Performance Analysis of VCR System By Varying Diameters of Helical Condenser Coil Using R-134a Refrigerant

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Abstract- *In this project, the design of condenser is going to be changed. Condensers are flow architectures needed to provide high rates of condensation (or cooling) per unit volume, in enclosures with fixed volume. Actually, their design has not changed from configurations consisting of the banks of horizontal tubes.*

We outline a free path to evolving the design by exploring new features of flow configuration like flattened tubes, multiple tube sizes, arrays of flattened tubes, vertical tubes with turbulent film flow, forced convection condensation instead of gravity driven condensation, and the optimal length of a horizontal tube, i.e., the number of tubes in a column aligned with vapor cross flow.

We show that the condensation density can be increased sizably by varying freely and without bias the morphology of the flow system, the shape and arrangement of the cooled surfaces on which condensation occurs. The evolution of technology is described in terms of the special time direction of the useful (purposeful) changes in the configuration (shapes, arrangements) of surfaces on which flow/condensation occurs.

I. INTRODUCTION

Vapor compression Refrigeration system is an improved type of air. The ability of certain liquids to absorb enormous quantities of heat as they vaporize is the basis of this system. Compared to melting solids (say ice) to obtain refrigeration effect, vaporizing liquid refrigerant has more advantages. To mention a few, the refrigerating effect can be started or stopped at will, the rate of cooling can be predetermined, the vaporizing temperatures can be governed by controlling the pressure at which the liquid vaporizes. Moreover, the vapor can be readily collected and condensed back into liquid state so that same liquid can be re circulated over and over again to obtain refrigeration effect. Thus the vapor compression system employs a liquid refrigerant which evaporates and condenses readily. The Vapor compression refrigeration system is now-a-days used for all purpose refrigeration. It is generally used for all industrial purposes from a small domestic refrigerator to a big air-conditioning plant.

Basic Components of a vapor compression system

Basic components of a vapor compression refrigeration system are shown in Figure
They are,

Compressor: It is motor driven; it sucks vapor refrigerant from evaporator and compresses.

Condenser: High pressure vapor refrigerant is condensed into liquid form in the condenser using cooling medium such as water.

Expansion Valve: High pressure refrigerant is throttled down to evaporator pressure; rate of flow is metered.

Evaporator: A cooling chamber in which products are placed; low pressure liquid refrigerant flows in the coils of evaporator and absorbs heat from products; the refrigerant vaporizes and leaves for compressor.

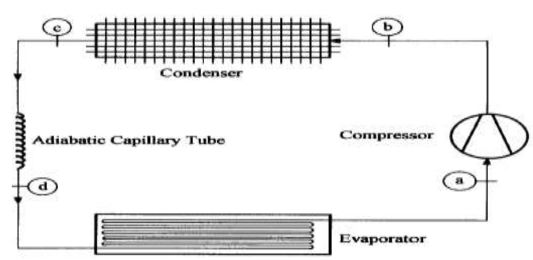

Figure 1. Schematic diagram of a vapor compression refrigeration system

Condensers and evaporators are basically heat exchangers in which the refrigerant undergoes a phase change. Next to compressors, proper design and selection of condensers and evaporators is very important for satisfactory performance of any refrigeration system. Since both condensers and evaporators are essentially heat exchangers, they have many things in common as far as the design of these components is concerned. However, differences exist as far as the heat transfer phenomenon is concerned. In condensers the refrigerant vapour condenses by rejecting heat to an external fluid, which acts as a heat sink. Normally, the external fluid does not undergo any phase change, except in some special cases such as in cascade condensers, where the external fluid (another refrigerant) evaporates. In evaporators, the liquid refrigerant evaporates by extracting heat from an external fluid (low temperature heat source).

The external fluid may not undergo phase change, for example if the system is used for sensibly cooling water, air or some other fluid. There are many refrigeration and air conditioning applications, where the external fluid also undergoes phase change. For example, in a typical summer air conditioning system, the moist air is dehumidified by condensing water vapour and then, removing the condensed liquid water. In many low temperature refrigeration applications freezing or frosting of evaporators takes place. These aspects have to be considered while designing condensers and evaporators.

The Carnot refrigeration cycle (Basic Cycle for VCRS)

Carnot refrigeration cycle is a completely reversible cycle, hence is used as a model of perfection for a refrigeration cycle operating between a constant temperature heat source and sink. It is used as reference against which the real cycles are compared. Figures 10.1 (a) and (b) show the schematic of a Carnot vapour compression refrigeration system and the operating cycle on T-s diagram.

The basic Carnot refrigeration system for pure vapour consists of four components: compressor, condenser, expansion valve and evaporator. Refrigeration effect (q4- 1 = qe) is obtained at the evaporator as the refrigerant undergoes the process of vaporization (process 4-1) and extracts the latent heat from the low temperature heat source. The low temperature, low pressure vapour is then compressed isentropic ally in the compressor to the heat sink temperature Tc. The refrigerant pressure increases from Pe to Pc during the compression process (process 1-2) and the exit vapour is saturated. Next the high pressure, high temperature saturated refrigerant undergoes the process of condensation in the condenser (process 2-3) as it rejects the heat of condensation (q2-3 = q_c) to an external heat sink at Tc.

The high pressure saturated liquid then flows through the turbine and undergoes isentropic expansion (process 3-4). During this process, the pressure and temperature fall from Pc,Tc to Pe, Te. Since a saturated liquid is expanded in the turbine, some amount of liquid flashes into vapour and the exit condition lies in the two-phase region. This low temperature and low pressure liquid-vapour mixture then enters the evaporator completing the cycle. Thus as shown in Fig.10.1 (b), the cycle involves two isothermal heat transfer processes (processes 4-1 and 2-3) and two isentropic work transfer processes (processes 1-2 and 3-4).

Heat is extracted isothermally at evaporator temperature Te during process 4-1, heat is rejected isothermally at condenser temperature Tc during process 2-3. Work is supplied to the compressor during the isentropic compression (1-2) of refrigerant vapour from evaporator pressure Pe to condenser pressure Pc, and work is produced by the system as refrigerant liquid expands Isentropically in the turbine from condenser pressure Pc to evaporator pressure Pe. All the processes are both internally as well as externally reversible, i.e., net entropy generation for the system and environment is zero.

Applying first and second laws of thermodynamics to the Carnot refrigeration cycle,

$$\oint \delta q = \oint \delta w$$
$$\oint \delta q = q_{4-1} - q_{2-3} = q_e - q_c$$
$$\oint \delta w = w_{3-4} - w_{1-2} = w_T - w_C = -w_{net}$$

$$COP_{Carnot} = \frac{\text{refrigeration effect}}{\text{net work input}} = \frac{q_e}{w_{net}} = \frac{T_e(s_1 - s_4)}{T_c(s_2 - s_3) - T_e(s_1 - s_4)} = \left(\frac{T_e}{T_c - T_e}\right)$$

Thus the COP of Carnot refrigeration cycle is a function of evaporator and condenser temperatures only and is independent of the nature of the working substance. This is the reason why exactly the same expression was obtained for air cycle refrigeration systems operating on Carnot cycle The Carnot COP sets an upper limit for refrigeration systems operating between two constant temperature thermal reservoirs (heat source and sink). From Carnot's theorems, for the same heat source and sink temperatures, no irreversible cycle can have COP higher than that of Carnot COP.

