بسم الله الرحمن الرحيم

Organisation of Islamic Cooperation

"Energetic and Exergetic analysis of R22 and R134 refrigerants as working fluids in a multipurpose domestic refrigeration system"

A thesis submitted to the department of Mechanical and chemical Engineering (MCE), Islamic University of Technology (IUT), in the partial fulfillment of the requirement for degree of Bachelor of Science in Technical Education in Mechanical Engineering.

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November, 2016

DECLARATION

This is to certify that the work presented in this thesis is the outcome of the investigation carried out by the authors listed below under the Supervision of **Sayedus Salehin,** lecturer in the department of Mechanical and Chemical Engineering, Islamic University of Technology (IUT), The Organization of the Islamic Cooperation (OIC), Dhaka, Bangladesh. It is hereby declared that this thesis which is submitted to the university for the Degree of Bachelor of Science in Technical Education in Mechanical Engineering has not or never been submitted by anyone for a degree at any other university or educational establishment.

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ACKNOWLEDGEMENT:

We express our heartiest gratefulness to Almighty Allah for His divine blessings, which made us possible to complete this thesis successfully.

First and foremost, we would like to express our special thanks of gratitude and acknowledge our profound indebtedness to incredible man who tirelessly shouldered us and gave us zeal and motivation during our work, **Sayedus Salehin**, Lecturer, Department of Mechanical and Chemical Engineering, IUT. His endless patience, scholarly guidance, continual encouragement, constant and energetic supervision, constructive criticism, valuable advice at all stage has made it possible to complete this project. We would also like to offer thanks to all who contributed in many ways during the project work. We acknowledge our sincere indebtedness and gratitude to our parents for their love and support in every day's life.

We, hereby, present our apologies for any error that might be found in this report despite of our best efforts.

Abstract

The performance of a domestic refrigeration system was measured by its coefficient of performance (COP), volumetric cooling capacity, cooling capacity, condenser capacity, and input power to compressor, discharge temperature, pressure ratio and refrigerant mass flow rate. Nowadays, a new characteristic has been added to the list to define the performance of the system. That new trend is the exergy destructed by the system. Nevertheless, considering the impact of the refrigerant being used to the environment is not to be neglected.

Hydrocarbon refrigerants such as R22 and R134a have been proven to be good performing in domestic refrigeration systems. Both of these two possess an Ozone Depletion Potential (ODP) as well as a Global Warning potential good (GWP) enough to be said eco-friendly. The refrigerant R22 is having an ODP of 0.055 and a GWP of 1500 (100 years). And when it comes to R134a, it has an ODP of 0 and a GWP of 1200 (100 years). These are one of the reason why they are being used worldwide.

Besides, R22 and R134a have shown satisfactory result in term of energy and exergy analysis when used to a simple vapor compression refrigeration system.

A multipurpose refrigeration system allows to get a system with two different cooling space. One space that would cool goods and keep them around 5 degree Celsius, and a second space that makes formation of ice from water and to freeze good to be possible and will have a temperature of approximatively -5 to -10

A study of a VCR system using each of these named refrigerants yielded to some appreciable result in term of energy, mainly C.O.P, and exergy analysis. Using, again, a multipurpose refrigeration system with a single compressor, R22 and R134a have presented satisfactory results with an acceptable cooling rate.

However, both refrigerants have shown good performances, but it is found that R134a has presented better C.O.P than R22.

NOMENCLATURE

C.O.P Coefficient of performance (–)
h Specific enthalpy (kJ/kg)
S Entropy (kj/kg-k)
T Temperature (_C)

$\dot{W}$ Work (kj/kg)

$\dot{Q}_H$ Heat rejected by the condenser (kj/kg)

$\dot{Q}_{L1}$ Heat absorbed by the first evaporator (kj/kg)

$\dot{Q}_{L2}$ Heat absorbed by the second evaporator (kj/kg)

$\dot{Q}_L$ Total heat absorbed (kj/kg)

Abbreviations

C.O.P Coefficient of performance
GWP Global Warming Potential
ODP Ozone Depletion Potential
VCRS Vapor Compression Refrigeration System
Evap Evaporator
Comp Compressor
Cond Condenser
Exp Expansion
CFC Chlorofluorocarbon
HCFC Hydro Chlorofluorocarbon

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1) Introduction:

Refrigeration is that process of transport heat from lower temperature region to higher temperature region.it also including the process of discharge unwanted heat from one place to another.so the job of refrigeration is to remove heat from substances and keep it in lower temperature. Removal of heat may be occurred by using ice, snow, chilled water or mechanical refrigeration.

Refrigeration has many applications like: food processing, preservation and distribution, it can be also used in industries process, it can be used to provide comfort air-conditioning, cryogenics.

Mechanical refrigeration is utilization components arranged in refrigeration system for the purpose of transferring heat.

Refrigeration system components

There are five major components of refrigeration system which are:

- Evaporator
- Compressor
- Condenser
- Expansion Valve
- Refrigerant; to conduct the heat from the product.

The Evaporator:

The purpose of the evaporator is to remove unwanted heat from the product, through the liquid refrigerant. The liquid refrigerant contained within the evaporator is boiling at a low-pressure.

The Compressor

The purpose of the compressor is to draw the low-temperature, low-pressure vapor from the evaporator via the suction line.

The Condenser:

The purpose of the condenser is to extract heat from the refrigerant to the outside air.

The Expansion Valve:

The purpose of the expansion valve is to reduce the pressure of the refrigerant as it passes through the orifice, which is located inside the valve. During reducing the pressure the temperature decreases to below surrounding air

1.1) Background:

Before the advent of the refrigerator, food was kept fresh through the use of icehouses or iceboxes, most of which were built outdoors up against bodies of freshwater to keep cool. The first of these storage units were packed with snow during the winter with later versions using chunks of ice brought down from the mountains. In 1748, the first artificial form of refrigeration was born by one of the early refrigeration inventors, William Cullen at the University of Glasgow. Throughout the 19th Century, the development of cooling technology exploded, resulting in much advancement in both air conditioning and refrigeration [1]. By 1911, the first home refrigerators were being manufactured by General Electric , selling for around $1,000—nearly twice as much as an automobile at the time. Up through the late 1920s, most refrigerators used combinations of toxic gases as refrigerants. After several fatal accidents involving gas leaks, Frigidaire, General Motors, and DuPont joined forces to find a safer solution. This solution was named Freon. Unlike its predecessors, Freon is colorless, odorless, nonflammable, noncorrosive, and best of all, nontoxic. Frigidaire patented the substance and General Motors and DuPont began Freon production in 1930 under the new company name, Kinetic Chemical.

Refrigerator and freezer units became more common at home during World War II, going into mass-production in the mid-1940s. Around this time, Albert Einstein had designed his own form refrigerator (known only as "Einstein's Refrigerator") which required no moving parts or electricity. He sold the patent to Electrolux, though it didn't last long in commercial production. Electrolux held on to the design mostly to keep it out of the hands of its competitors. Einstein used the royalties acquired by the patent to help fund the Manhattan Project, which brought about the development of the atomic bomb.
In the 1970s and 80s, discoveries were made linking CFC-compound gases (like Freon) to the depletion of the ozone layer. In the early 1990s, environmental concerns lead to the ban of Freon. Since then, modern refrigerators have used variations of tetrafluoroethane as a refrigerant.
Today, refrigerators have grown from more than a luxury and into a common necessity to every household. Technology has made the refrigerator both affordable to buy, but also energy-efficient, thanks to Energy Star standards.

1.2) History of refrigeration:

Around 500 B.C. the Egyptians and Indians made ice on cold nights by setting water out in earthenware pots and keeping the pots wet.

In 18th century England, servants collected ice in the winter and put it into icehouses, where the sheets of ice were packed in salt, wrapped in strips of flannel, and stored underground to keep them frozen until summer. At the beginning of the 19th century, ice boxes were used in England

Natural ice was harvested, distributed and used in both commercial and home applications in the mid-1800s. The ice trade between Boston and the South was one of the first casualties of the Civil War[2].

Wooden boxes lined with tin or zinc and insulated with various materials including cork, sawdust, and seaweed were used to hold blocks of ice and "refrigerate" food. A drip pan collected the melt water - and had to be emptied daily.

Pioneers in refrigeration included Dr. William Cullen, a Scotsman whose studies in the early 1700s dealt with the evaporation of liquids in a vacuum. Michael Faraday, a Londoner who in the early 1800s liquefied ammonia to cause cooling, and Dr. John Goorie of Apalachicola, Florida, who built a machine to make ice to cool the air for yellow fever patients in 1834. Today's compression refrigeration system operates on a concept adapted from Faraday’s experiments. It involves compressing gas into a liquid which will then absorb heat. In so doing it returns to gas. This is a simplified description of what happens in a home refrigerator, freezer, air conditioner or dehumidifier.

Warm winters in 1889 and 1890 created severe shortages of natural ice in the U.S. This stimulated the use of mechanical refrigeration for the freezing and storage of fish and in the brewing, dairy and meat packing industries. Commercial refrigeration techniques were also applied to railroad cars, were used in "coolers" in grocery stores and in various ways in manufacturing industries.

Two of the first home refrigerators both appeared in Fort Wayne, Indiana, where, in 1911, General Electric Company unveiled a unit invented by a French monk. In 1915 the first "Guardian" refrigerator - a predecessor of the Frigidaire - was assembled in a wash house in a Fort Wayne backyard.

Kelvinator and Servel models were among some two dozen home refrigerators introduced to the U.S. market in 1916. In 1920 the number had increased to more than 200. Compressors were generally driven by belts attached to motors located in the basement or in an adjoining room.

