	1.697177	0.889591	14.71544
42	16.09756	16.09756	252.3154	416.5548	1.174734	1.695881	0.893137	14.33436
43	16.48874	16.48874	253.6588	416.6967	1.178879	1.694577	0.896744	13.96377
44	16.8869	16.8869	255.0083	416.83	1.183028	1.693265	0.900417	13.60332
45	17.29211	17.29211	256.3641	416.9545	1.187182	1.691945	0.904156	13.25264
46	17.70446	17.70446	257.7265	417.07	1.19134	1.690614	0.907966	12.9114
47	18.12403	18.12403	259.0956	417.1761	1.195503	1.689273	0.911847	12.57927
48	18.5509	18.5509	260.4716	417.2726	1.199673	1.687921	0.915804	12.25593
49	18.98515	18.98515	261.8547	417.3591	1.203849	1.686557	0.91984	11.94108
50	19.42688	19.42688	263.2451	417.4354	1.208032	1.68518	0.923957	11.63443
51	19.87617	19.87617	264.6431	417.5011	1.212223	1.683789	0.928159	11.33569
52	20.33311	20.33311	266.049	417.5559	1.216423	1.682383	0.93245	11.0446

Table 8: Properties of saturated liquid and saturated vapor of R-134a

t [°C]	p_l [bar]	p_g [bar]	h_l [kJ/kg]	h_g [kJ/kg]	s_l [kJ/kgK]	s_g [kJ/kgK]	v_l [dm3/kg]	v_g [dm3/kg]
-25	1.063999	1.063999	167.1881	383.4492	0.874599	1.746092	0.728095	181.6225
-24	1.113045	1.113045	168.4735	384.0725	0.879754	1.745092	0.729698	174.0652
-23	1.163859	1.163859	169.7609	384.6946	0.884896	1.744115	0.731313	166.8849
-22	1.216484	1.216484	171.0504	385.3157	0.890025	1.743162	0.732941	160.0598
-21	1.270966	1.270966	172.342	385.9356	0.895142	1.742231	0.734581	153.5695
-20	1.32735	1.32735	173.6358	386.5543	0.900246	1.741322	0.736233	147.3949
-19	1.38568	1.38568	174.9317	387.1717	0.905338	1.740436	0.737899	141.5182
-18	1.446004	1.446004	176.2298	387.7879	0.910418	1.73957	0.739577	135.9226
-17	1.508367	1.508367	177.5302	388.4027	0.915487	1.738725	0.741269	130.5924
-16	1.572817	1.572817	178.8327	389.0161	0.920543	1.7379	0.742975	125.5131
-15	1.639401	1.639401	180.1376	389.6281	0.925588	1.737095	0.744694	120.6708
-14	1.708167	1.708167	181.4447	390.2386	0.930622	1.73631	0.746428	116.0526
-13	1.779165	1.779165	182.7541	390.8476	0.935645	1.735543	0.748176	111.6465
-12	1.852442	1.852442	184.0659	391.455	0.940657	1.734794	0.749938	107.4411
-11	1.928048	1.928048	185.3801	392.0608	0.945657	1.734064	0.751715	103.4256
-10	2.006033	2.006033	186.6966	392.6649	0.950648	1.733351	0.753508	99.59015
-9	2.086448	2.086448	188.0156	393.2673	0.955627	1.732655	0.755316	95.9252
-8	2.169343	2.169343	189.337	393.868	0.960597	1.731975	0.757139	92.4219
-7	2.254769	2.254769	190.6609	394.4668	0.965556	1.731312	0.758979	89.07192
-6	2.342779	2.342779	191.9873	395.0638	0.970505	1.730664	0.760835	85.86739
-5	2.433424	2.433424	193.3162	395.6588	0.975445	1.730032	0.762708	82.80091
-4	2.526756	2.526756	194.6477	396.2519	0.980374	1.729414	0.764598	79.86551
-3	2.62283	2.62283	195.9818	396.8429	0.985294	1.728812	0.766505	77.05461
-2	2.721698	2.721698	197.3185	397.4319	0.990205	1.728223	0.76843	74.36203
-1	2.823414	2.823414	198.6579	398.0188	0.995107	1.727648	0.770373	71.7819
0	2.928032	2.928032	200	398.6035	1	1.727086	0.772334	69.30871
1	3.035607	3.035607	201.3448	399.1859	1.004884	1.726537	0.774314	66.93725
2	3.146194	3.146194	202.6924	399.7661	1.009759	1.726	0.776313	64.66259
3	3.259849	3.259849	204.0428	400.3439	1.014626	1.725476	0.778332	62.48009
4	3.376628	3.376628	205.396	400.9193	1.019485	1.724963	0.780371	60.38534
5	3.496586	3.496586	206.7522	401.4923	1.024335	1.724462	0.78243	58.37419
6	3.619781	3.619781	208.1112	402.0627	1.029178	1.723971	0.78451	56.44271
7	3.74627	3.74627	209.4732	402.6306	1.034013	1.723491	0.786611	54.58717
8	3.876109	3.876109	210.8381	403.1958	1.03884	1.723022	0.788734	52.80405
9	4.009358	4.009358	212.2062	403.7584	1.04366	1.722562	0.79088	51.09001
10	4.146075	4.146075	213.5772	404.3181	1.048472	1.722111	0.793048	49.44188
11	4.286317	4.286317	214.9515	404.8751	1.053278	1.72167	0.79524	47.85667
12	4.430145	4.430145	216.3289	405.4291	1.058076	1.721237	0.797455	46.33154

