Performance Analysis of Vapour Compression Refrigeration system by using Azeotrops

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Abstract— The work has been carried out to evaluate the various thermodynamic performance parameters at different Evaporator & Condenser temperature for 0.5 tone of refrigeration cooling capacity with azeotropes as a refrigerants. In the present study R-500(R-12/R-152),R-502(R-22/R115),R-503(R-23/R-13),R504(R-32/R-115),R-407C(R-32/125/134a-23/25/52), R-410A (R-32/125-50/50), R-507A ( R-125/143a – 50/50) have been tried in place of R-22. The mixture of Refrigerant were chosen on the basis of available database of thermodynamic properties is generated using experimental and analytical data’s based on the Refrigeration equation available in refrigeration data book. The single stage vapour compression refrigeration cycle calculation have been performed to ascertain the suitability of these alternate refrigerants as substitute refrigerants for which shall be phased out in near future. This analysis will be helpful to determine the selection of components (Compressor, Condenser, Evaporator and Throttle valve.) used in commercial refrigeration applications.

Key words: component, Refrigerants, Simple V.C.R.S, TR: Azeotrops

I. INTRODUCTION

Nowadays, the vapour refrigeration systems are widely used for all purposes of refrigeration. The vapour refrigeration system are being used for the last 100 years but with the advancement in design of compressors and an increase in speed has increased its economy from the last few decades . It is generally used for all industrial purposes from a small domestic unit of 0.5 TR capacities to an air-conditioning plant of cinema hall of 200 TR capacities. The basic components of V.C.R.S are Compressor, Condenser, Expansion Valve or Throttle valve and Evaporator.

The modern units of the V.C.R have several advantages over the air refrigeration system. The main advantages are smaller size for given TR of refrigeration and less operating cost. The major disadvantages of the V.C.R.S are being eliminated by improvements in design, which result greater in safety and prevention of leaks. With the development of nontoxic and non-flammable refrigerants, this is generally used for all purpose refrigeration, from the comfort cooling in air-conditioning plant and food preservation to the production of medicine which are to be preserved in very low temperatures.

Depletion of Ozone layer has arise a serious alarm to the world, which leads rising awareness among all people in order the use of CFCs and therefore various measures have been taken for minimizing CFCs emission . CFCs are used in various applications in addition to Refrigeration and Air-conditioning hence minimizing the use of CFCs is made compulsory. However various steps have been taken to develop Ozone friendly substitutes such as azeotrops to meet the eco-friendly world.

II. SIMPLE V.C.R. SYSTEM

The reversed Carnot cycle with vapour as a refrigerator may be used as a practical cycle with some modifications. A single stage V.C.R.S consist of the following four process

1. Isentropic Compression
2. Heat rejection at constant pressure
3. Throttling of liquid through Expansion valve

Out of all refrigeration systems, the vapour compression system is the most important system for commercial and domestic utility. It is the most practical form of refrigeration. In this system the working fluid is a vapour. It evaporates and condenses or changes its states between the vapour and liquid phases without leaving the refrigerating plant. During evaporation, it absorbs heat from the cold body. This heat is used as its latent heat for converting it from the liquid to vapour. In condensing, it rejects heat to external body, thus resulting a cooling effect in the working fluid. This refrigeration system thus acts as a latent heat pump since it pumps its latent heat from the cold body or brine and rejects it or delivers it to the external medium. The vapour at low temperature and pressure enters the compressor, where it is compressed isentropically due to which its temperature and pressure increases. This vapour after leaving the compressor enters the “condenser” where it is condensed into high pressure liquid and is collected in a “receiver tank”. From receiver tank it passes through the “expansion valve”, here it is throttled down to a lower pressure and has a low temperature. After passing through expansion valve, it finally passes on to “evaporator” where it absorbs heat from the space being refrigerated and vaporizes to low pressure vapors. In simple saturation cycle the vapour obtained at the end of evaporation is normally dry saturated or superheated. Wet vapour is not desirable at the outlet of an evaporator.
A. Merits and demerits of vapor compression system over Air refrigeration system:

1) Merits:
- C.O.P. is high as the working of the cycle is very near to that of reversed Carnot cycle.
- The running cost of vapour-compression refrigeration system is very low as compare to air refrigeration system.
- For the same refrigerating capacity the size of the evaporator is small.
- The desired temperature of the evaporator can be achieved just by adjusting the Throttle valve of the unit.