In 1918 Kelvinator introduced the first refrigerator with any type of automatic control. One manufacturer's 1922 model had a wooden cabinet, a water-cooled compressor, two ice cube trays and nine cubic feet of storage space. It cost $714. In 1923 Frigidaire introduced the first self-contained unit. Steel and porcelain cabinets began appearing in the mid-20s. In the 1920s and '30s, consumers were introduced to freezers when the first electric refrigerators with ice cube compartments came on the market. Mass production of modern refrigerators didn't get started until after World War II [3].

In the 1930s Freon 12 was used to replace Sulphur dioxide as the most commonly used refrigerant.

During the 1940s frozen food storage became widely used by consumers

Refrigeration technology began hopping in the 1950s and '60s when innovations like automatic defrost and automatic ice makers first appeared.

The environment became a top priority in the 1970s and '80s, which lead to more energy-efficient refrigerators and elimination of chlorofluorocarbons in refrigeration sealed systems.

Today, the refrigerator is America's most used appliance, found in more than 99.5% of American homes and the rest of the world.

1.3) Refrigerants:

Early mechanical refrigeration system employed some natural refrigerants such as ammonia, methyl chloride and Sulphur dioxide. Being, toxic and flammable sulfur dioxide and methyl chloride rapidly disappeared from the market with the introduction of CFCs. These refrigerants had the benefits of being non-flammable and non-toxic. They were used in refrigerators, air conditioners, automobiles. But later it was realized that their high Ozone Depletion Potential (ODP) and Global Warming Potential (GWP) had devastating effects on our planet. Leakage of these refrigerants into the environment depletes the ozone layer and bring about global warming. Having being noticed two conferences prohibited the use of these refrigerants.

1.4) Montreal Protocol

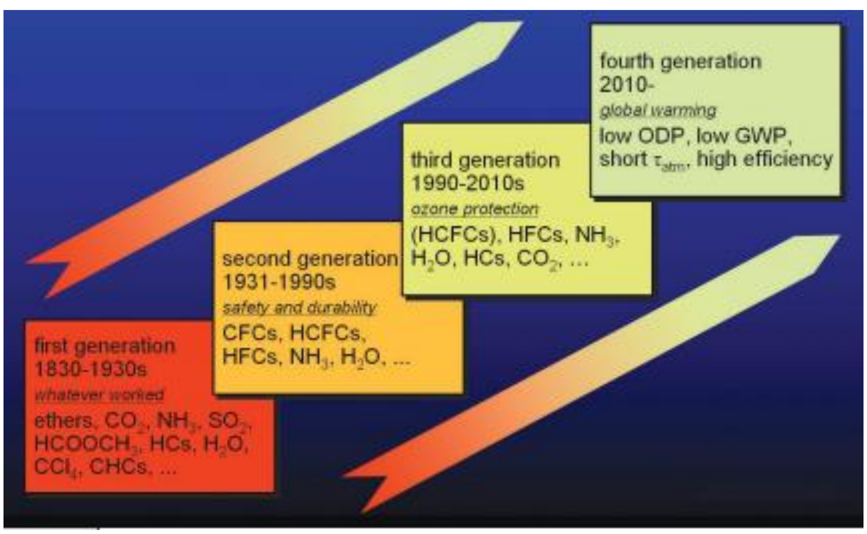
The United Nations environment programme conference held in Montreal in September 1987 the decision taken to phase out ozone depleting substances (ODS) within a fixed time period is known as Montreal Protocol. Some of the feature of MP is as follows.

1) Developed countries will phase out CFCs by 1996.
2) Developing countries will phase out CFCs by 2010 with freeze in 1999 and gradual reduction thereafter. Developed countries will phase out HCFCs by 2030 while developing countries have been provided a grace period of ten years i.e. phase out by 2040.
3) Global warming is another serious issue. Some naturally occurring substances mainly cause this but CFCs have very large global warming potential.

1.5) Kyoto Protocol

Kyoto protocol aims at phasing out of substances that will lead to global warming. And R134a is used in domestic refrigerator and other vapor compression systems as it was identified as a replacement to CFC-12, keeping in view its zero ozone depleting potential. R134a has 1300 global warming potential per 100 year, which is very high. The sale of R134a reported to AFEAS 1970-2003 is significantly increasing during the past two decades. The increased emission of R134a to the atmosphere are steadily increasing the concentration of greenhouse gases via leaks and mostly, in an indirect way, via energetic performance of refrigeration plant. This will lead to adverse climatic problem. Hence, R134a is one of the six chemicals in the—basket‖ that are to be phased out in the near future under Kyoto protocol.

Following this scientists came back towards natural refrigerants as the modern technology can harness the defects of these refrigerants.



1.6) Selection criteria of a refrigerant.

The thermodynamic efficiency of a refrigeration system depends mainly on its operating temperatures. However, important practical issues such as the system design, size, initial and operating costs, safety, reliability, and serviceability etc.

depend very much on the type of refrigerant selected for a given application. Due to several environmental issues such as ozone layer depletion and global warming and their relation to the various refrigerants used, the selection of suitable refrigerant has become one of the most important issues in recent times. Selection of refrigerant for a particular application is based on the following requirements:

i. Thermodynamic and thermo-physical properties
ii. Environmental and safety properties, and
iii. Economics

1.7) Thermodynamic and thermo-physical properties.

The requirements are:

a) **Suction pressure**: At a given evaporator temperature, the saturation pressure should be above atmospheric for prevention of air or moisture ingress into the system and ease of leak detection. Higher suction pressure is better as it leads to smaller compressor displacement.

b) **Discharge pressure**: At a given condenser temperature, the discharge pressure should be as small as possible to allow light-weight construction of compressor, condenser etc.

c) **Pressure ratio**: Should be as small as possible for high volumetric efficiency and low power consumption d) Latent heat of vaporization: Should be as large as possible so that the required mass flow rate per unit cooling capacity will be small.

e) **Isentropic index of compression**: Should be as small as possible so that the temperature rise during compression will be small

f) **Liquid specific heat**: Should be small so that degree of sub cooling will be large leading to smaller amount of flash gas at evaporator inlet

g) **Vapor specific heat**: Should be large so that the degree of superheating will be small

h) **Thermal conductivity**: Thermal conductivity in both liquid as well as vapor phase should be high for higher heat transfer coefficients

i) **Viscosity**: Viscosity should be small in both liquid and vapor phases for smaller frictional pressure drops.

1.8) Environmental and safety properties.

a) **Ozone Depletion Potential (ODP)**:

According to the Montreal protocol, the ODP of refrigerants should be zero, i.e., they should be non-ozone depleting substances. Refrigerants having non-zero ODP have either already been phased-out (e.g. R 11, R 12) or will be phased-out in near-future (e.g. R22). Since ODP depends mainly on the presence of chlorine or bromine in the molecules, refrigerants having either chlorine (i.e., CFCs and HCFCs) or bromine cannot be used under the new regulations.

b) **Global Warming Potential (GWP)**: Refrigerants should have as low a GWP value as possible to minimize the problem of global warming. Refrigerants with zero ODP but a high value of GWP (e.g. R134a) are likely to be regulated in future.

c) **Total Equivalent Warming Index (TEWI)**: The factor TEWI considers both direct (due to release into atmosphere) and indirect (through energy consumption) contributions of refrigerants to global warming. Naturally, refrigerants with as a low a value of TEWI are preferable from global warming point of view.

d) **Flammability**:

The refrigerants should preferably be non-flammable and nonexplosive. For flammable refrigerants special precautions should be taken to avoid accidents. Based on the above criteria, ASHRAE has divided refrigerants into six safety groups (A1 to A3 and B1 to B3). Refrigerants belonging to Group A1 (e.g. R11, R12, R22, R134a, R744, R718) are least hazardous, while refrigerants belonging to Group B3 (e.g. R1140) are most hazardous. Other important properties are:

e) **Chemical stability**:

The refrigerants should be chemically stable as long as they are inside the refrigeration system.

The table from the SHERPHA project shows the environmental impact and properties of some refrigerants.

Fluid	Boiling point (°C)	Critical temperature (°C)	Critical pressure (bar)	ODP [1]	GWP (100 yrs)	Oil	Flam.
R12	-29	100.9	40.6	0.9	8100	mineral	no
R22	-40.8	96.2	49.8	0.055	1500	mineral	no
Pure HFCs							
R23	-82.1	25.6	48.2	0	12000	ester	no
R32	-51.6	78.4	58.3	0	650	ester	yes
R125	-48.5	68.0	36.3	0	2500	ester	no
R143a	-47.6	73.1	37.6	0	4300	ester	yes
R134a	-26.5	101.1	40.7	0	1200	ester	no
R152a	-25.0	113.5	45.2	0	140	ester	yes
HFC mixtures							
R407C[3]	-44.0	86.8	46.0	0	1600	ester	no
R410A[2]	-50.5	72.5	49.6	0	1900	ester	no
R404A[2]	-46.4	72.1	37.4	0	3300	ester	no
Natural refrigerants							
R290 (propane)	-42.1	96.8	42.5	0	< 20	mineral	yes
R600a (isobutane)	-11.7	135.0	36.5	0	< 20	mineral	yes
CO_2 (R744)	-56.6 @ 5.2 bars	31.0	73.8	0	1	PAG	no
R717 (ammonia)	-33.3	132.2	113.5	0	0	mineral	yes

1.9) Reasons of choosing R22 and LPG for our projects:

- **Refrigerant R22**

A) Has less effect on ozone layer:

Refrigerant R22 is a hydroclhorofluorohydrocarbon (HCFC). It has one hydrogen atom in its compound and not all the hydrogen atoms from it are replaced by the halocarbons as it happens in chlorofluorohydrocarbons (CFCs). The halocarbons have high detrimental effect to the ozone layer of environment. Since R22 is HCFC it has lesser ozone destruction capability. The ozone destruction potential of

R22 is only 5% of refrigerant R11, which has the highest ozone destruction potential.