II. REFRIGERANTS

A detailed study of these refrigerants has thus become imperative. This unit is intended to serve as an introductory guide to the study of refrigerants.

- Naming convention for refrigerants,
- The different classifications of refrigerants,
- Properties of individual refrigerants, and
- Environmental effects related to the use of these refrigerants.

PRIMARY AND SECONDARY REFRIGERANTS:

Primary refrigerants are those which can be directly used for the purpose of refrigeration. If the refrigerant is allowed to flow freely into the space to be refrigerated and there is no danger of possible harm to human beings, then primary refrigerants are used. The refrigerants used in home refrigerators like Freon-12 are primary refrigerants. On the other hand, there may be certain situations in which we cannot allow the refrigerant to come in direct contact with the items being refrigerated, and then the refrigerant used is termed as a secondary refrigerant. As for example, we cannot allow a toxic refrigerant to be used for air conditioning in residential buildings. There are some refrigerants which are highly inflammable and so their direct use is forbidden for safety reasons. Again, it may so happen that if direct refrigeration, such as in cooling a big cold storage, is allowed, then the amount of refrigerant required may be so large that its cost becomes prohibitively high. These are some typical situations for which we favor the use of secondary refrigerants. Water and brine solutions are common examples of secondary refrigerants.

CLASSIFICATION OF REFRIGERANTS

Refrigerants can be broadly classified based on the following: Working Principle Under this heading, we have the primary or common refrigerants and the secondary refrigerants. The primary refrigerants are those that pass through the processes of compression, cooling or condensation, expansion and evaporation or warming up during cyclic processes. Ammonia, R12, R22, carbon dioxide come under this class of refrigerants. On the other hand, the medium which does not go through the cyclic processes in a refrigeration system and is only used as a medium for heat transfer are referred to as secondary refrigerants. Water, brine solutions of sodium chloride and calcium chloride come under this category. Safety Considerations Under this heading, we have the following three sub-divisions.

Safe refrigerants: These are the non-toxic, non-flammable refrigerants such as R11, R12, R13, R14, R21, R22, R113, R114, methyl chloride, carbon dioxide, water etc.

Toxic and moderately flammable: Di-chloroethylene methyl format, ethyl chloride, sulphur dioxide, ammonia etc. come under this category.

Highly flammable refrigerants: The refrigerants under this category are butane, isobutene, propane, ethane, methane, ethylene etc.

CHEMICAL COMPOSITIONS

They are further sub-divided as

Halocarbon compounds: Refrigerants these are obtained by replacing one or more hydrogen atoms in ethane or methane with halogens.

Azeotropes: These are the mixtures of two or more refrigerants and behave as a compound.

Oxygen and Nitrogen Compounds: Refrigerants having either oxygen or nitrogen molecules in their structure, such as ammonia, are grouped separately and have a separate nomenclature from the halogenated refrigerants.

Cyclic organic Compounds: The compounds coming under this class are R316, R317 and R318.

Inorganic Compounds: These are further divided into two categories:

- Cryogenic and
- Non cryogenic.

Cryogenic fluids are those which are applied for achieving temperatures as low as – 160 0C to – 273 0C. Above this temperature range, we can use a multi-stage refrigeration system to realize the desired temperature. But below – 160 0C, this is not possible since the COP of the cycle becomes very low. To attain temperatures below – 160 0C, we use refrigerants such as nitrogen, oxygen, helium, hydrogen etc. and for temperatures close to – 273 0C, magnetic cooling is employed. The inorganic compounds which are employed above the cryogenic temperature ranges come under the remaining sub-division of inorganic refrigerants.

Unsaturated Compounds: Compounds such as ethylene, propylene etc. are grouped under this head and grouped under the 1000 series for convenience. Miscellaneous This group contains those compounds which cannot be grouped under the other components. They are indicated by the 700 series with the last numbers being their molecular weight. Examples include air, carbon dioxide, sulphur dioxide etc. As we can see from the above sub-divisions, they are not mutually exclusive. A compound may come under more than one sub-division. Hence, the importance of adopting the various naming conventions to designate the different refrigerants cannot be underestimated.

DESIGNATION OF REFRIGERANTS

The American Society of Refrigerating Engineers (ASRE) has developed certain conventions for use in naming different types of refrigerants. These naming conventions differ according to the type of refrigerant. Each refrigerant type is denoted by a different series. Thus, we have separate series for halogenated refrigerants and other types. The naming conventions are simple and easy to 56 Refrigeration and Air Conditioning follow. These conventions are now accepted worldwide and help to name the large variety of refrigerants available commercially nowadays.

Halocarbon Compounds: these are represented by a three digit nomenclature. Here, the first digit represents the number of carbon atoms in the compound minus one, the second digit stands for the number of hydrogen atoms plus one while the third digit stands for the number of fluorine atoms. The remaining atoms are chlorine. As an example, let us consider the refrigerant having R22 as its three digit nomenclature.

According to the above mentioned convention,
No. of C atoms in R22: C – 1 = 0 => C = 1
No. of H atoms in R22: H + 1 = 2 => H = 1
No. of F atoms in R22: F = 2

Since there is only one carbon atom in the compound, this compound has originated from the methane series (CH_4). From the calculation, we can see there is one hydrogen atom and two fluorine atoms. The remaining valence bond of carbon will be balanced by chlorine.

Chemical formula of R22 is $CHClF_2$ and has the name Mono chloro difluoro methane taking again the example of R134a, we can calculate its chemical formula as above which gives us
No. of C atoms: C – 1 = 1 => C = 2
No. of H atoms: H + 1 = 3 => H = 2
No. of F atoms: F = 4
Therefore, no. of Cl atoms: Cl = 0

DESIRABLE PROPERTIES OF REFRIGERANTS

The vast number of refrigerants available in the market today allows us to choose a refrigerant depending upon the operating conditions of the refrigeration system. As such, there is no refrigerant that can be advantageously used under all operating conditions and in all types of refrigeration systems. In spite of that, we can state certain desirable properties that a refrigerant should posses.

