

**DEVELOPMENT OF AIR BLAST FREEZER FOR THE STORAGE  
OF SOME FRUITS**

**BY**

**AJAYI, Israel Sunday**

**(MEE/01/9019)**



**JANUARY, 2011**

## APPROVAL PAGE

**DEVELOPMENT OF AIR BLAST FREEZER FOR THE STORAGE  
OF SOME FRUITS**

**AJAYI, ISRAEL SUNDAY**

**(MEE/01/9019)**

A THESIS IN THE DEPARTMENT OF MECHANICAL ENGINEERING,  
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UNIVERSITY OF TECHNOLOGY, AKURE, ONDO STATE, NIGERIA.

**JANUARY, 2011**

## CERTIFICATION

This work has not been presented elsewhere for the award of a degree or any other purpose.

Ajayi, Israel Sunday  
Candidate's Name

  
Signature

21/09/2011  
Date

I certify that this work has been carried out by Mr Ajayi Israel Sunday, in the Department of Mechanical Engineering of the Federal University of Technology, Akure.

Dr. M. A. Akintunde  
Supervisor's Name

  
Signature

21/11/2011  
Date



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AJAYI, ISRAEL SUNDAY.



JANUARY, 2011

## DEDICATION

I wholeheartedly dedicate this research work to my LORD and Saviour JESUS CHRIST;  
for HE is my all in all.

## ABSTRACT

The need for conservation of Agricultural produce is highly essential considering the global food crisis. Several methods of food preservation do not normally conserve the organoleptic and nutritional value of the preserved food. The development of blast freezer gives room for conservation of nutritional and organoleptic values of compatible fruits and vegetables.

In this work, a blast freezer was designed for a maximum load of 20 kg. The various heat loads to the refrigerating chamber were considered in the design and a fan was incorporated into the refrigerating chamber for the purpose of circulating the cold air around the finned evaporator. The system was tested under no-load and load conditions, during the test, the parameters required for the evaluation of the system were measured. These parameters include flow rate, ambient, condensing and evaporating temperatures which were used to determine important parameters such as Refrigerating Effect, Compression Work and Coefficient of Performance of the system. Refrigerant 134a was used because it is one of the adjudge environmental friendly refrigerantg. Afterwards, three fruit samples viz: grape, orange and apple were stored for the period of seven days. The organoleptic and nutritional characteristics were determined before the storage and after the storage. Samples were selected from the fruits and left in the open space in the laboratory and were also analyzed at the end of seventh days. The results were compared with the sample stored in the system and analysis shows that the preserved products were able to retain most of the organoleptic and nutritional values while the control sample

lost most of its organoleptic and nutritional values when compared with the state of the produce when fresh.

Food Item	Loss (%)
Apple	10
Banana	15
Carrot	20
Cauliflower	25
Cucumber	30
Green Beans	35
Green Peas	40
Green Spinach	45
Green Tomatoes	50
Leafy Greens	55

### DETERMINATION

#### DETERMINATION

1. Apple	10
2. Banana	15
3. Carrot	20
4. Cauliflower	25
5. Cucumber	30
6. Green Beans	35
7. Green Peas	40
8. Green Spinach	45
9. Green Tomatoes	50
10. Leafy Greens	55

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## CHAPTER ONE

### INTRODUCTION

#### 1.1 Background

The development of air blast freezer for the storage of agricultural produce under the present food crisis is very appropriate. Arising from the worldwide food crisis, there is a need to preserve agricultural produce, in order to ameliorate the crisis. The storage of food items and agricultural produce is an essential aspect of food preservation. It increases the shelf life of the products, preserves quality, makes products available throughout the year, stabilizes price and prevents unnecessary field losses (Ogunlowo et al, 2005). This is now the emphasis in refrigeration and air-conditioning industries which is exclusively devoted to the peaceful service to cover fundamental needs. Modern technology has made it possible to support our globe and refrigeration is part of this development. It is essential to the prevention of losses and conservation of both quality and nutritional value of perishable foods. This has opened the possibility of a true world market of such commodities on a continuous year round basis. Storage technology is diversified, including the biological, chemical, insect and pest, economic and engineering aspects (Odeyemi and Daramola, 2000).

Many perishable foodstuffs are produced on a seasonal basis, meaning that they are only available for part of the year. During this short period the rate of production is higher than market absorption capacity and it is therefore necessary to process or preserve the surplus in order to avoid wastage. According to FAO (2003) survey on post harvest losses in developing countries, 25% of cereals are wasted due to negligence. In other words, one quarter of the production never reaches the consumer efforts and money

invested are therefore wasted. Fruit and vegetables are likely to spoil very rapidly and become unsuitable for consumption. It is difficult to give an estimate of losses in developing countries, but some organizations claim that for certain products, up to half the crop can be lost. Many authors (Ademosun,1997, Agbetoye, 2006) have reported on the need to develop indigenous technology for engineering the various aspects of our agricultural operations including storage.

Physiological deterioration is one of the causes of post harvest losses of fresh produce. As the plant no longer has access to water and nutrients, it draws on its reserves, when these are exhausted, the plants ages rapidly and starts to spoil. If the product is not damaged or attacked by spoilage organism, it will become unsuitable for consumption because of natural decay. The major physiological processes that cause ageing are respiration and transpiration. Fresh produce also deteriorates and decays after harvest because of microbial infections. If infections are not eradicated or inactivated, they can constitute risk for consumers because of toxins produced. Perishable staples are liable to low temperature injury, which is physiological deterioration at temperature near, but above freezing (Walker, 1992).

The success of Air Blast Freezer lies in its capacity to prolong the period during which perishable foodstuffs remain in an acceptable state by slowing down decay or physiological changes. Refrigeration makes it possible to market safe foodstuff to non producing region and to provide high quality products. Chilling or freezing are particularly necessary when perishable food are to be transported to distant and better paying markets. Farmers suffer heavy crops and money losses in the post harvest period during which the harvested crops pass through a series of steps such as threshing, drying,

storage and final processing. Those among them who have no storage facilities suffer more losses through food spoilage, in order to avoid such, they rush their crops to the market immediately after harvesting. This often results in the fall of the market and attendant fall in the prices.

All types of food contains proteins, carbohydrates, fats (lipids) vitamins and minerals. The protein and minerals like iron, calcium and phosphorus helps for tissue building and growth of the body. The vitamins and minerals are essential to safeguard the body against diseases. The destruction of any one of the above mentioned components causes the spoilage of the food. The spoilage period depends upon the type of the food. Perishable foods like meat, fish, milk and many fruits and vegetables beging to deteriorate immediately after havesting unless properly preserved. The semi-perishables like eggs, onions and potatoes can be kept for several weeks in a cool dry place. The non-perishable food like cereals, pulses and nuts can be stored for a long period of time. The spoilage of food comes in form of bad odours, uncommon colour, bad taste and physical appearance. The advantage of food preservation according to (Ogunlowo et al, 2005) includes; preservation of quality, stabilization of market prices, steady and regular supply of food materials, increase in variety of food product and enhancing the potential of crop. The employment of blast freezer will be a viable option for food preservation in the areas in which the greatest post-harvest losses of foodstuffs occur.

An Air blast freezer is a freezer in which air at a very low temperature is circulated by blowers or fans used to cool and preserve Fruits and Vegetables. It is a thermally insulated compartment or cabinet in which air at subfreezing temperature is maintained for the rapid cooling and storing of perishable items especially food. The two

most common types of freezer in use in the fish industry are the plate freezer and the air blast freezer. The plate freezer usually takes up less space and requires less power than a blast freezer with the same output, but its use is normally confined to freezing packs of uniform thickness with smooth flat surfaces. The big advantage of blast freezer is its versatility: it can cope with a variety of irregularly shaped products. Arora, (1997) Wherever there is a wide range of shapes and sizes to be frozen, the blast freezer is the better choice.

Air Blast freezers use air as the heat transfer medium and depend on contact between the product and the tray inside the cooling chamber. Sophistication in airflow control and conveying techniques varies from crude blast freezing chambers to carefully control impingement freezer. The earliest blast freezers consisted of cold storage rooms with extra fans and a surplus of refrigeration. Improved airflow control and mechanization of conveying techniques have made heat transfer more efficient and product flow less labour intensive (ASHRAE, 2002).

There are considerable numbers of designs and arrangement of air blast freezer, there are two main types. In one, the product moves through the freezer during the process: this is a continuous freezer. In the other the product remains stationary: this is a batch freezer. In the continuous freezer the product is carried through on trucks and they are normally operated on a semi-batch principle; the trucks remain stationary except when a fresh truck is pushed into one end of the tunnel, thus moving the others along to release a finished one at the other end. Continuous freezers can be further divided into series-flow and cross flow-types. In a series-flow freezer the air flow is in line with the

trucks or conveyor; in a cross-flow freezer the air flow is across the line of movement of the product.

In a series-flow freezer, normally only one fan and one cooler are used, and the product is moved in the opposite direction to the air flow; thus the coldest air meets the coldest, or nearly frozen, product at the exit end. In this type of freezer, it is essential to switch off the fan during the short period of loading and unloading so that warm air is not drawn into the freezer. A switch should be located near the input door, or contact switches should be fitted to both doors so that the fan is off when either door is open. In the cross-flow freezer there are usually several fans and often more than one cooler unit; trucks entering or leaving the freezer interfere very little with the air flow. Where a conveyor is used with permanent flap openings at loading and discharge ends, the cross flow arrangement is essential. A slight disadvantage of a cross-flow tunnel is that the evaporator nearest the entrance has the most work to do and therefore accumulates more frost than the other evaporators. To avoid having to defrost it more often than the others, the entrance cooler can be made with more widely spaced fins. The batch freezer is more flexible and is used when a variety of products is to be frozen, often at the same time, on the individual trolleys or pallets ( Arora, 1997).

Freezing is a method of food preservation that slows the physical changes chemical and microbiological activity that cause deterioration in foods. Reducing temperature slows molecular and microbial activities in food thus extending useful storage life (Earle, 2000). Freezing systems can be grouped by their basic method of extracting heat from foods. These methods includes, blast freezing (convection, contact freezing (conduction), cryogenic freezing (convection and /or conduction),

cryomechanical freezing (convection and /or conduction) (ASHRAE, 2002) Blast freezing method uses low temperature for the food preservation which stops the activities of the spoilage agencies, this is the most modern and commonly used method for the preservation of almost all types of food. The outstanding feature of this method is that it maintains the taste of the food and also conserve the nutritional value.

Freezing is used for preserving the fresh food for considerable longer period of providing proper temperature and humidity conditions in the stored by maintaining considerably low temperature generally retard the activities of the spoiling agents. The temperature required to be provided depends upon the type of food and period of preservation. The temperature required to be provided depends upon the type of food and period of preservation. The freezing rate affects the quality of frozen food and the zone of maximum crystal formation refers the region between  $0^{\circ}\text{C}$  and  $5^{\circ}\text{C}$  where the removal of the fusion takes place. Enzymes in the frozen state remain active, although at a reduced rate. Vegetables are blanched or heated in preparation for freezing to ensure enzyme inactivity and thus to avoid degradation of flavor. Blanching has also been proposed for fish, in order to kill cold-adapted bacteria on their outer surface. In the freezing of meats various methods are used depending on the type of meat and the cut. Pork is frozen soon after butchering, but beef is hung in a cooler for several days first to tenderize the meat (Encarta, 2004).

## 1.2 Objectives of the research

The objectives of this research are to;

- i. design and and construct a Blast Freezer;
- ii. evaluate the performance of the Blast Freezer; and



- iii. assess the effects of the Blast Freezer on stored fruits.

### **1.3 Justification of the research**

Fruits hold a key position in the development of a country. It is the basis of existence of the population. The more self-sufficient a country is in fruits and vegetables, the less its vulnerability and greater its independence. In developing and under developed countries, a very good percentage of the population belong to the low income class, and are directly involved in the production of food even to feed the high income class.

However, the lack of technical and socio-economic information on alternative or improved processing and preservation technologies available to these people means that much fruits and vegetables get wasted. Excess production in the rural areas is rarely preserved for times when fresh food would not be available. The use of blast freezer allow for preservation of different compatible fruits simultaneously using a single system. This method will greatly improve the quality of fruits and be of great benefit to people living in rural areas. In addition to these, early harvest of farm products will be possible and hence a reduction in field loss.

#### **1.4.0 Components of blast freezer.**

Blast freezer are made up of the following component which interact together to achieve the goal of the research:

##### **1.4.1 The cabinet**

The cabinet of the freezer is rectangular in shape and is made of mild steel in the outside surface and aluminum in the inner surface and insulated in between with polysterene.

This three layers prevent heat transfer from outside into the refrigerated space. The white colour of the outside surface area of the freezer ensure reflection of heat.

#### **1.4.2 Compressor.**

The compressor is the motor (or engine) of the cooling system. In a self de-frosting refrigerator compressor may be behind a panel. It runs whenever the refrigerator calls for cooling. It compresses refrigerant that is in a low pressure gaseous state to a high pressure gas and circulate the same in the system.

#### **1.4.3 Condenser**

The condenser is a series of tube with fins attached to them. It is always somewhere on the outside of the freezer. It is coiled up and placed near compressor. The high pressure refrigerator gas coming from the compressor flows through the condenser and become a liquid. As this occur the refrigerant gives off heat. The heat is conducted away from the tube by the fins.

#### **1.4.4 Control device (capillary tube)**

The metering device or capillary tube is a tiny copper tube. The capillary tube is attached from the end of the condenser to the beginning of the evaporator. The capillary tube control the pressure and flows of refrigerant as it enters the evaporator. Once the liquid refrigerant has travelled through the length of the condenser, it is forced through the capillary tube.

#### **1.4.5 Evaporator**

The evaporator is located inside the cabinet, when the liquid refrigerant comes out of the capillary tube, it is injected into the larger tube of evaporator and cause a pressure drop. This pressure drop allows the refrigerant to expand back into gaseous state. This change

of state from liquid to gas absorbs heat. The gaseous refrigerants travel through the evaporator tube and down to the compressor to begin the circulation process again. Because the evaporator is absorbing heat it is very cold to the touch. The coldness cause any humidity in the air to freeze on the evaporator as ice or frost. The cabinet used is of three layers and the outside layer is painted white to aid reflection of heat.

#### **1.4.6 Fan**

The fan is another component that is placed directly behind the evaporator inside the cabinet. Its function is to increase the velocity at which the cold air leaves the evaporator and ensure proper circulation of refrigerated air in the cabinet.

#### **1.5.0 Refrigerant**

A refrigerant is a compound used in a heat cycle that undergoes a phase change from a gas to a liquid and back. The two main uses of refrigerants are in refrigerators /freezers and air conditioners. Since it was discovered in the 1980s that the most widely used refrigerants were major causes of ozone depletion, a worldwide phase out of ozone-depleting refrigerants has been undertaken. These are being replaced with "ozone-friendly" refrigerants. The ideal refrigerant has good thermodynamic properties, is noncorrosive, and safe. The desired thermodynamic properties are a boiling point somewhat below the target temperature, a high heat of vaporization , a moderate density in liquid form, a relatively high density in gaseous form, and a high critical temperature. Since boiling point and gas density are affected by pressure, refrigerants may be made more suitable for a particular application by choice of operating pressure.

The refrigerants are the working fluid of the cycles which alternatively vaporizes and condenses as it absorbs and given off heat respectively. Before it can be used in the

vapour compression cycle a fluid should possess certain chemical, physical and thermodynamic properties that make it both safe and economical to use. Dichlorofluoromethane R12 ( $\text{CCl}_2\text{F}_2$ ) primarily used in medium and high temperature refrigeration. Others include R22, R134a, R500, R502 e.t.c. The choice of refrigerant is becoming importance as result of pollution factor of the refrigerant (William et al, 1995).

### **1.6.0 Refrigerations**

Refrigeration is the process of removing heat from one location to another by the use of a refrigerant in a closed cycle. Oil management, gas and liquid separation, subcooling, superheating and piping of refrigerant liquid and gas; and two phase flow are all part of refrigeration, ASHRAE (2002). The primary purpose of refrigeration is lowering the temperature of the enclosed space or substance and then maintaining that lower temperature. The term cooling refers generally to any natural or artificial process by which heat is dissipated. The process of artificially producing extreme cold temperatures is referred to as cryogenics.