13	4.577618	4.577618	217.7095	405.9801	1.062868	1.720812	0.799694	44.86378
14	4.728796	4.728796	219.0933	406.5282	1.067654	1.720396	0.801959	43.45085
15	4.883739	4.883739	220.4805	407.0731	1.072433	1.719987	0.804249	42.09032
16	5.042507	5.042507	221.871	407.6148	1.077206	1.719585	0.806565	40.77987
17	5.205163	5.205163	223.2649	408.1533	1.081973	1.719189	0.808908	39.51732
18	5.371767	5.371767	224.6623	408.6884	1.086735	1.718801	0.811279	38.30059
19	5.542382	5.542382	226.0633	409.2201	1.09149	1.718418	0.813677	37.1277
20	5.717069	5.717069	227.4677	409.7483	1.096241	1.718041	0.816104	35.99678
21	5.895892	5.895892	228.8759	410.273	1.100986	1.717669	0.818561	34.90603
22	6.078914	6.078914	230.2877	410.7939	1.105727	1.717302	0.821048	33.85375
23	6.266198	6.266198	231.7032	411.3112	1.110463	1.716939	0.823566	32.83832
24	6.457808	6.457808	233.1226	411.8245	1.115194	1.71658	0.826116	31.85821
25	6.653809	6.653809	234.5458	412.334	1.119921	1.716226	0.828698	30.91194
26	6.854266	6.854266	235.973	412.8394	1.124644	1.715874	0.831314	29.99812
27	7.059244	7.059244	237.4041	413.3406	1.129363	1.715525	0.833965	29.11542
28	7.268808	7.268808	238.8394	413.8376	1.134079	1.715179	0.836651	28.26256
29	7.483026	7.483026	240.2788	414.3303	1.138791	1.714835	0.839373	27.43834
30	7.701963	7.701963	241.7224	414.8185	1.1435	1.714492	0.842132	26.64159
31	7.925687	7.925687	243.1703	415.3022	1.148207	1.71415	0.84493	25.87122
32	8.154265	8.154265	244.6226	415.7811	1.15291	1.71381	0.847768	25.12618
33	8.387766	8.387766	246.0794	416.2553	1.157611	1.713469	0.850646	24.40546
34	8.626258	8.626258	247.5407	416.7245	1.162311	1.713129	0.853566	23.7081
35	8.86981	8.86981	249.0067	417.1887	1.167008	1.712788	0.856529	23.03319
36	9.118492	9.118492	250.4773	417.6476	1.171704	1.712445	0.859536	22.37986
37	9.372374	9.372374	251.9528	418.1012	1.176398	1.712101	0.862589	21.74726
38	9.631527	9.631527	253.4333	418.5494	1.181092	1.711756	0.86569	21.13459
39	9.896021	9.896021	254.9187	418.9918	1.185784	1.711407	0.868839	20.5411
40	10.16593	10.16593	256.4093	419.4285	1.190477	1.711056	0.872038	19.96605
41	10.44133	10.44133	257.9051	419.8593	1.195169	1.7107	0.875289	19.40874
42	10.72228	10.72228	259.4062	420.2839	1.199862	1.710341	0.878593	18.86849
43	11.00887	11.00887	260.9128	420.7022	1.204555	1.709977	0.881953	18.34468
44	11.30116	11.30116	262.425	421.114	1.209249	1.709608	0.88537	17.83668
45	11.59924	11.59924	263.9429	421.5191	1.213944	1.709233	0.888846	17.3439
46	11.90318	11.90318	265.4667	421.9173	1.218641	1.708851	0.892383	16.86578
47	12.21305	12.21305	266.9965	422.3085	1.22334	1.708463	0.895984	16.40178
48	12.52894	12.52894	268.5324	422.6923	1.228042	1.708066	0.89965	15.95138
49	12.85091	12.85091	270.0745	423.0685	1.232746	1.707661	0.903384	15.51408
50	13.17905	13.17905	271.6232	423.437	1.237454	1.707247	0.907189	15.08941
51	13.51345	13.51345	273.1784	423.7974	1.242165	1.706823	0.911067	14.6769
52	13.85417	13.85417	274.7404	424.1495	1.246881	1.706389	0.915021	14.27611