B) Low compressor displacement: For producing the same compression the displacement required by the compressor with refrigerant R22 is small compared to refrigerant R12. In fact the displacement required for R22 is 60% of that required for R12. This means that for the given displacement of the compressor the system using refrigerant R22 produces 65% more refrigeration capacity than the system using the refrigerant R12. This translates into higher refrigeration efficiency and lower power consumption, which is very crucial in the large industrial applications though it is important for the domestic applications as well.

C) Greater water absorbing capacity: Refrigerant R22 has greater water absorbing capacity than R12. This is very important in low temperature applications since the water in refrigerant R22 would have less troubling effects on the refrigeration system. Anyways, even minor amount of water in the refrigeration system is undesirable.

- **Refrigerant R134a [4]:**

The refrigerant R134a is the chemical compound tetrafluoroethane comprising of two atoms of carbon, two atoms of hydrogen and four atoms of fluorine. Its chemical formula is CF_3CH_2F. The molecular weight of refrigerant R134a is 133.4 and its boiling point is -15.1 degree F.

Refrigerant R134a is a hydrofluorocarbon (HFC) that has zero potential to cause the depletion of the ozone layer and very little greenhouse effect. R134a is the nonflammable and non-explosive, has toxicity within limits and good chemical stability. It has somewhat high affinity for the moisture. The overall physical and thermodynamic properties of refrigerant R134a closely resemble with that of refrigerant R12. Due to all the above factors, R134a is considered to be an excellent replacement for R12 refrigerant.

A**) Power required per ton of refrigeration:** For the evaporator temperatures of -7 degree C and above the isentropic discharge temperature from the compressor for both the refrigerants is same. The total horsepower required per ton of refrigeration is also same. For the temperatures below -7 degree C, if R12 is replaced by R134a there will be significant loss of the refrigerating effect, and in such cases it is advisable to use the blends of refrigerants as the replacement instead of using R134a.

B) Low temperature application: For the instance where the saturation temperature is -15.08 degree F at the standard barometric pressure, and if the evaporator temperature is below 0 degree F, the pressure in the evaporator will be still well above the vacuum Thus the refrigerant R134a can be used for the low temperature applications also without the need to produce vacuum in low pressure side of the refrigeration system.

C) Heat transfer coefficients: The heat transfer coefficients for refrigerant R134a are higher than R12 in different conditions depending on the temperature. If the refrigerants exist in single liquid phase the heat transfer coefficient of R134a is higher by 27 to 37% and if they are in gaseous phase it is higher by 37 to 45%. If the refrigerants exist in two phases, liquid and gaseous, the heat transfer coefficient for R134a is higher by 28 to 34% in the evaporator and 35 to 41% in the condenser.

The process of retrofitting R12 system with R134a is quite an easy process. First of all, complete R12 should be removed from the system and recovered in the container. Then all the lubricating oil from the system should be removed and the maximum amount of oil allowed to be remained inside the system is 5% of the total amount of oil present in the system. The mineral oil should be replaced with ester based synthetic oil. The drier and the oil filter also should be replaced. The amount of R134a required in the system is about 90 to 95% of R12. Labels should be placed in the systems that have been retrofitted with R134a describing the new refrigerant and the lubricating oil.

D**) Miscibility of R134a with oil:** Oil is used as the lubricant in the compressor of the refrigeration and the air conditioning system. When refrigerant is sucked and discharged by the compressor, it picks up some oil particles. It is important that the refrigerant is miscible with the oil so that it can be easily separated from it. Refrigerant R12 is highly miscible with mineral oil, while R134a is miscible with the synthetic oil or lubricant. Thus when the refrigeration equipment is being altered for the use of R134a instead of R12, all the mineral oil should be removed from the system and it should be replaced with ester based synthetic oil.

E) Refrigerating effect per pound of refrigerant: The refrigerating effect produced by one pound of R134a is about 22% more than that produced by R12. Thus the mass flow rate of the R134a required per ton of refrigeration is about 18% lesser than R12. This means for the given capacity of the refrigeration system the amount of R134a required is 18% less than if R12 was used.

1.10) Domestic Refrigeration:

A refrigerator (colloquially **fridge**) is a popular household appliance that consists of a thermally insulated compartment and a heat pump(mechanical, electronic or chemical) that transfers heat from the inside of the fridge to its external environment so that the inside of the fridge is cooled to a temperature below the ambient temperature of the room. Refrigeration is an essential food storage technique in developed countries. The lower temperature lowers the reproduction rate of bacteria, so the refrigerator reduces the rate of spoilage. A refrigerator maintains a temperature a few degrees above the freezing point of water. Optimum temperature range for perishable food storage is 3 to 5 °C (37 to 41 °F). A similar device that maintains a temperature below the freezing point of water is called a **freezer**. The refrigerator replaced the icebox, which had been a common household appliance for almost a century and a half. For this reason, a refrigerator is sometimes referred to as an **icebox** in American usage.

The first cooling systems for food involved using ice. Artificial refrigeration began in the mid-1750s, and developed in the early 1800s. In 1834, the first working vapor-compression refrigeration system was built. The first commercial ice-making machine was invented in 1854. In 1913, refrigerators for home use were invented. In 1923 Frigidaire introduced the first self-contained unit. The introduction of Freon in the 1920s expanded the refrigerator market during the 1930s. Home freezers as separate compartments (larger than necessary just for ice cubes) were introduced in 1940. Frozen foods, previously a luxury item, became commonplace.

Freezer units are used in households and in industry and commerce. Commercial refrigerator and freezer units were in use for almost 40 years prior to the common home models. Most households use the freezer-on-top-and-refrigerator-on-bottom style, which has been the basic style since the 1940s. A vapor compression cycle is used in most household refrigerators, refrigerator–freezers and freezers. Newer refrigerators may include automatic defrosting, chilled water and ice from a dispenser in the door.

Domestic refrigerators and freezers for food storage are made in a range of sizes. Among the smallest is a 4 L Peltier refrigerator advertised as being able to hold 6 cans of beer. A large domestic refrigerator stands as tall as a person and may be about 1 m wide with a capacity of 600 L. Refrigerators and freezers may be free-standing, or built into a kitchen. The refrigerator allows the modern family to keep food fresh for longer than before. Freezers allow people to buy food in bulk and eat it at leisure, and bulk purchases save money.

2) Vapor compression refrigeration cycle:

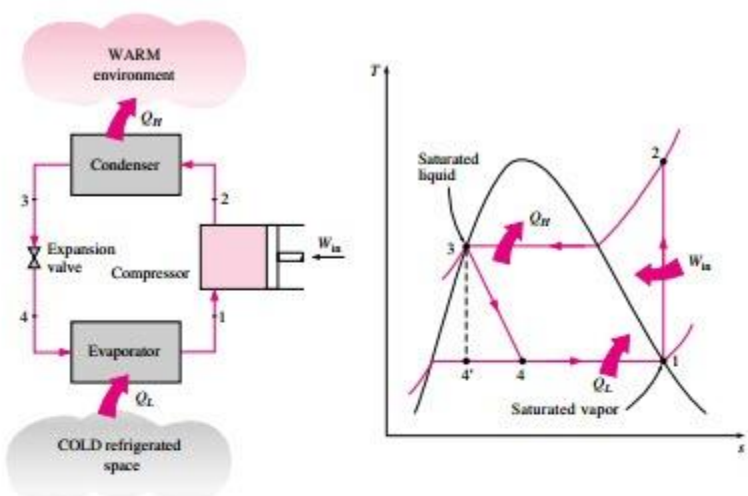


FIGURE 8–53
Schematic and *T-s* diagram for the ideal vapor-compression refrigeration cycle.

Figure1: Schematic and T-s diagram for the ideal Vapor-compression refrigeration cycle.

The above two diagrams represent vapor compression cycle and its four processes are Vaporization, Compression, Condensation and then Expansion.

The top diagram shows refrigeration circuit, whereas the bottom one is the correspondent P-h diagram. The process initiates with vaporization of the refrigerant in the evaporator and it is completed at point **2**. Compression is used to increase pressure of the refrigerant, in order that it can condense at a higher temperature (point **3)**. When the entire vapor has condensed, (point **4)**, the pressure is decreased in an expansion device, and the refrigerant is returned to its initial condition **1**.

Note that Expansion is a steady or constant enthalpy process. It is drawn as a vertical line on the P-h diagram. No heat absorption or rejection during this expansion, the liquid passes through a valve, similar to water coming out of a tap. Difference is, that due to the liquid being saturated at the beginning of expansion, by the end of the process it is somewhat vapor. Point **1** is inside the curve and not on the curve as rendered in the Evaporation process. The refrigerant at the start of the vaporization is already partly evaporated! What amount? This depends on the shape of the curve, and the start and finish pressures.

In other way, the Compression process is shown as a curve. It is not a constant enthalpy process. The energy used to compress the vapor turns to heat, and accelerates its temperature. This tends to increase the temperature of the vapor, making point **3** moves further into the superheated part of the diagram as compression continues. Point **3** is outside the curve and not on the curve as described in the Compression process. This means that before Condensation can begin, the vapor has to be cooled down.