Cold is the relative difference in amount of heat, hence in order to decrease a temperature, one "removes heat". In order to satisfy the Second Law of Thermodynamics, some form of work must be performed to accomplish this. This work is traditionally done by mechanical work but can also be done by magnetism, laser or other means.

#### **1.6.1 Current application of refrigeration**

Probably the most widely-used current applications of refrigeration are for the air-conditioning of private homes and public buildings, and the refrigeration of foodstuffs in homes, restaurants and large storage warehouses. The use of refrigerators in our kitchens

for the storage of fruits and vegetables has allowed us to add fresh salads to our diets year round, and to store fish and meats safely for long periods.

In commerce and manufacturing, there are many uses for refrigeration. Refrigeration is used to liquefy gases like oxygen, nitrogen, propane and methane for example. In compressed air purification, it is used to condense water vapor from compressed air to reduce its moisture content. In oil refineries, chemical plants, and petrochemical plants, refrigeration is used to maintain certain processes at their required low temperatures (for example, in the alkylation's of butanes and butane to produce a high octane gasoline component). Metal workers use refrigeration to temper steel and cutlery. In transporting temperature-sensitive foodstuffs and other materials by trucks, trains, airplanes and sea-going vessels, refrigeration is a necessity.

Dairy products are constantly in need of refrigeration, and it was only discovered in the past few decades that eggs needed to be refrigerated during shipment rather than waiting to be refrigerated after arrival at the grocery store. Meats, poultry and fish all must be kept in climate-controlled environments before being sold. Refrigeration also helps keep fruits and vegetables edible longer.

### **1.6.2 Methods of refrigeration**

Methods of refrigeration can be classified as non-cyclic, cyclic and thermoelectric.

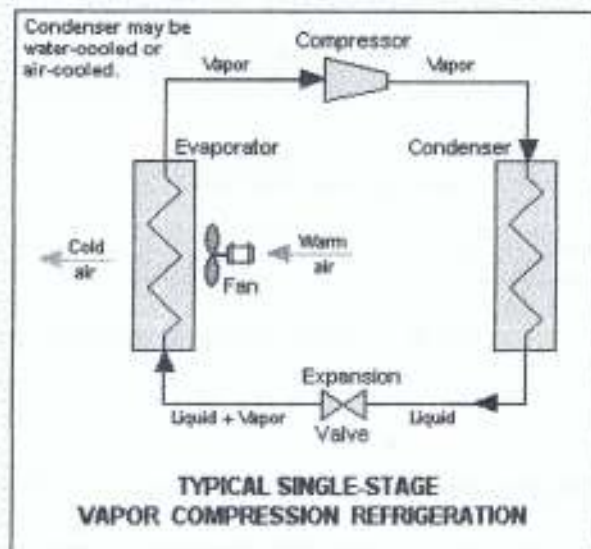
**(a) Non- cyclic refrigeration.** In these methods, refrigeration can be accomplished by melting ice or by subliming dry ice. These methods are used for small-scale refrigeration such as in laboratories and workshops, or in portable coolers.

Ice owes its effectiveness as a cooling agent to its constant melting point of 0 °C (32 °F). In order to melt, ice must absorb 333.55 kJ/kg of heat. Foodstuffs maintained at this temperature or slightly above have an increased storage life. Solid carbon dioxide known as dry ice, is used also as a refrigerant. Having no liquid phase at normal atmospheric pressure, it sublimates directly from the solid to vapor phase at a temperature of -78.5 °C (-109.3 °F). Dry ice is effective for maintaining products at low temperatures during the period of sublimation.

**(b) Cyclic Refrigeration.** This consists of a refrigeration cycle, where heat is removed from a low-temperature space or source and rejected to a high-temperature sink with the help of external work, and its inverse, the thermodynamic power cycle. In the power cycle, heat is supplied from a high-temperature source to the engine, part of the heat being used to produce work and the rest being rejected to a low-temperature sink. This satisfies the second law of thermodynamics. A refrigeration cycle describes the changes that take place in the refrigerant as it alternately absorbs and rejects heat as it circulates through a refrigerator. It is also applied to HVACR work, when describing the "process" of refrigerant flow through an HVACR unit, whether it is a packaged or split system.

Heat naturally flows from hot to cold. Work is applied to cool a living space or storage volume by pumping heat from a lower temperature heat source into a higher temperature heat sink. Insulation is used to reduce the work and energy required to achieve and maintain a lower temperature in the cooled space. The operating principle of the refrigeration cycle was described mathematically by Sadie Carnot in 1824 as a heat engine. The most common types of refrigeration systems use the reverse-Ranking vapor-compression cycle, although absorption heat pumps are used in a minority of

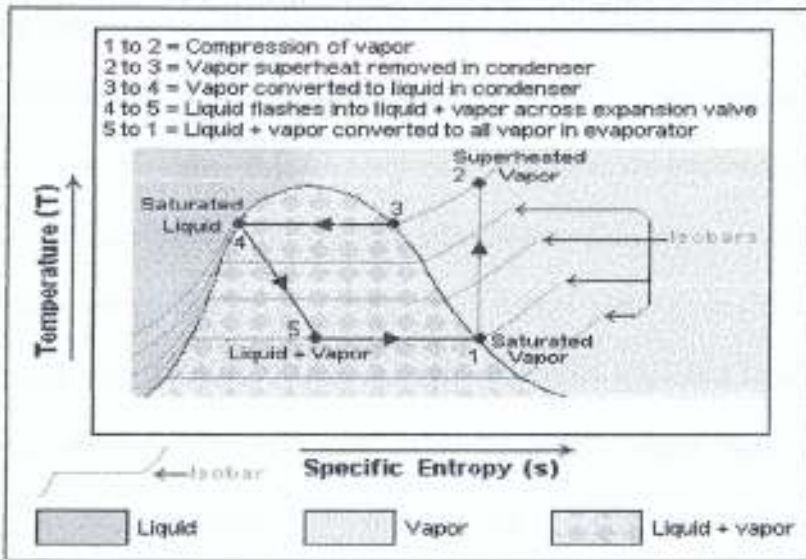
applications. Cyclic refrigeration can be classified as: vapor cycle and gas cycle. Vapor cycle refrigeration can further be classified as: Vapour compression refrigeration and Vapour absorption refrigeration. The vapor-compression cycle is used in most household refrigerators as well as in many large commercial and industrial refrigeration systems. Fig1.0 provides a schematic diagram of the components of a typical vapor-compression refrigeration system.



**Fig. 1.0. Vapor compression refrigeration system components (History, 2007)**

The thermodynamics of the cycle can be analyzed on a diagram as shown in Figure 1.1. In this cycle, a circulating refrigerant such as Freon enters the compressor as a vapor. From point 1 to point 2, the vapor is compressed at constant entropy and exits the compressor superheated. From point 2 to point 3 and on to point 4, the superheated vapor travels through the condenser which first cools and removes the superheat and then condenses the vapor into a liquid by removing additional heat at constant pressure and temperature. Between points 4 and 5, the liquid refrigerant goes through the expansion

valve (also called throttle valve) where its pressure abruptly decreases, causing flash evaporation and auto-refrigeration of, typically, less than half of the liquid.



**Fig. 1.1. Temperature-Entropy diagram (History, 2007)**

That results in a mixture of liquid and vapor at a lower temperature and pressure as shown at point 5. The cold liquid-vapor mixture then travels through the evaporator coil or tubes and is completely vaporized by cooling the warm air (from the space being refrigerated) being blown by a fan across the evaporator coil or tubes. The resulting refrigerant vapor returns to the compressor inlet at point 1 to complete the thermodynamic cycle. The above discussion is based on the ideal vapor-compression refrigeration cycle, and does not take into account real-world effects like frictional pressure drop in the system, slight thermodynamic irreversibility during the compression of the refrigerant vapor, or non-ideal gas behavior (if any). Vapour compression refrigerating system present peculiarities with respect to other refrigeration systems

because it is commonly used in a wide range of commercial and industrial application (Akintunde et al, 2006).

In the early years of the twentieth century, the vapor absorption cycle using water-ammonia systems was popular and widely used. After the development of the vapor compression cycle, the vapor absorption cycle lost much of its importance because of its low coefficient of performance (about one fifth of that of the vapor compression cycle). Today, the vapor absorption cycle is used mainly where fuel for heating is available but electricity is not, such as in recreational vehicles that carry Liquified Petroleum gas. It is also used in industrial environments where plentiful waste heat overcomes its inefficiency. The absorption cycle is similar to the compression cycle, except for the method of raising the pressure of the refrigerant vapor. In the absorption system, the compressor is replaced by an absorber which dissolves the refrigerant in a suitable liquid, a liquid pump which raises the pressure and a generator which, on heat addition, drives off the refrigerant vapor from the high-pressure liquid. Some work is required by the liquid pump but, for a given quantity of refrigerant, it is much smaller than needed by the compressor in the vapor compression cycle. In an absorption refrigerator, a suitable combination of refrigerant and absorbent is used. The most common combinations are ammonia (refrigerant) and water (absorbent), and water (refrigerant) and lithium bromide (absorbent).

When the working fluid is a gas that is compressed and expanded but doesn't change phase, the refrigeration cycle is called a gas cycle. Air is most often the working fluid. As there is no condensation and evaporation intended in a gas cycle, components corresponding to the condenser and evaporator in a vapor compression cycle are the hot

and cold gas-to-gas heat exchangers in gas cycles. The gas cycle is less efficient than the vapor compression cycle because the gas cycle works on the reverse Brayton cycle instead of the reverse Rankine cycle. As such the working fluid does not receive and reject heat at constant temperature. In the gas cycle, the refrigeration effect is equal to the product of the specific heat of the gas and the rise in temperature of the gas in the low temperature side. Therefore, for the same cooling load, a gas refrigeration cycle will require a large mass flow rate and would be bulky. Because of their lower efficiency and larger bulk, air cycle coolers are not often used nowadays in terrestrial cooling devices. The air cycle machine is very common, however, on gas turbine-powered jet aircraft because compressed air is readily available from the engines' compressor sections. These jet aircraft's cooling and ventilation units also serve the purpose of pressurizing the aircraft.

## CHAPTER TWO

### LITERATURE REVIEW



The American Society of Refrigerating Engineers defines refrigeration as “the science of providing and maintaining temperature below that of surrounding and maintaining atmosphere. This implies the development of temperature differential rather than the establishment of a given temperature level. The science of refrigeration utilizes several method of providing temperature differential. They vary from the simplicity of the spring house where cool water removes heat from warm fresh milk, to the complex machinery required for the manufacture of ice cream or the production of considerably low temperature known as cryogenics (ASHRAE,2002).

The use of ice to refrigerate and thus preserve food goes back to prehistoric times. Through the ages, the seasonal harvesting of snow and ice was a regular practice of the most of the ancient culture; Chinese, Hebrews, Greeks, Romans and Persians. Ice and snow were stored in caves or dugouts lined with straw or other insulating materials. The Persians stored ice in pits called yakhchals. Rationing of the ice allowed the preservation of foods over the warm periods. The practice worked well down through the centuries with icehouses remaining in use into the twentieth century (History, 2007).

In the 16<sup>th</sup> century, the discovery of chemical refrigeration was one of the first steps towards artificial means of refrigeration.(History, 2007). Sodium nitrate or potassium nitrate when used to add to water, lowered the water temperature and created a sort of refrigeration bath for cooling substances. In Italy, such a solution was used to chill wine. Cooling drinks came into vogue by 1600 in France. Instead of cooling water at night, people rotated long-necked bottles in water in which saltpeter had been dissolved.

This solution could be used to produce very low temperature and to make ice. By the end of 17<sup>th</sup> century, iced liquors and frozen juices were popular in French society (History,2007)

The first known method of artificial refrigeration was demonstrated by William Cullen at the University of Glasgow in Scotland in 1756. Cullen used a pump to create a partial vacuum over a container of diethylether, which then boiled, absorbing heat from the surrounding air. The experiment even created a small amount of ice, but had no practical application at that time. In 1805, an American inventor, Oliver Evans designed the first refrigeration machine that used vapour instead of liquid. Evans never constructed his machine, but one similar to it was built by an American physician. John Gorrie. In 1820, the british scientist Michael Faraday liquefied ammonia and other gases by using high pressures and low temperature. An American living in Great Britain, Jacob Perkins, obtained the first patent for a vapour- compression refrigeration system in 1834. Perkins built a prototype system and it actually worked, although it did not succeed commercially (History, 2007).

In 1842, an American physician, John Gorrie designed the first system for refrigerating water to produce ice. He also conceived the idea of using his refrigeration system to cool the air for comfort in homes and hospitals (i.e air-conditioning). His system compressed air, then partially cooled the hot compressed air with water before allowing it to expand while doing part of the work required to drive the air compressor. That isentropic expansion cooled the air to a temperature low enough to freeze water and produce ice, or to flow through a pipe for effecting refrigeration otherwise as stated in his

patent granted by the U.S patent office in 1851. Gorrie built a working prototype, but his system was a commercial failure (History, 2007).

Alexander Twining began experimenting with vapour compression refrigeration in 1848 and obtained patents in 1850 and 1853. He is credited with having initiated commercial refrigeration in the united states by 1856. Meanwhile, James Harrison who was born in Scotland and subsequently emigrated in Australia, begun operation of a mechanical ice-making machine in 1851 on the banks of the Barwon River at Rocky point in Geelong. His first commercial ice-making machine followed 1854 and his patent for an ether liquid-vapour compression refrigeration to breweries and meat packaging houses and by 1861, a dozen of his systems were in operation (History,2007).

Australian, Argentine and American concerns experimental with refrigerated shipping in the mid 1870s, the first commercial success coming when Willian Soltau Davidson fitted a compression refrigeration unit to the new Zealand vessel Dunedin in 1882 leading to a meat and dairy boom in Australasia and south America. The first gas absorption refrigeration system using gaseous ammonia dissolved in water (referred as "aqua ammonia") was developed by Ferdinand Carre at France in 1859 and patented in 1860. due to the toxicity of ammonia, such systems were not developed for use in homes, but were used to manufacture ice for sale. In the United States, the consumer public at that time still used the ice box with ice brought in form commercial suppliers, many of whom were still harvesting ice and storing it in an icehouse.

Thaddeus Lowe, an American balloonist from the civil war, had experimented over the years with the properties of gases. One of his mainstay enterprises was the high volume production of hydrogen gas. He also held several patents on ice making machine.

His “compression ice machine” would revolutionize the cold storage industry. In 1869 he and other investors purchased an old steamship onto which they loaded one of Lowers refrigeration units and began shipping fresh fruit from new York to the Gulf coast area, and fresh meat from Galveston, Texas back to new York. Because of Lowe’s lack of knowledge about shipping, the business was a costly failure and it was difficult for the public to used to the idea of being able to consume meat that had been so long out of the packing house.

By the 1870s breweries had become the largest users of commercial refrigeration units, though the ice-harvesting industry had grown immensely by the turn of the 20<sup>th</sup> century, production and sewage had begun to creep into natural ice, making it a problem in the metropolitan suburbs. Eventually breweries began to complain of tainted ice. This raised demand for more modern and consumer ready refrigeration and ice making machines. In 1895 German Engineer Carl von Linde set up a large scale process for the production of liquid air and eventually liquid oxygen for use in safe household refrigerators (History,2007)

Refrigerated railroad cars were introduced in the U.S in the 1840s for the short-run transportation of dairy products. In 1867 J.B Sutherland of Detroit Mihigan patented the refrigerator car designed with ice tanks at either end of the car and ventilator flaps near the floor which would create a gravity draft of cold air through the car. By 1900 the meat packing houses of Chicago had adopted ammonia cycle commercial refrigeration. By 1914 almost every location used artificial refrigeration, the big meat packers, Armour, Swift and Wilson had purchased the most expensive units which they installed on train cars and in branch houses and storage facilities in the more remote distribution areas. It

was not until the middle of the 20<sup>th</sup> century that refrigeration units were designed for installation on tractor-trailer rigs (trucks or lorries). Refrigerated vehicles are used to transport perishable goods, such as frozen foods, fruit and vegetables and temperature sensitive chemicals. Most modern refrigerators keep the temperature between -40 and +20 and have a maximum payload of around 2400 kg gross weight (in Europe) (Bookrag, 2007).

