TECHNOECONOMIC ASSESSMENT OF ALUMINIUM SUCTION BASED DOMESTIC REFRIGERATOR

A PROJECT REPORT
SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT
FOR THE AWARD OF THE DEGREE
OF

MASTER OF TECHNOLOGY
IN
THERMAL ENGINEERING

SUBMITTED BY

ANKIT
(2K20/THE/04)

UNDER THE SUPERVISION OF

DR. ANIL KUMAR
ASSOCIATE PROFESSOR

DEPARTMENT OF MECHANICAL, PRODUCTION & INDUSTRIAL
AND
AUTOMOBILE ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY
BAWANA ROAD, DELHI-110042

MAY, 2022

CANDIDATE'S DECLARATION

I, ANKIT, 2K20/THE/04 Student of M,Tech (Thermal Engineering), hereby declare that the project dissertation titled "**TECHNOECONOMIC ASSESSMENT OF ALUMINIUM SUCTION BASED DOMESTIC REFRIGERATOR**" which is submitted by me to the Department of Mechanical Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any degree, Diploma Associateship, Fellowship or other similar title or recognition.

Place: Delhi ANKIT

Date: 25/05/2022 (2K20/THE/04)

CERTIFICATE

I hereby certify that the project dissertation titled "**TECHNOECONOMIC ASSESSMENT OF ALUMINIUM SUCTION BASED DOMESTIC REFRIGERATOR**" which is submitted by Ankit, Roll No 2K20/THE/04 Department of Mechanical Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of **Master of Technology,** is a record of the project work carried out by the students under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this university or elsewhere.

Place: Delhi   Dr. ANIL KUMAR

Date: 25/05/2022   SUPERVISOR

ACKNOWLEDGEMENT

It is a matter of great pleasure for me to present my dissertation report on **"TECHNOECONOMIC ASSESSMENT OF ALUMINIUM SUCTION BASED DOMESTIC REFRIGERATOR".**

First and foremost, I am profoundly grateful to my guide **Dr. ANIL KUMAR, Associate Professor, Mechanical Engineering Department** for his expert guidance and continuous encouragement during all stages of thesis. I feel lucky to get an opportunity to work with him. Not only understanding the subject, but also interpreting the results thereon from the graphs was very thought provoking. I am thankful to the kindness and generosity shown by him towards me, as it helped me morally complete the project before actually starting it.

I would like to extend my gratitude to **Prof. S.K. GARG, Head, Mechanical Engineering Department** for providing this opportunity to carry out the present thesis work.

Finally and most importantly, I would like to thank **my family members and seniors** for their help, encouragement and prayers through all these months. I dedicate my work to them.

Place: Delhi ANKIT

Date: 25/05/2022 (2K20/THE/04)

ABSTRACT

The main objective of the present study is to enhance the performance of domestic refrigerator, working on vapor compression refrigeration cycle. Enhancement of domestic refrigerator performance with Copper suction and capillary has been reported by many of the researchers. This thesis shows the results of an experimental work based on the aluminium suction line. Conventionally copper was used for making capillary tube and suction line for the enhancement of overall performance, copper suction line is changed into aluminium suction line. Results show that some of the important factors which help in improving the overall performance of a domestic refrigerator involve energy consumption, ice making time and pull down time. These factors reduced to a significant margin as compared to conventional Copper suction and capillary tube. Low cost material of aluminium also helped in cost reduction without degrading the quality of product which also helps large manufacturing industries. Power consumption reduced by 7.24%, Ice making time reduced by 6.27%, Pull down time reduced by 6.39% by using aluminium based suction line and capillary tube. Total reduction observed in expenditure is 68.49% that helped project to save cost**.** This research work will be helpful for the researchers to develop a new low cost model of domestic refrigerator and will help in enhancing the overall performance.

LIST OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: INTRODUCTION

Refrigeration is a technology which absorb heat at low temperature such that temperature can be maintained below surrounding temperature by rejecting heat to the surrounding. The most common refrigerant used for refrigerators presently is R600a and R32 for air conditioning. Both refrigerators and air conditioners works on the principle of vapour compression refrigeration system.

1.1. A BRIEF HISTORY OF REFRIGERATION

The methods of production of cold by mechanical processes are quite recent. Earlier in 1748, William Coolen of Glasgow University produced refrigeration by creating partial vacuum over ethyl ether. But his experience could not be implemented. In 1834 development took place when Perkin used a hand operated machine.

At the time when steam engine was used the pace of development was slow. By introducing electric motors and compressors, application of refrigeration increased. Recent development include finding Freon free refrigerants because it contains chlorine which are responsible for ozone layer in upper atmosphere. Cryogenics was also used for very low temperature refrigeration. Mainly three types of refrigeration applications are used which is window air conditioner, split type air conditioner and domestic refrigerator. Working principle is same for domestic refrigerator and air conditioner. This thesis work is mainly for domestic refrigerator.

1.2. DOMESTIC REFRIGERATOR

Domestic refrigerator mainly consists of four basic component i.e. evaporator, compressor, condenser, expansion valve

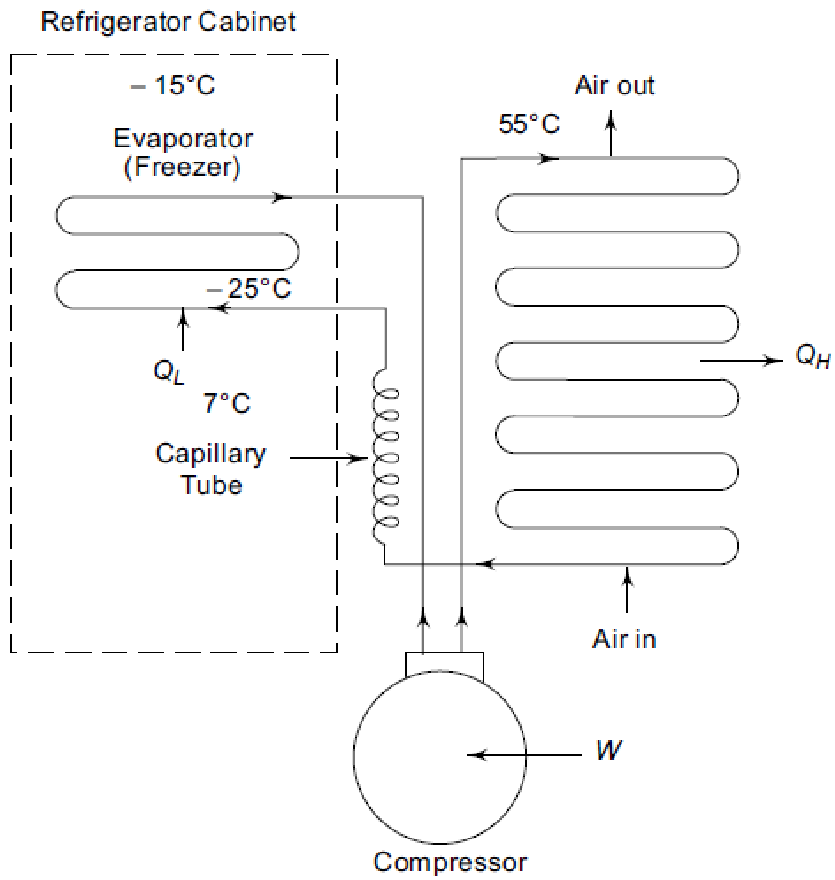

Figure 1.1 Schematic diagram of domestic refrigerator

Evaporator: It is located in the freezer compartment of refrigerator. The freezer forms the coldest part with temperature of about -15ºC. Below the freezer section is chiller tray, down to chiller is fresh food compartment and the bottom most part is crisper section where vegetables and fruits are stored. Natural convection current maintain temperature gradient between evaporator section and crisper compartment. Cold air is heavier which flows down to crisper compartment from evaporator compartment and warm air is lighter which rises above from the vegetable compartment to freezer or evaporator section. Evaporator temperature maintained in freezer is about -15ºC and average mean temperature is about 7ºC.

Refrigerating machines are work consuming device, refrigerant flow from low temperature to high temperature by consuming work. Most common examples of work consuming devices are cold storage, domestic refrigerators, central air conditioning plants, air liquefication plant etc.