There are still a few more puzzles to learn before this cycle can be turned into a practical refrigeration machine. Find out what they are by looking at the Simple Practical Cycle.

Maximum Efficiency of the Vapor Compression Cycle.

It takes too much of heat to evaporate liquid. In other words a small quantity of liquid circulating in a refrigerator can perform a large amount of cooling. This is one reason why the vapor compression cycle is broadly used. The refrigeration system can be small and compact. Also from a practical perspective, heat exchange is much better when using change of state - evaporation and condensation. Nonetheless, the expansion of the high pressure liquid, (process **4 – 1)** above is irreversible. And so the efficiency of this cycle can never at all approach Carnot efficiency [5].

2.1) Function of different components:

Figure 2 shows the different parts of a refrigeration system. We shall further discuss the functions of each and every part of the system.

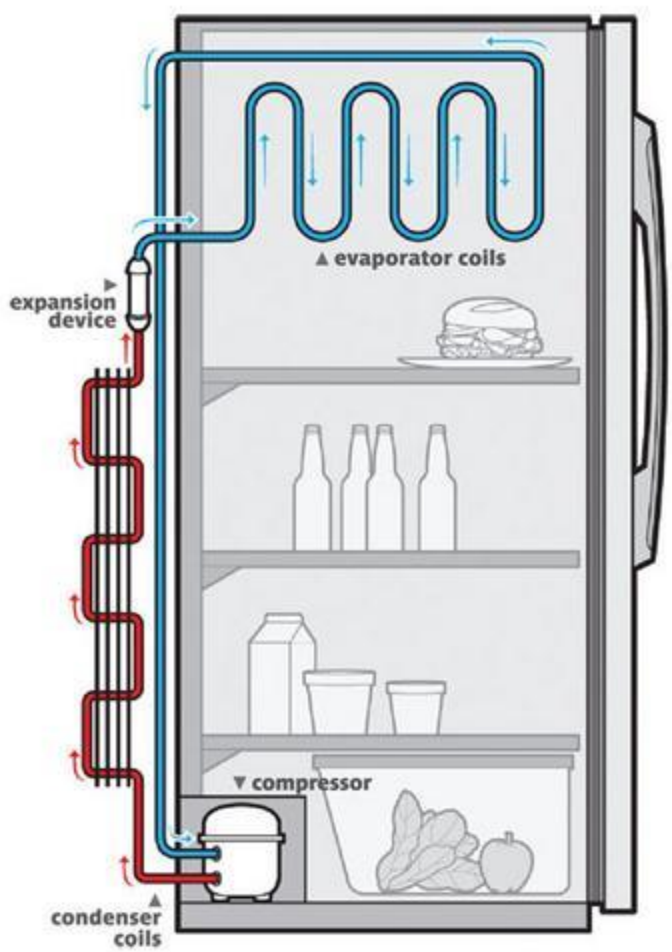


Figure2: Parts of a domestic refrigerator

A. Compressor: The function of the compressor is to draw refrigerant vapor from the evaporator and to raise its temperature and pressure to such a point that it may be easily condensed with normally available condensing media. It also maintains a continuous flow of the refrigerant through the system.

The compressor performs dual functions. 1. It compresses the gas (which now contains heat from the eggs) and 2. It moves the refrigerant around the loop so it can perform its function over and over again. We want to compress it because that is the first step in forcing the gas to return to a liquid form. This compression process unfortunately adds some more heat to the gas but at least this process is also conveniently named; The Heat of Compression. The graphic portrays a reciprocating compressor which means that it has piston(s) that go up and down. On the down stroke refrigerant vapor is drawn into the cylinder. On the upstroke those vapors are compressed. There are thin valves that act like check valves and restricts the vapor backflow. They open and close in response to the refrigerant pressures being exerted on them by the action of the piston. The hot compressed gas is discharged out the discharge line. It continues towards the last main component.

B. Condenser: The function of the condenser is to provide a heat transfer surface through which heat passes from the refrigerant to the condensing medium which is either water or air.

The condenser is similar in appearance to the evaporator. It utilizes the principles to effect heat transfer as the evaporator does. However, this time the purpose is to reject heat so that the refrigerant gas can condense back into a liquid in preparation for a return trip to the evaporator. If the hot compressed gas was at 135 °F and the air being sucked through the 90 °F condenser fins was at heat will flow downhill like a ball wants to roll down an inclined plane and be rejected into the air stream. Heat will have been removed from one place and relocated to another as the definition of refrigeration describes. As long as the compressor is running it will impose a force on the refrigerant to continue circulating around the loop and continue removing heat from one location and rejecting it into another area.

The condenser removes heat given off during the liquefaction of vaporized refrigerant. Heat is given off as the temperature drops to condensation temperature. Then, more heat (specifically the latent heat of condensation) is released as the refrigerant liquefies. There are air-cooled and water-cooled condensers, named for their condensing medium. The more popular is the air-cooled condenser. The condensers consist of tubes with external fins. The refrigerant is forced through the condenser. In order to remove as much heat as possible, the tubes are arranged to maximize surface area. Fans are often used to increase air flow by forcing air over the surfaces, thus increasing the condenser capability to give off heat.

C. **Expansion valve:**

Expansion valves are flow-restricting devices that cause a pressure drop of the working fluid. The valve needle remains open during steady state operation. The size of the opening or the position of the needle is related to the pressure and temperature of the evaporator. There are three main parts of the expansion valve that regulate the position of the needle. A sensor bulb, at the end of the evaporator, monitors the temperature change of the evaporator. This change in temperature creates a change in pressure on the diaphragm.

For example, if the temperature in the evaporator increases, the pressure in the diaphragm increases causing the needle to lower. Lowering the needle allows more of the working fluid into the evaporator to absorb heat. The pressure at the inlet of the evaporator affects the position of the needle and prevents the working fluid from flowing back into the compressor. Since the pressure before the valve is higher than the pressure after the valve, the working fluid naturally flows into the evaporator. The pressure at the inlet of the evaporator acts on the diaphragm. There is also a spring providing a constant pressure closing the valve needle. The spring constantly restricts the amount of working fluid entering the evaporator.

The pressure spring can be adjusted to increase or decrease pressure based on temperature needs. The pressure created by the spring acts on the opening of the valve. When the pressure of the sensor bulb acting on the diaphragm is greater than the combined pressure of the evaporator and spring, the valve opens to increase the flow rate of the working fluid. An increase of flow rate lowers the temperature of the evaporator and allows for more heat absorption.

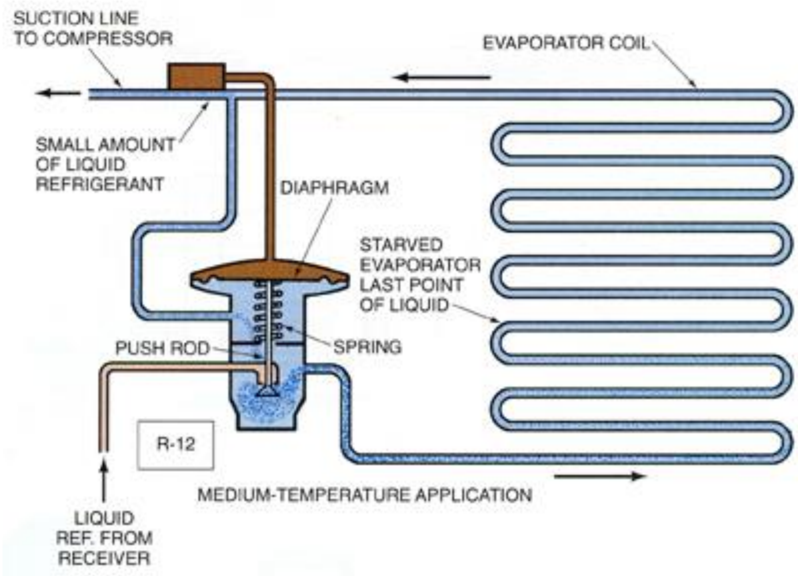


Figure 3.

There are two main types of thermal expansion valves:1. Internally or 2. Externally equalized expansion valves. The difference between the two is how the evaporator pressure affects the position of the needle. In internally equalized valves, the evaporator pressure against the diaphragm is the pressure at the *inlet* of the evaporator, whereas in externally equalized valves, the evaporator pressure against the diaphragm is the pressure at the *outlet* of the evaporator. Externally equalized thermostatic expansion valves compensate for any pressure drop through the evaporator.

Internally equalized valves can be used on single circuit evaporator coils having low pressure drop. Externally equalized valves must be used on multi-circuited evaporators with refrigerant distributors. Externally equalized TXVs can be used on all applications; however, an externally equalized TXV cannot be replaced with an internally equalized TXV [6].

D**. Evaporator**:

It is in the evaporators where the actual cooling effect takes place in the refrigeration and the air conditioning systems. For many individuals the evaporator is the main part of the refrigeration system and they consider other parts as less useful. The evaporators are heat exchanger surfaces that transfer the heat from the substance to be cooled to the refrigerant, thus removing the heat from the substance. The evaporators are used for wide variety of diverse applications in refrigeration and air conditioning processes and hence they are available in wide variety of shapes, sizes and designs. They are also classified in different manner depending on the method of feeding the refrigerant, construction of the evaporator, direction of air circulation around the evaporator, application and also the refrigerant control.

In the domestic refrigerators the evaporators are commonly known as the freezers since the ice is made in these compartments. In case of the window and split air conditioners and other air conditioning systems where the evaporator is directly used for cooling the room air, it is called as the cooling coil. In case of large refrigeration plants and central air conditioning plants the evaporator is also known as the chiller since these systems are first used to chill the water, which then produces the cooling effect.