In 1973, Prof James Lovelock reported finding trace amounts of refrigerant gases in the atmosphere. In 1974, Sherwood Rowland and Mario Molina predicted that chlorofluorocarbon refrigerant gases would reach the high stratosphere and therefore damage the protective mantle of the oxygen allotrope, ozone. In 1985 the "ozone hole" over the Antarctic had been discovered and 1990 Rowland and Molina's prediction was proved correct. Searching for an alternative for home use refrigeration, Scharfenstein(Germany) developed a propane-based CFC as well as an HFC, free refrigerator in 1992 with assistance from Greenpeace (History,2007).

The tenets of the Montreal protocol were put in effect in the united states via the clean Air Act legislation in August 1988. The clean Air Act was further amended in 1990. This was a direct result of a scientific report released in June 1974 by Rowland – Molina, detailing how chlorine in CFC and HCFC refrigerants adversely affected the ozone layer. This report prompted the FDA and EPA to ban CFCs as a propellant in 1978. Cryogenic technology sprung up as a tool for research and development, but its ultimate importance to man lies in its varied industrial, nuclear and electronic applications. Cryogenic techniques received a tremendous impetus with their spectacular use in missile and space propulsion system. The applications of cryogenic phenomenon

to computers, gyroscopes, infrared techniques, biology and controlled nuclear power techniques are much less spectacular, but these developments are equally as important as the present use of high energy cryogenic propellants in man conquest space (Bookrag, 2007).

The ultra low temperature refrigeration work has increased tremendously in the past few years. Commercial units are now manufactured which produce temperature below  $-80^{\circ}\text{C}$  for various applications. An example is the testing of various instruments and appliances such as radios, cameras, clocks and meters which may be subjected to low temperatures in arctic climates. Test chambers which are designed for simulating conditions encountered by military and other aircraft are being used increasingly. They are used for testing instruments, clothing, military weapons and equipments those are normally carried in an airplaine. The first low temperature refrigeration systems were developed primarily for the solidification of carbon dioxide and the liquification of gases such as air,  $\text{O}_2$  and  $\text{N}_2$ . Oxygen was liquefied in 1877 by Coilletet and Pictet. Hydrogen was liquified in 1933 by Dervar using Joule Thomson effect. Liquification of helium was accomplished by H.Kameslingh Onnes in 1908 in the famous cryogenic laboratories of the University of Leiden. In 1933, Debye and Gianque used the adiabatic demagnetization of paramagnetic salts producing temperature of 0.7 K, Nowadays, a temperature of 0.001 K is successfully achieved by using cascading of demagnetization method. In the present chapter, different methods used for production of low temperature and its uses are discussed (Bookrags, 2007).

Thermoelectric refrigeration is a pretty recent development in the field of refrigeration. In 1921 Seebeck (German Physicist) observed that if a closed circuit was

made of two dissimilar metals, an electrical current flowed in the circuit when the two junctions were maintained at different temperatures. However he failed to realize the significance of his discovery. This fact is very important in refrigeration work because a number of control devices and testing instruments depend on this action for operation.

In 1834 Jean Peltier discovered that when a direct current is passed through a junction of two dissimilar metals, the junction became either hot or cold. Peltier, like Seebeck, failed to see the significance of this finding in relationship to thermoelectric cooling. In 1838 Emil Lenz clearly showed the importance of both Peltier's and Seebeck discovery by placing a drop of water on a junction of two dissimilar metals and passing a direct current through the circuit. When the current flowed in one direction, the water froze. When the flow of current reversed, the ice melted. However, Lenz, like his predecessors, failed to realize the significance of his findings and the knowledge remained dormant for over 100 years, mainly due to the unavailability of materials (semi-conductors) which could produce wide temperature differences. It was not until 1930's that available materials (semi-conductors) were developed that made the application of Seebeck's and Peltier's discovery applicable to spotcooling. In the period of 1940's progress in thermoelectric thermo-electric refrigeration was limited mostly to the scientific laboratories. In the early 1960's many companies began an intense desire to manufacture refrigeration equipment based on thermo-electric principle (Bookrag, 2007).

The importance of thermoelectric refrigeration was realized much later compared with its merits. The development of semi-conductor technology enhanced the feasibility of thermoelectric coolers to a great extent. If proper materials are found, it is quite possible that this kind of cooling will win the field of refrigeration over the other methods

even at present. It is better than absorption refrigeration and has started competing with compression refrigeration of low capacity also, this is because of its specific advantages of silent working and little maintenance service due to no moving parts. It is decent looking and so compact that domestic coolers reduces to 2/3 of present coolers. These advantages will certainly make the customer to change over his choice from conventional coolers to this new type, in spite of little higher cost. In spite of these advantages, COP for thermoelectric refrigeration reduces very fast with decreasing refrigerator temperature. (Bookrags, 2007).

In Nigeria, mobile refrigerator was constructed (Isinkalu, 2000) but its operation was electricity dependent. Also mobile refrigerator was constructed in Federal University of Technology, Akure (Falade and Onanuga, 2004) but it was electricity dependent. (Ajayi et al, 2006) constructed Power Packed Mobile Refrigerator which can be used in local areas where there is no electricity and Akinola et al, 2008 developed Hawking refrigerator. In 2007 Obadina researched and constructed a system with a view of determining the effect of environmental change on storage and on storage and display life of perishable products. Thus the development of blast freezer will give birth to a system that cool perishable products simultaneously using a single system. With the past and advanced knowledge, it will not be difficult to develop a blast freezer for the preservation of some fruits.

### **2.1.0 Types of freezer**

#### **2.1.1 Contact or plate freezer**

Contact freezer makes use of a number of horizontal plate coils which are smooth on both sides. An electrically operated hydraulic piston compresses the packages of the

product between the plate. This ensure firm contact on both sides which increases heat transfer rate and provide quick freezing. Jackstone froster Ltd has developed a fully automated horizontal plate freezer (ASHRAE, 2002).

### **2.1.2 Inline freezer**

One form of contact freezer manufactured by Sanndvic Ltd employs a continous in line solid stainless belt within a tunnel. The product is placed on top of the belt and brine refrigerant sprayed on the other side. This system is limited to thin products because freezing takes place from one side only. An advantage with this freezer is that the frozen product can easily be removed from the belt (Arora, 2000).

### **2.1.3 Spiral freezer**

Floor space requirements are minimized by the use of spiral belt felt which have a higher ratio of belt length to required floor area. The increased belt length allows product to remain longer in the freezer and so increases the product of thickness which can be frozen (Arora, 2000).

### **2.1.4 Blast freezer**

It consists of a cabinet in which cooled air inside is being circulated into the products inside the cabinet through the aid of blower or fan. Blast freezer provides the privilege of preserving different agricultural produce stored in different plate or tray in the cabinet to be preserved simultaneously with the aid of single system. Blast freezers are used for freezing fishery products as shrimp, fish fillets, steaks, scallops or pre-cooked products packed in family size packages. Recently, they are used for freezing fish fillets wrapped in moisture. Vapour proof heat sensible packaging and for freezing unpacked shrimp and

pre-cooked fish sticks. Space and equipment requirement for blast freezer vary considerably with each installation (Arora,2000).

### **2.2.0 Ice Refrigeration system**

Ice was the only refrigerating means available for many years. It is still used in many refrigerating applications. The usual ice refrigerator consist of an insulated cabinet equipped with a tray or tank at the top for holding shelves for food are located below the ice compartment. Cold air flows downward from ice compartment and cools the food on the shelves below. Air returns from the bottom of the cabinet up, the sides and back of the cabinet which is warmer, flows over the ice and again flows down over the shelves to be cooled. Ice refrigeration has one advantage in particular, the interior of the is maintained at fairly high relative humidity, therefore the food stored in this type of refrigerator does not dry out rapidly (Arora, 1997).

### **2.2.1 Steam jet refrigeration**

Steam jet refrigeration system using a high vacuum in evaporator and steam ejector as compressor have been utilized for many years, the major difficulties in the development of this system for the use of industrial purposes were very high vacuum required to be maintained in the evaporator, enormous volume of vapour to be compressed and high freezing point of water. This system cannot be used below 0°C temperature. Steam jet units gained their first wave of popularity during 1930. Now steam jet units are gaining importance especially for industrial uses with the development in design and construction of the ejectors. In these special fields, steam jet refrigeration proved to be more economical compared with other refrigeration system (Arora, 1997).



### 2.2.2 Vapour compression refrigeration

Vapour compression refrigeration is one of the refrigeration cycles available for use. It has been and is the most widely used method for air-conditioning of large public buildings, private residences, hotels, hospitals, theaters, restaurants and automobiles. It is also used in domestic and commercial refrigerators, large scale warehouses for storage of food and meats, refrigerated trucks and railroad cars and 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 vapour compression refrigeration systems.

The vapour-compression refrigeration system uses a circulating liquid refrigerant as the medium which absorb and remove heat from the space to be cooled and subsequently rejects that heat elsewhere. All such systems have four components: a compressor, a condenser, an expansion valve (also called throttle valve), and an evaporator. Circulating refrigerant enters the compressor in a thermodynamic state known as saturated vapour and is compressed to higher pressure, resulting in a higher temperature as well. The hot, compressed vapour is then in a thermodynamic state known as superheated vapour and it is at temperature and pressure at which it can be condensed with typically available cooling water or cooling air. That hot vapour is routed through a condenser where it is cooled and condensed into liquid by flowing through a 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 the case) In as much as these components are connected in closed loop in the vapour compression

refrigeration cycle, Akintunde (2003) argued that for these components to function effectively, a balanced point must be reached between these components..

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.

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. To complete the refrigeration cycle, the refrigerant vapor from the evaporator is again a saturated vapor and is routed back into the compressor. It should be noted that, Saturated vapors and saturated liquids are vapors and liquids at their saturation temperature and saturation pressure. A superheated vapor is at a temperature higher than the saturation temperature corresponding to its pressure.

### **2.2.3 Vapour absorption refrigeration**

The idea of vapour absorption refrigeration system is to avoid compression of the refrigerant. In this type of refrigeration system, the vapour produced by the evaporation of the refrigerant, in the cold chamber, passes into a vessel containing a homogenous mixture of ammonia and water (known as aqua-ammonia). In this chamber, the vapour is absorbed, which maintains constant low pressure, thus facilitating its further evaporation. The refrigerant is liberated in the vapour state subsequently by direct application of heat, and at such a pressure that condensation can be effected at the temperature of the air or by cold water.

The low pressure ammonia vapour, leaving the evaporator, enters the absorber where it is absorbed in the weak ammonia solution. This process takes place at a temperature slightly above than that of the surroundings. The strong ammonia solution is then pumped through a heat exchanger to the generator, where a high pressure and temperature is maintained. Under these conditions, the ammonia vapour is driven from the solution. This happens because of the heat transfer from a high temperature source. The ammonia vapour enters into the condenser, where it gets condensed, in the same way as in the vapour compression system. It can be economically justified only in those cases where a suitable source of heat is available which would otherwise be wasted (Arora, 2000).

### **2.2.4 Magnetic Refrigeration**

The world's first successful permanent magnet, room temperature magnetic refrigerator became operational on September 18 at the Astronautic Technology center in Madison,

United State of America. The Magnetic refrigerator uses gadolinium, a metallic element that exhibits a large magneto caloric effects (heats up when exposed to a magnetic field is removed), the material is alternatively magnetized and demagnetized by rotating a wheel containing gadolinium through a magnetic field (ASHRAE, 2002).

Magnetic refrigeration, or adiabatic demagnetization, is a cooling technology based on the magneto caloric effect, an intrinsic property of magnetic solids. The refrigerant is often a paramagnetic salt, such as cerium magnesium nitrate. The active magnetic di poles in this case are those of the electron shells of the paramagnetic atoms. A strong magnetic field is applied to the refrigerant, forcing its various magnetic dipoles to align and putting these degrees of freedom of the refrigerant into a state of lowered entropy. A heat sink then absorbs the heat released by the refrigerant due to its loss of entropy. Thermal contact with the heat sink is then broken so that the system is insulated, and the magnetic field is switched off. This increases the heat capacity of the refrigerant, thus decreasing its temperature below the temperature of the heat sink. Because few materials exhibit the required properties at room temperature, applications have so far been limited to cryogenics and research (Bookrag, 2007).

Researchers said that magnetic refrigeration is more energy efficient than conventional vapour cycle refrigeration. the prototype provides a cooling range similar to a household air-conditioner without harmful emission, which is unavoidable when using conventional refrigerants. The heat transfer fluid in the prototype is water. The magnetic refrigerator is now being tested and optimised to achieve large temperature swings and is being tailored to provide the cooling power required for specific markets such as house refrigeratos, air-conditioning, electronics cooling and fluids chilling. Other methods of

refrigeration include the air cycle machine used in aircraft; the vortex tube used for spot cooling, when compressed air is available; and thermo acoustic refrigeration using sound waves in a pressurized gas to drive heat transfer and heat exchange (Bookrag, 2007).

### 2.3.0 Refrigerants

Mechanical cooling is based on some low boiling point substances called refrigerants. Refrigerant is a heat carrying medium which during their cycle (i.e compression, condensation, expansion and evaporation) in the refrigeration system absorb heat from a low temperature system and discard the heat so absorbed to higher temperature system (Khurmi and Gupta, 1978). Refrigerant are the working fluids in refrigeration, air-conditioning and heat pumping systems. They absorb heat from one area, such as air-conditioned space, and reject it to another, such as outdoors, usually through evaporation and condensation respectively, (ASHRAE, 2001). They accomplish energy transfer by absorbing heat as they evaporate at low temperature and pressure and reject this heat as they condense at high temperature. There is no ideal refrigerant due to the wide differences in the condition of requirement of various applications. Therefore no one refrigerant is universally suitable for all application hence a refrigerant approaches the "ideal" only on the extent that its properties must meet the condition and requirement of a particular application. Until concerns about depletion of the ozone layer arose in the 1980s, the most widely used refrigerants were the halomethanes R-12 and R-22, with R-12 being more common in automotive air conditioning and small refrigerators, and R-22 being used for residential and light commercial air conditioning, refrigerators, and freezers. Some very early systems used R-11 because its relatively high boiling point

allows low-pressure systems to be constructed, reducing the mechanical strength required for components (Bookrag 2007).

New production of R-12 ceased in the United States in 1995, and R-22 is to be phased out by 2020. R-134a and certain blends are now replacing chlorinated compounds. One popular 50/50 blend of R-32 and R-125 now being increasingly substituted for R-22 is R410A, often marketed under the trade name Puron (Bookrag,2007). Another popular blend of R-32, R-125, and R-134a with a higher critical temperature, and lower GWP than R-410A is R-407C. While the R-22 and other ozone depleting refrigerants are being phased out, they still have value and can be easily sold (U.N, 1996). Early mechanical refrigeration systems employed sulfur dioxide gas or anhydrous ammonia, with small home refrigerators primarily using the former. Being toxic, sulfur dioxide rapidly disappeared from the market with the introduction of Freon. Ammonia is still used. Use of highly purified liquefied propane gas as a refrigerant is gaining favor, especially in systems designed for R-12, R-22 or R-134a. Moreover, propane is nontoxic (U.N, 1994).

An odorant, such as ethyl mercaptan, can be added in trace amounts to alert persons of system leaks. CFC's or chlorofluorocarbons are used as refrigerants in some commercial air conditioning and refrigeration systems. CFC's are considered to be 100% ozone depleting, meaning that they are the standard for efficiency in the catalytic breakdown of ozone. In most residential air conditioners and many refrigeration systems it is R-22 or Freon which is a hydrochlorofluorocarbon or HCFC. HCFC's are considered to be 5% ozone depleting and are less of a danger to the Earth's vital ozone layer. However, non-ozone layer depleting refrigerants are the most desirable.

The refrigerants of first group must possess such physical properties as will enable them to repeat continuously a liquid to gas and gas to liquid transformations. Air was used as refrigerant in many refrigeration systems in olden days considering most safest refrigerant, Ammonia, Carbon dioxide, and Sulphur dioxide were also used as successful refrigerants for different purposes. The Montreal protocol is an International treaty that controls the production of Ozone depleting substances including refrigerants (U.N. 1994 and 1996). The safety classification in ASHRAE Standard 34, refrigerants are classified according to the hazard involved in their use. The toxicity and flammability classification yield six safety groups, (A<sub>1</sub>, A<sub>2</sub>, A<sub>3</sub>, B<sub>1</sub>, B<sub>2</sub> and B<sub>3</sub>.) for refrigerants, group A<sub>1</sub> refrigerants are the least hazardous and Group B<sub>3</sub> are the most hazardous. The safety classification in ASHRAE Standard 34 consists of a capital letter designates the toxicity of the refrigerant at concentrations below 400 mL/m<sup>3</sup> (ASHRAE, 2001).