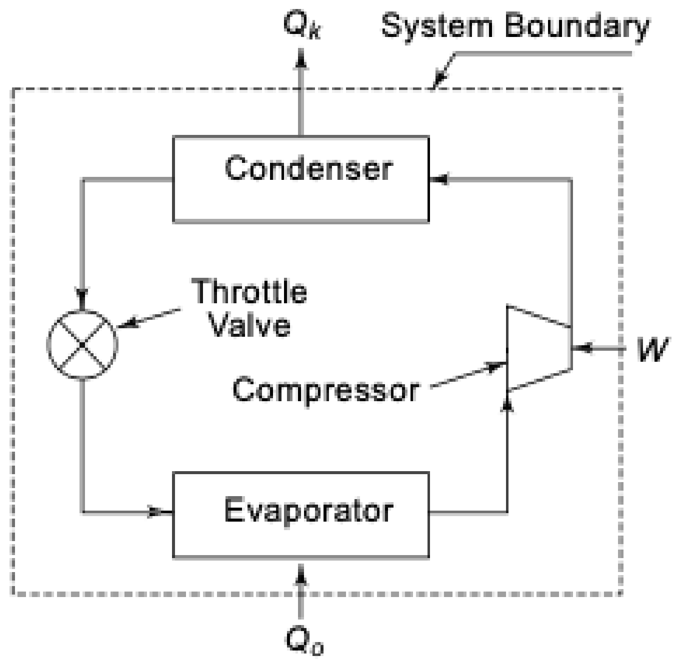

Figure 1.2 An actual refrigerator: Simple vapour compression system

1. Heat Q_0 is absorbed by evaporating R600a refrigerant at a low pressure and low temperature.
2. In compressor, refrigerant is compressed at high pressure at superheated state which increases temperature.
3. Heat is then rejected to the surrounding from the condenser at high temperature.

Simple vapor compression refrigeration system mainly consists of 4 parts evaporator, compressor, condenser and capillary. A capillary tube is an expansion device of smaller diameter use for reducing temperature and pressure of refrigerant before going to evaporator section. Material of capillary tube plays a very important role in the performance of a vapour compression refrigeration system.

1.3. VAPOUR COMPRESSION REFRIGERATION SYSTEM

Refrigerator works on the principle of vapour compression refrigeration cycle. This cycle consists of four processes, which are

- Isentropic compression.
- Constant pressure heat rejection.
- Throttling in an expansion valve.
- Constant pressure heat addition.

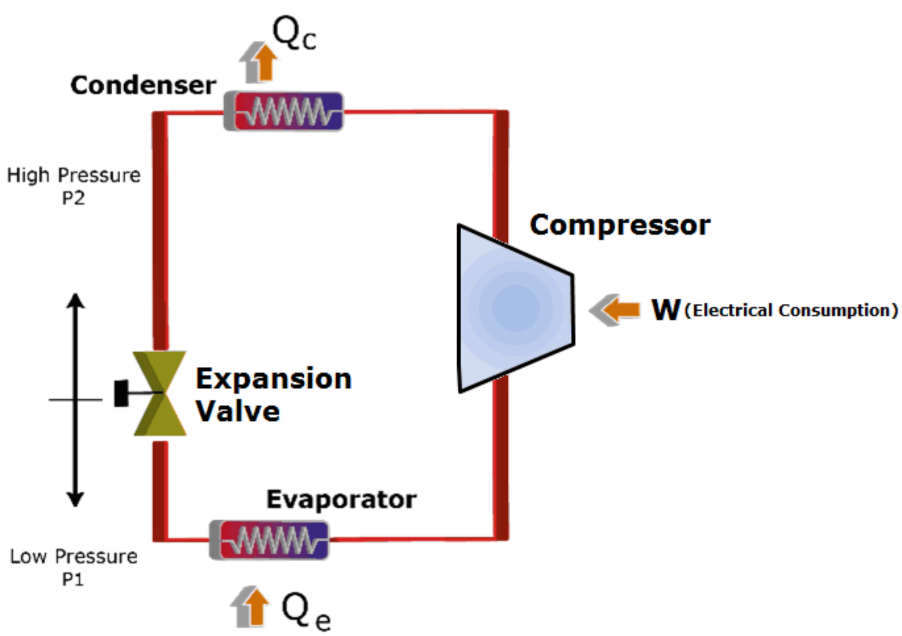

Figure 1.3 Schematic diagram of vapour compression refrigeration system

Liquid refrigerant is used as a medium to remove heat to surrounding and absorb heat from space to be cooled in vapour compression refrigeration cycle. Fig 1 shows a typical single stage vapour compression refrigeration cycle. Refrigerant in the state of saturated vapour enters the compressor and circulate which is then compressed to higher pressure resulting in higher temperature. The hot compressed vapour also known as superheated vapour. Now the superheated vapour is passed through condenser where the circulating vapour reject heat to surrounding from system by air. Now the condensed liquid in thermodynamic state is in saturated liquid state, from here it is routed to capillary tube (expansion valve) where pressure and temperature decreases abruptly maintaining isenthalpic process. Now refrigerant passes through evaporator which absorbs heat from the enclosed space making space colder and subsequently reject to environment. After completing the refrigeration cycle refrigerant vapour is again saturated vapour and goes back to compressor.

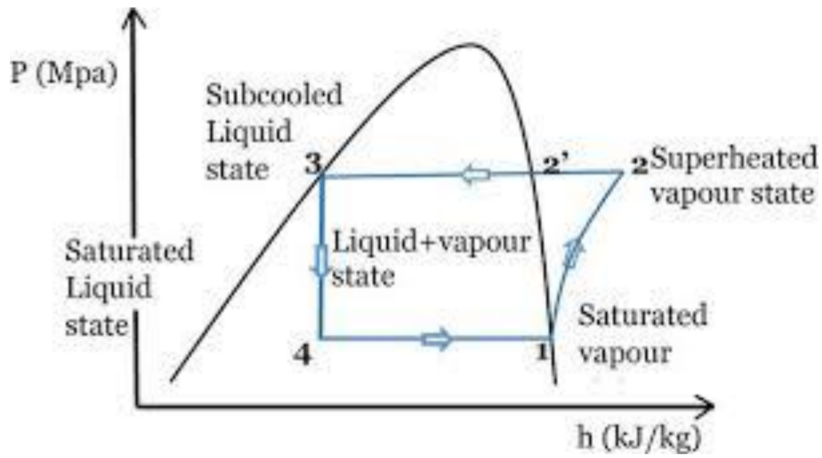

Figure 1.4 Vapour compression cycle on P-h diagram

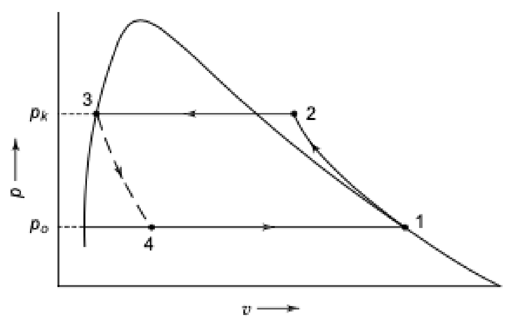

Figure 1.5 Vapour compression cycle on p-v diagram

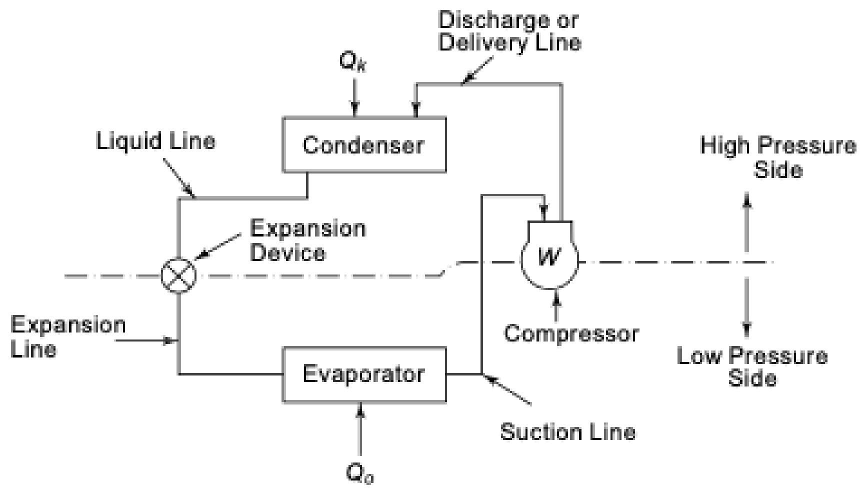

Figure 1.6 Vapour compression cycle

1.3.1. Internal Parts of Domestic Refrigerator

Refrigerant: It passes through all parts of refrigerator and produces cooling effect in refrigerator.