Appendix-D

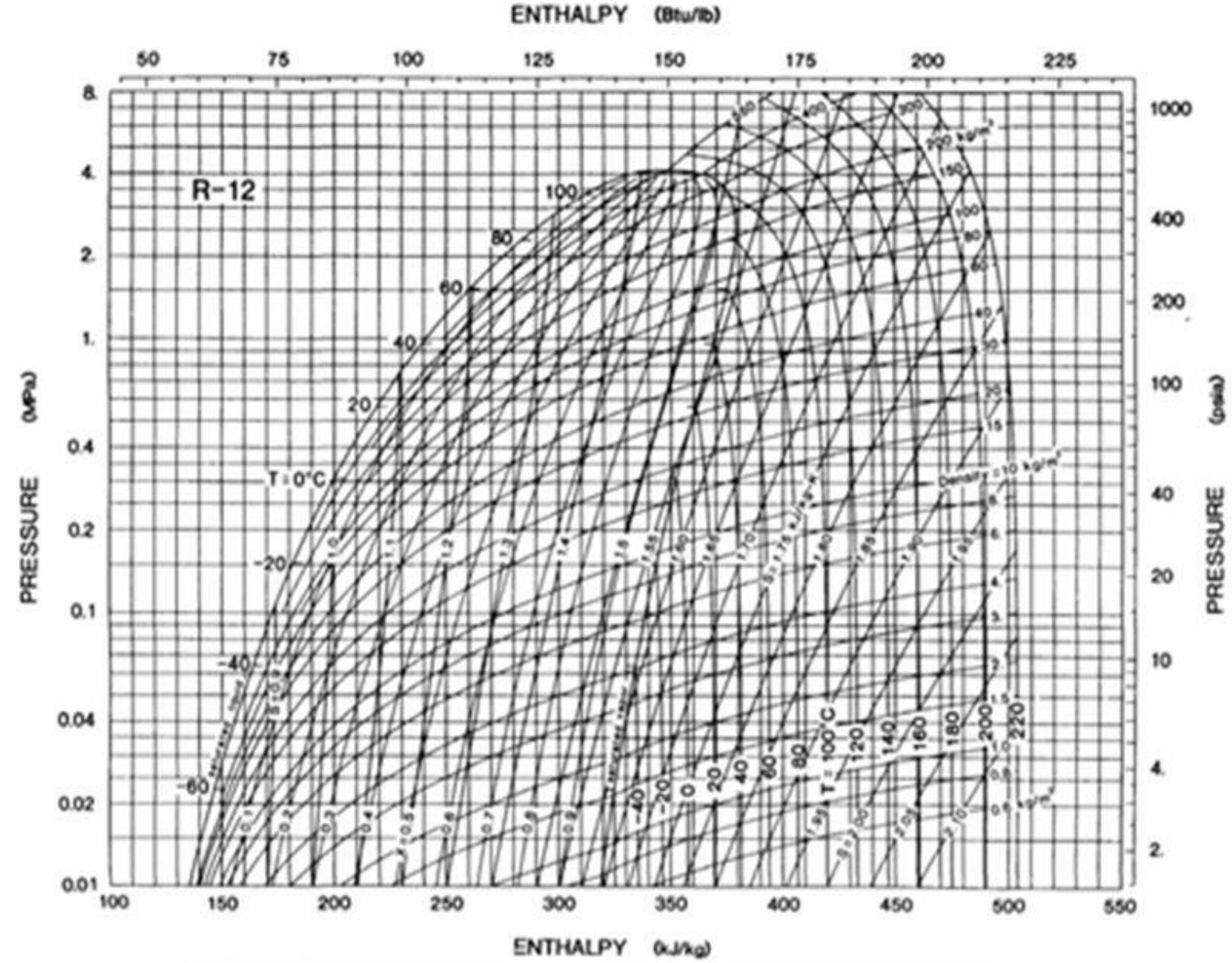


Figure 6: Pressure-enthalpy diagram of superheated R-12 vapor.