Emissions from automotive air-conditioning are a growing concern because of their impact on climate change. From 2011 on, the European Union will phase out refrigerants with a global warming potential (GWP) of more than 150 in automotive air conditioning (GWP = 100 year warming potential of one kilogram of a gas relative to one kilogram of CO<sub>2</sub>). This will ban potent greenhouse gases such as the refrigerant HFC-134a—which has a GWP of 1410—to promote safe and energy-efficient refrigerants. (Bookrag, 2007). One of the most promising alternatives is the natural refrigerant CO<sub>2</sub> (R-744). Carbon dioxide is non-flammable, non-ozone depleting, has a global warming potential of 1, but is toxic and potentially lethal in concentrations above 5% by volume. R-744 can be used as a working fluid in climate control systems for cars, residential air conditioning, hot water pumps, commercial refrigeration, and As of July 1, 1992 it is

illegal to release refrigerants into the atmosphere (intentional or accidental) because they can cause severe damage to the ozone layer. When CFCs are removed they should be recycled to clean out any contaminants and return it to a usable condition. Refrigerants should never be mixed together. Some CFCs must be managed as hazardous waste even if recycled, and special precautions are required for their transport, depending on the legislation of the country's government (U.N, 1996).

### 2.3.1 Numbering of refrigerant

The R-# numbering system was developed by DuPont and systematically identifies the molecular structure of refrigerants made with a single halogenated hydrocarbon (Arora, 2000). The meaning of the codes is as follows: *Rightmost digit*: Number of fluorine atoms per molecule. *Tens digit*: One plus the number of hydrogen atoms per molecule. *Hundreds digit*: The number of carbon atoms minus one. Omitted for methyl halides, which have only one carbon atom. *Thousands digit*: Number of double bonds in the molecule. This is omitted when zero, and in practice is rarely used, since most candidate compounds are unstable. *A suffix with a capital B* and a number indicates the number of bromine atoms, when present. This is rarely used. Remaining bonds not accounted for are occupied by chlorine atoms. *A suffix of a lower-case letter a, b, or c* indicates increasingly unbalanced isomers. As a special case, the R-400 series is made up of zeotropic blends (those where the boiling point of constituent compounds differs enough to lead to changes in relative concentration because of fractional distillation) and the R-500 series is made up of so-called azeotropic blends. The rightmost digit is assigned arbitrarily by ASHRAE, an industry organization. For example, R-134a has 4 fluorine

atoms, 2 hydrogen atoms, 2 carbon atoms, with an empirical formula of tetrafluoroethane. The "a" suffix indicates that the isomer is unbalanced by one atom, giving 1,1,1,2-Tetrafluoroethane. R-134 without the "a" suffix would have a molecular structure of 1,1,2,2-Tetrafluoroethane—a compound not especially effective as a refrigerant. (Arora, 2000).

The same numbers are used with an R- prefix for generic refrigerants, with a "Propellant" prefix (e.g., "Propellant 12") for the same chemical used as a propellant for an aerosol spray, and with trade names for the compounds, such as "Freon 12". Recently, a practice of using HFC- for hydrofluorocarbon CFC- for chlorofluorocarbon, and HCFC- for hydrochlorofluorocarbon has arisen, because of the regulatory differences among these groups. (Arora,2000).

### **2.3.2 Cryogenics Refrigerants**

The temperature range of  $-157^{\circ}\text{C}$  to  $-273^{\circ}\text{C}$  is known as cryogenic range, and refrigerants used for producing these temperatures are known as cryogenics refrigerants. These temperature may be produced by evaporating cryogenics liquid which have very low boiling points at atmospheric pressure. The common cryogenics refrigerant are  $\text{O}_2$ , Air,  $\text{N}_2$ , and He. Nowadays, these fluids are used for different specific purposes, the containers used for storing these liquids are made of special materials capable of withstanding extremely low temperatures, containers are heavily insulated to reduce the loss of cryogenic refrigerant by boiling. (Arora, 2000).

### Refrigerants blends

Blends of refrigerants occur when two or more refrigerants are mixed together together to form a different refrigerant having a different properties from the the constituents. (Gutkowski, 1996).

**R401A** is a HCFC zeotropic blend of R-32, R-152a, and R-124. It is designed as a replacement for R-12. **R404A** is a HCFC "nearly azeotropic" blend of 52 wt.% R-143a, 44 wt.% R-125, and 4 wt.% R-134a. It is designed as a replacement of R22 and R502 CFC. Its boiling point at normal pressure is -46.5 °C, its liquid density is 0.485 g/cm<sup>3</sup>. **R406A** is a zeotropic blend of 55 wt.% R-22, 4 wt.% R-600a, and 41 wt.% R-142b. **R407A** is a HCFC zeotropic blend of 20 wt.% R-32, 40 wt.% R-125, and 40 wt.% R-134a. **R407C** is a zeotropic hydrofluorocarbon blend of R-32, R-125, and R-134a. The R-32 serves to provide the heat capacity, R-125 improves flammability, R-134a reduces pressure. **R408A** is a zeotropic HCFC blend of R-22, R-125, and R-143a. It is a substitute for R502. Its boiling point is -44.4 °C. **R409A** is a zeotropic HCFC blend of R-22, R-124, and R-142b. Its boiling point is -35.3°C. Its critical temperature is 109.4 °C. **R410A** is a near-azeotropic blend of R-32 and R-125. It's common in air conditioning systems. **R500** is an azeotropic blend of 73.8 wt.% R-12 and 26.2 wt.% of R-152a. **R502** is an azeotropic blend of R-22 and R-115

### 2.3.4 Types of Refrigerant

There are eight type of refrigerant which are commonly use and these include; Halocarbon (R12, R11, R13, e.t.c), Cyclic organic compound ( C316, C318), Miscellaneous organic compound (methane, ethane), Azeotropes (R500 i.e R12/ R152a), Oxygen Compound (R610, ethylesther), Nitrogen compound (R630, methylamine), Inorganic compound (R702, Hydrogen) and Unsaturated organic compound.

### 2.3.5 Classification of refrigerants

The refrigerants are classified into two groups: viz, Primary refrigerants and Secondary refrigerants. Primary refrigerants directly take part in the refrigeration system while secondary refrigerants are first cooled with the help of primary refrigerants and are further used for cooling purposes. The classification of primary refrigerants is made of different groups as follows (Khurmi and Gupta, 2007).

(a) Halocarbon Compounds: This group of refrigerants was invented and developed by Charles Kettering and Dr. Thomas Miggley in 1928 (Khurmi and Gupta, 2007).

These refrigerants are sold in the market under trade names as Freon, Genetron, Isotron, and Arcton. This group includes refrigerants which contain one or more of three halogens, chlorine, fluorine, and bromine.

(b) Azeotropes: The refrigerants under this group consist of mixtures of different refrigerants which do not separate into their components with the changes in pressure or temperature or both. They have fixed thermo-dynamic properties.

(c) Hydro-carbons: Most of the organic compounds are considered as refrigerant under this group. Many hydro-carbons are successfully used as refrigerants in industrial and commercial installation.

(d) Inorganic compounds: The refrigerants under this group were universally used for all purposes before the introduction of halocarbon group. They are still used for different purposes due to their inherent thermodynamic and physical properties.

(e) Unsaturated organic compounds: The refrigerants under this group are mainly hydrocarbon with ethylene and propylene base.

### **2.3.6 Refrigerants effects on ozone layer**

Ozone is a form of oxygen, one of three forms that can be found in our earth atmosphere. Without ozone, our planet would be a very different place because it shields us all against harmful radiation from the sun (ultraviolet (UV) radiation), life or at least, life as we know it wouldn't exist. If the ozone layer breaks down, UV rays will reach the Earth's surface, with the result being a dramatic increase in the number of cases of skin cancer and eye cataracts. The effect on the food chain could also be disastrous. Because UV rays kill plankton would eventually starve and disappear. This would then affect the next link in the chain-those creatures that live off of fish and so it would continue throughout the chain (Dobson, 2005).

Most refrigerant are made up of chlorofluorocarbons (CFC) gases like R<sub>12</sub>, R<sub>22</sub> etc. Any of these refrigerants through leakages and during charging releases chlorine gases to the atmosphere. Any compartment that contain chlorine will lead to the decrease in ozone levels by removing one oxygen atom from the ozone molecule, thus converting to oxygen. There is no natural occurrence of such compound in the upper atmosphere, but vast amounts have built up and over time due to our increased use of man-made chlorine based compounds, of which CFC's (Chlorofluorocarbons) are the most common since

the use of CFC's in 1930, primarily to cool fridge's has been causing depletion in ozone layer but unnoticed. The CFC's rise from the surface of the earth and into the stratosphere where they are bombarded by UV light. This releases the chlorine atoms that react with the ozone molecules and we know that before long, ozone becomes oxygen and we are left with less protection (Dobson, 2005).

However, the use of hydro fluorocarbon HFC comes into play which has turned out to be a good replacement for the CFC and a good prevention for the continuous ozone layer depletion. HFC's enable safe, efficient, refrigeration and air-conditioned as well as foam insulations system to be implemented cost effectively across a wide range of application containment and maintaining refrigerant and blowing agent choices, including HFC's, is the best way forward for both industry, end users and the environment (Dobson, 2005).

### **2.3.7 Refrigerants effect on Global warming**

"Climate change" is the generally used to describe the effects of the increase in greenhouse effect due to human intervention. This is also known as "Global warming". The greenhouse effect is a natural phenomenon in which the earth is warmed by the retention of solar heat on the atmosphere. The greenhouse effect is also experienced on a larger scale on earth. The surface of the earth, which warm up during the day as a result of the absorption of solar energy, cools down at night by radiating part of its energy into deep space as infrared radiation (Yunus et al, 1996). This retention is mainly due to water vapour and carbon dioxide and without it the earth would be at  $-6^{\circ}\text{C}$  to  $18^{\circ}\text{C}$  depending on whether or not cloud reflectivity is included. Fourier first postulated the association of

CO<sub>2</sub> with global warming in 1827 (Dobson, 2005). Temperature rises due to climate change. In 1999, a notably warm year, mean temperature was 0.6<sup>o</sup>C higher than even the 1960-1990 average change in CO<sub>2</sub> levels over the year, CO<sub>2</sub> emissions are mainly due to burning of fossil fuels, the mechanism of climate are complex and the effects have been masked in much of the 20<sup>th</sup> century by the opposing effects of acid rain and sulphur aerosols from general pollution. Reduced pollution levels in developed countries have enabled the true effects of increased CO<sub>2</sub> levels to become apparent.

Current predictions suggest a most likely temperature increase of 2<sup>o</sup>C to 3<sup>o</sup>C and sea level rise of 0.5 metres over the 21<sup>st</sup> century, but the estimates have a large degree of uncertainty. The full consequences of these changes are unknown. Melting of all Greenland ice would raise sea level 8 metres, polar ice, buttressed by the 11R-N02001-5 fields are being melted from below by the Gulf Stream. This will give a positive feedback due to the reduced reflectivity of water compared to ice. What is certain is that the temperature changes are large and rapid compared to historic trends, and they come at a time when temperatures are at 120,000 year high, in an interglacial period. It is also certain that the sea level rise will have disastrous effects for many low-lying communities in developing countries (Dobson, 2005).

Refrigeration sector stakeholders are actively involved in greenhouse gas emission reduction campaigns as was highlighted in the 11R statement to the sixth UNFCCC meeting in Beijing in November 2000 (Dobson, 2005). The CFC's and HCFCs were the refrigerant fluids of choice for many applications for many years up to the early 1990s, after which the non-ozone depleting HFCs became favoured. The Montreal Protocol accelerated the rate of CFC and HCFC phase out in order to reduce

ozone depletion and this was only possible by using HCFs in many application. There has been grown in use of hydrocarbons, but this is been limited by safety considerations (Dobson, 2005).

## **2.4.0 Components of Refrigerating System**

### **2.4.1 Evaporator**

The evaporator is an important devise used in the low pressure side of a refrigeration system. An evaporator is a heat transfer surface in which a volatile liquid is vapourised for the purpose of removing heat from the refrigerated space or product. The liquid refrigerant from the expansion valve enters into the evaporator where it boils and changes into vapour. The function of an evaporator is to absorb heat from the surrounding location or medium which is to be cooled, by means of a refrigerant. Evaporators are manufactured in wide varieties of types, shapes and design, because of the many and diverse application of mechanical refrigeration. It may be classified in a number of different ways such as types of construction, method of liquid feed, operating conditions, method of air (liquid) circulation, types of refrigerant control and application (Gutkowski, 1996).In refrigeration system, there are types of evaporator which are usually in use.

#### **2.4.1.1 Plate Evaporator**

The plate evaporator as shown in Fig. 2.0 are widely used in home freezer, refrigerator, beverages cooler, ice cream cabinet, locker plant e.t.c In this type of evaporator the coils are either welded on one side of a plate or between the two plates which are welded together at the edges.



**Figure 2.0 Plate evaporator (Fapetu 2002)**

#### **2.4.1.2 Bare Tube Coil Evaporator**

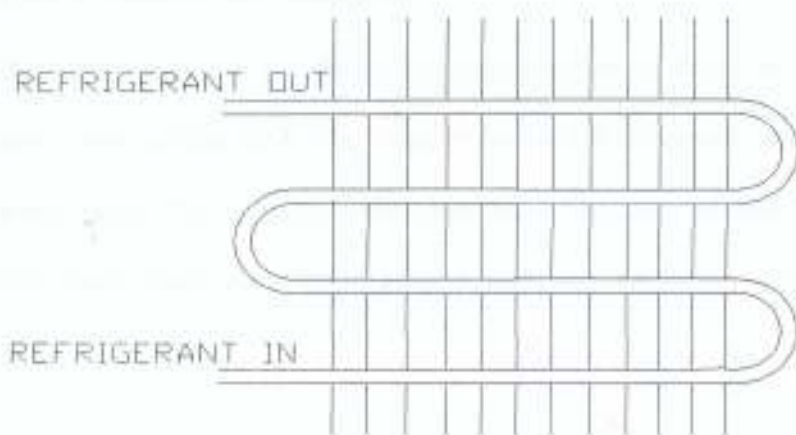
The simplest type of evaporator is the bare tube coil evaporator as shown in Fig. 2.1. It is also known as prime-surface evaporator. Because of its simple construction, the bare tube coil is easy to clean and defrost. The bare tube coil evaporators may be used for any type of refrigeration requirement. Its use is however limited to the application where the box temperature are under  $0^{\circ}\text{C}$  and in liquid cooling, because the accumulation of ice or frost on these evaporators has less effect on the heat transfer than on those equipped with fin. The bare tube coil evaporators are also extensively used in house-hold refrigerators because they are easier to keep and clean.



**Figure 2.1 Bare tube coil evaporator (Khurmi, 1987)**

### 2.4.1.3 Finned Evaporator

The finned evaporator as shown in Fig. 2.2 consist of bare tube or coils over which the metal plates or fins are fastened. The metal fins are constructed of thin sheets of metal having good thermal conductivity since the fins greatly increases the contact surfaces for heat transfer therefore the finned evaporators are also called extended surface evaporators. The finned evaporators are primarily designed for air conditioning applications where the refrigeration temperature is above  $0^{\circ}\text{C}$ .



**Figure 2.2 Finned evaporator (Fapetu 2002)**

#### 2.4.1.4 Shell and Tube Evaporator

The shell and tube evaporator as shown in figure 2.3 is similar to shell and tube condenser. It consist of a number of tubes enclosed in a cylindrical shell. This evaporators are generally used to chill water or brine solutions.