2) Demerits:
- Initial cost is high.
- The major disadvantages are inflammability, leakage of vapour and toxicity of refrigerant like ammonia (R 717).

B. Function of each Component of a Simple Vapor Compression System

The brief descriptions of various parts of a simple vapour compression system are as follows:-

1) Compressor - The function of a compressor is to increase the pressure and temperature of the vapour by consuming the external work.

2) Discharge line or hot vapour line - A hot gas or discharge line supplies the high-pressure & high-temperature vapour from the compressor to the condenser.

3) Condenser - The function of a condenser is to provide a heat transfer surface which results in to condensation of vapour refrigerant in high pressure liquid refrigerant.

4) Receiver tank - A receiver tank is used to provide storage for condensed liquid so that a uniform supply of refrigerant is available to the evaporator.

5) Liquid line - A liquid line carries the liquid refrigerant from the receiver tank to the throttle valve..

(6) Expansion valve or throttle valve - Its function is to regulate the supply of refrigerant to the evaporator and to reduce the pressure and temperature of liquid refrigerant. So that liquid will vaporize in the evaporator at the desired low temperature and take out maximum amount of heat.

(7) Evaporator - An evaporator provides a heat transfer surface through which heat can pass from the refrigerated space into the vaporizing refrigerant and producing refrigeration effect.

(8) Suction line - The suction line supplies the low pressure vapour refrigerant from the evaporator to Suction inlet of the compressor.

C. Vapour Compression Cycle on Temperature-Entropy (T-s) Diagram

1) When vapour is dry saturated at the inlet of compressor:

Work done by the compressor = \( W = \text{Area} \ '2-3-4-b-2' \)

Heat absorbed = \( \text{Area} \ '2-1-g-f-2' \)

\[
\text{C.O.P.} = \frac{\text{Refrigerating effect}}{\text{Work done}} = \frac{\text{Area} \ '2-1-g-f-2'}{\text{Area} \ '2-3-4-b-2'}
\]

\( (h_1 = h_4, \text{ since during the throttling expansion 4-1 the total heat content remains unchanged}) \)

a) Pressure-Enthalpy (P-h) Chart

The diagram commonly used in the analysis of the refrigeration cycle is:
- Pressure-enthalpy (P-h) chart
- Temperature-entropy (T-s) chart.
Out of which, the Pressure-Enthalpy diagram seems to be the more useful.

The condition of the refrigerant in any thermodynamic state can be represented as a point on the P-h chart. The point on the P-h chart that represents the condition of the refrigerant in anyone particular thermodynamic state may be located if any two properties of the refrigerant for that state are known, the other properties of the refrigerant for that state can be determined directly from the chart for studying the performance of the machines.

![P-h chart](image)

**Fig. 2.3: Pressure – Enthalpy (P-h) chart[25]**

The chart is dividing into three areas that are separated from each other by the saturated liquid and saturated vapour lines. The region on the chart to the left of the saturated liquid line is called the sub-cooled region. At any point in the sub-cooled region the refrigerant is in the liquid phase and its temperature is below the saturation temperature corresponding to its pressure. The area to the right of the saturated vapour line is superheated region and the refrigerant is in the form of a superheated vapour. The section of the chart between the saturated liquid and saturated vapour lines is the two phase region and represents the change in phase of the refrigerant between liquid and vapour phases. At any point between two saturation lines the refrigerant is in the form of a liquid vapour mixture. The distance between the two lines along any constant pressure line, as read on the enthalpy scale at the bottom of the chart, is the latent heat of vaporization of the refrigerant at that pressure.