In the evaporator the refrigerant enters at very low pressure and temperature after passing through the expansion valve. This refrigerant absorbs the heat from the substance that is to be cooled so the refrigerant gets heated while the substance gets cooled. Even after cooling the substance the temperature of the refrigerant leaving the evaporator is less t than that of the substance. The refrigerant leaves the evaporator in vapor state, mostly superheated and is absorbed by the compressor.

Types of evaporator

In the large refrigeration and air conditioning plants the evaporator is used for chilling the water. In such cases shell and tube type of heat exchangers are used as the evaporators. In such plants the evaporators or the chillers are classified as:

(1) Dry expansion type of evaporators and

(2) Flooded type of the evaporators

In case of the dry expansion type of chillers or evaporators the flow of the refrigerant to the evaporators is controlled by the expansion valve. The expansion valve allows the flow of the refrigerant depending on the refrigeration load. In case of the shell and tube type of evaporators the refrigerant flows along the tube side, while the substance to be chilled (usually water or brine) flows long the shell side. In case of the flooded the evaporator is filled with the refrigerant and constant level of the refrigerant is maintained inside it. In these evaporators or the chillers the refrigerant is along shell side while the substance to be chilled or freezer flows along the tube side of the heat exchanger.

Though this classification can also be applied to the domestic refrigerators and air conditioners, the evaporators used in these systems are classified based on their construction. They are classified based on the construction as:

(1) Bare tube evaporators

(2) Plate surface evaporators

(3) Finned evaporators

The bare tube evaporators are the simple copper coil evaporators over which the substance to be cooled flows. The plate surface evaporators are commonly used in the household refrigerators. These evaporators are also in the form of coil which is attached to the plate. The finned evaporators are also made of copper coil with fins on the external surface as well on the internal surface. In the next articles we shall see all these evaporators in greater details.

Figure4: Evaporator of a domestic refrigerant

2.2) Description of a vapor compression refrigeration system:

Vapor-Compression Refrigeration or **vapor-compression refrigeration system (VCRS)**, in which the refrigerant undergoes phase changes, is one of the many refrigeration cycles and is the most widely used method for air-conditioning of buildings and automobiles. It is also used in domestic and commercial refrigerators, large-scale warehouses for chilled or frozen storage of foods and meats, refrigerated trucks and railroad cars, and a host of other commercial and industrial services. Oil refineries, petrochemical and chemical processing plants, and natural gas processing plants are among the many types of industrial plants that often utilize large vapor-compression refrigeration systems.

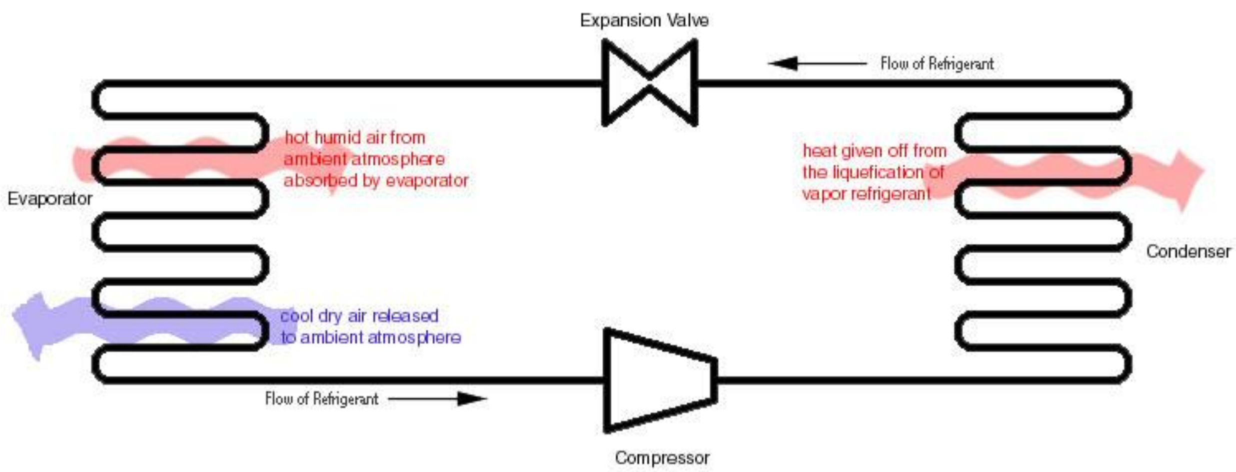


Figure6: Vapor compression refrigeration

The vapor-compression uses a circulating liquid refrigerant as the medium which absorbs and removes heat from the space to be cooled and subsequently rejects that heat elsewhere. Figure 1 depicts a typical, single-stage vapor-compression system. All such systems have four components: a compressor, a condenser, a thermal expansion valve (also called a throttle valve or metering device), and an evaporator. Circulating refrigerant enters the compressor in the thermodynamic state known as a saturated vapor and is compressed to a higher pressure, resulting in a higher temperature as well. The hot, compressed vapor is then in the thermodynamic state known as a superheated vapor and it is at a temperature and pressure at which it can be condensed with either cooling water or cooling air flowing across the coil or tubes. This is where the circulating refrigerant rejects heat from the system and the rejected heat is carried away by either the water or the air (whichever may be the case).

The condensed liquid refrigerant, in the thermodynamic state known as a saturated liquid, is next routed through an expansion valve where it undergoes an abrupt reduction in pressure. That pressure reduction results in the adiabatic flash evaporation of a part of the liquid refrigerant. The auto-refrigeration effect of the adiabatic flash evaporation lowers the temperature of the liquid and vapor refrigerant mixture to where it is colder than the temperature of the enclosed space to be refrigerated.

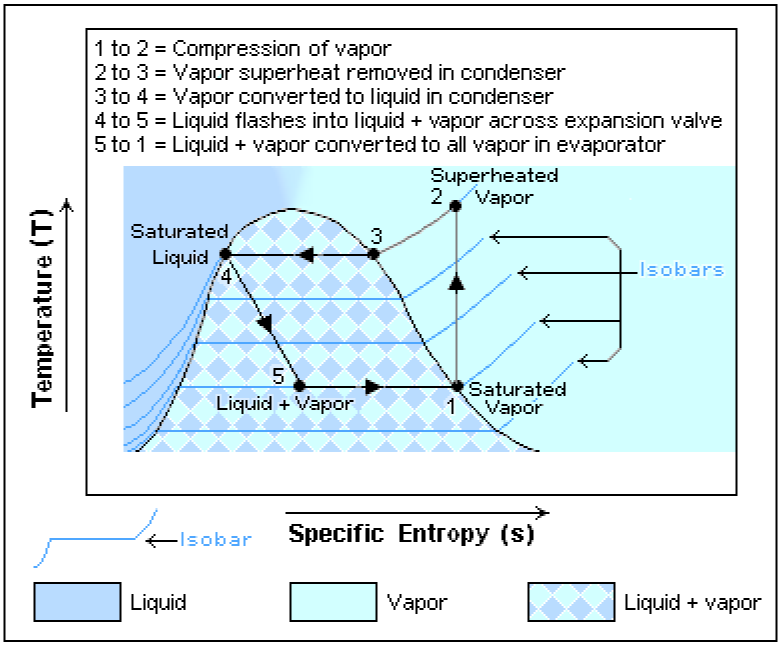


Figure6: T-s diagram of a VCRS

The cold mixture is then routed through the coil or tubes in the evaporator. A fan circulates the warm air in the enclosed space across the coil or tubes carrying the cold refrigerant liquid and vapor mixture. That warm air evaporates the liquid part of the cold refrigerant mixture. At the same time, the circulating air is cooled and thus lowers the temperature of the enclosed space to the desired temperature. The evaporator is where the circulating refrigerant absorbs and removes heat which is subsequently rejected in the condenser and transferred elsewhere by the water or air used in the condenser. [7]

To complete the refrigeration cycle, the refrigerant vapor from the evaporator is again a saturated vapor and is routed back into the compressor.

"Freon" is a trade name for a family of haloalkane refrigerants manufactured by DuPont and other companies. These refrigerants were commonly used due to their superior stability and safety properties: they were not flammable at room temperature and atmospheric pressure, nor obviously toxic as were the fluids they replaced, such as sulfur dioxide. Haloalkanes are also an order(s) of magnitude more expensive than petroleum derived flammable alkanes of similar or better cooling performance.

Unfortunately, chlorine- and fluorine-bearing refrigerants reach the upper atmosphere when they escape. In the stratosphere, CFCs break up due to UV radiation, releasing their chlorine free radicals. These chlorine free radicals act as catalysts in the breakdown of ozone through chain reactions. One CFC molecule can cause thousands of ozone molecules to break down. This causes severe damage to the ozone layer that shields the Earth's surface from the Sun's strong UV radiation, and has been shown to lead to increased rates of skin cancer. The chlorine will remain active as a catalyst until and unless it binds with another particle, forming a stable molecule. CFC refrigerants in common but receding usage include R-11 and R-12.

Newer refrigerants with reduced ozone depletion effect such as HCFCs (R-22, used in most homes today) and HFCs (R-134a, used in most cars) have replaced most CFC use. HCFCs in turn are being phased out under the Montreal Protocol and replaced by hydrofluorocarbons (HFCs), such as R-410A, which lack chlorine. However, CFCs, HCFCs, and HFCs all have large global warming potential.

More benign refrigerants are currently the subject of research, such as supercritical carbon dioxide, known as R-744. These have similar efficiencies compared to existing CFC and HFC based compounds, and have many orders of magnitude lower global warming potential.