These properties can be divided into

- favorable thermodynamic,
- chemical and
- physical properties

Thermodynamic Properties:

- **Critical Temperature and Pressure:** The critical temperature of the refrigerant should be as high as possible above the condensing temperature in order to have a greater heat transfer at a constant temperature. If this is not taken care of, then we will have excessive power consumption by the refrigeration system. The critical pressure should be moderate and positive. A very high pressure will make the system heavy and bulky whereas in case of very low pressures, there is a possibility of air leaking into the refrigerating system.
- **Specific Heat:** The specific heat of the liquid should be as small as possible. This ensures that the irreversibility's associated with throttling are small and there is greater sub cooling of the liquid. On the other hand, the specific heat of vapor should be high, to have less superheating of the vapor.
- **Enthalpy of Vaporization:** this should be as large as possible to minimize the area under superheat and the area reduction due to throttling. Also, the higher value of enthalpy of vaporization lowers the required flow rate per ton of refrigeration.
- **Conductivity:** The conductivity of the refrigerant should be as high as possible so that the size of the evaporator and condenser is manageable. From this viewpoint, ammonia has a better conductivity than that of R12 or R22 and is more suitable than the latter. But, ammonia is toxic and this does not allow its use in home refrigeration systems.
- **Evaporator and Condenser Pressure:** Both the evaporator and condenser pressures need to be above atmospheric pressure otherwise there is a possibility of air leaking into the system. Presence of air drastically reduces the capacity of the refrigeration system. Also, due to presence of moisture in air, acids or other corrosive compounds may form and this may affect the tubing of the refrigeration system.
- **Compression Ratio:** The compression ratio needs to be as small as possible otherwise the leakage of

refrigerant occurs across the piston. Also, the volumetric efficiency is affected.

- **Freezing Point:** It should be as low as possible or else there will be a possibility of blockage of passages during flow of fluid through evaporator. Volume of Refrigerant Handled per Ton of Refrigeration
- This should be as small as possible in order to have a small size of the compressor. The type of compressor is decided by this value. For refrigerants like R12, R500, R22 etc., a reciprocating compressor is suitable. For others like R11 and water, a centrifugal compressor is required to handle the large volume.
- **Coefficient of Performance:** The Coefficient of performance or COP has a direct bearing on the running cost of the refrigeration system. Higher the magnitude of COP, lower will be the running cost. Since, the COP of any refrigeration system is limited by the Carnot COP, for large operating pressures a multi-stage refrigeration system should be employed. CO2 has a very low COP. Hence, it is not suitable for use as a refrigerant.
- **Density;** The density of the refrigerant should be as large as possible. In reciprocating compressors, the pressure rise is accomplished by squeezing the entrapped fluid inside the piston-cylinder assembly. Hence, density decides the size of the cylinder. Again in centrifugal compressors pressure rise is related to the density of the vapor. A high value of density results in high pressure rise.
- **Compression Temperature:** Whenever a refrigerant gets compressed, there is a rise in the temperature of the refrigerant resulting in the heating of the cylinder walls of the compressor. This necessitates external cooling of the cylinder walls to prevent volumetric and material losses. Refrigerants having lowest compression temperatures are thus better than others.

Chemical Properties:

- **Chemical Stability and Inertness:** It should be chemically stable for the operating ranges of temperature. Also, it should not react with the materials of the refrigeration system or with which it comes into contact. Further, it should be chemically inert and must not undergo polymerization reactions at either the lower or higher ranges of temperatures.
- **Action on Rubber or Plastics:** Rubber and plastics are used extensively in the refrigeration system. These materials are mostly used in the seals and gaskets of the refrigeration system. They help to prevent the leakage of the refrigerant and ensure the smooth functioning of the compressor. The refrigerant should not react with them or else there might be leakage of refrigerant from the system or loss of functioning of the compressor.
- **Flammability:** The refrigerant should be inert and not catch fire when subjected to high temperatures. From this viewpoint CO2 is the most suitable as it is not only non-flammable, but also acts as a fire-extinguisher. Ethane, butane, isobutene are highly undesirable as they catch fire quickly.
- **Effect on Oil:** The refrigerant should not react with the lubricating oil else, there is a possibility of loss of lubricating action due to either thickening or thinning of the oil. It should not be soluble in the oil else there will be reduction in the viscosity of the lubricating oil.
- **Effect on Commodity:** If the refrigerant is directly used for chilling, then it should not affect the commodity kept in the conditioned space. Also, in case where direct cooling is not employed, the refrigerant should still not affect the commodity if there is any leakage. Toxicity: The refrigerant used in air conditioning, food preservation etc. should not be toxic as they will come into contact with human beings.

Physical Properties:

- **Leakage and Detection:** Since pressures higher than atmospheric are usually employed in refrigeration systems, there is a possibility of leakage of refrigerants after long period of operation. It is desirable to detect this leak early else the system would operate under reduced capacity or stop functioning altogether. Hence, it is desirable that the refrigerant has a pungent smell so that its leakage can be detected immediately.
- **Miscibility with Oil:** The refrigerant should not be miscible with the oil else the lubricating strength will be reduced.
- **Viscosity:** It should be as small as possible to ensure that the pressure drop in the system is as small as possible. A low viscosity refrigerant will require less energy for its circulation through the refrigeration system

SAFETY CRITERIA:

Under safety criteria, we consider the toxicity, flammability, action on perishable food and formation of explosive compound on exposure to air. An refrigerant should be non-toxic, non-flammable, have no effect on food products and should not react with atmospheric air. No refrigerant satisfy these criteria fully. We can therefore, group refrigerants into different sub-groups based on their flammability and toxicity levels.

ECONOMIC CRITERIA

Apart from the thermodynamic, chemical, physical and safety criteria, there is another criterion by which we judge an ideal refrigerant. The economic criterion takes into account the cost of the refrigerant, the availability and supply levels of the refrigerant, cost of storage and handling. We discuss each of these in detail below.

- Cost of Refrigerant: The cost of the refrigerant has a big impact on the overall cost of the refrigeration system. Hence, its cost should be as low as possible. From this viewpoint, ammonia and water are ideally suited, but their low thermodynamic and chemical properties restrict their use in all types of refrigeration systems. Particularly, for flooded type evaporator or condenser, the refrigerant amount required is high and their cost needs to be factored in while making the initial investments.
- Availability and Supply: The refrigerant should be easily available in the market and in abundant quantity. This ensures that the cost of the refrigerant is not prohibitive. An abundant and free supply of the refrigerant ensures that refrigeration systems will be designed specifically for use with them.
- Storage and Handling: The refrigerant should be such that it can be conveniently stored and handled during transportation and charging. It should be stored in as small a pressure vessel as possible. Also, if we have to handle a toxic or flammable refrigerant, then the cost involved will be higher compared to handling and storage cost of non-toxic and non-flammable refrigerant.

From the above discussions of the ideal properties of refrigerants, we can come to the conclusion that none of the refrigerants in current use and available satisfy these conditions fully. As such, we have to make a detailed analysis of the different factors like cost, performance of the refrigeration system and safety issues before deciding on using a particular refrigerant.