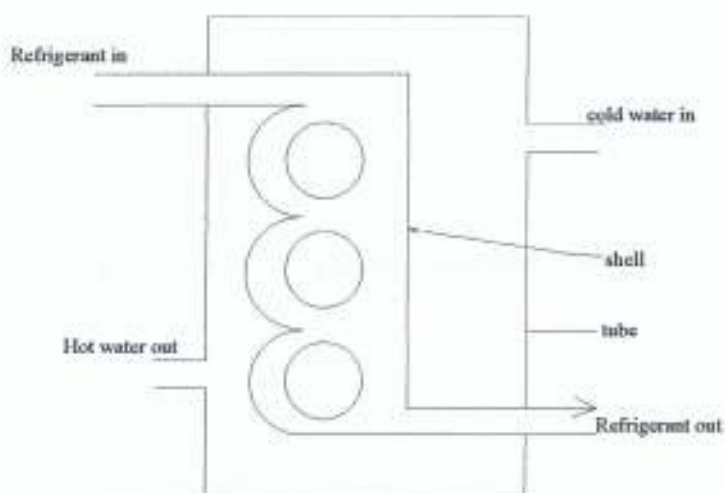
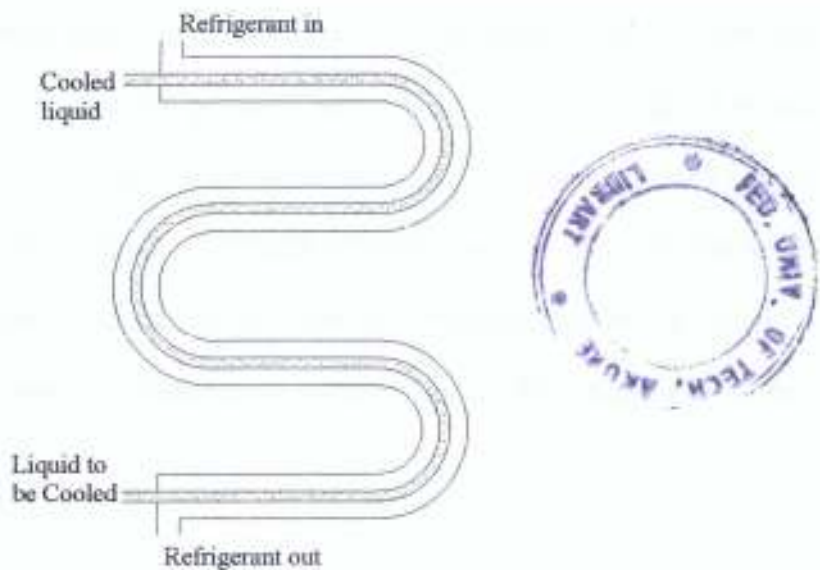


Figure 2.3 Shell and tube evaporator (Fapetu 2002)

#### 2.4.1.5 Double tube evaporator

The tube evaporator (or double tube evaporator) as shown in figure 2.4 consist of one tube inside another tube. The liquid to be cooled flows through the inner tube. The liquid to be cooled flows through the inner tube while the primary refrigerant or secondary refrigerant (water, air or brine) circulates the space between the tubes.



**Fig.2.4 Double tube evaporator (Khurmi, 1987)**

## 2.4.2 Condenser

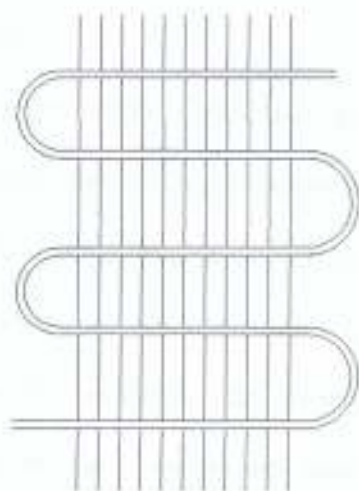
The condenser is an important device used in high pressure side of a refrigeration system. Their function is to remove heat of the hot vapour refrigerant discharged from the compressor. The condenser is a heat exchanger that removes condensation from the refrigerant vapour passes through the wall of the condenser to the condensing medium. As a result of the loss of heat to the condensing medium, the refrigerant vapour is first cooled to the saturation temperature and then condensed to the liquid state (Govinder 1985). The selection of condenser depend upon the capacity of the refrigeration system, the type of refrigerant used and the of cooling medium available.

In systems involving heat transfer, a condenser is a device or unit used to condense a substance from its gaseous to its liquid state, typically by cooling it. In so doing, the latent heat is given up by the substance, and will transfer to the condenser coolant. Condensers are typically heat exchangers which have various designs and come

in many sizes ranging from rather small (hand-held) to very large industrial-scale units used in plant processes. For example, a refrigerator uses a condenser to get rid of heat extracted from the interior of the unit to the outside air. Condensers are used in air conditioning, industrial chemical processes such as distillation, steam power plants and other heat-exchange systems. Use of cooling water or surrounding air as the coolant is common in many condensers. In a refrigeration system there are three types of condenser being used such as.

#### 2.4.2.1 Natural air-cooled condenser

In a natural convection air cooled condenser shown in fig. 2.5, the heat transfer from the condenser coils to the air is by natural convection. Methods used for condensing pressure control in air-cooled condenser includes , cycling fan motor, air throttling or bypassing, coil flooding and fan motor control (ASHRAE, 2002).



**Fig. 2.5 Natural convection condenser (Fapetu, 2002)**

### 2.4.2.2 Forced convection condenser

In forced convection air cooled condenser shown in fig. 2.6, the fan (either propeller or centrifugal) is used to force the air over the condenser coils to increase its transfer capacity.

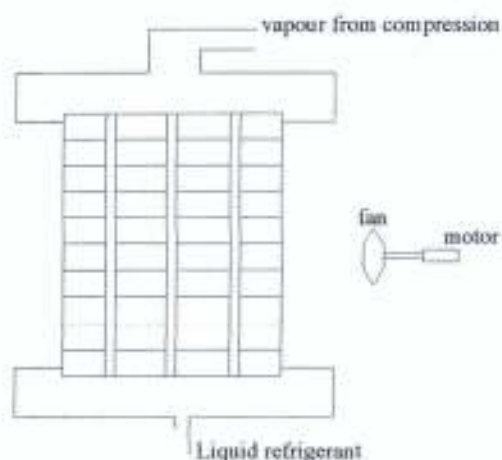


Fig. 2.6 Forced convection condenser (Arora, 1997)

### 2.4.2.3 Evaporative condenser

Fig. 2.7 shows an evaporative condenser which uses both air and water as cooling medium. Although there are some increases in the temperature of the air passing through the condenser, condensation of the refrigerant in the condenser result primarily from the evaporation of the water sprayed over the condenser. These condenser perform the combined function of water cooled condenser and cooling tower. In its operation the water is pumped from the sump to a spray header and sprayed through nozzles over the condenser coils through which the hot vapour refrigerant from the compressor is passing. The heat transfers from the refrigerant through the condensing tube walls and into the water that is wetting the outside surface the tube. At the same time, a fan draws air from

the bottom side of the condenser and discharged out of the top of the condenser coils to evaporate and absorb the latent heat of evaporation from the remaining water to cool it. The eliminator is produced above the spray header to stop particles of water escaping along with the discharge air.

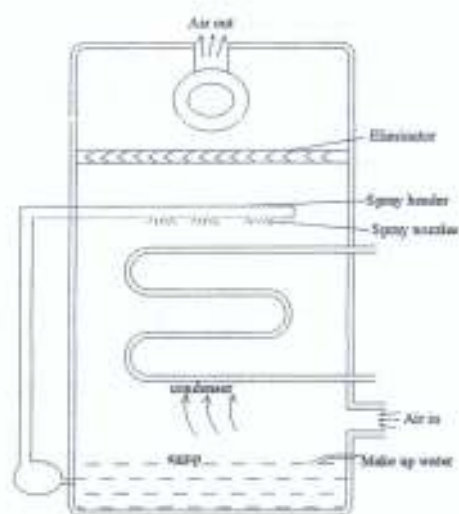


Fig 2.7 Evaporative condenser (Khurmi and Gupta 1987)

### 2.4.3 Compressor

The compressor gives the pressure head required to raise the refrigerant from the low evaporator pressure to the high condenser pressure in a near isentropic process. It is a machine used to compress the vapour refrigerant from the evaporator and to raise its pressure so that the corresponding saturation temperature is high than that of the cooling medium. It also continually circulates the refrigerant through the refrigerating system.

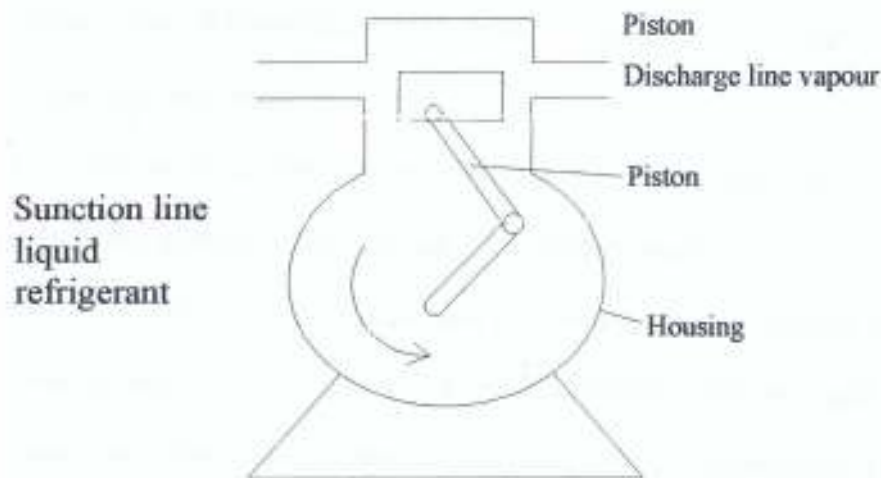
There are four basic types of compressor: Reciprocating piston compressor, Rotary compressor, Screw type compressor and Centrifugal compressor.

The reciprocating and rotary types are positive displacement compressors, compression of the vapour being accomplished mechanically by means of a compressing

member. In the reciprocating compressor, the compressing member is a reciprocating piston, whereas in the rotary compressor, the compressing member take the form of a roller, vane or lobe. The centrifugal, on the other hand, has no compressing member, compression of the vapour being accomplished primarily by action of the centrifugal force which is developed as the vapour is rotated by high speed impeller. Reciprocating compressor is employed in the development of the blast freezer. Compressor are either driven by electric motor or by internal combustion engine.

#### **2.4.3.1 Operation of reciprocating compressor**

Figure 2.8 shows a typical reciprocating compressor. This type is dominant in domestic refrigerating and consist of a cylinder in which it slides a piston which is connected to crankshaft by means of a connecting rod which convert rotary motion of the crankshaft to the up and down motion of piston. During the induction stroke partial vacuum open the inlet valve while the pressure of the compressed refrigerant is enough to open the exhaust valve during the compression stroke. The exhaust valve during the compression stroke closes and open at the end of compression stroke. The exhaust valve which operate at high temperature and pressure is susceptible to carbon formation which can cause leakage due to imperfect seating.



**Fig. 2.8 Reciprocating Piston Compressor Refrigerant control** (Khurmi and Gupta, 2007)

This is an automatic flow control device placed between the liquid line and the evaporator. It supplies or meters the correct quantity of refrigerant to the evaporator. It maintains a pressure differential between the low side and high side, while metering liquid refrigerant from the high side to the low side at the desired rate.

#### **2.4.4 Types of refrigerant control**

There are five main types of refrigerant control: Capillary tube, Thermostatic expansion valve, Low pressure side float, Automatic expansion valve and High pressure side float.

Of these five, the capillary tube, automatic expansion valve and thermostatic expansion valve are in use.

##### **2.4.4.1 Capillary tube**

The last of the elements in vapour compression cycle, after the compressor, condenser, and evaporator is the expansion device. The purpose of the expansion device is two fold:

it must reduce the pressure of the liquid refrigerant and it must regulate the flow of refrigerant to the evaporator.

The word capillary means "hair-like" that is very small tube of sufficient length to produce the metering effect desired. The relative position of a capillary tube is usually soldered or clamped to the suction line for heat exchanger processes, capillary tubes with internal diameter of 0.66 mm to 1.4 mm are common, and the length may be anywhere from a few meter to several meters depending upon the application. The internal wall of the capillary tube is rough, thus offering friction resistance to the flow of refrigerant which result in a pressure drop along the length of the tube. On this pressure drop, the liquid refrigerant at inlet evaporator is considerably reduced in pressure with corresponding drop in temperature. Generally liquid receiver is not used with a system employing capillary tube, accordingly the amount to refrigerant charge is always critical. The simplicity and the cost saving advantages of the capillary tube are so compelling that today practically all household refrigerators being built and many of the smaller size package-type commercial refrigeration systems employ a capillary tube to the almost complete exclusion of other refrigerant control.

#### **2.4.4.2 Refrigerant Miscibility with oil in Compressor**

Oil is highly needed for the lubrication of the compressor and is contained in the crankcase of the compressor where it is subject to contact with the refrigerant. It is assumed that oil does not react chemically with refrigerant (i.e chemically stable) when miscibility is concerned, Refrigerant like R12 is miscible with oil, while R22 is only partially miscible, ammonia is not miscible with oil at all.

## 2.5.0 Fruits and vegetables preservation

Maximum storage life can be obtained only by storing high quality commodities soon after harvest. Different lots of fruits may vary greatly in their storage behaviour due to variety in climate, soil and cultural conditions, maturity and handling processes (ASHRAE, 2002). Fresh fruits and vegetables for storage should be as free as possible from bruises and decay. These defects reduce the value of the product and may cause rapid deterioration not only of the damaged fruit often exhibits increased ethylene production, which cause rapid ripening of many types of climacteric fruits and vegetables having storage characteristics together, some may emit ethylene, causing a more sensitive crop to ripen prematurely (Mitcham,1997). Delayed ripening of fruit by removal of endogenously produced ethylene has been used to enable bananas, oranges and plaitains to be transported at ambient temperatures instead of under refrigeration (Walker,1992).

The blast freezer is develop to preserve fruits and vegetables within the first seven days after harvest, such that its freshness and sweetness is maintained. Recommended storage temperature depends on the cultivar. For most apple varieties, cool storage at  $0^{\circ}$  to  $1^{\circ}\text{C}$  is recommended (Kader et al, 1992). Odeyemi and Daramola, (2000) noted that refrigeration is the effective means for storing fruits and vegetables within a speculated period without loosing its freshness and sweetness. To ensure this, the specific heat, heat of respiration, storage temperature and storage life of the selected fruits are considered. Most produce is shipped from the point of production to regional or local distributors, such as terminal markets, independent wholesalers or chain store distribution centers. Produce orders are assembled at these sites and then shipped to retail stores, restaurants or institutions. Produce and floral items lose quality during these marketing steps, and the

amount of quality loss accumulates at each step. The consumer will receive good quality produce only if each operation in the handling chain minimizes abuse caused by improper temperature and RH, moisture loss, ethylene damage, odour contamination, and excessive storage time. Kader, (1997) noted that long exposure of fruits and vegetable to rain or excessive damp weather before harvest increases danger of fruits decay.

Products should be received at their proper long-term storage temperature and then stored at that temperature. Fruits and vegetable can be divided into three categories according to their optimum temperature requirements. The RH of the storage atmosphere should be 85 to 95% however for vegetables stored at low temperatures it should be 90 to 98%. The lowest temperature range of 0 to 2°C should be used for the majority of the green, non-fruit vegetables and temperature fruits and melons. Many green vegetables and most floral products are quite sensitive to ethylene damage. Ethylene must be kept away from these products. The tables 2.1 and 2.2 show the fruits and vegetables that are compatible during storage and their storage temperature with humidity the humidity ratio (Fruits, 2009).

Table 2.1 shown above contains various vegetables that should be stored within the temperature of 0°C and 2°C and also required the relative humidity that must be in the range of 90% and 98%. The period of preservation must not be more than seven days. The esterised (\*) fruits and vegetables are sensitive ethylene damage, therefore they must not be stored with ethylene producing fruits and vegetables.