2.3) Multipurpose refrigeration system with single compressor:

As we can notice that in domestic refrigeration, most of the time it requires more than one temperature range. A cooling space is needed to keep some food in a low temperature of around 4 to 6 °C. However, a freezing space is required for making ice blocks or keeping some goods that will need lower than 0 °C to be preserved. For such a purpose a cooling space of around -5 to -10 °C becomes a must, hence the refrigerant should enter the second evaporator at approximatively -16 °C, thus the heat transfer rate will be reasonable. The same logic will be applied to the working fluid entering the first evaporator, say 0°C, as well as the entry of the condenser, likely 32 to 36°C for an ambient temperature of 28°C.

For this purpose, a multipurpose refrigeration system is created to have evaporation at different temperature and pressure. The system can be made using two expansion valve and two evaporators which will be connected with compressor at the exits of the evaporators. However using such a system may yield to a bulky and uneconomical system. This can be built in a more economical way as well as less complicate in structure with less component. Connecting each and every exit of evaporator to a single compressor will get the job done and one single compressor will take care of the compression process for the whole system.

A simplified filed schematic of the unit and the t-s diagram of the cycle are shown in Fig.7 below.

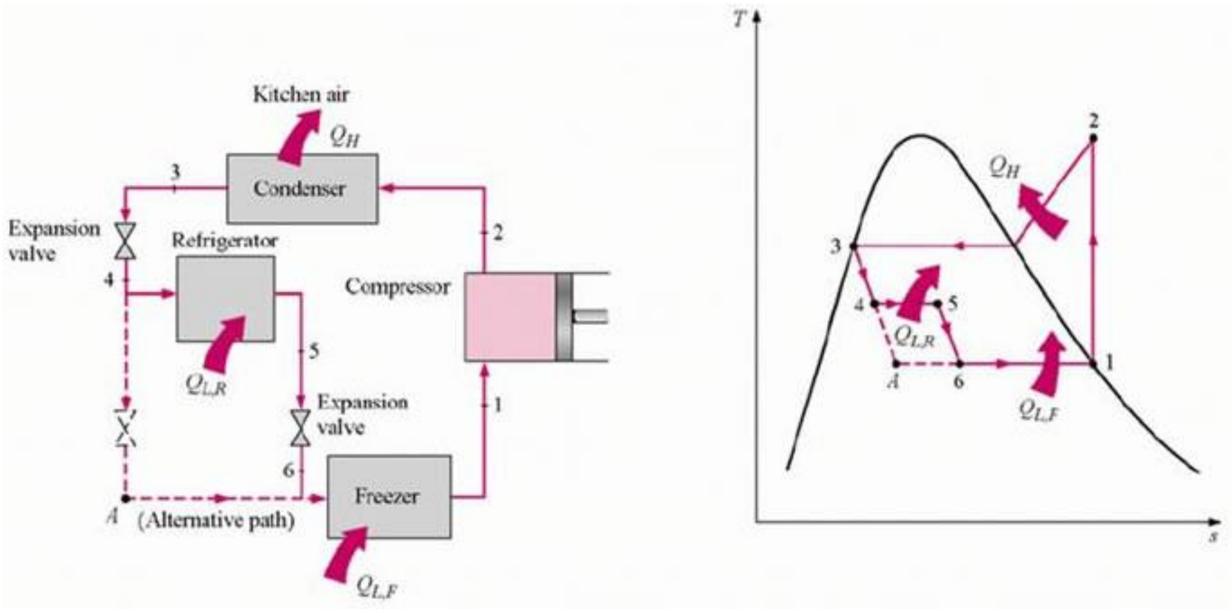


Figure7: Schematic and T-S diagram of a multipurpose system [8]

The entire refrigerant leaving the freezer compartment is subsequently compressed by a single compressor to the condenser pressure.

The coefficient of performance of such a system is given by takin adding up the heat absorbed by the two evaporators and divide it by the work of the compressor.

3) Energy and Exergy analysis:

3.1) Energy analysis:

The energy analysis is based on the first law of thermodynamics which states that which states that energy is neither created nor destroyed but converted from one form to another. The energy analysis is made possible by the energy balance. Analysis of the energy balance will result would reveal the use of energy in different parts of the process and allow to comparing the efficiency and process parameters with the currently achievable values in the most modern installations. Thermodynamic processes releases huge amount of heat energy to the atmosphere. Heat transfer between the system and surrounding environment takes place at a finite temperature difference which is a major source of irreversibility. Irreversibility causes the system to degrade. These losses can be evaluated using the energy analysis. Energy analysis is still the most common used method in thermal systems. Energy analysis is measured in refrigerators using the coefficient of performance (COP). It is the ratio of the useful refrigeration to the net work done. It is desirable to obtain a high COP as it implies that refrigerator only requires a small amount of work.

3.2) Exergy analysis:

The world population is in need of energy to tackle the economic crisis going on and as well offer sanitation, increase health benefits and the reduction of pollutants decimating our environment. New sources of energy are being discovered every day in different parts of the world. Estimating the amount of energy usable is cardinal. What we really need to know is the work potential of the source that is the amount of energy we can extract from the source. This is known as exergy which can also termed availability. It is the maximum useful work that can be obtained as a system undergoes a process between two specified states. Scientists and engineers have been using exergy analysis to improve the functioning of processes and systems.

Although being new in the scientific world, its origin can be traced back for almost 200 years. The idea of maximum of energy was brought forth by Carnot. Rudolph Clausius with his second law of thermodynamics laid the bases of exergy and exergy analysis. But the term ‘exergy’ was coined by the German scientist Zoran Rant to denote the useful energy. Josiah Williard Gibbs who played an important role in thermodynamics. One of the most of the remarkable one was methods for ameliorating the second law of thermodynamics. These work enabled the second law analysis to be employed in real systems in the modern era.

In actual processes, energy is lost as a result of irreversibility's and the entropy of the system increases. Exergy analysis is relevant for identifying and quantifying both of exergy destruction within a process due to irreversibility (cannot be used to work and should be possibly eliminated) and the exergy losses e.g. the transportation of exergy to the environment. Exergy destruction is neglected in the evaluation of a system according to energy balance of first of thermodynamics. These energy inefficiencies help to highlight the areas of energy improvement potentials within a system and also from the impact on the environment. The energy analysis is mostly used in thermal systems and it follows the first law of thermodynamics which talks about the conversation of energy. But it gives no information on how, where, and how much the system performance is degraded. To bring about the optimum performance of the system and identify the sites of exergy destruction exergy analysis is used.

The exergy is widely used in different systems. It has been found that major exergy losses have been caused in the refrigerator – freezer followed by air conditioner, washing machine, fan, rice cooker, iron, VCD/VCR/DVD player, and about 21% of total losses are caused by the refrigerator-freezer and 12% of the total losses are caused by the air conditioner. So, it indicates that a major part of exergy losses in the energy sector is caused in the vapor compressor system (refrigerator and air conditioner, 33%). Refrigerators are widely use domestically. In the past halogenated refrigerants where used in our refrigerators. But this latter was a major contributor to the global warming and it usage was banned. Following this scientists were urged to conduct researches to bring about new ecologically friendly refrigerants. Based on different researches different refrigerants will yield results due to the exergy analysis and can thus be used to determine the optimum parameters of the refrigerants and improving the overall system. Energy and exergy analyses need some mathematical formulations for the simple vapor compression refrigeration cycle. In the vapor compression system, there are four major components: evaporator, compressor, condenser, and expansion valve. External energy (power) is supplied to the compressor and heat is added to the system in the evaporator, whereas in the condenser heat rejection is occurred from the system. Heat rejection and heat addition are dissimilar to different refrigerants, which cause a change in energy efficiency for the systems. Exergy losses in various components of the system are not same. A temperature and pressure are denoted by T_0 and P_0, respectively. Exergy is consumed or destroyed due to entropy created depending on the associated processes. To specify the exergy losses or destructions in the system, thermodynamic analysis is to be made.

4) Mathematical modeling:

The diagram below shows the schematic diagram of multipurpose domestic refrigeration system with single compressor. In this project, we will be using R22 and R134a as refrigerant of the system.

To perform our comparison between these two refrigerant, we will emphasize on the energy analysis, namely the C.O.P, and the exergy destruction of the system for each and every working fluid.

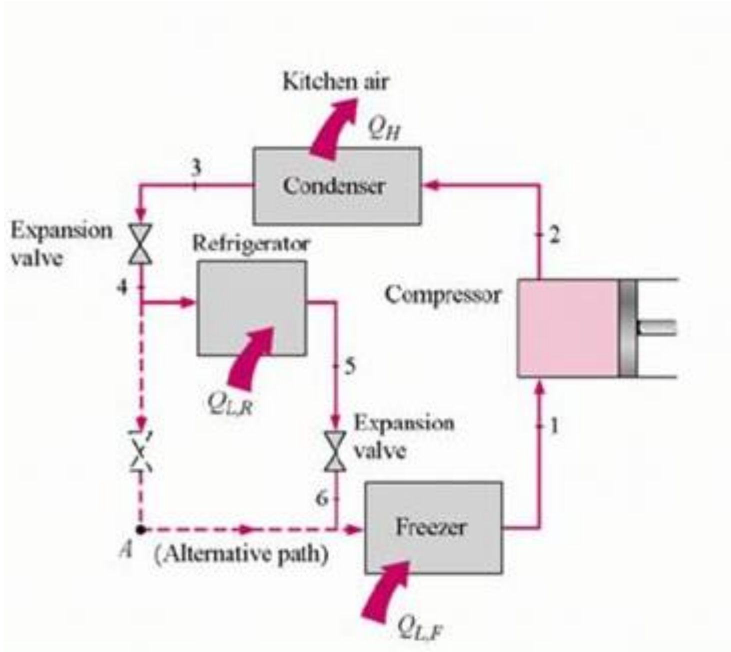


Figure8: Schematic diagram of a multipurpose system

The system is a modification of the usual vapor compression system by using two expansion valve instead of one, which will allow us to obtain different cooling space with different temperature. However, the other components remains untouched.