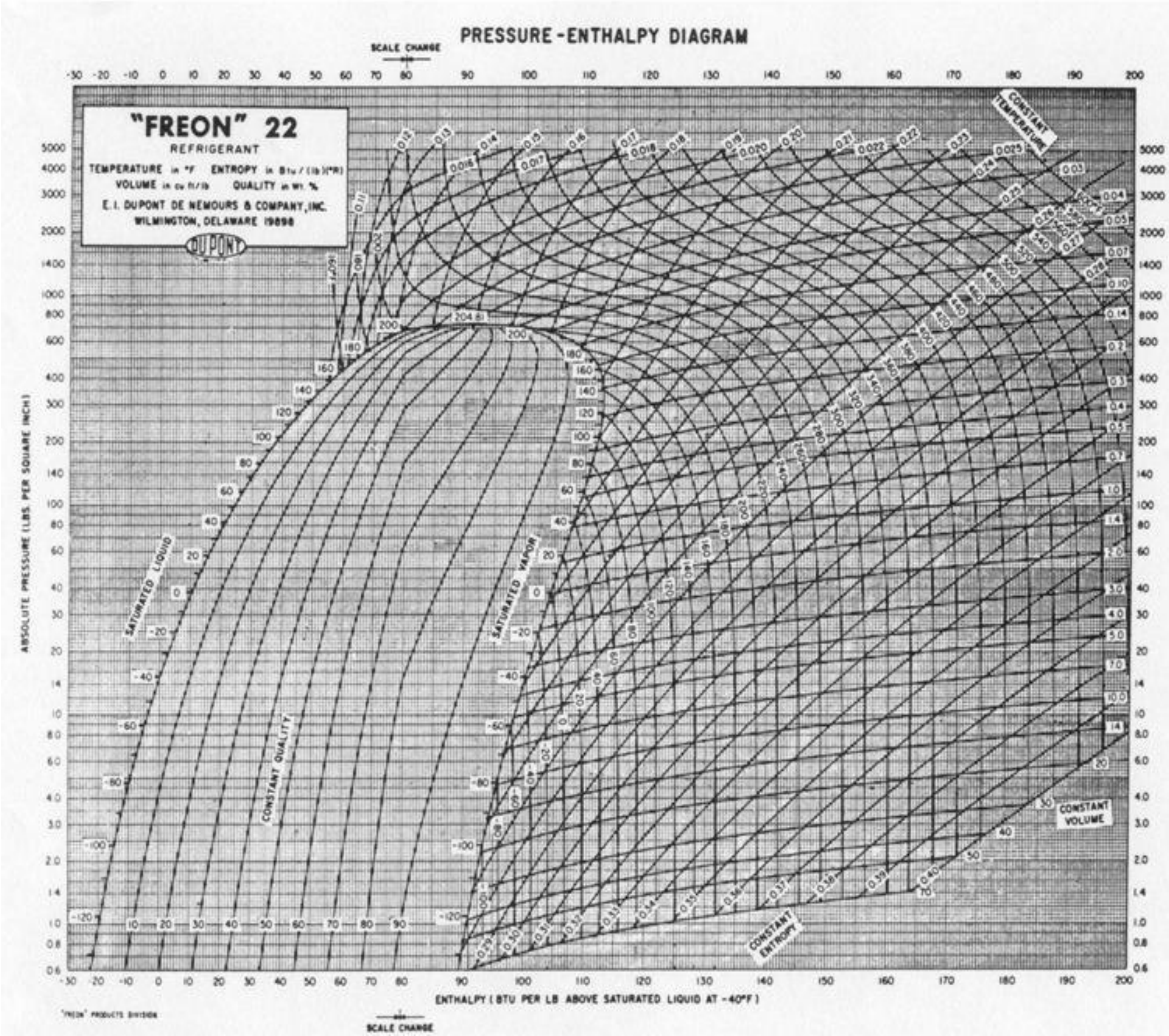


Figure 7: Pressure-enthalpy diagram of superheated R-22 vapor.