The horizontal lines extending across the chart are lines of ‘constant pressure’ and the vertical lines are lines of constant enthalpy. The lines of ‘constant temperature’ in the sub-cooled region are almost vertical on the chart and parallel to the lines of constant enthalpy. In the center section, since the refrigerant changes state at a constant temperature and pressure, the lines of constant temperature are parallel to and coincide with the lines of constant pressure. At the saturated vapour line the lines of constant temperature change direction again and, in the superheated vapour region, fall of sharply toward the bottom of the chart.

The straight lines which extend diagonally and almost vertically across the super-heated vapour region are lines of constant entropy. The curved, nearly horizontal lines crossing the superheated vapour region are lines of constant volume. P-h chart gives directly the changes in enthalpy and pressure during a process for thermodynamic analysis.

**b) Factors Affecting the Performance of a Vapour Compression System**

The factors which affect the performance of a vapour compression system are given below:

1. **Effect of suction pressure**

The effect of decrease in suction pressure is shown in Fig. 1.6

The C.O.P. of the original cycle,

\[ \text{C.O.P.} = \frac{h_2 - h_1}{h_3 - h_2} \]

The C.O.P. of the cycle when suction pressure is decreased,

\[ \text{C.O.P.} = \frac{h_2' - h_1'}{h_3' - h_2'} = \frac{(h_2 - h_3) - (h_2' - h_3')}{(h_2 - h_2') + (h_2' - h_3') + (h_3' - h_3)} \]

This shows that the refrigerating effect is decreased and work required is increased. The net effect is to reduce the refrigerating capacity of the system (with the same amount of refrigerant flow) and the C.O.P.

2. **Effect of delivery pressure**

It shows the effect of increase in delivery pressure.

The C.O.P. of the original cycle,

\[ \text{C.O.P.} = \frac{h_2 - h_1}{h_3 - h_2} \]

The C.O.P. of the cycle when delivery pressure is increased,

\[ \text{C.O.P.} = \frac{h_2 - h_1'}{h_3' - h_2} = \frac{(h_2 - h_1) - (h_1' - h_1)}{(h_3 - h_2) + (h_3' - h_3)} \]
In - , of course, keeping in view the - , therefore overall effect of - - - - - ment were used. All the refrigerants - g mediums. The term - . It is seen that any of the following methods: - spent to obtain the extra cold increase of C.O.P. provided that no further energy has to be - is evident from the figure the - Fig. 1.8(b - below the condensing temperature for a given pressure - ‗Subcooling‘ is the process of cooling the liquid refrigerant below the condensing temperature for a given pressure. In - Fig. 1.8(b - the process of sub-cooling is shown by 4-4‘. As is evident from the figure the effect of sub-cooling is to - increase of C.O.P. provided that no further energy has to be - spent to obtain the extra cold coolant required. The sub-cooling or under cooling may be done by any of the following methods: - - inserting a special coil between the condenser and the expansion valve. - - circulating greater quantity of cooling water through the condenser. Using water cooler than main circulating water.

![Fig. 2.5: Effect of delivery pressure](Image)

**Fig. 2.5: Effect of delivery pressure [25]**

The effect of increasing the delivery/discharge pressure is just similar to the effect of decreasing the suction pressure. The only difference is that the effect of decreasing the suction pressure is more predominant than the effect of increasing the discharge pressure.

The following points may be noted:

- As the discharge temperature required in the summer is more as compared with winter, the same machine will give less refrigerating effect (load capacity decreased) at a higher cost.
- The increase in discharge pressure is necessary for high condensing temperatures and decrease in suction pressure is necessary to maintain low temperature in the evaporator.