Compressor: It is placed at rear and bottom area of refrigerator. It sucks the refrigerant from evaporator and increases the pressure and temperature. It is driven by motor and is major power device of refrigerator. Almost all refrigerator is having hermitically sealed compressor. Refrigerant in compressor is in gaseous state.

Condenser: It is a thin coil of copper tubing placed at back of refrigerator. Refrigerant from compressor come in condenser loses heat after coming in contact with surrounding air. It is placed externally to increase heat transfer rate.

Expansion Valve or capillary tube: Capillary is thin tube of very less internal diameter made up of copper or Aluminium. When refrigerant passes temperature and pressure drops suddenly iso enthalpically.

Evaporator: It is a heat exchanger made up of several turns of Copper or Aluminium. Plate type of evaporator is used to evaporate refrigerant from liquid to vapour while absorbing heat in the process and again sucked in the compressor.

Thermostat: It is used to control the temperature inside the refrigerator whose sensor is attached to evaporator. By using knob we can control temperature manually. When set temperature reaches electric supply stops and when temperature fall compressor again start working.

Defrost system: It helps in removing excess ice from the surface of evaporator manually.

Suction line heat exchanger: The suction line heat exchanger mostly used in commercial refrigerators. Suction line heat exchanger is used to heat the suction line above dew point temperature of ambient air. Suction line heat exchanger assembled according to double pipe arrangement. The hot liquid refrigerant from condenser used to superheat cold vapour in suction line. This ensures that no liquid enters compressor.

Dry compression is preferred over wet compression because liquid refrigerant may get trapped in cylinder head and can damage cylinder and valves of compressor. Lubricating oil may be washed away by liquid refrigerant droplets thus increase wear.

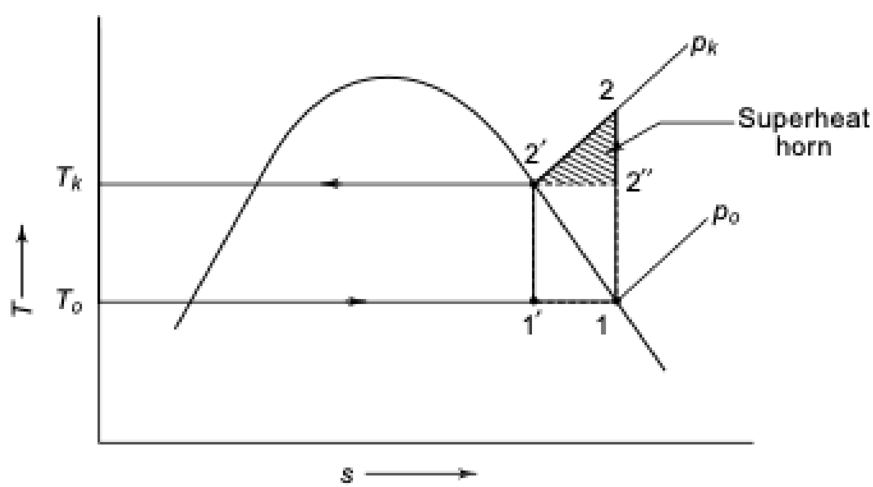

Figure 1.7 Wet and dry compression

Therefore, it is desirable to compress vapour initially by dry saturated or superheated when using reciprocating compression. As shown in figure, refrigerant state at the end of compression is at superheated state. The increased work in dry compression appears as the area 2-2’-2” generally known by name superheat horn. However, wet compression is favourable in a machine like centrifugal or a screw compressor with no valves. Power consumption per ton in case of wet refrigerant is less as compared to dry compression but cannot be used in case of reciprocating compressor.

In refrigerators smaller throttling device is used compared to power plants. Thus the net work required is small compared to that in power plant.

1.3.2. Actual Vapour compression refrigeration cycle

As refrigerant flows through condenser, piping and evaporator there will be drop in pressure. There will be heat losses or gains depend on difference of temperature between refrigerant and surrounding. Compression will be polytropic with friction and no isentropic process involve in actual vapour compression cycle.

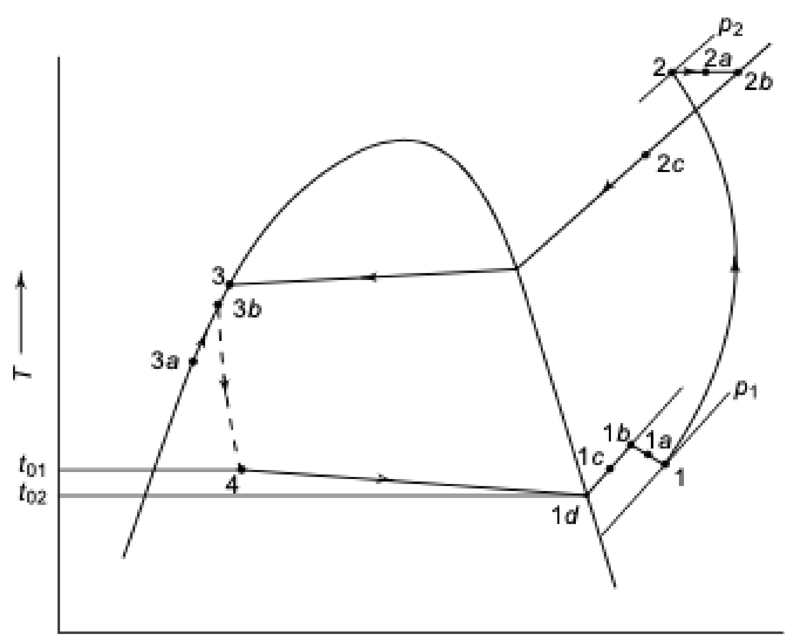

Figure 1.8 Actual vapour compression cycle on T-s diagram

1.4. REFRIGERANTS

Ether was the first refrigerant to be used. Earlier the most common used organic refrigerants are chloro-fluoro derivatives of CH_4 and C_2H_6. Chlorofluorocarbons(CFCs) are the fully halogenated with chlorine in their molecules and hydrochlorofluoro carbons contain H atoms in the molecules along with F and Cl atoms. HCFCs and CFCs are high COP refrigerants having low toxicity , non flammability and material compability that led to wide use as a refrigerant. n-butane were used earlier but now a days isobutane(R600a) are used as a refrigerant in refrigerator.

1.4.1. Refrigerant Properties

1. Normal Boiling point

The boiling point corresponding to 1 atmosphere is called normal boiling point. We want the evaporator pressure to be slightly higher than the surrounding pressure to avoid any air leakage in the system. Air leakage in the system brings water vapour which can freeze at low temperature hence chocking the system.

Refrigerants with low NBP are desirable to operate the evaporator at higher pressure than surrounding.

Lower NBP refrigerants are called as high pressure refrigerants and high NBP refrigerants as lower pressure refrigerants.

2. Critical Temperature

Refrigerants with higher critical temperature than the condensing temperature are preferable. The critical temperature of CO_2 and ethene is less than summer ambient temperature in India, thus not preferred.

3. Latent heat and specific heat

High latent heat reduces the requirement of mass flow of the refrigerant. Hence high latent heat is desirable. Specific heat of the liquid refrigerant is low. Ammonia has high latent heat of vapourisation but it is not used in domestic refrigerator because of its toxic and flammable nature.

4. Pressure ratio

The pressure ratio must not be very high because it results in lower volumetric efficiencies.

5. Freezing temperature

Freezing temperature should be as low as possible to avoid freezing of refrigerant at low temperature. Water has high freezing temperature therefore it can not be used for most of the applications.

6. Compressor discharge temperature

It should be low to prevent overheating of compressor.

7. Viscosity

The viscosity of the refrigerant should be low to avoid viscous losses.

8. Specific volume at compressor inlet

Low specific volume at compressor inlet is desirable because high specific volume results in larger sized compressor.

1.4.2. Leak detection test

1. Halide detection test

   In the presence of freons the bluish flame of hydrocarbon changes into bluish green.

2. Sulphur stick/ Ribbon test

   In presence of sulphur ammonia forms white fumes of ammonium sulphide.