COMMON REFRIGERANTS

The refrigerants which are available commercially in the market are numerous. Some of them which are in common use are mentioned below:

Air: Air (molecular weight 28.97, specific heats cp = 1.04 kJ/kgK and cv = 0.712 kJ/kg-K) is one of the earliest refrigerant to be used in the refrigeration systems. Its advantages are that it is available free of cost, is non-toxic and non-flammable and does not affect the commodity if pure. However, air suffers from a number of drawbacks. Air contains moisture and this reacts with the material of the evaporator and condenser severely affecting their working capacity. Further, there is a possibility that the passages may be blocked by the formation of ice from this moisture. The COP of air is of the order of 0.6 and thus, not suitable for use in refrigeration systems on a commercial scale. It is mainly used for air conditioning in aircrafts where efficiency of operation is of secondary importance.

- **Ammonia:** Ammonia (molecular weight 17) is one of the oldest refrigerants and it was commonly employed in places where toxicity effects were of secondary importance. Its advantages are its low cost, low specific volume, high COP (of the order of 4.0) and high refrigeration effect per unit mass of the refrigerant. Its primary drawback is its toxicity which prevents its use in air conditioning and food preservation systems. Ammonia has a boiling point of -33 0C at atmospheric pressure.
- **Carbon Dioxide:** Carbon dioxide (molecular weight 44) is a non-toxic and non-poisonous refrigerant. Also, it is not only non-flammable but and is an excellent extinguishing agent as well. Its other advantages are that it is chemically stable, immiscible with the lubricating oil and does not affect the metal used in the system. It has a low specific volume and this requires volume displacement per ton of refrigeration. However, its critical pressure is too high. Also, its critical temperature is only 31 0C which makes it unsuitable for use in countries with a hot climate like India. It is an excellent refrigerant for low temperature refrigeration.
- **Sulphur Dioxide:** Sulphur dioxide (molecular weight 64) is a colorless, suffocating and irritating gas and is twice as heavy as air at atmospheric conditions. It was mostly used as a household refrigerant in the older days, but has since been discarded for better refrigerants. It suffers from a lot of disadvantages. Sulphur dioxide reacts with water forming sulphurous acid, which in presence of oxygen becomes sulphuric acid, a corrosive compound for metals. It is non-flammable but attacks foodstuff on coming in contact with it. It is also partially miscible with the lubricating oil.
- **Hydrocarbons**: this group consists of colorless fluids normally in gaseous state and made up of various

combinations of carbon and hydrogen. Most of the refrigerants from this category are suitable for low temperature refrigeration. Isobutene falls in this category and has been suitable for domestic refrigeration. They are non-poisonous, but are flammable and highly explosive when exposed to air. The molecular weight and boiling point of each gas varies according to the number of hydrogen and carbon atoms. The larger the number of hydrogen and carbon atoms, the heavier is the gas and higher is its boiling point.

- **Halocarbon Refrigerants:** The halocarbon refrigerants are formed by replacing one or more of hydrogen atoms of methane or ethane by one or more atoms of the three halogens: fluorine, chlorine or bromine.
- Some of the refrigerants coming under this category are mentioned below:
- **Refrigerant R12:** the refrigerant R12 is the most widely used refrigerant in the domestic and large commercial establishments. Its chemical formula is CCl2F2 and its boiling point is -300C at 1 bar. It is a non-flammable, non-explosive, non-irritating, non-toxic and odorless refrigerant. It remains chemically stable up to 550 0C. Also, it does not affect the material of the refrigeration system. It is available in abundance and is quite cheap. However, its use is being discontinued nowadays for its contribution to ozone depletion which will be discussed later.
- **Refrigerant R13:** Its chemical formula is CClF3. it is a non-flammable, non-toxic and stable refrigerant. It is very suitable for achieving low temperatures in a cascade refrigeration system. Its specific volume is high and therefore, it is suitable for centrifugal compressors. However, it also has a negative effect on ozone depletion.
- **Refrigerant R22:** Its chemical formula is CHClF2. it is also a non-toxic, non-flammable, non-corrosive and non-irritating refrigerant. It is the most common refrigerant for use in large refrigeration systems and is preferred to R12.
- **Refrigerant R114:** Its chemical formula is C2Cl2F4. Its boiling point corresponding to 1 bar is about 30C. It has properties very similar to those of R12 with respect to water and oil combination. It is not suitable for low temperature refrigeration since it has negative evaporator pressure even at around 9 0C. It is non-toxic, non-explosive and non-corrosive even in the presence of water.

III. TYPES OF CONDENSERS

As already mentioned, condenser is an important component of any refrigeration system. In a typical refrigerant condenser, the refrigerant enters the condenser in a superheated state. It is first de-superheated and then condensed by rejecting heat to an external medium. The refrigerant may leave the condenser as a saturated or a sub-cooled liquid, depending upon the temperature of the external medium and design of the condenser. Figure shows the variation of refrigeration cycle on T-s diagram. In the figure, the heat rejection process is represented by 2-3'-3-4. The temperature profile of the external fluid, which is assumed to undergo only sensible heat transfer, is shown by dashed line. It can be seen that process 2-3' is a de-superheating process, during which the refrigerant is cooled sensibly from a temperature T2 to the saturation temperature corresponding condensing pressure, T3'. Process 3'-3 is the condensation process, during which the temperature of the refrigerant remains constant as it undergoes a phase change process.

In actual refrigeration systems with a finite pressure drop in the condenser or in a system using a zoetrope refrigerant mixture, the temperature of the refrigerant changes during the condensation process also. However, at present for simplicity, it is assumed that the refrigerant used is a pure refrigerant (or an Azeotropes mixture) and the condenser pressure remains constant during the condensation process. Process 3-4 is a sensible, sub cooling process, during which the refrigerant temperature drops from $T_3$to T_4.

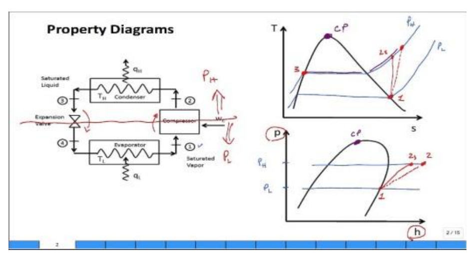

Figure 2.

P- H DIAGRAM:

The most convenient chart for studying the behavior of a refrigerant is the p-h chart, in which the vertical ordinates represent pressure and horizontal ordinates represent enthalpy. A typical chart is shown Fig., in which a few important lines of the complete chart are drawn. The saturated liquid line and saturated vapor line merge into one another at the critical point. A saturated liquid is one which has a temperature equal to the saturation temperature corresponding to its pressure. The spaces to the left of the saturated liquid line will, therefore, be sub cooled liquid region. The space between the liquid and the vapor lines is called wet vapor region and to the right of the saturated vapor line is a superheated vapor region.