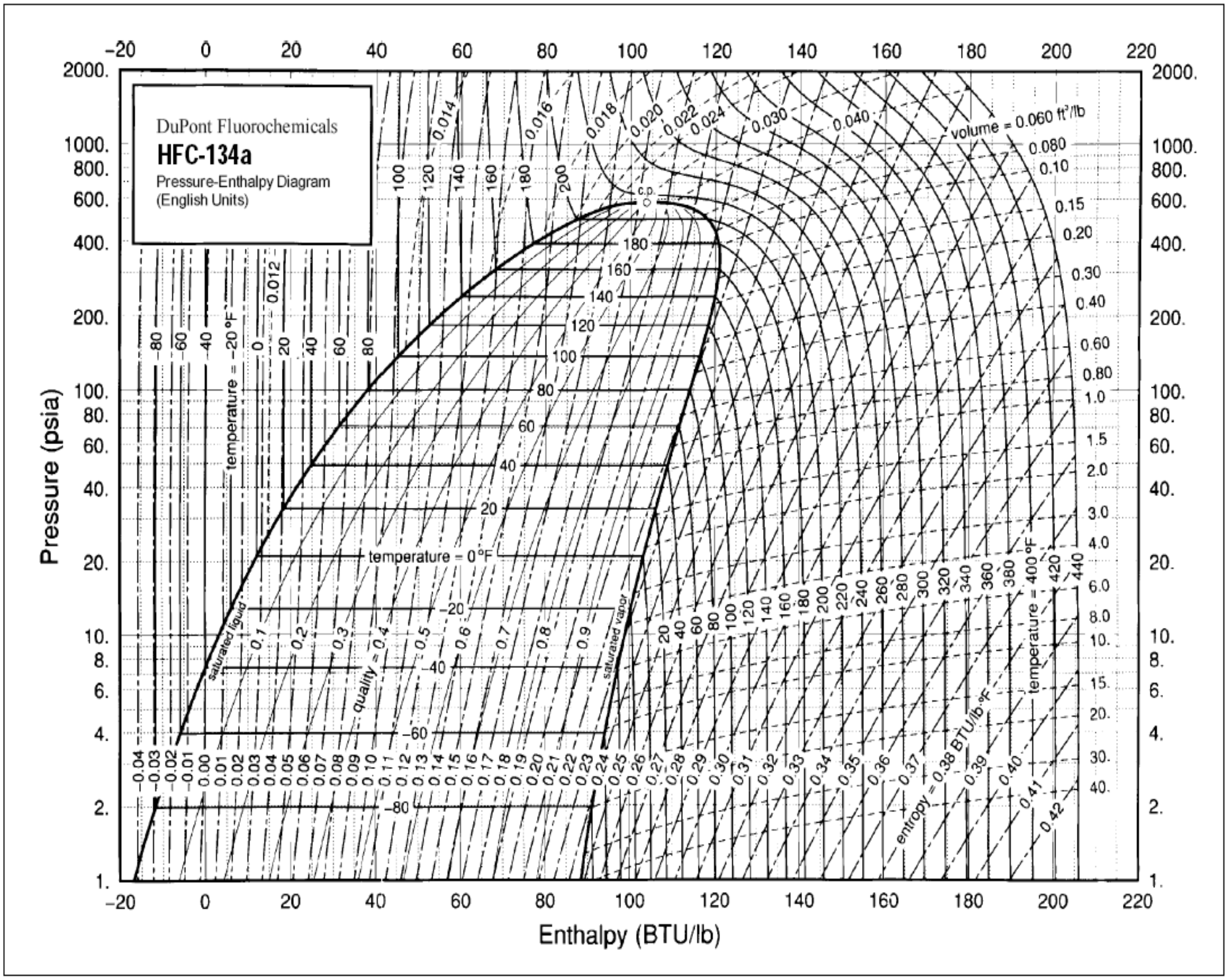


Figure 8: Pressure-enthalpy diagram of superheated R-22 vapor.