3. Ammonia Swab test

Cloth dipped in ammonia is used for leak detection of SO_2. White fumes confirm leakage.

1.5. COMPRESSORS

For compressors, mainly two types of machines used:

- Positive displacement machines: Reciprocating, rotary, scroll and screw
- Non- positive displacement machines: Centrifugal compressor

Positive displacement compressors prevent undesired reversal of flow while non positive displacement compressors can't prevent reversal of flow. In industry mainly reciprocating type of machines used in refrigerators.

Reciprocating compressors can be classified according to enclosed pattern

1. Hermetically sealed
2. Semi sealed
3. Open type

Motors remain enclosed in Semi hermetic and hermetic compressors and cylinder and crank case remains inside the dome. Through suction vapours motor windings are cooled which gives an edge of less noise, no leakage and compactness. Cast iron is used to make crank case which enclosed shaft and oil sump. Cylinder is also integral with crank case or in distinct cylinder block. Forged steel is used to make crank shaft with hardened bearing surface and balanced dynamically. Piston is also made up of cast iron with a clearance of 0.0004 cm per cm of cylinder diameter. Suction and discharge valves are most crucial parts in reciprocating compressors. The design of valves should be such that it provide long life and low pressure drops.

1.6. CONDENSERS

Heat is rejected in a vapour compression refrigeration machine. In the first few coil of condenser desuperheating takes place which is very small, mainly condenser deals with latent heat. There are three types of condenser namely

1. Evaporative condenser
2. Air cooled condenser
3. Water cooled condenser

1.6.1. Evaporative condensers

The refrigerant reject its heat to water and water reject its heat to air in evaporated form of water. In cooling tower air leaves with high humidity. Thus, it acts as both cooling tower and condenser. Large ammonia plants uses evaporative condensers as they are cheaper.

1.6.2. Air cooled condensers

Natural or forced circulation used to remove heat in air cooled condensers. Copper, steel or aluminium tubing provided to make condensers which improve heat transfer coefficient of air side. Refrigerators and small water cooler use air cooled condenser and air conditioners use forced circulation of air with 5-7 fins per cm.

1.6.3. Water cooled condensers

Water cooled condenser are of shell and coil, shell and tube, double tube types. Shell and coil condenser contains electrically welded closed shell consist of water coil of finned tube. In shell and tube types refrigerant condensing in shell and water flowing through tubes.

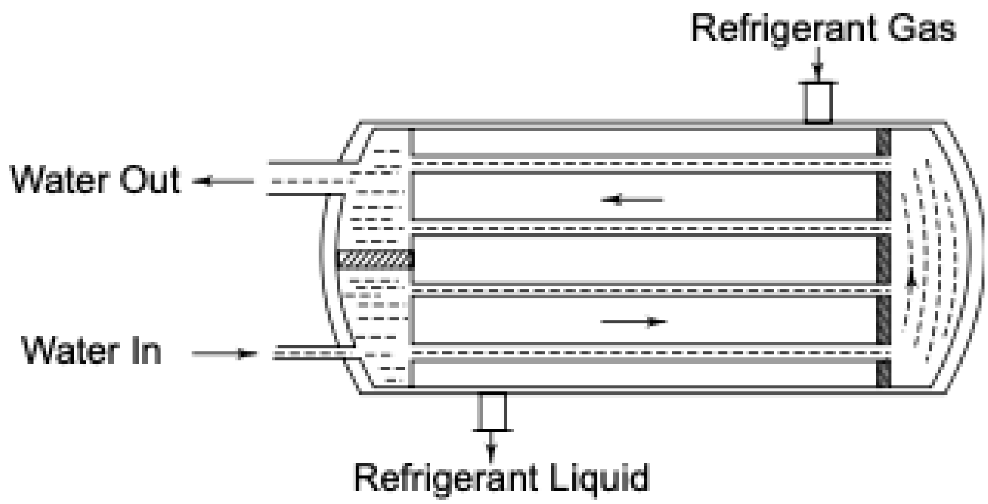

Figure 1.9 Two pass water cooler shell and tube condenser

In double tube water flows in inner tube and refrigerant condenses in outer tube in opposite direction.

1.7. EXPANSION DEVICES

An expansion device offer resistance to flow irreversibly so that the pressure drops, it can be called as throttling process. An expansion device can perform two function. One is it supply liquid to evaporator and the other is it expand the liquid refrigerant from condenser to evaporator.

Two types of expansion device are as follows:

1. Constant restriction type
2. Variable restriction type

Constant restriction type is a narrow diameter bore with a long tube such as capillary tube.

Variable restriction device, flow depends on area of flow or extent of opening such as automatic expansion valve and thermostatic expansion valve.

1.7.1. CAPILLARY TUBE

Fixed restriction device is a capillary tube which is a narrow and long tube connecting condenser and evaporator. There is a decrease in pressure when refrigerant passes through capillary tube due to following reason:

1. Friction causes pressure drop, pressure drop is due to fluid viscosity.
2. Acceleration results in pressure drop, flashing of liquid refrigerant takes place into vapour.

Pressure drop is equal to pressure difference at end of tube. Pressure drop is inversely proportional to tube diameter and directly proportional to tube length. Number of capillary tube can be taken but for designed flow and pressure drop a particular capillary tube has to be taken. Because of low cost easily availability for split air conditioner, water cooler, refrigerator, window air conditioner capillary tube is commonly used.

1.8. EVAPORATORS

It is the component of refrigeration system from where heat is removed from body to be cooled by refrigerant. Evaporators are categorised as dry and flooded evaporators.

In dry evaporators, for superheating the vapour a part of heat transfer surface is used. For expansion of refrigerant capillary tube is used.

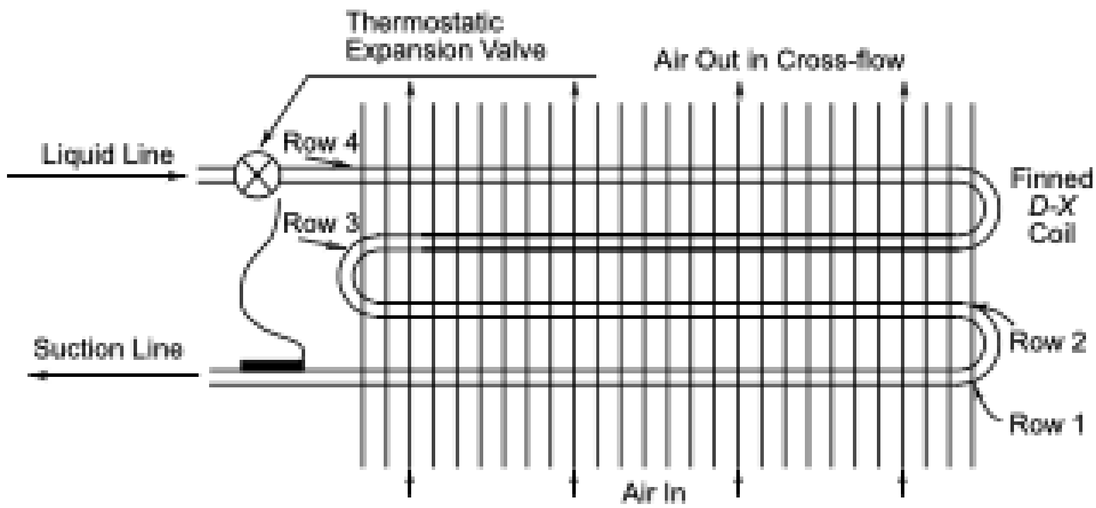

Figure 1.10 Direct expansion cooling coil dry evaporator with thermostatic expansion valve

In flooded evaporator, entire heat transfer surface is covered by liquid refrigerant. For the expansion of refrigerant float valve is used.