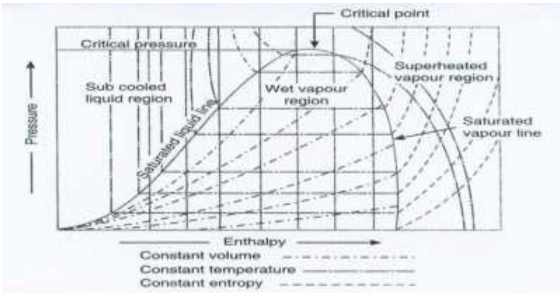

Figure 3. Pressure – Enthalpy (P-h) chart

CLASSIFICATION OF CONDENSERS:

Based on the external fluid, condensers can be classified as:

a) Air cooled condensers
b) Water cooled condensers, and
c) Evaporative condensers

Air-cooled condensers:

As the name implies, in air-cooled condensers air is the external fluid, i.e., the refrigerant rejects heat to air flowing over the condenser. Air-cooled condensers can be further classified into natural convection type or forced convection type.

a) Natural convection type:

In natural convection type, heat transfer from the condenser is by buoyancy induced natural convection and radiation. Since the flow rate of air is small and the radiation heat transfer is also not very high, the combined heat transfer coefficient in these condensers is small. As a result a relatively large condensing surface is required to reject a given amount of heat. Hence these condensers are used for small capacity refrigeration systems like household refrigerators and freezers. The natural convection type condensers are either plate surface type or finned tube type. In plate surface type condensers used in small refrigerators and freezers, the refrigerant carrying tubes are attached to the outer walls of the refrigerator. The whole body of the refrigerator acts like a fin. Insulation is provided between the outer cover that acts like fin and the inner plastic cover of the refrigerator. It is for this reason that outer body of the refrigerator is always warm. Since the surface is warm, the problem of moisture condensation on the walls of the refrigerator does not arise in these systems. These condensers are sometimes called as flat back condensers.

The finned type condensers are mounted either below the refrigerator at an angle or on the backside of the refrigerator. In case, it is mounted below, then the warm air rises up and to assist it an air envelope is formed by providing a jacket on backside of the refrigerator. The fin spacing is kept large to minimize the effect of fouling by dust and to allow air to flow freely with little resistance.

In the older designs, the condenser tube was attached to a plate and the plate was mounted on the backside of the refrigerator. The plate acted like a fin and warm air rose up along it. In another common design, thin wires are welded to the serpentine tube coil. The wires act like fins for increased heat transfer area. Figure shows the schematic of a wire-and-tube type condenser commonly used in domestic refrigerators. Regardless of the type, refrigerators employing natural convection condenser should be located in such a way that air can flow freely over the condenser surface.

b) Forced convection type:

In forced convection type condensers, the circulation of air over the condenser surface is maintained by using a fan or a blower. These condensers normally use fins on air-side for good heat transfer. The fins can be either plate type or annular type. Figure 22.3 shows the schematic of a plate-fin type condenser. Forced convection type condensers are commonly used in window air conditioners, water coolers and packaged air conditioning plants. These are either chassis mounted or remote mounted. In chassis mounted type, the compressor, induction motor, condenser with condenser fan, accumulator, HP/LP cut- out switch and pressure gauges are mounted on a single chassis. It is called condensing unit of rated capacity. The components are matched to condense the required mass flow rate of refrigerant to meet the rated cooling capacity. The remote mounted type, is either vertical or roof mounted horizontal type. Typically the air velocity varies between 2 m/s to 3.5 m/s for economic design with airflow rates of 12 to 20 cmm per ton of refrigeration (TR). The air specific heat is 1.005 kJ/kg-K and density is 1.2 kg/m3. Therefore for 1 TR the temperature rise Δta = 3.5167/(1.2x1.005 x 16/60) = 10.9oC for average air flow rate of 16 cmm. Hence, the air temperature rises by 10 to 15oC as compared to 3 to 6oC for water in water cooled condensers.

The area of the condenser seen from outside in the airflow direction is called face area. The velocity at the face is called face velocity. This is given by the volume flow rate divided by the face area. The face velocity is usually around 2m/s to 3.5 m/s to limit the pressure drop due to frictional resistance. The coils of the tube in the flow direction are called rows. A condenser may have two to eight rows of the tubes carrying the refrigerant. The moist air flows over the fins while the refrigerant flows inside the tubes. The fins are usually of aluminum and tubes are made of copper. Holes of diameter slightly less than the tube diameter are punched in the plates and plates are slid over the tube bank.

Then the copper tubes are pressurized which expands the tubes and makes a good thermal contact between the tube and fins. This process is also known as bulleting. For ammonia condensers mild steel tubes with mild steel fins are used. In this case the fins are either welded or galvanizing is done to make a good thermal contact between fin and tube. In case of ammonia, annular crimpled spiral fins are also used over individual tubes instead of flat-plate fins. In finned tube heat exchangers the fin spacing may vary from 3 to 7 fins per cm. The secondary surface area is 10 to 30 times the bare pipe area hence; the finned coils are very compact and have smaller weight.

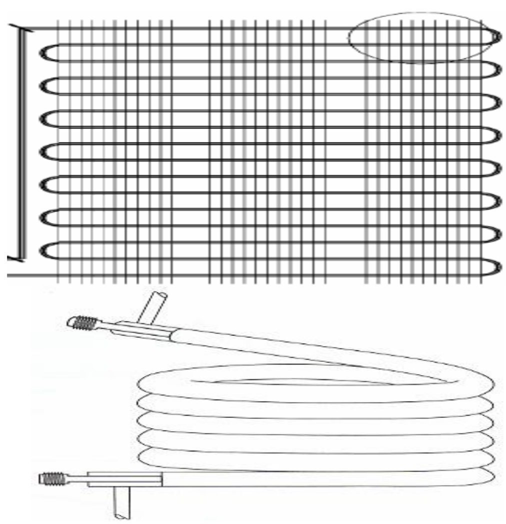

Figure 4. Forced convention Type

Water cooled condensers:

In water cooled condensers water is the external fluid. Depending upon the construction, water cooled condensers can be further classified into:

1. Double pipe or tube-in-tube type
2. Shell-and-coil type
3. Shell-and-tube type

- **Double Pipe or tube-in-tube type:** Double pipe condensers are normally used up to 10 TR capacities. Figure shows the schematic of a double pipe type condenser. As shown in the figure, in these condensers the cold water flows through the inner tube, while the refrigerant flows through the annulus in counter flow. Headers are used at both the ends to make the length of the condenser small and reduce pressure drop. The refrigerant in the annulus rejects a part of its heat to the surroundings by free convection and radiation. The heat transfer coefficient is usually low because of poor liquid refrigerant drainage if the tubes are long.
- **Shell-and-coil type:** These condensers are used in systems up to 50 TR capacity. The water flows through multiple coils, which may have fins to increase the heat transfer coefficient. The refrigerant flows through the shell. In smaller capacity condensers, refrigerant flows through coils while water flows through the shell. Figure 22.5 shows a shell-and-coil type condenser. When water flows through the coils, cleaning is done by circulating suitable chemicals through the coils.
- **Shell-and-tube type:** This is the most common type of condenser used in systems from 2 TR up to thousands of TR capacity. In these condensers the refrigerant flows through the shell while water flows through the tubes in single to four passes. The condensed refrigerant collects at the bottom of the shell. The coldest water contacts the liquid refrigerant so that some sub cooling can also be obtained. The liquid refrigerant is drained from the bottom to the receiver. There might be a vent connecting the receiver to the condenser for smooth drainage of liquid refrigerant. The shell also acts as a receiver. Further the refrigerant also rejects heat to the surroundings from the shell. The most common type is horizontal shell type. A schematic diagram of horizontal shell-and-tube type condenser and Vertical shell-and-tube type condensers are usually used with ammonia in large capacity systems so that cleaning of the tubes is possible from top while the plant is running.