4.1) Energy calculation:

The compressor, in state 1 to 2, plays its usual role which is to compress the working fluid at a high pressure and temperature above the atmospheric conditions. This will allow an efficient heat transfer from the

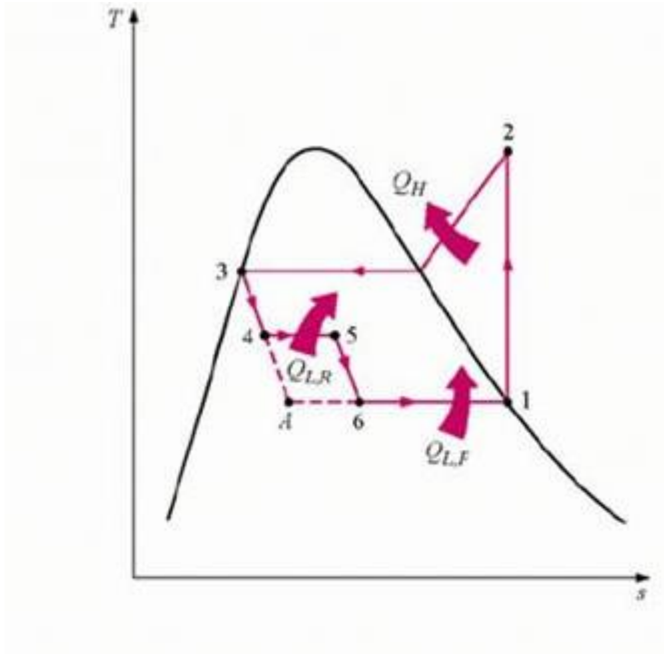


Figure8. T-s diagram of a multipurpose system

working fluid to the atmosphere to take place. This will yield after a work done by the compressor. It is given below

$\dot{W}_{Comp}$= ṁ $(h_2 - h_1)$ (1)

Where: ṁ is the mass flow rate of the working fluid

h_2 and h_1 enthalpy at point 1 and 2

From the compressor, the working fluid enters the condenser at high temperature and pressure. Rejection of heat to the atmosphere takes place. The amount of heat rejected ($\dot{Q}_H$) is found out by:

$\dot{Q}_H = \dot{m}(h_2 - h_3)$ (2)

The fluid then enters in the first expansion valve. It is now throttled to the desired temperature of the cooling space where some goods and cold water are stored.

At the exit of this expansion process, the working fluid is engaged to a first evaporation in the cooler part before proceeding for the second expansion to lower pressure for a freezing purpose.

Vaporization with lower temperature and pressure can occur now.

Heat absorption of the first evaporation is given by:

$$\dot{Q}_{L1} = \dot{m}(h_5 - h_4) \qquad \text{.... (3)}$$

Heat absorption of the second evaporation is given by:

$$\dot{Q}_{L2} = \dot{m}(h_1 - h_6) \qquad \text{.... (4)}$$

The addition on the heat absorbed in these two phase will give the total heat taken by the working fluid

$$\dot{Q}_L = \dot{Q}_{L1} + \dot{Q}_{L2} \qquad \text{.... (5)}$$

We are not to forget that the processes 3-4 and 5-6 are isenthalpic. Hence

$h_3 = h_4$ and

$h_5 = h_6$.

The coefficient of performance of the system is now given by the ration of heat absorbed by the evaporators ($\dot{Q}_L$) by the work of the compressor ($\dot{W}_{Comp}$)

$$\text{C.O.P} = \frac{\dot{Q}_L}{\dot{W}_{Comp}} \qquad \text{.... (6)}$$

That completes our energy analysis.

4.2) Exergy calculation:

This consists of the determination of exergy destruction of each and every component of the system, thus we will have the exergy total of the whole system.

The expression of exergy at any given state is:

$$\varphi = \dot{m}\,[(h - h_0) - T_0(s - s_0)] \qquad \ldots\ldots (7)$$

The exergy destroyed in the compressor is,

$$\dot{E}_{D\,comp} = \dot{m}[(h_2 - h_1) - T_0(s_1 - s_2)] + \dot{W}_{el} \qquad \ldots\ldots (8)$$

Where, $\dot{W}_{el}$ is the electrical power driving the compressor

The exergy destroyed by the condenser is given by:

$$\dot{E}_{D\,cond} = \dot{m}(h_2 - h_3) - T_0(s_2 - s_3) - \dot{Q}_{cond}\left(1 - \frac{T_0}{T_{cond}}\right) \qquad \ldots\ldots(9)$$

The exergy destroyed by the expansion valve is given by:

$$\dot{E}_{D\,exp} = \dot{m}(s_4 - s_3) \qquad \ldots\ldots(10)$$

The exergy destruction in the evaporator is given by:

$$\dot{E}_{D\,evap} = \dot{m}(h_4 - h_1) - T_0(s_4 - s_1) - \dot{Q}_{evap}\left(1 - \frac{T_0}{T_{evap}}\right) \qquad \ldots\ldots(11)$$

Summing up the exergy destruction in each and every component will result to the exergy total destroyed in the cycle

$$\dot{E}_{D\,Total} = \dot{E}_{D\,comp} + \dot{E}_{D\,cond} + \dot{E}_{D\,exp} + \dot{E}_{D\,evap}$$

5) Results and discussion.

Our results will be presented in form of tables showing the values obtained after the energy and exergy analysis of both R22 and R134a.

Energy and exergy have been calculated with different temperature in the condenser and evaporators considering the atmospheric temperature to be 28 Degree Celsius.

In this project, all temperatures are considered to be in Degree Celsius.

These data, on the above tables 1 &2, was obtained by energy and exergy of the chosen refrigerants, namely R22 and R1234a analysis of different components varying the temperature of the condenser and the evaporator. Later on we will have a deeper discussion about the variation in C.O.P and exergy destruction as well of the system.

T_{cond}	$T_{evap\ 3-4}$	$T_{evap\ 5-6}$	C.O.P	$\dot{E}_{Dcomp}$	$\dot{E}_{Dcond}$	$\dot{E}_{Dexp}$	$\dot{E}_{Devap}$	$\dot{E}_{DTotal}$
34	-4	-14	5.54357	2.76567	1.95692	0.47440	134.490	139.6869
30	-2	-10	5.726115	1.80272	1.25674	0.43090	87.7575	91.2479
32	0	-10	5.179348	2.91424	1.75077	0.09226	120.29	125.0477
36	2	-16	5.221818	3.39203	2.08471	1.62875	8.83657	15.9421