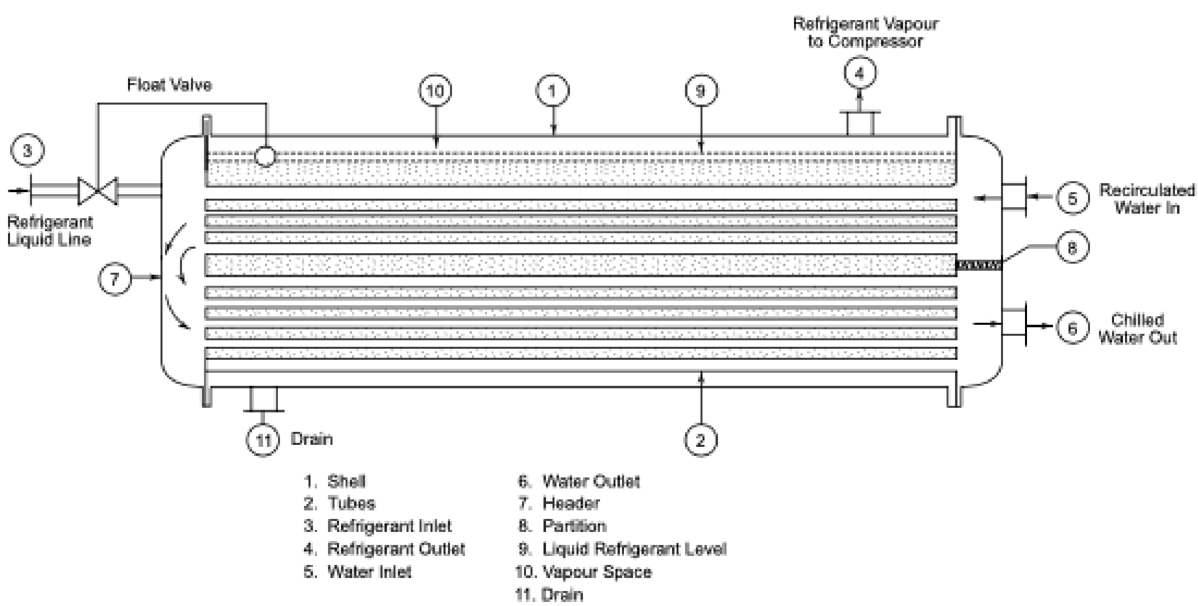

Figure 1.11 Flooded chiller

There are a number of direct expansion evaporators such as:

1. Chiller of direct expansion type
2. Cooling coil of direct expansion type for air with forced convection
3. Coil of direct expansion type for air blast freezer
4. Natural convection evaporators for freezers of domestic refrigerators
5. Coils of evaporator submerged in brine solution

Compressor-capillary tube performance characteristics

For the given length and bore of capillary tube, mass flow rate depends on pressure difference of inlet and outlet. Mass flow rate decreases with increase in evaporator pressure and increase with increase in condenser pressure.

1.9.MAINTENANCE OF VAPOUR COMPRESSION SYSTEM

To prevent component from contamination with dirt, moisture, foreign matter etc. utmost care should be taken since this system is a closed one. While installing, care should be taken for each components like evaporator, compressor, condenser and capillary tube such that they must be in lines and for repair and replacement they must be isolated from rest of the system.

Before the plant is started it is necessary to check leaks if any. After installation all joints and fittings are tested for leakage by a pressure test.

Pressure test is performed with either N_2 or CO_2 gas. If N_2 Is used, with the help of needle valve nitrogen gas cylinder is connected to plant.

CHAPTER 2: LITERATURE REVIEW

The most widely used type of domestic refrigerator works on the principle of vapour compression refrigeration cycle (VCRS). For food preservation domestic refrigerator is an essential appliance. Today most of the domestic refrigerators uses R600a as a refrigerants as R600a is having low ozone potential depletion and low global warming potential.

The Montreal and Kyoto [1] protocol already provided that, high chlorine content in HFC was also responsible for high GWP. Hydrocarbon are natural materials that include propane(R290), n-butane (R-600), iso butane (R-600a), and pentane.

Bolaji et al [2] stated that hydrocarbons are excellent refrigerants in many ways for their higher energy efficiencies, critical point, solubility and heat transfer. Also, they have no GWP or zero ODP and are safe because they are non-inflammable and non-toxic. HCs are compatible with almost all materials; they can be used as a replacement of R12 and R134a. When change of state takes place, they do not behave like a single substance hence they evaporate and condense between different temperatures.

Telang et al [3] experimentally studied the effect of capillary tube in different length and different Configuration on the Performance of Simple Vapour Compression Refrigeration System. Several capillary tubes of different length were taken and mass flow rate, refrigerating effect, compressor work, COP were compared for different lengths and configurations. The data shows that maximum mass flow rate is for straight capillary tube, refrigerating effect is maximum for helical coiled capillary tube, helical coiled capillary tube takes least space and straight capillary tube takes maximum space and COP is increased by increasing length of capillary tube.

Thakar et al [4] experimentally analysed the performance of domestic refrigerators using various alternative refrigerants. Several refrigerants were taken and their compression ratio, compressor power per ton, compressor work done, volumetric refrigerant capacity and refrigerating effect were compared. It was found out that compressor power increases as evaporator temperature increases, compression ratio increases as temperature decreases, volumetric refrigerant capacity decrease as the evaporator temp decreases, compressor work increases as the evaporator temperature increases, net refrigerating effect decreases as evaporator temperature increases.

Pathak et al [5] experimentally studied the Effect of capillary tube diameter and configuration on the performance of a simple vapour compression refrigeration system. The data shows that as the diameter of capillary goes on decreasing evaporator temperature and refrigeration effect tends to decrease.

Kumar et al [6] did optimization of capillary tube parameters in vapour compression system using environment friendly refrigerant R1234yf. Capillary tube of different length and diameter were taken for R1234yf and effect of capillary tube size on various properties were observed. It was observed that by keeping diameter constant and increasing length, COP increases due to increased refrigerating effect. Mass flow rate increases with increase in diameter of capillary tube, Maximum difference in terms of cooling capacity or COP is less than 5% which provides the substitute of R134a.

Oyedepo et. al studied the effect of capillary tube length and refrigerant charge on the performance of domestic refrigerator with R12 and R600a. It was observed that COP Obtained by using R600a is 6.3% more than that of R12, work done by compressor decreases with decrease in length of capillary tube and the average power consumption for R600a is 24% lower than R12. Cooling capacity of R600a is 9.18% higher than R12. Results show that R 600a perform better than R12 by increasing capillary tube length [7].

In tropical climate refrigerators experience higher condensation temperature and lower evaporation temperature. Environment temperature is about 43°C, according to ISO standard, condenser temperature up to 64°C and evaporator temperature lower than -20°C are experienced for different charges and capillary tube [8].

Thermostatic expansion valve's performance characteristic is most suitable for refrigerant plant. Capillary tube is fixed restriction type of device mostly used as expansion valve in domestic refrigerator. The pressure drop through capillary tube is mainly due to friction of fluid viscosity and acceleration due to the flashing of liquid refrigerant into vapour. For given refrigerant pressure drop is inversely proportional to bore diameter and directly proportional to length of capillary tube [9].

Khalsa et al [10] proposed the paper about the performance evaluation of domestic refrigerator by employing evaporative heat exchanger of helical type before hot wall condenser which can be utilized for defrost water evaporation. This reduces superheated refrigerant temperature and condenser load for the improvement of the overall performance. With the use of evaporative cooling COP of system increases by 25.3%, reduces run time of compressor by 10.6% and energy consumption by 7.3%.

Sahoo [11] emphasizes on researching and implementing suction line heat exchanger by combining adiabatic capillary tube in domestic refrigerator working on vapour compression refrigeration. R600a works as an eco friendly refrigerant has additional advantage as it works on low operating pressure range from 0.7 bar to 6 bar for small sized compressor. The use of suction line heat exchanger is installed between evaporator and condenser to heat up the low temperature vapour by consuming fresh condensate heat. As a result condensate become subcooled which increases the heat extraction capacity and reduces flash vapourisation. Thus, SLHX enhances the performance of refrigerator by increasing the coefficient of performance(COP) by 7% theoretically and 3% experimentally.

Edison et al [12]experimentally studied and developed effective suction gas heat exchanger for hermetically sealed compressor. Water taken as coolant for single tube counter flow heat exchanger. When inlet temperature is low compressor consume less work as superheating losses are less. Although COP values are less compared to carnot COP but values with heat exchanger is 7% higher than that without heat exchanger. Using heat exchanger energy consumption value is 12% less than without heat exchanger within a time frame of 90 minutes. Density, mass flow rate and volumetric efficiency increases by using heat exchanger. Required refrigeration temperature achieved in less time by using heat exchanger.