Evaporative condensers:

In evaporative condensers, both air and water are used to extract heat from the condensing refrigerant. Evaporative condensers combine the features of a cooling tower and water-cooled condenser in a single unit. In these condensers, the water is sprayed from top part on a bank of tubes carrying the refrigerant and air is induced upwards. There is a thin water film around the condenser tubes from which evaporative cooling takes place. The heat transfer coefficient for evaporative cooling is very large. Hence, the refrigeration system can be operated at low condensing temperatures (about 11 to 13 K above the wet bulb temperature of air). The water spray countercurrent to the airflow acts as cooling tower. The role of air is primarily to increase the rate of evaporation of water. The required air flow rates are in the range of 350 to 500 m^3/h per TR of refrigeration capacity.

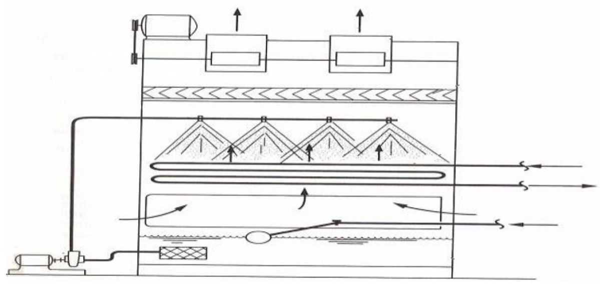

Figure 5.

Evaporative condensers are used in medium to large capacity systems. These are normally cheaper compared to water cooled condensers, which require a separate cooling tower. Evaporative condensers are used in places where water is scarce. Since water is used in a closed loop, only a small part of the water evaporates. Make-up water is supplied to take care of the evaporative loss. The water consumption is typically very low, about 5 percent of an equivalent water cooled condenser with a cooling tower. However, since condenser has to be kept outside, this type of condenser requires a longer length of refrigerant tubing, which calls for larger refrigerant inventory and higher pressure drops. Since the condenser is kept outside, to prevent the water from freezing, when outside temperatures are very low, a heater is placed in the water tank. When outside temperatures are very low it is possible to switch-off the water pump and run only the blowers, so that the condenser acts as an air cooled condenser.

Another simple form of condenser used normally in older type cold storages is called as atmospheric condenser. The principle of the atmospheric condenser is similar to evaporative condenser, with a difference that the air flow over the condenser takes place by natural means as no fans or blowers are used. A spray system sprays water over condenser tubes. Heat transfer outside the tubes takes by both sensible cooling and evaporation, as a result the external heat transfer coefficient is relatively large. The condenser pipes are normally large, and they can be either horizontal or vertical. Though these condensers are effective and economical they are being replaced with other types of condensers due to the problems such as algae formation on condenser tubes, uncertainty due to external air circulation etc.

SELECTION OF CONDENSER FOR A VCR SYSTEM

Condenser: Condenser is the component which is placed next to compressor in a vapor compression refrigeration system. It removes heat absorbed by refrigerant in the evaporator and the heat of compression added in the compressor and condenses it back to liquid.

Selection of condenser: The condenser is one of the most important components of refrigeration system. Its function is to dissipate heat absorbed by the refrigerant during evaporation (refrigeration effect) and compression (Heat of compression).There are three different type of condensers classified on the basis of cooling used to dissipate heat. These are.

- Air cooled
- Water cooled
- Evaporative type

Air-cooled condenser can be natural convection type or forced convection type. In this project air-cooled condenser is used which is the most common type in use. Before sizing a condenser, careful evaluation should include, consideration of initial cost, operating cost , service life and type of load. A condenser that is too large can be expensive and create operating problems in lower ambient conditions; an undersized condenser can cause operating problems in higher ambient conditions. It is therefore

Important parameters to consider before sizing a condenser:

1. Gross heat rejection
2. Ambient temperatures
3. Condensing temperature
4. Temperature difference (TD)
5. Air flow

The heat transfer through the condenser is by conduction, condenser capacity is a function of the fundamental heat transfer equitation.

Qc = U.A. (LMTD)

Where

Qc = Condenser capacity in KJ/Sec. (Ref. Effect Heat of Comp. +Motor Wdg. Heat)

U = Overall heat transfer coefficient KJ/h-m2 0K

A = Effective surface area in m2

LMTD = the log mean temperature difference between the condensing refrigerant and medium.

From the above equation it is evident that for any fixed value of 'U' the capacity of condenser is directly proportional to the surface area of the condenser and to the temperature difference between the condensing refrigerant and condensing medium.

IV. EXPERIMENTAL SETUP

The figure shows the experimental setup of the refrigerator. In order to know the performance characteristics of the vapor compression refrigeration system the temperature and pressure gauges are installed at each entry and exit of the components. Experiments are conducted on existing and helical condenser coils having the refrigerator capacity of 165liters. All the values of pressures and temperatures are tabulated.

DESIGN OF HELICAL CONDENSER:

The helical condenser is the applications for helical tubing coils range from copper helical coil with end fixture the aerospace industry to the refrigeration (ACR), petroleum, and brewing industry. In this present work remove the existing condenser and install the helical design condenser to the refrigerator (165 liters).To taken the temperatures and pressure readings and calculate the performance of the system.

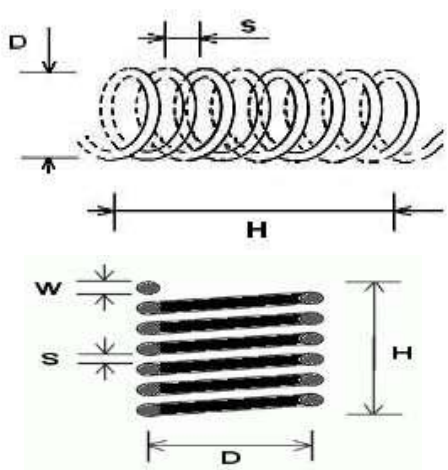

Figure 6. Helical shape. Fig. side view of the helical shape.