**Table 2.1 Compatible fresh vegetables during 7-day storage with temperature of 0<sup>o</sup> to 2<sup>o</sup>C and 90% to 98% RH.**

<i>Alfalfa sprouts</i>	<i>Chinese cabbage *</i>	<i>mint</i>
<i>Amaranth*</i>	<i>Chinese turnip</i>	<i>muchroom</i>
<i>Anise*</i>	<i>collard*</i>	<i>mustard greens*</i>
<i>Artichoke</i>	<i>corn; swwet, baby</i>	<i>parsley*</i>
<i>Argular*</i>	<i>cut vegetables</i>	<i>parsnip</i>
<i>Asparagus*</i>	<i>daikon*</i>	<i>radicchio</i>
<i>Beans; fava lima</i>	<i>endive*-chicory</i>	<i>radish</i>
<i>Bean sprouts</i>	<i>escarole*</i>	<i>rutabaga</i>
<i>Beet</i>	<i>finnel*</i>	<i>rhubarb</i>
<i>Belgian endive*</i>	<i>garlic</i>	<i>salsify</i>
<i>Bok choy*</i>	<i>green onion*</i>	<i>scorzonera</i>
<i>Broccoli</i>	<i>herbs (not basil)</i>	<i>shallot*</i>
<i>Broccoflower*</i>	<i>horseradish</i>	<i>snowpea*</i>
<i>Carrot*</i>	<i>kailon*</i>	<i>Swiss chard*</i>
<i>Cauliflower*</i>	<i>kale*</i>	<i>turnip</i>
<i>Celeriac</i>	<i>kohlrabi</i>	<i>turnip greens*</i>
<i>Celery*</i>	<i>leek*</i>	<i>waterchestnut</i>
<i>Chard*</i>	<i>lettuce*</i>	<i>watercress*</i>

\* sensitive to ethylene damage.

Source: [http://WWW.vegetables n fruits.com](http://WWW.vegetablesnfruits.com)

The Table 2.2 shows compatible fruits and melon that should be stored within the temperature of 0<sup>o</sup>C and 2<sup>o</sup>C and also required the relative humidity of 85% RH and 95% RH for seven days period of preservation. The italicized fruits and melons are sensitive to ethylene damage, therefore they must not be stored with ethylene producing fruits. The fruits and melons that carried the superscripts (\*) can produce significant ethylene, therefore it must not be stored with fruits that are sensitive to ethylene.

**Table 2.2: Compatible fruits and melons with temperature 0° C to 2° C, 85% to 95% RH.**

Apple <sup>o</sup>	elderberry	<i>prune</i>
apricot <sup>o</sup>	fig	<i>quince</i>
avocado, ripe <sup>o</sup>	gooseberry	raspberry
Barbados cherry	grape	strawberry
Blackberry	loganberry	<i>kiwifruit<sup>o</sup></i>
Blueberry	logan	boysenberry
Caimito	loquat	lychee
Cashew apple	nectarine	cherry
Peach	coconut	pear(Asian )
Currant	<i>persimmon</i>	<i>fresh-cut fruits</i>
Date	<i>plum,ripe</i>	<i>plumcot, ripe</i>
Dewberry		

**Source:** <http://WWW.vegetables n fruits.com>

The right hand portion of Table 2.3 shows the compatible vegetables that required the storage temperature of 7°C to 10°C and relative humidity of 85% and 95% for proper preservation for a period of seven days, while the left hand portion of the table shows various vegetables that can be stored within the temperature of 10°C and 13°C with relative humidity of 85% and 95% for proper preservation for a period of seven days. The vegetables in italic are sensitive to ethylene damage; hence they must not be stored with ethylene producing fruits or vegetables.

**Table 2.3: Compatible vegetables**

7 to 10°C with 85 to 95% RH	13 to 18°C with 85 to 95% RH
<i>Basil*</i>	Bitter melon
Beans, snap, green, wax	<i>Boniato*</i>
Cactus leaves (nopales)*	Cassava
Calabaza	Dry onion
<i>Chayote*</i>	Ginger
Cowpea southern pea	Jicama
<i>Cucumber*</i>	Potato
<i>Eggplant*</i>	Pumpkin
Kiwano (horned melon)	<i>Squash; winter (hard rind)*</i>
Long bean	<i>Sweet potato*</i>
<i>Malanga*</i>	Taro (dasheen)
<i>Okra*</i>	Tomato; ripe, partially ripe & mature green
Pepper, bell, chili	<i>Yam*</i>
<i>Squash; summer, (soft rind)*</i>	
Tomatillo	
Winged bean	

\* sensitive to ethylene damage

Source: [http://WWW.vegetables n fruits.com](http://WWW.vegetablesnfruits.com)

In Table 2.4, the left hand side of the table shows various fruits that required storage temperature of 7°C to 10°C with relative humidity of 85% to 95% for a proper preservation for a period of seven days while the right hand side portion of the table shows various fruits that required storage temperature of 13°C to 18°C with relative humidity of 85% to 95% for effective preservation for a period of seven days. The fruits

in the italic are sensitive to ethylene damage, hence must not be stored with ethylene producing fruits. The fruits superscripts (°) produce significant ethylene during storage

**Table 2.4: Compatible fruits**

7 to 10 <sup>0</sup> C with 85 to 95% RH		13 to 18 <sup>0</sup> C with 85 to 95% RH	
Avocado, unripe	<i>lime</i>	<i>Atemoya</i>	<i>sapodilla</i>
Babaco	limequat	banana <sup>°</sup>	sapote <sup>°</sup>
Cactus pear, tuna	mandarin	breadfruit <sup>°</sup>	soursop <sup>°</sup>
Calmondin	mango ripe	canistel <sup>°</sup>	watermelon
Carambola	olive	casaba melon <sup>°</sup>	
Cranberry	orange	cherimoya <sup>°</sup>	
Custard apple <sup>°</sup>	passion fruit	Crenshaw melon <sup>°</sup>	
Durian, ripe	pepino	Honey dew melon <sup>°</sup>	
Feijoa	pineapple	Jaboticaba	
granadilla <sup>°</sup>	pummelo	jackfruit <sup>°</sup>	
<i>grapefruit</i>	sugar apple	mamey <sup>°</sup>	
quava <sup>°</sup>	tamarind	mangosteen <sup>°</sup>	
melon <sup>°</sup>	tangelo	papaya <sup>°</sup>	
kumquat	tangerine	Persian melon <sup>°</sup>	
<i>lemon</i>	ugli fruit	Plantain <sup>°</sup>	
		Rambutan	

\*Sensitive to ethylene damage ° produce significant ethylene

Source: <http://WWW.vegetables n fruits.com>

Table 2.5 shows the specific heat, heat of respiration, and the storage temperature of some Horticultural crops grown in North Carolina. The specific heat is the heat required to raise the temperature of a unit mass of a substance through 1<sup>0</sup>C. The heat of respiration is the amount of heat given off by a crop during storage. Fruits and vegetables are living

crop because after harvesting they still breathe through which they give out some amount of heat depending on the quantity in the storage. The heat of respiration of a fruit when is freshly harvested and is still warm differs from the heat of respiration when the fruits have been cooled. The storage temperature is the specified temperature that is conducive for any crop. The values of specific heat, heat of respiration and storage temperature are required for the design of a Blast Freezer.

**Table 2.5: Specific Heat and Heat of respiration for Horticultural Crops grown in North Carolina.**

Commodity	Specific Heat	Respiration (cool) kJ/kg/h	Respiration (warm) kJ/kg/h	Approximate safe Temp (°C)
Apples, summer	3.640	0.75312	1.422	-1.1 - 4.4
Apples, fall	3.640	0.050	1.004	-1.1 - 4.4
Asparagus	3.932	1.025	10.55	0 - 1.66
Beans, Butter	3.054	0.595	2.928	2.77 - 5
Beans, string	3.807	0.673	3.702	4.4 - 7.22
Beans topped	3.765	0.1171	0.3849	0
Blue berries	3.5982	0.1171	3.1296	-0.55 - 0
Brambles	3.640	0.3849	2.9748	-0.55 - 0
Broccoli	3.849	0.3849	5.757	0
Cabbage	3.932	0.00423	1.6752	0
Canta couple	3.932	0.1046	1.2761	7.22 - 10
Cucumbers	4.0584	0.4978	0.71128	-0.55 - 0
Grapes	3.598	0.05857	0.7489	0.5 - 0
Green onions	3.807	0.4016	2.945	0
Leafy greens	3.765	0.4184	4.326	0

Okra	3.849	1.0752	6.6232	7.22 - 10
Peaches	3.807	0.09629	1.9497	-0.5 - 0
Cashew	1.26	0.288		
Peas	3.054	0.66944	6.501	4.44
Peppers	3.9329	0.1924	1.0543	7.22
Potatoes	3.514	0.117152	0.2301	3.33
Squash	3.975	0.67362	3.142	5 - 10
Strawberries	3.849	0.2886	3.6484	0
Sweet corn	3.305	0.7782	6.8784	0
Carrot	1.43	0.00423		
Watermelons	3.933	0.1422	0.4602	4.4
Tomatoes ripening	3.975	0.2883	0.7865	7.77 - 10

*Source: A text book of Refrigeration and Airconditioning (Arora , 1997)*

Table 2.6 shows the mean specific heat of some selected agricultural produce, which is the average of the values of specific heat obtained after experimental trials on each produce. It is the quantity of heat required to raise the temperature of unit mass of each produce through one degree centigrade ( $1^{\circ}\text{C}$ ). The mean specific heat is necessary to determine the design of a system for the storage of the fruits and vegetables

**Table 2.6 Mean specific heat of some selected fruits**

Fruits	Specific heats (kJ/kg.K)
Citrus	0.892-0.94
potatoes	1.301
soyabean	1.576
fish	4.10
Beef meat	3.56

Source: <http://WWW.vegetablesnfruits.com>





## CHAPTER THREE

### 3.0 DESIGN AND CONSTRUCTION OF BLAST FREEZER

The cooling load capacity of the blast freezer was determined by considering various sources of heat into the refrigerated space. It is the summation of the heat which usually evolves from several different sources (Dossat, 1978). The heat sources considered in the design of this blast freezer are:

- i. Transmission Load (TL); Heat transferred to the refrigerated space through the surfaces.
- ii. Product Load; Heat removed and produced by the product brought into the refrigerated space.
- iii. Infiltration Load: Heat gains associated with air entering the refrigerated space.

Assuming 12-hour operation per day, the following parameters were used as calculated and determined, considering the area and volume of the refrigerated chamber.

Surface Area of the cabinet =  $0.6441 \text{ m}^2$

Volume of refrigerated space =  $0.2619 \text{ m}^3$

Thickness of the cabinet =  $0.008 \text{ m}$

Room Temperature =  $27^\circ\text{C}$

Refrigerated space temperature =  $0^\circ\text{C}$

Product weight =  $20 \text{ kg}$

Based on the above data and other acceptable standard, various load were obtained as detailed below;

**3.1 Transmission Load (TL):** It is the measure of heat flow rate by conduction through walls of the refrigerated space from the outside in unit time. The determination of

transmission gain load is calculated using equation (1) as given by (Dossat 1979), which is derived from Fouriers law, mathematically written as  $Q \propto A \cdot dt/dx$ , (Rajput,1990).

$$Q = AU \frac{dt}{dx} \dots \dots \dots (1)$$

Therefore

U for the three layers that comprises of mild steel plate, polystyrene insulator, and aluminum plate is given by equation (2)

$$U = \frac{1}{\frac{1}{f_o} + \frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{x_3}{k_3} + \frac{1}{f_i}} \dots \dots \dots (2)$$

where

$f_o$  = outside convection coefficient = 4.0

$f_i$  = inside convection coefficient = 1.65

$x_1$  = thickness of mild steel plate = 0.002 m

$k_1$  = thermal conductivity of mild steel plate = 58 W / m.K

$x_2$  = thickness of polyesthene = 0.004 m

$k_2$  = thermal conductivity of polystyrene = 0.34 W / m.K

$x_3$  = thickness of aluminum plate = 0.002 m

$k_3$  = thermal conductivity of alluminium = 204.2 W / m.K

Therefore U =0.841

Where:

Q = the rate of heat transfer in (W)

A = the outside surface area of the wall = 0.6441 m<sup>2</sup>

$U =$  overall co-efficient of heat transmission  $= 0.841(\text{W}/\text{m}^2\text{K})$

$\Delta T =$  the temperature differential across the wall  $= 27^\circ\text{C} - 0^\circ\text{C} = 27^\circ\text{C}$

Therefore from equation 1

$$Q = (0.644)(0.841) \frac{(27)}{0.008} = 0.14 \text{ kW}$$

**3.2 Infiltration load (IL) :** This is the heat gains which is associated with the air entering the refrigerated space. By applying equation (3) for the infiltration load (Dossat, 1979)

$$Q = m (h_0 - h_1) \dots \dots \dots (3)$$

where;

$m =$  air infiltration rate into the refrigerated space  $(\text{L}/\text{s}) = 0.0036$

$h_0 =$  enthalpy of the outside air  $(\text{kJ}/\text{kg}) = 230.22$

$h_1 =$  enthalpy of inside air  $(\text{kJ}/\text{kg}) = 200.00$

$$Q = (0.00036)(230.22 - 200.00) \\ = 0.0108 \text{ kW}$$

### 3.3 Product Load (PL)

This is the heat which is removed from and produced from product brought into the refrigerated space. By applying the equation (4) given by (Dossat, 1979)

$$Q = \frac{MC(\Delta T)}{T} \quad (4)$$

where

$Q_p =$  the quantity of heat given by the product  $(\text{kW})$

$M =$  mass of the product  $= 20 \text{ kg}$

$C =$  specific heat capacity  $= 3.98 \text{ kJ}/\text{kg}$



$\Delta T$  = change in product temperature =  $27^{\circ}\text{C}$

$T$  = time

The developed system was to accommodate 20 kg of any produce and the maximum specific heat capacity for any produce was selected for above  $0^{\circ}\text{C}$  temperature

$$Q = \frac{(20)(3.98)(27)}{12} = 0.1790 \text{ kW}$$

In addition to the product load is the heat of respiration which is the heat given off by the products as it respire. The maximum heat of respiration as given by Arora was chosen which is  $8.733 \text{ kJ/kg}$  at storage temperature of  $0^{\circ}\text{C}$ . Heat of respiration is given

by

equation (5)

$$H_r = MCh \dots\dots\dots(5)$$

Where:

$M$  = mass of the produce in kg = 20 kg

$Ch$  = heat of respiration =  $8.733 \text{ kJ/kg}$

$$(20)(8.733) = 0.174 \text{ kW}$$

$$= 0.174 \text{ kW}$$

$$\text{Therefore total product load} = (0.1790 + 0.174) \text{ kW} = 0.353 \text{ kW}$$

Total cooling load ; this is summation of all the heat load

Where:

$\sum Q_{TL}$  = summation of all total heat load

$Q_T$  = Transmission load =  $0.014 \text{ kW}$

$Q_I$  = infiltration load =  $0.0108 \text{ kW}$

$$Q_{TP} = \text{total product load} = 0.353 \text{ kW}$$

$$\sum Q_{TL} = 0.3778 \text{ kW}$$

**3.4 Safety factor:** A safety factor of 10% used in other to account for instrumentation and experimental errors, heat loads of (10% of 0.3778 ) kW was used; this is 10% above the calculated value.

### 3.5 Required Equipment Capacity (R.E.C)

It is defined as the capacity at which equipment will perform more effectively. It is measured in kW and for 12 hours running time.

$$\text{R.E.C} = (\text{Total cooling load}) (24\text{hours}) / 12\text{hours}$$

$$= \frac{(0.41558)(24)}{12}$$

$$= 0.83116 \text{ kW}$$

### 3.6 Compressor Analysis (for selection)

Determination of compressor size to use the Required Equipment Capacity (R.E.C)

$$= 0.83116 \text{ kW} / 12\text{hours}$$

$$1 \text{ h.p} = 0.746 \text{ kW}$$

$$x \text{ h.p} = 0.83116 \text{ kW}$$

$$x = \frac{0.83116}{0.746}$$

Therefore Compressor size = 1.0 hp

The compressor size required to produce the refrigerating capacity of 0.83116 kW daily is approximately 1.0 hp. The evaporator and condenser were selected based on this compressor capacity.