Liquid suction heat exchanger had a great impact on mechanical refrigeration system as investigated theoretically using different refrigerants. Equations based on thermodynamic properties of working fluid was solved by using Engineering equation solver. The results were obtained for three different refrigerants i.e. R134a, R600a and R22. Results showed R134a has 12% higher COP compared with R22 and 7% higher COP compared to R600a refrigerant. Using liquid suction heat exchanger COP can be improved and enhanced upto 20% based on operating condition and refrigerant type. Refrigerating effect or cooling effect using R600a were recorded high when used in modified and non modifies systems.

Taghavi et al modified the system to enhance efficiency and cooling capacity of refrigerator. Experimental exergy analysis was performed in which suction pipe was used to absorb heat from compressor. COP increased to 4% by modification, improvement did not cost extra rather expenditure decreases by reducing the length of capillary tube and suction line. Irreversibility of compressor is highest among parts of refrigerator. As the mass flow rate of refrigerant increases, cooling capacity increase and irreversibility of compressor and evaporator decreases with suction pipe.

Sathawane et al experimentally concluded the effect of suction and discharge line evaporative cooling on the performance of VCRS. Wood fibre and coconut coir used to cover the suction line which acts as an insulator to reduce the temperature of refrigerant going into compressor which reduces the specific volume and work required by the compressor. The performance was evaluated for pull down load of 150, 300 and 450 watt and found that COP increased by 7.22% using cool pad and wood fibre on both suction and discharge line. Evaporative cooling saved time of 12% in the system and increases energy saving up to 14%.

Rajput et al reviewed flow of refrigerants through a capillary tube. Author discussed about capillary tubes of different types depending on ways of working and shape. Capillary tube of diameter 0.5 mm to 2.0 mm and length 2m to 6 m used in domestic refrigerator and air conditioning. Authors reviewed that flow is adiabatic inside capillary tube as long as refrigerant was in liquid state and as flashing occur the temperature falls rapidly. Flashing causes the total energy converted into kinetic energy. Capillary tube is bonded with suction line by means of wrapping which resulted in increasing refrigerating effect.

Guo et al conducted experiment for suction pipe to secure oil return to compressor. Author mounted compressor at the top of evaporator. A suction pipe was designed to remove problem of accumulation of oil. Experiments conducted and lubricating oil allowed to return to compressor.

2.1. RESEARCH GAPS

1. The research in the area of aluminium suction and capillary is very limited and it needs to be explored.
2. The field of suction line yet to be explored by many researchers.
3. Limited literature available for low cost development of refrigerators
4. Limited researches have been conducted to minimize ice making time and pull down time.

2.2. RESEARCH OBJECTIVE

1. Development of aluminium suction and capillary tube for direct cool refrigerator and comparing the performance characteristics with copper suction and capillary tube.
2. To study the cost effectiveness of aluminium suction and capillary tube over copper.
3. To study ice making time, pull down time and rated energy consumption of suction and capillary tube of aluminium over copper.

CHAPTER 3: METHODOLOGY

3.1.EXPERIMENTAL SETUP

In present experimental work, direct cool refrigerator used R600a as refrigerant for single door house hold with a total capacity of 200L.

Table 1 Property of Refrigerant

Name of Refrigerant	Critical Pressure (MPa)	Critical Temperature(K)	ODP(Yes/No)	GWP
R600a	3.63	407.81	No	4

It consists of thermostat, deep freezer, chiller tray, hermetically sealed reciprocating compressor, air cooled condenser, aluminium and copper suction tube, Aluminium and Copper capillary tube. Initially copper suction and capillary used for conducting ice making test and pull down test and measuring energy consumption. For better performance aluminium suction and capillary is used and previous test is repeated for aluminium too. Several thermocouples were used to calibrate temperature inside freezer section, chiller compartment, fresh food compartment and crisper zone. The capillary outlet attached to evaporator and the refrigerant starts flowing. During experimentation, the test set up was located at test condition as shown in figure 3.1.

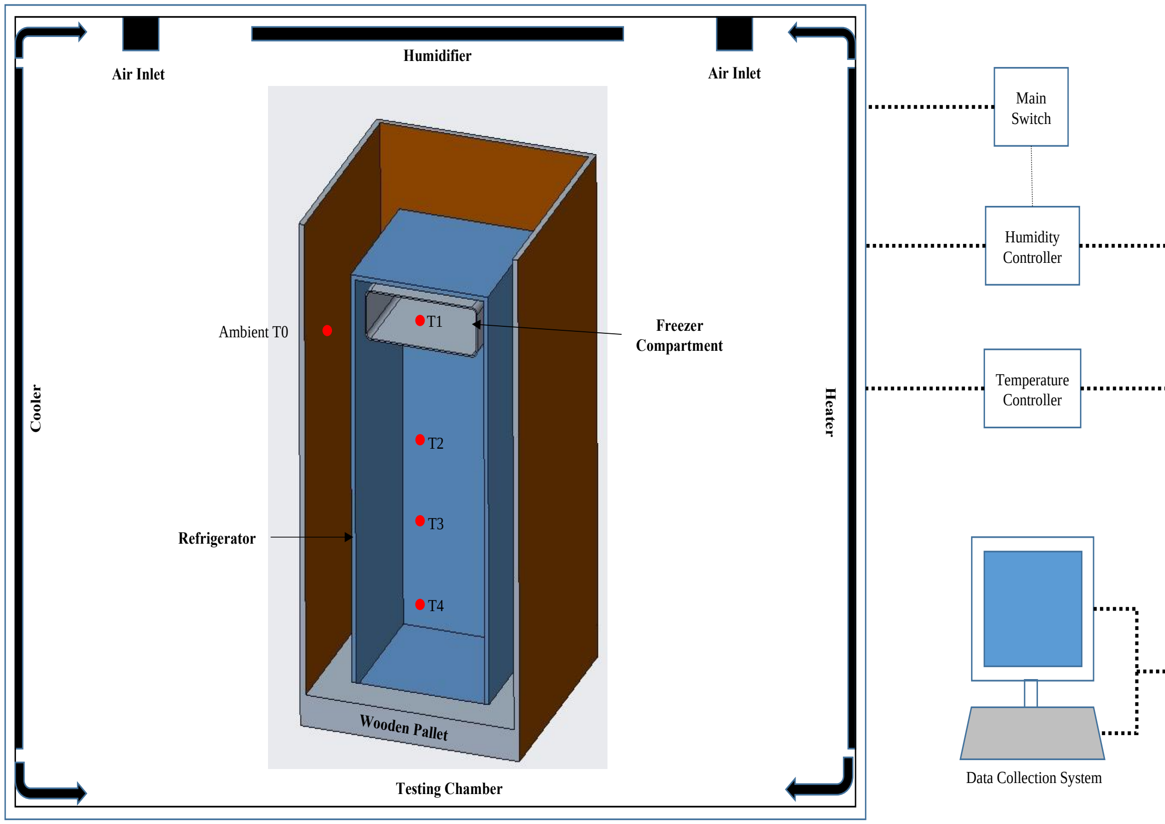

Figure 3.1 Schematic view of Test Rig

Conventionally, copper was used in suction and capillary in domestic refrigerator. Now aluminium is used in suction and capillary in domestic refrigerator. Use of aluminium decreases the cost of production and increases the overall performance. Domestic refrigerator consists of following parts for experiments.

(a) Compressor

(b) Condenser

(c) Dryer

(d) Capillary tube

(e) Drip tray

(f) Capillary soldered with suction

(g) Evaporator with evaporator panel

BEE standards were taken as reference for conducting energy consumption test.

Figure 3.2 Copper Suction and capillary.   **Figure 3.3** Aluminium Suction and Capillary

3.2. EXPERIMENTAL PROCEDURE

3.2.1. Ice-Making Test

The purpose of Ice-making test is to check the ice making capability of the refrigerator. For this process, temperature is maintained at ambient temperature that is +43°C. After attaining stable operating condition, the test was continued till freezing time. Thermostats were set in such a manner that stable operating conditions obtained in coldest position, before starting the test. Water filled up to 5 mm from top in ice and placed in the evaporator. Figure 3.4 (a, b) shows the thermocouple attached at different compartment for ice making and pull down test.