Table 1. Tabular column of Helical Condenser coil Parameters.

Parameter	***dimension***
Diameter of design coil D [mm]	250
Diameter of tube W [mm]	6.35
Spacing S [mm]	60
Turns	12
Length of tube[mm]	9420
Height H [mm]	740

Domestic refrigerator selected for the project has the following specifications:

Refrigerant used: R-134a
Capacity of The Refrigerator: 165 liters
Compressor capacity: 0.16 H.P.

Figure 7. existing condenser and modeled condenser

Table 2. Dimensions Condenser Evaporator Expansion valve

Dimensions	Condenser	Evaporator	Expansion valve
Length (m)	9.5	7.62	3.6
Diameter (mm)	6.4	6.4	0.9

PERFORMANCE CALCULATIONS:

Analysis of the condenser:

Thermal analysis in the heat exchangers can be done in two ways.

1. LMTD Method (Logarithmic Mean Temperature Difference)
2. NTU Method (Number of Heat transfer Units)

LMTD Method is useful when the inlet and outlet fluid temperatures of condenser and air are known. NTU Method is useful when the heat exchanger is designed for the particular mass flow rate. For the given conditions LMTD Method is suitable.

1. LMTD Method:

In a heat exchanger, the temperature of the heating and cooling fluids do not in general, remain constant, but vary from point to point along the length of the heat exchanger.

Since the temperature difference between the two fluids keeps changing, the rate of heat transfer also changes along the length of the heat exchanger as shown.

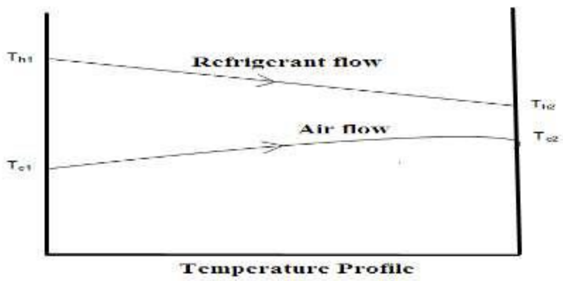

Figure 8. Temperature Profile

The rate of heat transfer can be calculated from the relation

$Q = U\ A\ \Delta T$

Since ΔT changes from point to point in a heat exchanger, we propose to use ΔTm, a suitable mean temperature difference between the two ends of a heat exchanger. The rate of heat transfer can be rewritten as

Where

ΔTm = Log Mean Temperature Difference (LMTD)

A = surface area of condenser in $m^2 = \Pi DL$

$$\Delta Tm = \frac{\Delta T1 - \Delta T2}{\ln\frac{\Delta T1}{\Delta T2}}$$

$\Delta T_1 = Th_1 - TC_1$

$\Delta T_2 = Th_2 - TC_2$

U = overall heat transfer coefficient in w/m^2k

A_0 = outside tube Area in m^2

A_i = inside tube Area in m^2

h_i = convective heat transfer coefficient of R-134(a) in $w/\ m^2k$

h_0 = convective heat transfer coefficient of Air in w/m2k = 10 $w/\ m^2k$

r_0 = outside radius of pipe in m

r_i= inside radius of pipe in m

K = thermal conductivity of copper in w/m-k

If $A_o = A_i$ the above equation can be reduced to

$U = 1/\ (1/\ h_i + 1/h_o)$

Properties of R-134(a) at bulk mean temperature at various condenser speeds are taken

Bulk mean temperature of condenser can be calculated by

= (Condenser inlet temp + Condenser outlet temp.)/2

In order to calculate convective heat transfer coefficient of R-134(a) the following steps are to be followed and the convection is of forced convection.

ReD = (pvD)/μ

Pr = (μ Cp)/K

Where

Re_D = Reynolds number

p = Density of R-134(a) in kg/m^3

v = velocity in m/sec = 3 to 4 m/sec

D= Diameter of the pipe in m

μ = viscosity in pa.s

C_p= specific heat in j/kgk

K= thermal conductivity in w/mk

Forced convection correlations in turbulent pipe flow are given by Dittus-Boelter

$NUD = 0.023ReD^{4/5}Pr^n$

$NUD = h_iD/K$

Where

D= Diameter of the pipe = 6.35x10-3m

Pr = Prandtle number

n = 0.4 for heating of the fluid and 0.3 for cooling of the fluid

The Dittus-Boelter equation is valid for

$0.7 < Pr < 160$ and $ReD > 10000$

The Dittus-Boelter equation is good approximation where temperature differences between bulk fluid and heat transfer surface are minimal.

Nusselt number:

In heat transfer at boundary (surface) within a fluid, the Nusselt number is the ratio of convective to conductive heat transfer across (normal to) boundary. Named after Wilhelm Nusselt, it is a dimensionless number.

A Nusselt number is close to one for slug or laminar flow. It varies for turbulent flow. For forced convection, the Nusselt number is generally a function of the Reynolds number and Prandtle number, or Nu = f (Re, Pr)

V. RESULTS AND DISCUSSIONS

CALCULATIONS

Existing System Temperatures with actual condenser

Compressor Suction Temperature T1 =18.1°C

Compressor Discharge Temperature T2 =56.2°C

Condensing Temperature T3 =32.8°C

Evaporator Temperature T4 =-14.1°C

Pressures

Compressor suction pressure P1 =0.98 bar

Compressor discharge pressure P2 =11.28bar

Condenser pressure P3 =11.28 bar

Evaporator pressure P4 =0.98 bar

Enthalpies

From pressure-enthalpy chart for R-134a, enthalpy values at state points 1,2,3,4. The state points are fixed using pressure and temperature and each point.
h1 = 620 kJ/kg h2 = 642 kJ/kg
h3 = 640 kJ/kg h4 = 580 kJ/kg

Calculation Performance Parameters

Net Refrigerating Effect (NRE) = h1-h4= 620-580 = 40 kJ/kg
Mass flow rate to obtain one TR, kg/min.
Mr = 210/NRE = 210/40 = 5.25 kg/min.
Work of Compression = h2-h1 =642-620 = 22 kJ/kg
Heat Equivalent of work of compression per TR
M_r x (h2-h1) = 5.25 x 22 = 115.5 kJ/min
Theoretical power of compressor =115.5/60 = 1.925 kW
Coefficient of Performance (COP) = h1-h4 /h2-h1 = 40/22 = 1.81

Helical Condenser with 250mm diameter

Compressor Suction Temperature T1 =17.3°C
Compressor Discharge Temperature T2 =47.5°C
Condensing Temperature T3 =29.4°C
Evaporator Temperature T4 =-17.2°C

Pressures

Compressor suction pressure P1 =1.28 bar
Compressor discharge pressure P2 =12.85bar
Condenser pressure P3 =12.85 bar
Evaporator pressure P4 =1.28 bar