### 3.7 Determination of Refrigerating Effect

The refrigerating effect ( $Q_e$ ) was calculated using equation (6) as given by Arora 1989 and the refrigerant was R134a which enthalpy values was gotten from Arora 2000.

$$Q_e = (h_{ev} - h_{ed}) \dots\dots\dots(6)$$

where ( $h_{ev} - h_{ed}$ ) is the difference in the enthalpy at evaporator and condenser temperature respectively,

Evaporator Temperature  $T_e = -2^{\circ}\text{C}$

Condenser temperature  $T_c = 69^{\circ}\text{C}$

Degree of superheating =  $15^{\circ}\text{C}$

Ambient temperature =  $27^{\circ}\text{C}$

for refrigerant 134a,

$$h_{ed} \text{ at } 69^{\circ}\text{C} = 280.40 \text{ kJ/kg}$$

$$h_{ev} \text{ at } -2^{\circ}\text{C} = 249.28 \text{ kJ/kg}$$

$$Q_e = 31.12 \text{ kJ/kg}$$

### 3.8 Determination of Mass Flow Rate (m)

The mass flow rate was estimated using equation (6) as given by Dossat, 1979

$$m = \frac{R.E.C}{R.E} \dots\dots\dots(6)$$

$$\frac{0.83116}{31.12} = 0.0267 \text{ kg/s}$$

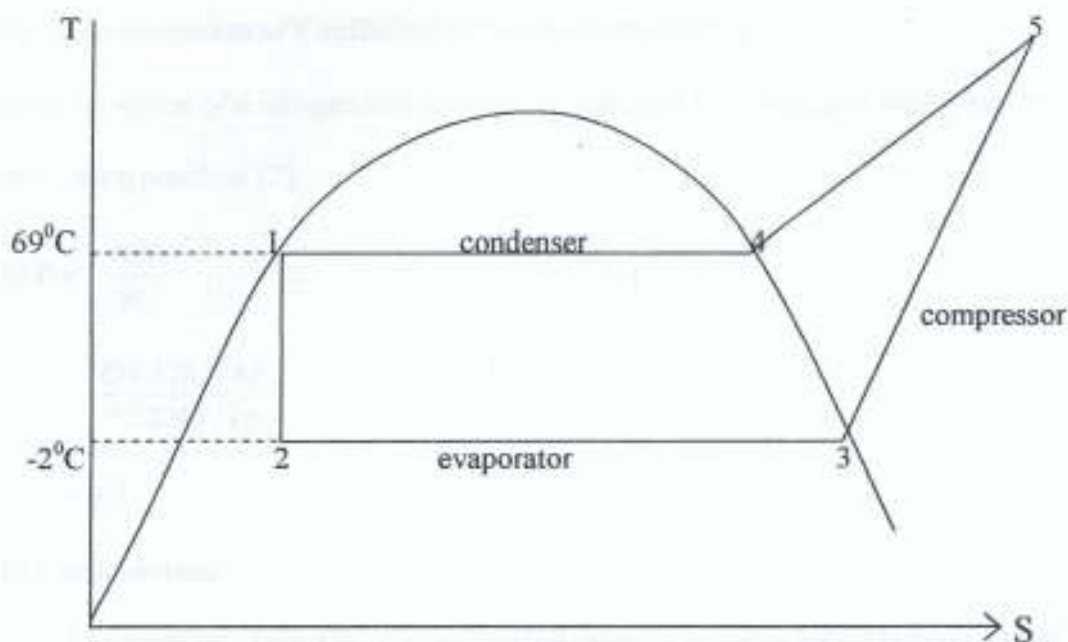


Fig. 3.1 Temperature – entropy diagram for the system

Fig. 3.1 shows the temperature – entropy diagram of the refrigerating system. The diagram aid the calculation of the work done by the compressor.

### 3.9 Determination of Work Done by Compressor (W)

$$W = h_5 - h_3$$

$$s_1 = s_2 = s_g \text{ at } -2^\circ\text{C}$$

$$s_1 = s_2 = 0.93253 \text{ kJ/kg.K}$$

$$s_2^1 = s_g \text{ at } 30^\circ\text{C} = 0.96031 \text{ kJ/kg.K}$$

$$\text{since } s_2 = 0.96031 \text{ kJ/kg.K}$$

Therefore the refrigerant is superheated at stage 5 from Fig. 4.1 ( s and h were taken from thermodynamic table ), (Yunus et al, 2008)

at superheating temperature of  $15^\circ\text{C}$

$$h_{2^0c} = 249.28 \text{ kJ/kg}$$

$$h_{69^0c} = 301.5 \text{ kJ/kg}, \text{ CW} = 52.22 \text{ kJ/kg}$$

### 3.10 Determination of Coefficient of Performance (COP)

The performance of a refrigerating machine is expressed by the ratio of useful heat to work. Using equation (7)

$$\text{C.O.P} = \frac{R.E.}{W} \dots\dots\dots (7)$$

$$\frac{31.12\text{kJ} / \text{kg}}{52.22\text{kJ} / \text{kg}}$$

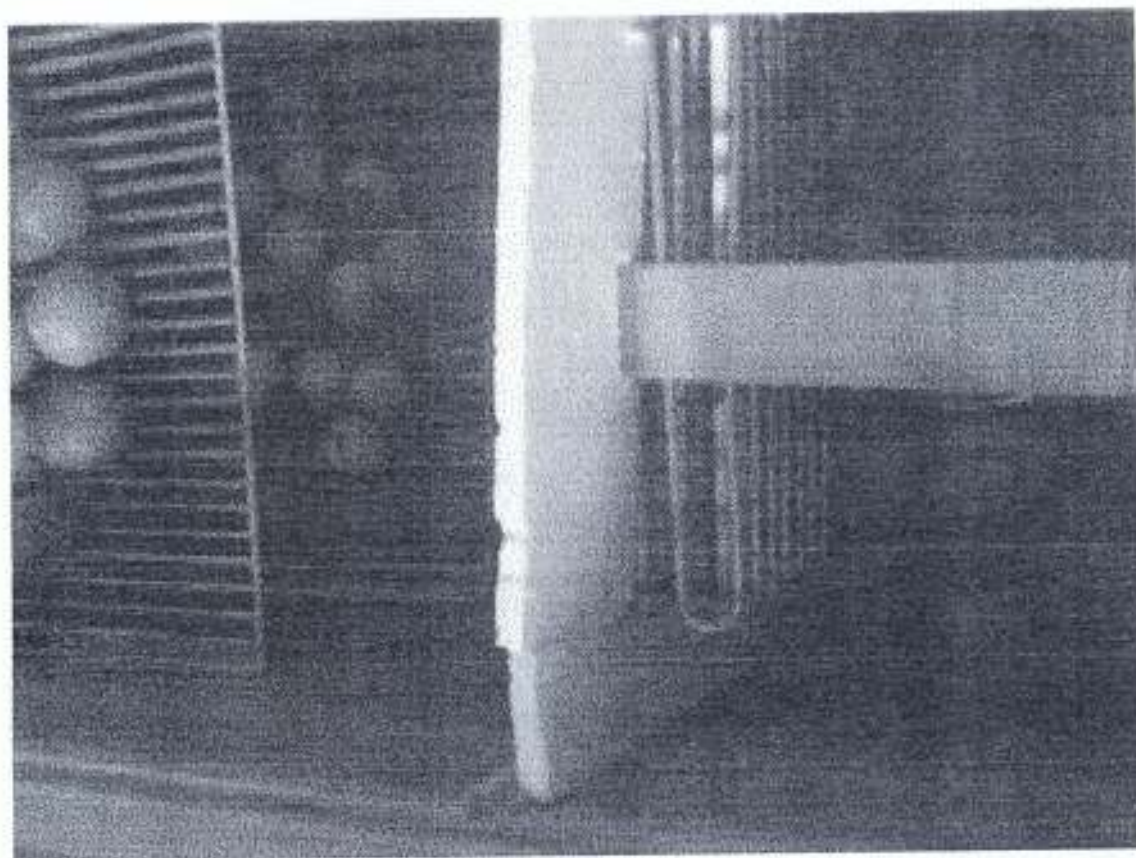
$$= 0.7$$

### 3.11 Construction.

In the development of blast freezer, consideration were given to different factors such as; economic value of the projects, simplicity of the technique, serviceability and availability of the materials. Fruits and vegetables were placed on the trays in the other end of the cabinet. The evaporator was demarcated with insulator and steel plate from the refrigerating space to prevent interaction. The outer components and accessories were fitted using bolts and nuts, these are the Condenser, Compressor and Evaporator. Plate 3.1 shows the pictorial view of the blast freezer and plate 3.2 shows the top view of the blast freezer during performance evaluation. Figure 3.2 and 3.3 are the isometric and orthographic view of the Blast freezer.

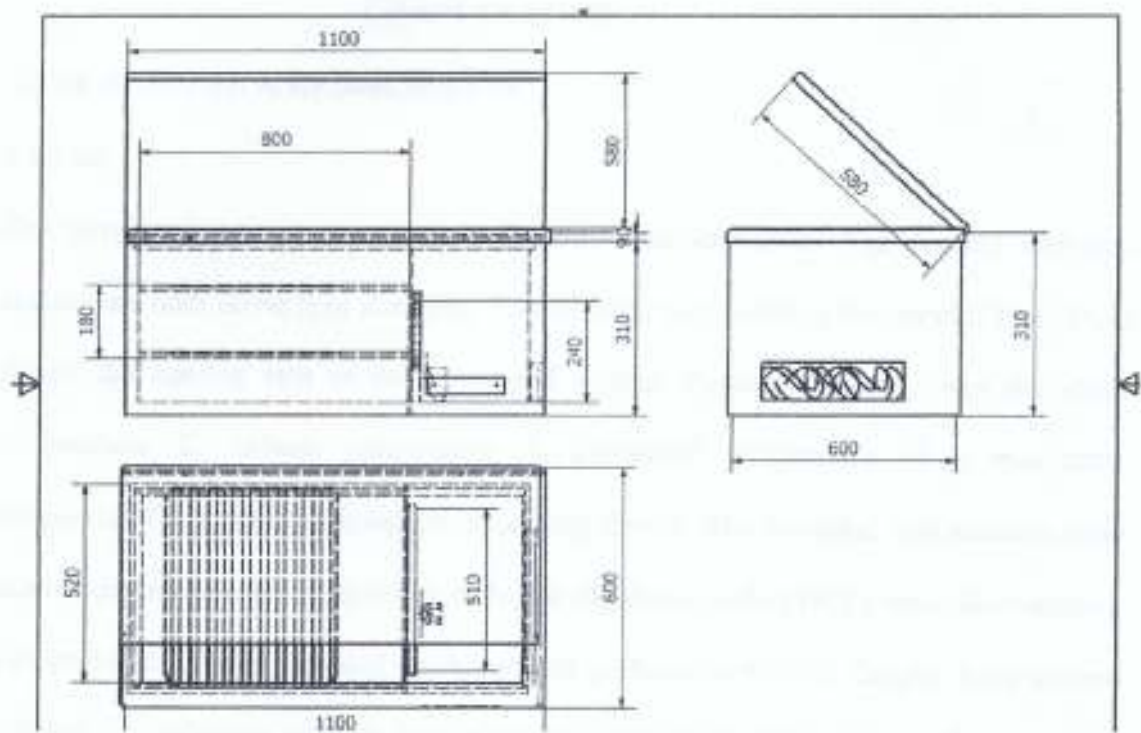


**Plate 3.1 Pictorial view of the Blast Freezer**



**Plate. 3.2** Top view of the Blast Freezer during experimentation

**Fig. 3.2** Isometric view of the Blast Freezer



**Fig. 3.3 Orthographic View of the Blast Freezer**



## CHAPTER FOUR

### TEST RESULTS AND DISCUSSION

#### 4.1 Test

The developed system was tested with fruits and vegetables. The cooling rate was determined both on no load and when 5 kg of fruits was stored in the system. Table (4.1) shows the cooling rate of the developed system. Parameters taken were the room temperature  $T_r$ , cabinet temperature  $T_c$ , condenser temperature ( $T_{cd}$ ), evaporator temperature ( $T_{ev}$ ) using temperature measuring device. The recorded temperatures were used to determine other parameters such as Refrigerating effect (R.E), mass flow rate(m), Compression Work(C.W) and coefficient of performance(COP). Graphs were plotted relating the variations of these parameters with condenser and evaporator temperatures. Table 4.2 shows the measured and calculated parameters at various condenser and evaporator temperatures. Graphs in Fig. 4.1 to Fig. 4.5 and Table 4.1 to 4.9 were the obtained experimental results.

#### 4.2 Result and discussion

Table 4.1 shows the cooling rate of the developed system. It will takes 160 minutes to reduce the cabinet temperature from  $26^{\circ}\text{C}$  to  $-1^{\circ}\text{C}$  but more time when loaded. These refrigerating space temperatures measured are the temperature of the refrigerated on the stored fruits and vegetables. The space temperature cannot go below  $-1^{\circ}\text{C}$  regardless of period of operation for the designed temperature. Table 4.2 shows the determined parameters from the condenser and evaporator temperature measured at stipulated interval in the course of performance evaluation.

**Table 4.1. Cooling rate of the refrigerating chamber**

Time (mins)	Load Temperature (°C)	No Load Temperature (°C) Ev Temp	Cooling Rate with load. Ev Temp	Cooling Rate on no load
0	26	26	0.00	0.00
20	20	18	23.88	31.84
40	16	14	19.90	23.88
60	11	10	19.90	21.23
80	5	4	20.90	21.89
100	1	0	19.90	20.70
120	0	-1	17.25	17.91
140	-1	-1	15.35	15.35
160	-1	-1	13.43	13.43

**Table 4.2. Parameters measured during performance evaluation.**

Tev (0°C)	Tcd (0°C)	Qe(kJ/kg)	C.W (kJ/kg)	COP	m (kg/s)
26	28	1	36.82	0.027	0.831
20	50	13.39	39.91	0.335	0.062
15	60	19.57	42.61	0.459	0.042
5	63	25.4	48.39	0.524	0.033
3	65	27.64	49.58	0.558	0.030
1	67	29.06	50.62	0.587	0.028
0	68	29.55	51.05	0.578	0.028
-2	69	31.12	52.22	0.700	0.026

Fig.4.1 shows the variation of cooling rates on no-load and when loaded with time. As it can be observed in the figure, the cooling rates increase with time for the first 20 minutes. This is due to the fact that the temperature was very high and there is much heat to be removed. There is a slight fall within the next 40 minutes. During this period of time the system is trying to maintain stability. After the first 60 minutes the rate at which the heat is being removed was relatively stable. The temperature maintained in the system at

this time ranges between  $4^{\circ}\text{C}$  and  $-1^{\circ}\text{C}$ . This is the required temperature for storage of most agricultural produce. Hence the produce used in the experimentations can be preserved at that this temperature range. Fig.4.2 shows that, the Compression work (C.W) and the refrigerating effect (R.E) increase with the decrease in evaporator temperature. This shows that compressor compresses refrigerants at higher rate at low evaporator temperature and cooling effect is high at lower evaporator temperature. Fig. 4.3 shows that the coefficient of performance increases with decrease in evaporator temperature and the mass flow rate decreases with decrease in evaporator temperature, because at low evaporator temperature the cooling effect of the system is high. This shows that the system perform better at lower temperature and the rate of flow of refrigerant is slow at lower temperature. In Fig.4.4, the Compression work and the Refrigerating effect increase with increase in condenser temperature. This shows that compression work and cooling effect are higher at high condenser temperature. Fig. 4.5 shows that the COP increases and mass flow rate decreases with increase in condenser temperature till the optimum temperature is reached.

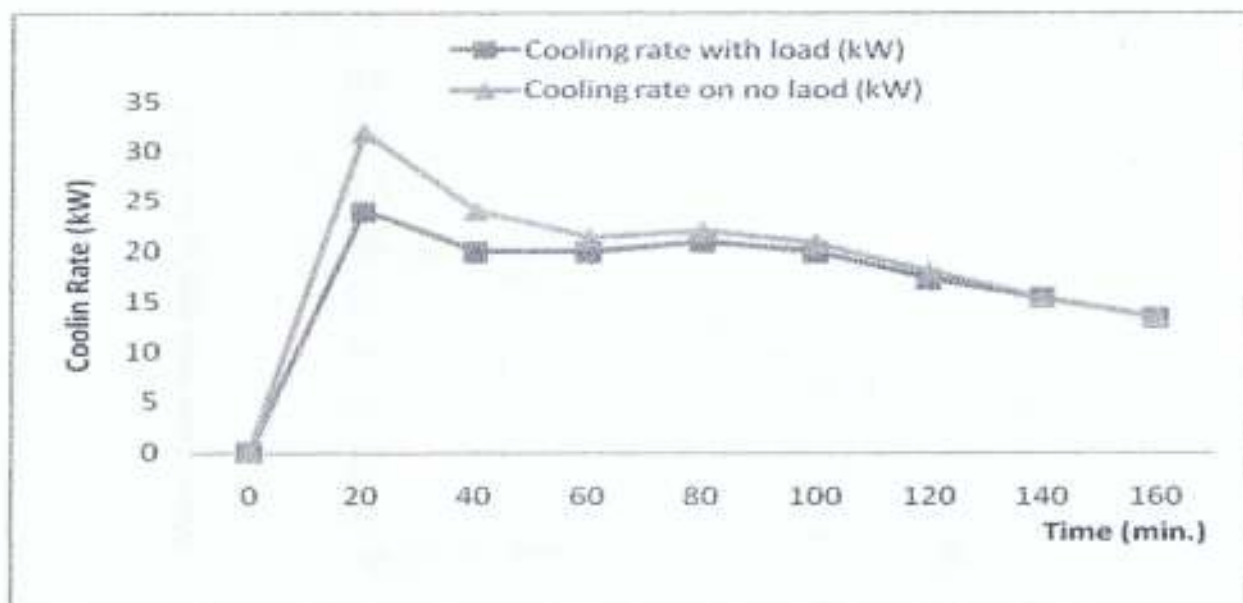


Fig. 4.1 Graph of Load and No-Load Temperature and Time.