(a)

(b)

Figure 3.4 (a,b) Thermocouple attached at different compartment for ice making and pull down test

3.2.2. Pull down test

For pull down test experiments, the compartment doors of cabinet kept open, and it remained electrically disconnected at ambient temperature of +43°C for at least 8 h immediately before the start of the test. During the test, all refrigeration systems control like thermostat, automatic defrost control etc. were electrically disconnected or inactivated to ensure compressor should perform continuously. If the motor overload protector (OLP) provided, it should not to be inactivated or disconnected. After soaking, the cabinet door was kept closed and pull down time required for the mean cabinet air temperature was from +43°C to +7°C was measured. Test duration is for 6 hours continuous run after soaking refrigerator for 8 hours at 43℃. Refrigerator run at 230 V, 50 Hz supply

3.2.3. Rated Energy Consumption Test

The purpose of rated energy consumption test is to measure the energy consumption value comparatively for the refrigerator operating under identical conditions for the refrigerators made by different manufacturers. For conducting rated energy consumption test ambient temperature maintained at +32°C in standard test room [10]. Refrigerator ran on no load condition and the temperature of evaporator not exceeded by 5 ± 0.5°C at geometric centre. After the stabilized conditions was reached the energy consumption measured for 6 hour period. Uncertainties for testing condition are discussed in Table 2.

Table 2 Uncertainties for testing condition

Parameter	**Uncertainty**
Chamber Temperature	±0.5°C
Relative humidity	±0.5%
Voltage	±0.5 V
Frequency	±0.5 Hz
Pressure of Refrigerant	±0.13 psi (for Evap. outlet)
Temperature of refrigerant	±0.5°C
Compressor run%	±0.3%
Energy meter reading	±0.001 KWh

CHAPTER 4: RESULTS AND DISCUSSION

4.1. RATED ENERGY CONSUMPTION

Yearly energy consumption per year in kWh for 200 Litre, 1 Star non-Inverter with Copper suction was compared with Aluminium suction. Copper is better conductor than aluminium thus having better thermal and electrical conductivity and lesser resistance. Using ohm law V=IR, as voltage is same and resistance offered by copper is lower than aluminium, copper offers more amount of current. Using equation $P=I^2R$, I denotes current and R denotes resistance, the value of I is more for copper than that of aluminium suction and capillary. Thus, power consumption is more when copper is used. It was found that Copper suction consumes 244.6 kWh/year while energy consumption for Aluminium suction is 226.88 kWh/yr (shown in Fig 16). It was observed that a total of 7.24% of total energy can be saved by using Aluminium suction instead of copper suction.

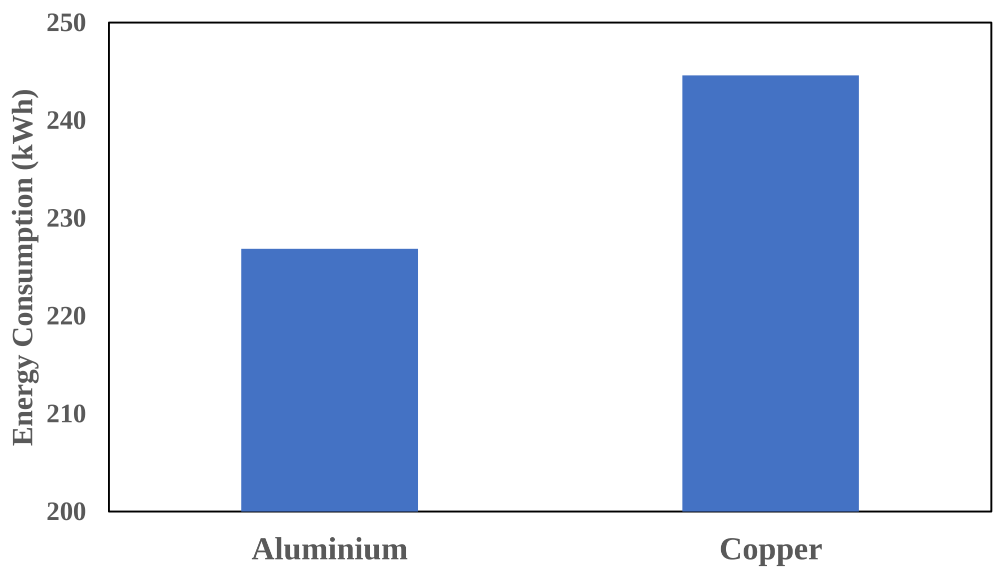

Figure 4.1 Variation in energy consumption in kWh per year for Aluminium and Copper

4.2. ICE-MAKING TIME

Ice making time for 200 Litre, 1 Star Non-Inverter with Copper suction compared with Aluminium Suction. The inside temperature of -5°C achieved in 96.54 minutes for copper suction and 90.48 minutes for Aluminium suction. Thus, 6.06 minutes or 6.27% of time was saved for achieving lower temperature of - 5°C. Machine run time was 90 minutes, voltage maintained approximately at 230V with approximately 0.43 ampere current supply. Necessary conditions were maintained while performing experiments. Variation in ice making time in minutes for Aluminium and Copper is presented in figure 7.

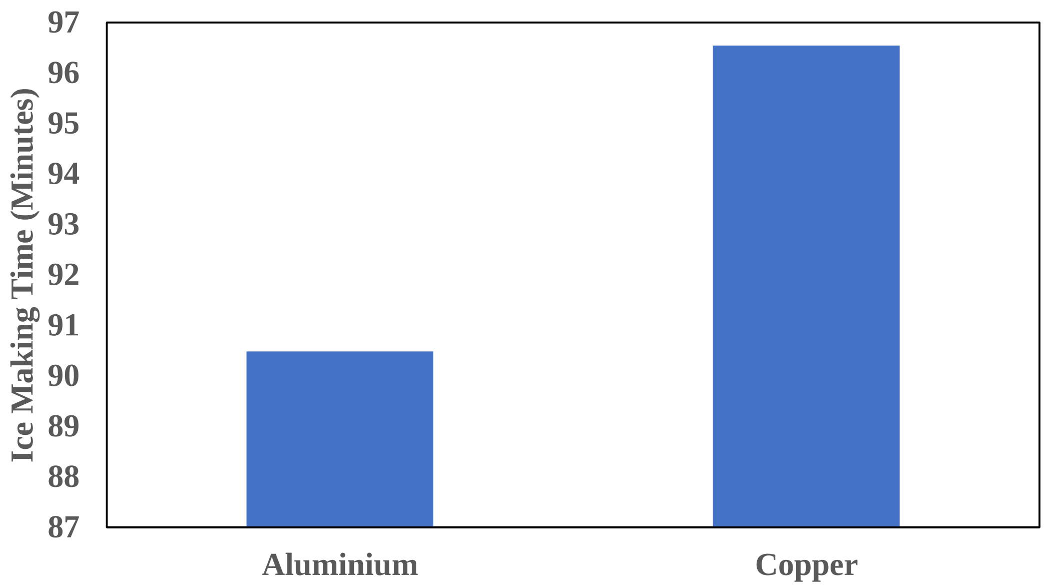

Figure 4.2 Variation in ice making time in minutes for Aluminium and Copper

4.3. PULL DOWN TIME

Pull down test conducted for 200 Litre, 1 Star Non-Inverter with Copper Suction and Aluminium suction whose test conditions are mentioned in test procedure. Pull down time for freezer compartment at -8°C of copper suction was 111.1 minutes. Pull down temperature for freezer compartment at -8°C was 104 minutes. Figure 8 shows the variation in pull down time in minutes for Aluminium and Copper.