Table1: Illustrating the energy and exergy variation using R22 refrigeration

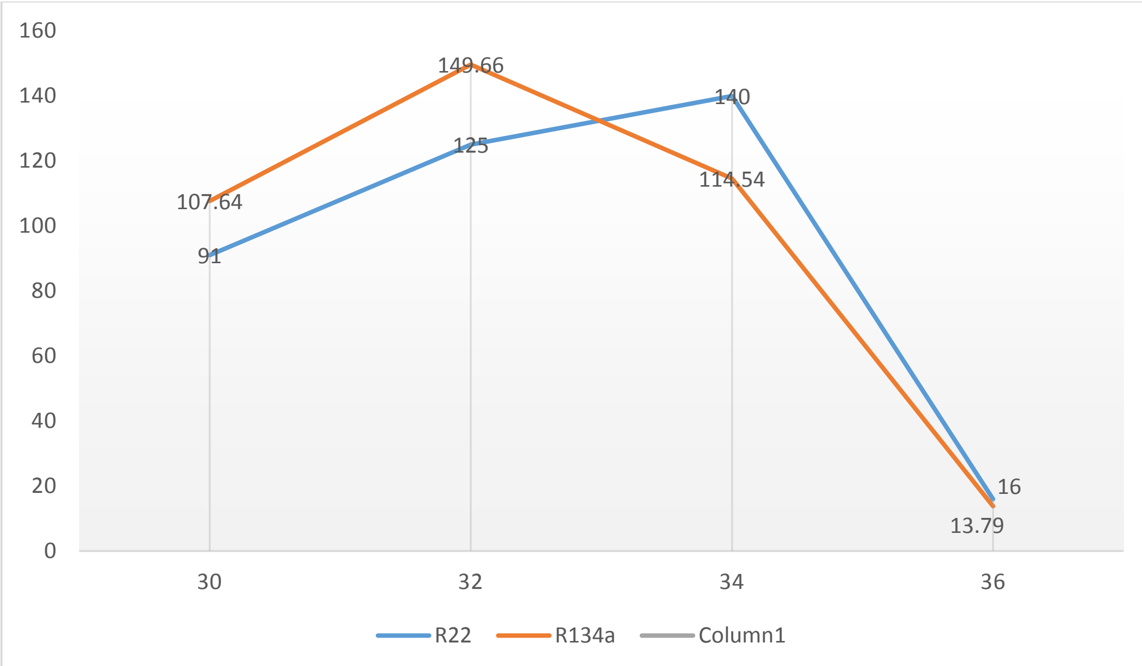


Figure9.a: variation of exergy destruction with change in temperature

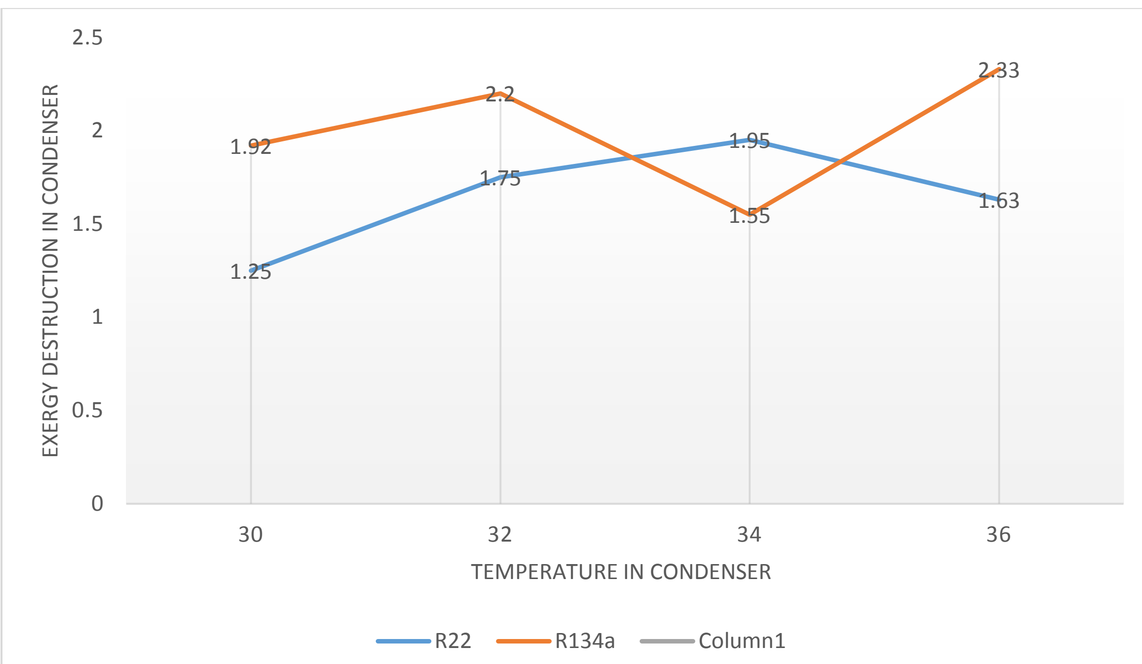


Figure9.b: variation of exergy destruction in the condenser with change in temperature

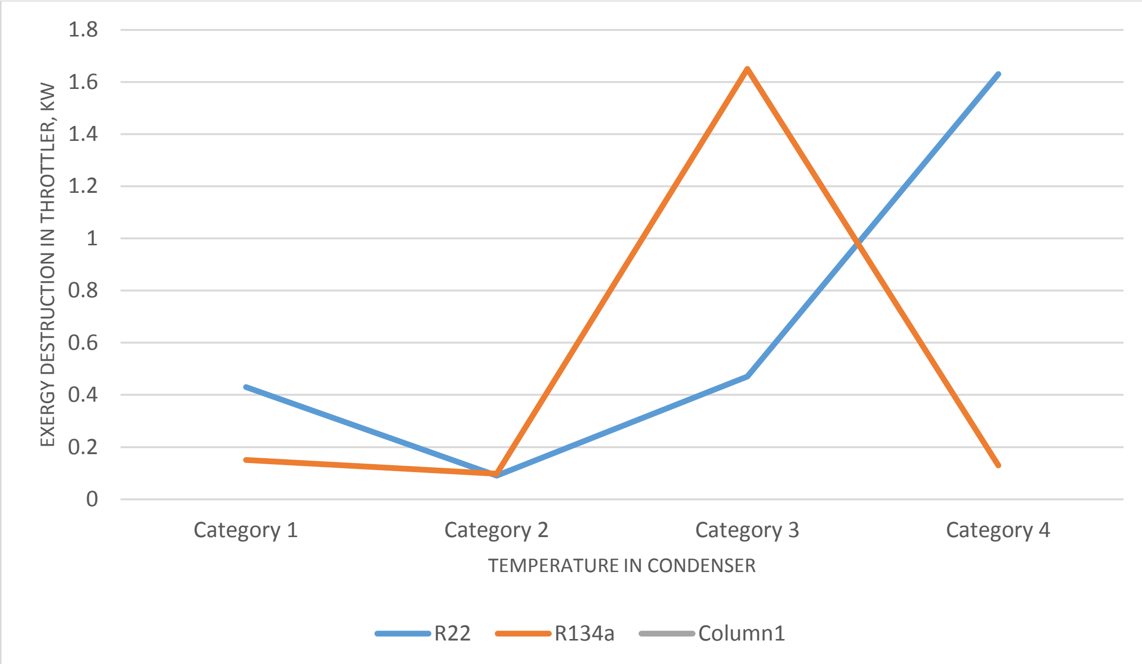


Figure9.c: variation of exergy destruction within the expansion valve with change in temperature

Referring to Table1, it can be notice that the coefficient or performance and exergy destruction varies with the change of temperature as well as from one component to another. The exergy destruction is more inside the evaporators and less within the throttling valve.

When it comes to the C.O.P, we can notice a slight variation along with the change in temperature of the components.

T_{cond}	$T_{evap\ 3-4}$	$T_{evap\ 5-6}$	C.O.P	$\dot{E}_{Dcomp}$	$\dot{E}_{Dcond}$	$\dot{E}_{Dexp}$	$\dot{E}_{Devap}$	$\dot{E}_{DTotal}$
34	-4	-14	7.803999	1.68285	1.54513	1.65029	109.661	114.5393
30	-2	-10	7.97801	1.99344	1.92494	0.15311	103.569	107.6405
32	0	-10	9.49644	1.93234	2.20078	0.09824	145.43	149.6614
36	2	-16	5.261079	3.39867	2.33321	0.12669	7.93318	13.79064

Table2: Illustrating the energy and exergy variation using R132a refrigerant

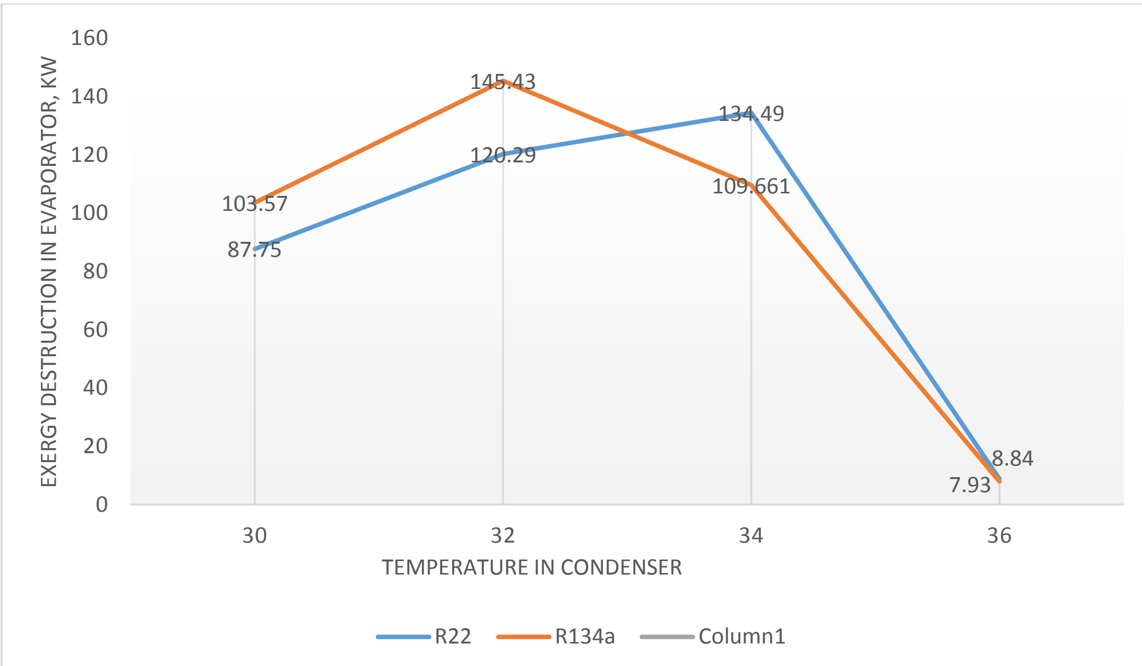


Figure9.d: variation of exergy destruction within the evaporator with change in temperature

The tables can clearly show that both exergy destruction and the coefficient of the performance of the system have improved with R132a refrigerant. Which suggests more of using it in replacement with R22.

5) Conclusion:

The main focus of this project was to study the performance of a multipurpose domestic refrigeration system using different refrigerants such as R22 and R134a.

After diligent experimentations and calculations within different temperature in all components, namely compressor, condenser, throttle valve and evaporator, we can see that R134a have given interesting result in term of exergy destruction as well as the coefficient performance of the system.

Furthermore, we can see that R134a have its best performance when condenser temperature is 32, evaporator (4-5) temperature is at 0 degree and that of the second evaporator is at -10. However, R22 illustrates its optimum performance, referring to C.O.P, at 30, -2, -10 degree Celsius respectively at the condenser, first evaporator and the second evaporator.

In a nutshell, in term of performance, we acknowledge the good performance of both of these refrigerants in term of energy as well as exergy analysis, compare to some other HCFC refrigerants. But still R134a will prime on R22.

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