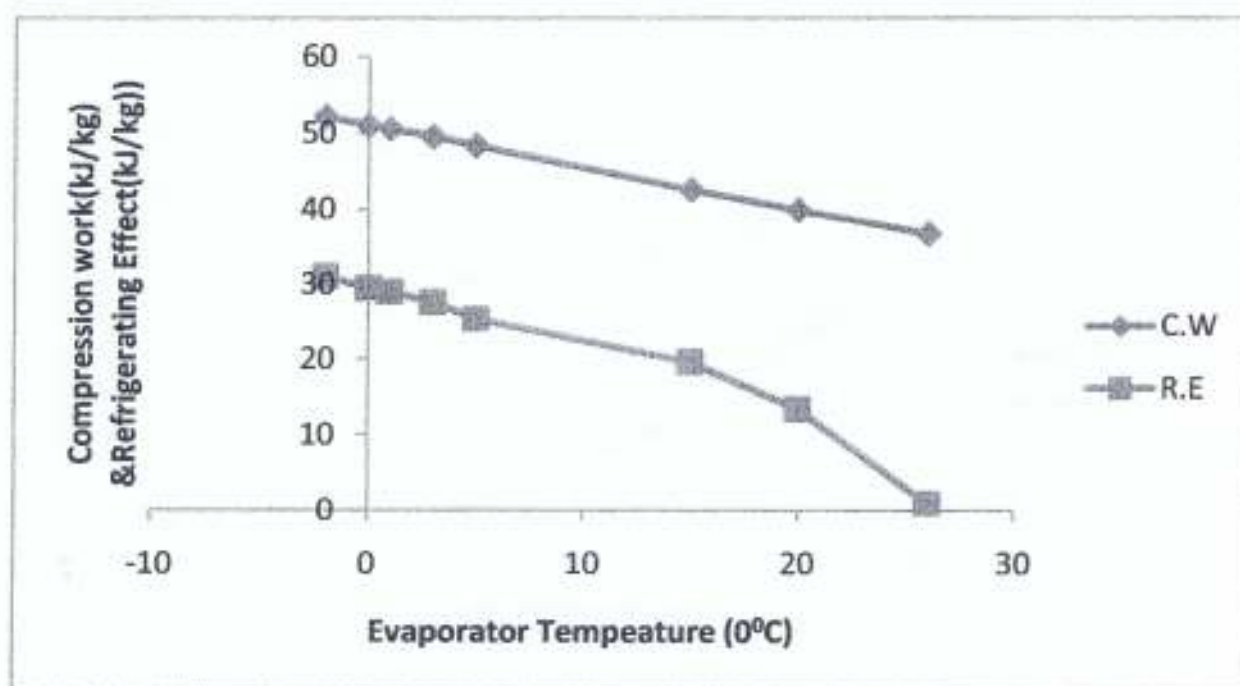


Fig. 4.2 Graph of Compression work and Refrigerating Effect against Evaporator Temperature.

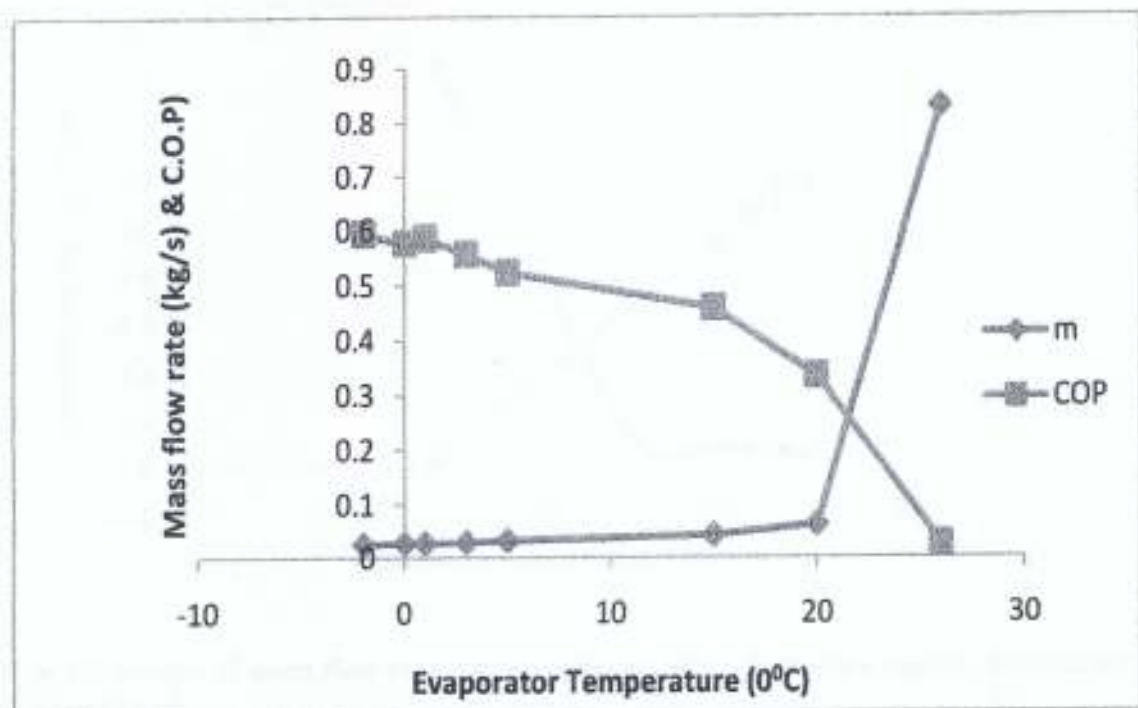


Fig 4.3 Graph of mass flow rate and Coefficient of Performance against Evaporator Temperature

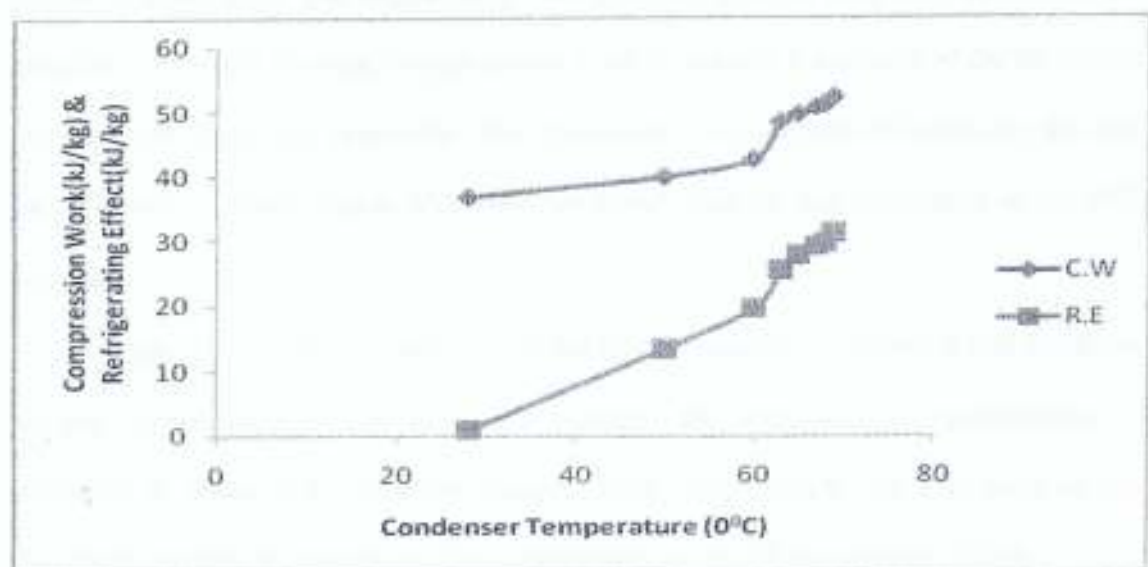
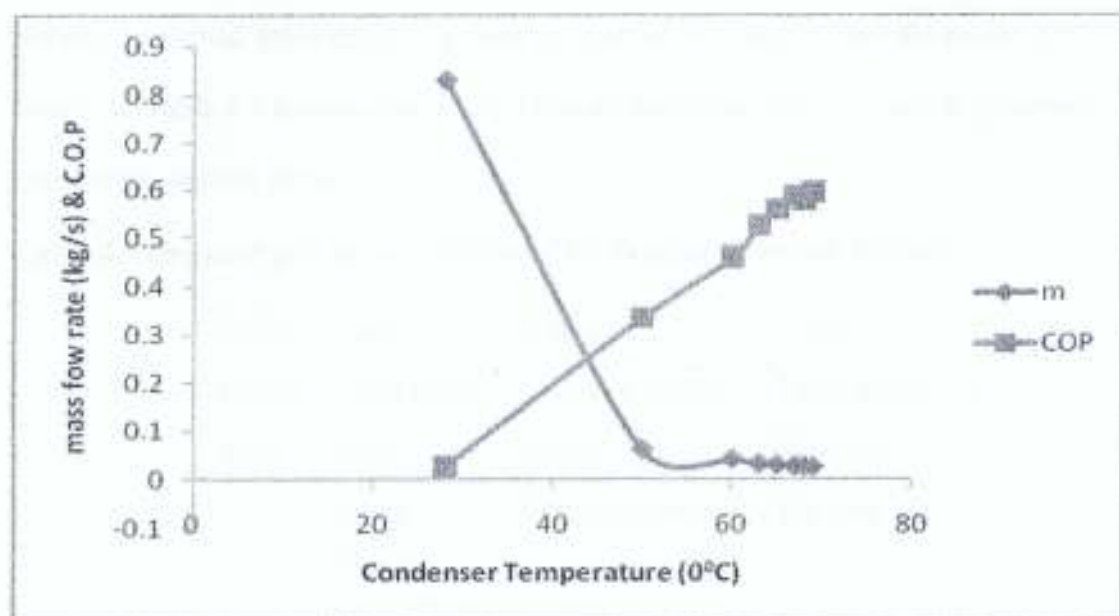


Fig. 4.4 Graph of compression work and Refrigerating Effect against Condenser Temperature.



**Fig. 4.5 Graph of mass flow rate and Coefficient of performance against Condenser Temperature.**

Fruits and vegetables samples consist of Apple, Orange and Grape were stored for a period of seven days. The organoleptic and nutritional analysis tests were carried on the samples before and after the storage period in order to study the effects of the developed system on the fruits and vegetables. The organoleptics test includes the attributes that can be observed by sense organs while the nutritional analysis was conducted in the FST laboratory.

Table 4.3 shows the summary of the observation of five observers of the fruits sample before storage. The observers recorded the organoleptic characteristics as indicated in Table (4.4) after the storage period which satisfy the efficiency of the developed system in conserving the organoleptic values of the produce. There is close range in the nutritional qualities of the fruits sample before and after storage as indicated in Table 4.5 and Table 4.6 which show a clear difference from the control sample as shown in Table 4.7. It is clear in Table 4.8 that the rate at which nutritional qualities of

the non preserved fruits decreased from the normal was higher than the preserved fruits sample in Table 4.9 because the air blast freezer developed has been able to preserved the nutritional qualities of the fruits.

**Table 4.3 Organoleptic characteristics of fruits samples before storage.**

Fruits	Apple	Orange	Grape
Colour	Light green	Greenish yellow	Light green
Taste	Sweet	Sweet	Sour taste
	Odour Pleasant	Partially pleasant	Pleasant

**Table 4.4 Organoleptic characteristics of fruits samples after storage period.**

Fruits	Apple	Orange	Grape
Colour	Light green	Greenish yellow	Light green
Taste	Sweet	Sweet	Sour taste
Odour	Pleasant	Partially pleasant	Pleasant

**Table 4.5 Nutritional characteristics of fruit sample before storage.**

Fruits	Apple	Orange	Grape
Acidity	0.0413	0.0609	0.0805
Vitamin C	11.11	50	38.88
Glucose	14.6	9.4	8.0
Total solid	15.5%	9%	7%
PH	3.90	3.80	3.55

**Table 4.6. Nutritional characteristics of fruit samples after storage.**

Fruits	Apple	Orange	Grape
Acidity	0.0161	0.0371	0.0427
Vitamin C	10.5	42.10	36.84
Glucose	14.10	9	8.0
Total solid	14.5%	5.0	5.71%
PH	3.96	3.58	4.50

**Table 4.7 Nutritional characteristics of fruit samples that was not stored.**

Fruits	Apple	Orange	Grape
Acidity	0.0126	0.0224	0.0357
Vitamin C (mg/100ml)	9.47	26.31	31.57
Glucose	10.30	8.40	8.30
Total solid	12.8%	6.6	6%
PH	4.04	3.57	3.84

**Table 4.8 Percentage decrease of the Nutritional values of preserved fruit samples**

Fruits	Apple	Orange	Grape
Acidity	15%	39%	46.9%
Vitamin C	5.4%	1.5%	5.2%
Glucose	3.4%	4.2%	0%
Total Solid	6.4%	44%	18.4%
PH	15%	5.7%	26.7%

**Table 4.9 Percentage decrease of the Nutritional values of the non-preserved fruits sample**

Fruits	Apple	Orange	Grape
Acidity	61%	50%	50%
Vitamin C	14.7%	47.3%	18.8%
Glucose	10.2%	10.3%	11%
Total Solid	17.4%	26.6%	14.2%
PH	11.11%	6%	8%

## CHAPTER FIVE



### 5.0 CONCLUSION AND RECOMMENDATION

#### 5.1 Conclusion

A blast freezer of capacity 0.8311 kW has been designed and constructed in accordance with the set objectives for this research. The blast freezer developed uses the vapour compression refrigerating system and a finned type evaporator which has the distinct advantage of lowering the temperature of the stored item above the freezing point, was incorporated. The system having a cooling load of 0.4155 kW was designed for a full load of 20 kg of fruits and vegetables or combination of both.

The system was tested on no – load condition and the parameters measured were the room temperature, condenser and evaporator temperature using temperature measuring devices. Parameters such as Refrigerating effect ( $Q_c$ ), mass flow rate ( $m$ ), compression work (CW) and Coefficient of Performance (COP) were calculated to be, 31.12 kJ/kg, 0.0267 kg/s, 52.22 kJ/kg and 0.7 respectively. During the performance evaluation, the test result shows that compression work and the Refrigerating effect increase with decrease in evaporator temperature and that coefficient of performance increase with decrease in evaporator temperature. This shows that the system performs better at lower temperature and the flow rate of refrigerant is slow at lower temperature. Compression work and the refrigerating effect increase with condenser temperature. Also COP increases and mass flow rate decreases with increase in condenser temperature till the optimum is reached.

The system was also tested with 5 kg of fruits in order to study its effect on the stored produce. The observation of five observers show that the system was able to retain the organoleptics and nutritional values of the stored produce after seven days of storage which proves the efficiency of the Blast freezer. The nutritional values such as Acidity, Total solid, Vitamin C and pH of the stored fruits decrease in that order.

## **5.2 Recommendation**

In general, the performance and evaluation results are quite encouraging, but more could still be done to improve on its Coefficient of Performance. The following are thereby recommended.

It is recommended that the system be subjected to test throughout a whole year for more performance evaluation and that fins evaporator used should be replaced with other types like, plate and coil and tube evaporator for comparison. It is also recommended that the air-cooled condenser be replaced with water and evaporative condenser in order to measure their performance. The computer program written should be used in further development of such systems.

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