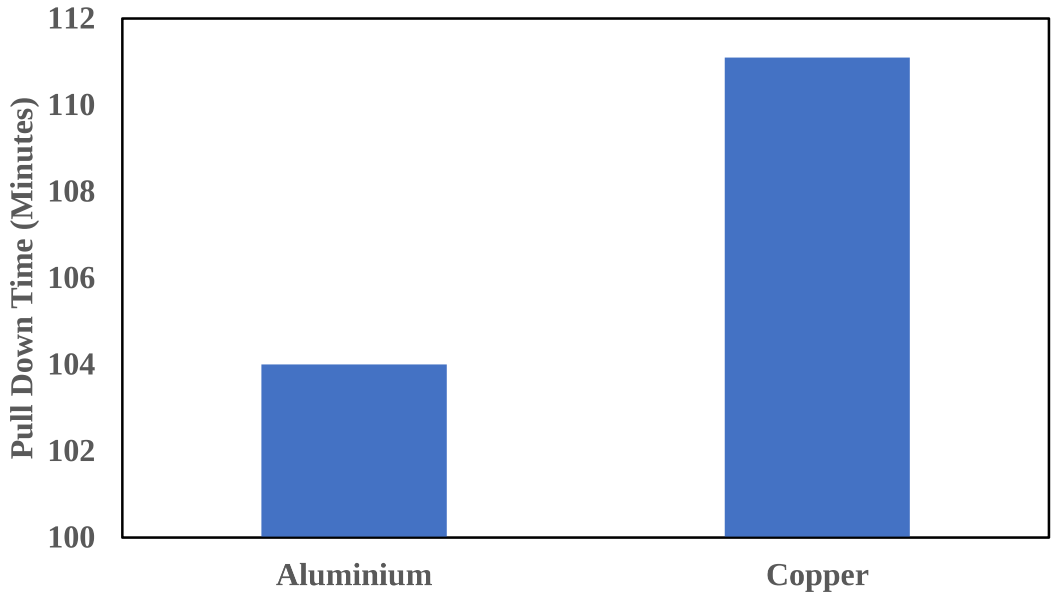

Figure 4.3 Variation in pull down time in minutes for Aluminium and Copper

4.4. COST ANALYSIS

Cost is one of the crucial factor throughout the project. Market conditions, procurement method and planning capability are one of the most significant factor affecting cost and qualities. The procurement cost of Aluminium and Copper is Rs 235 per kg ($3.04) and Rs 745.8 ($9.65) per kg respectively. Thus, total reduction in costing is 68.49% that helped project to save cost. Figure 9 shows the variation of cost for Aluminium and Copper.

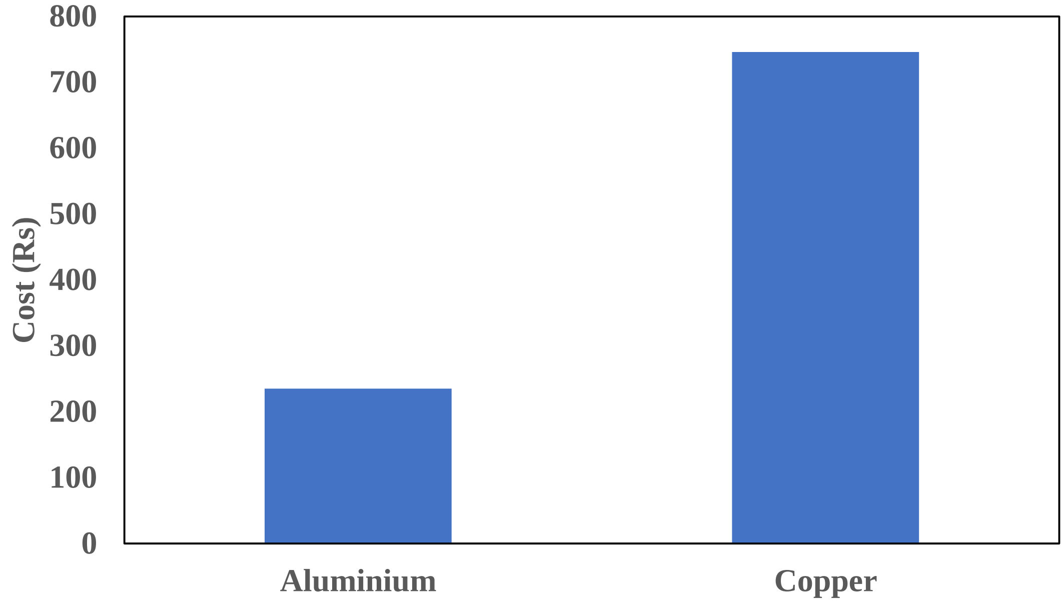

Figure 4.4 Variation in cost for Aluminium and Copper

CHAPTER 5: CONCLUSIONS

This work is intended on domestic refrigerator modification which utilized techno-economic effect on domestic refrigerator. Using Aluminium suction and capillary enhancement of performance is observed in refrigerator. Based on experimental results conclusions can be drawn as follows:

- Electricity can be saved by using Aluminium suction instead of copper suction and power consumption reduced by 7.24%
- In freezer compartment Ice can be prepared in a shorter period of time. Thus, by using aluminium suction time to make ice reduced by 6.27%.
- Pull down time for given refrigerator also decreased by using aluminium suction. Thus, saving 6.39% of time by using aluminium suction.
- Total reduction in expenditure by replacing copper suction and capillary with aluminium suction is 68.49%.

The research work will instruct in developing a new low cost model of domestic refrigerator and will help in enhancing the overall performance.

REFERENCES

1. UNEP, U. (2006). Handbook for the Montreal protocol on substances that deplete the ozone layer. *UNEP/Earthprint*.
2. Bolaji, B. O., & Huan, Z. (2013). Ozone depletion and global warming: Case for the use of natural refrigerant – A Review. *Renewable and Sustainable Energy Reviews*, *18*, 49–54. https://doi.org/10.1016/j.rser.2012.10.008
3. Telang, S. M., & Walk, P. P. (n.d.). *An Experimental Study of the Effect of Capillary tube in Different Length and Different Configuration on the Performance of Simple Vapour Compression Refrigeration System*. Retrieved March 9, 2022, from https://mail.irjet.net/archives/V6/i7/IRJET-V6I7336.pdf
4. Thakar S.M., Prajapati R.P., & Solanki D.C. (2017). Performance analysis of a domestic refrigerator using various alternative refrigerant. *IOSR Journal of Mechanical and Civil Engineering*, *14*(03), 92–103. https://doi.org/10.9790/1684-14030192103.
5. Pathak, S. Shekhar, Shukla, P., Chauhan, S., & Srivastava, A. K. (2014). An experimental study of the effect of capillary tube diameter and configuration on the performance of a simple vapour compression refrigeration system. *IOSR Journal of Mechanical and Civil Engineering*, *11*(3), 101–113. https://doi.org/10.9790/1684-1132101113
6. Gaurav., & Kumar, R. (2017). Optimization of capillary tube parameters in vapour compression system using environmentally friendly refrigerant R1234YF. *International Journal of Engineering and Technology*, *9*(1), 243–248. https://doi.org/10.21817/ijet/2017/v9i1/170901426
7. Oyedepo, S.O., Fagbenle, R.O., Babarinde, T.O., Odunfa, K.M., Oyegbile, A.D., Leramo, R.O., Babalola, P.O., Kilanko, O. K., & Adekeye, T. (2016). *Effect of Capillary Tube Length and Refrigerant Charge on the Performance of Domestic Refrigerator with R12 and R600a*. Retrieved March 9, 2022.
8. *ISO 15502:2005/cor 1:2007*. ISO. (2007, December 17). Retrieved April 10, 2022, from https://www.iso.org/standard/45432.html
9. Arora, C.P. (2013). Refrigeration and air conditioning. McGraw Hill Education
10. Khalsa, K. P., & Sadhu S. (2021). Experimental study of domestic refrigerator performance improvement with evaporative condenser. *International Journal of Air-Conditioning and Refrigeration*, *29*(02). https://doi.org/10.1142/s2010132521500152
11. *ISO 15502:2005/cor 1:2007*. ISO. (2007, December 17). Retrieved April 10, 2022, from https://www.iso.org/standard/45432.html
12. Edison, G. (2012). Enhanced coefficient of performance by effective suction line cooling-an experimental report. *Indian Journal of Science and Technology*, *5*(10), 1–9. https://doi.org/10.17485/ijst/2012/v5i10.13

13. Sathawane, R. K., & Patil, S. A. (2016). *Effect of Suction and Discharge Line Evaporative Cooling on the Performance of VCRS*, *3*(10). https://doi.org/10.17148/IARJSET.2016.31026
14. Gupta, P. R. C., & Rajput, K. S. (2018). *Flow of Refrigerants through a Capillary Tube - A Review*, *3*(12), 99–105.
15. GUO, T. I. A. N. D. O. N. G., LEE, W. O. N. J. O. N. G., DO, S. A. N. G. C. H. U. L., & JEONG, J. I. H. W. A. N. (2012). Suction pipe design criterion for r-134a refrigerators to secure oil return to compressor. *International Journal of Air-Conditioning and Refrigeration*, *20*(04), 1250018. https://doi.org/10.1142/s2010132512500186