Enthalpies

From pressure-enthalpy chart for R-134a, enthalpy values at state points 1,2,3,4. The state points are fixed using pressure and temperature and each point.
h1 = 648 kJ/kg
h2 = 656 kJ/kg
h3 = 623kJ/kg
h4 = 565 kJ/kg

Calculation Performance Parameters

Net Refrigerating Effect (NRE) = h1-h4= 648-565 = 73 kJ/kg
Mass flow rate to obtain one TR, kg/min.
Mr = 210/NRE = 210/73 = 2.876kg/min.
Work of Compression = h2-h1 =656-623 = 33kJ/kg
Heat Equivalent of work of compression per TR
M_r x (h2-h1) = 2.876 x 33 = 94.908 kJ/min
Theoretical power of compressor =94.908/60 = 1.58 kW
Coefficient of Performance (COP) = h1-h4 /h2-h1 = 73/33 = 2.21

Helical condenser with 200 Diameter:

Compressor Suction Temperature T1 =19.2°C
Compressor Discharge Temperature T2 =47.8°C
ng Temperature T3 =31.2°C
Evaporator Temperature T4 =-9°C

Pressures

Compressor suction pressure P1 =1.05 bar
Compressor discharge pressure P2 =10.2bar
Condenser pressure P3 =10.2 bar
Evaporator pressure P4 =1.05 bar

Enthalpies

From pressure-enthalpy chart for R-134a, enthalpy values at state points 1,2,3,4. The state points are fixed using pressure and temperature and each point.
h1 = 629 kJ/kg
h2 = 649kJ/kg
h3 = 606kJ/kg
h4 = 591 kJ/kg

Calculation Performance Parameters

Net Refrigerating Effect (NRE) = h1-h4= 629-591 = 38 kJ/kg
Mass flow rate to obtain one TR, kg/min.
Mr = 210/NRE = 210/38 = 5.52kg/min.
Work of Compression = h2-h1 =649-629 = 20kJ/kg
Heat Equivalent of work of compression per TR
M_r x (h2-h1) = 5.52 x 20 = 110.4 kJ/min
Theoretical power of compressor =110.4/60 = 1.84 kW
Coefficient of Performance (COP) = h1-h4 /h2-h1 = 38/20= 1.92

Table 3. Tabular column of results

S no	***Parameter***	***Existing system R-134a***	***Helical condenser with design change***	
			200 Diameter	***250 Diameter***
1	Net Refrigerating effect(KJ/Kg)	*40*	*38*	*73*

2	Mass flow rate to obtain 1TR(KJ/min)	*5.25*	*5.52*	*2.876*
3	Work of compression(KJ/kg)	*22*	*20*	*33*
4	Compressor power, KW	*1.92*	*1.84*	*1.58*
5	**Co efficient of performance**	***1.81***	***1.92***	***2.21***

PERFORMANCE OF A VAPOR COMPRESSION REFRIGERATION CYCLE

The performance of vapor compression refrigeration cycle with helical condenser and the existing condenser and variation in coil diameter has the considerable effect. To illustrate these effects the calculated values of helical condenser and various diameter of the coil have been plotted on graphs.

Effect of helical condenser coil diameter (D) on net refrigeration effect.

From the calculations it is observed that the net refrigeration effect of condenser is to be varied at different diameters of helical coil condenser is shown in bellow fig. The net refrigeration effect of helical condenser is more than the net refrigeration effect of existing condenser.

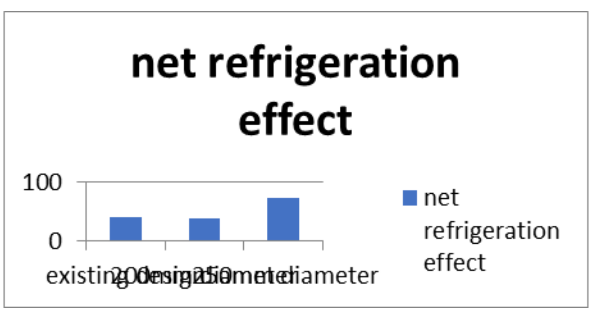

Figure 9. Effect of helical condenser coil diameter (D) on net refrigeration effect.

Effect of helical condenser coil diameter (D) on coefficient of performance.

From the calculations it is observed that the performance of the refrigeration system increases as the diameter of the coil increases and it is maximum at the 250 mm. After that the cop of system is stat to decreasing the. Due to more heat transfer sub cooling occurs at the exit of the condenser and hence the performance of the system increases.

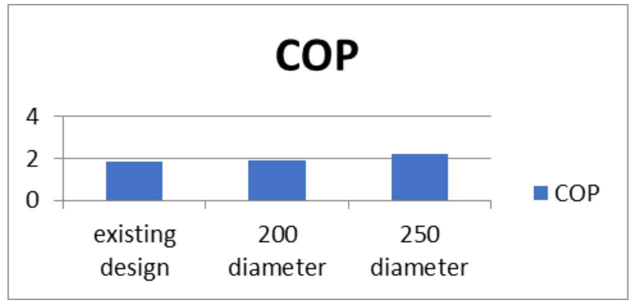

Figure 10. Effect of helical condenser coil diameter (D) on coefficient of performance.

Effect of condenser on coefficient of performance

From the above results it is observed that the net refrigeration effect of helical condenser is more than the net refrigeration effect of existing condenser and work of compression of helical condenser is less than the existing condenser than the COP of helical system is to be more than the existing condenser as shown in bellow fig.

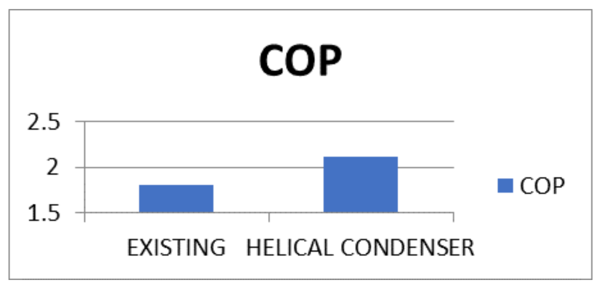

Figure 11. Effect of condenser on coefficient of performance

VI. CONCLUSION

In the present work experiments are conducted for the helical design condenser by taking different Diameter (D) of the condenser coil for a domestic refrigerator of 165 liters capacity. By incorporating the helical condenser in the refrigerator the COP enhanced by 0.4, as a result of 33 kj/kg increase in refrigeration effect and 2.37 kj/kg reduction in compressor work and increase in heat rejection 11kj/kg. The performance of helical condenser is also changed at different diameters so, design of diameter helical condenser coil plays a prominent role.

It is advantageous to provide a helical condenser at the inlet of the capillary tube and maintain the condenser pressure and the performance of vapor compression refrigeration system can be enhanced with the help of the helical condenser. Finally, it is concluded by change the shape of existing design to helical condenser the coefficient of performance is increased and heat transfer rate is increased and maximum value of heat transfer is attain at 250mm coil diameter (D).

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