(3) **Effect of superheating**

As may be seen from the Fig. 1.8 (a) the effect of superheating is to increase the refrigerating effect but this increase in refrigerating effect is at the cost of increase in amount of work spent to attain the upper pressure limit. Since the increase in work is more as compared to increase in refrigerating effect, therefore overall effect of superheating is to give a low value of C.O.P.

(4) **Effect of sub-cooling of liquid**

‗Sub-cooling‘ is the process of cooling the liquid refrigerant below the condensing temperature for a given pressure. In - Fig. 1.8(b - the process of sub-cooling is shown by 4-4‘. As is evident from the figure the effect of sub-cooling is to increase the refrigerating effect. Thus sub-cooling results in increase of C.O.P. provided that no further energy has to be - spent to obtain the extra cold coolant required.

The sub-cooling or under cooling may be done by any of the following methods:

- - inserting a special coil between the condenser and the expansion valve.
- - circulating greater quantity of cooling water through the condenser.

Using water cooler than main circulating water.

![Fig. 2.6: Effect of superheating and sub-cooling of liquid](Image)

**Fig. 2.6: Effect of superheating and sub-cooling of liquid [25]**

(5) **Effect of suction temperature and condenser temperature**

The performance of the vapour compression refrigerating cycle varies considerably with both vaporizing and condensing temperatures. Of the two, the vaporizing temperature has far the greater effect. It is seen that the capacity and performance of the refrigerating system improve as the vaporizing temperature increases and the condensing temperature decreases. Thus refrigerating system should always be designed to operate at the highest possible vaporizing temperature and lowest possible condensing temperature, of course, keeping in view the requirements of the application.

### III. Refrigerants

A ‘refrigerant’ is defined as any substance that absorbs heat through expansion or vaporization and loses it through condensation in a refrigeration system. The term ‘refrigerant’ in the broadest sense is also applied to such secondary cooling mediums as cold water or brine, solutions. Usually refrigerants include only those working mediums which pass through the cycle of evaporation, recovery, compression, condensation and liquefaction. These substances absorb heat at one place at low temperature level and reject the same at some other place having higher temperature and pressure. The rejection of heat takes place at the cost of some mechanical work. Thus circulating cold mediums and cooling mediums (such as ice and solid carbon dioxide) are not primary refrigerants. In the early day’s only four refrigerants, Air, ammonia (NH₃), Carbon dioxide (CO₂), Sulphur dioxide (SO₂), possessing chemical, physical and thermodynamic properties permitting their efficient application and service in the practical design of refrigeration equipment were used. All the refrigerants change from liquid state to vapour state during the process.

**A. Classification of Refrigerants**

The refrigerants are classified as follows:

- Primary refrigerants.
- Secondary refrigerants.

1. **Primary refrigerants** are those working mediums or heat carriers which directly take part in the refrigeration system and cool the substance by the absorption of latent heat e.g. Ammonia, Carbon dioxide, Sulphur dioxide, Methyl chloride, Methylene chloride, Ethyl chloride and Freon group etc.
(2) Secondary refrigerants are those circulating substances which are first cooled with the help of the primary refrigerants and are then employed for cooling purposes, e.g. ice, solid carbon dioxide etc. These refrigerants cool substances by absorption of their sensible heat. The primary refrigerants are grouped as follows:

- Halocarbon compounds- In 1928, Charles Kettering and Dr. Thomas Mighen invented and developed this group of refrigerant. In this group are included refrigerants which contain one or more of three halogens, chlorine and bromine and they are sold in the market under the names as Freon, Genetron, Isotron, and Areton. Since the refrigerants belonging to this group have outstanding merits over the other group’s refrigerants, therefore they find wide field of application in domestic, commercial and industrial purposes[6]

The list of the halocarbon-refrigerants commonly used is given below:

R-10 — Carbon tetrachloride (CCl₄)
R-11 — Trichloro-monofluoro methane (CCl₃F)
R-12 — Dichloro-difluoro methane (CCl₂F₂)
R-13 — Mono-bromotrifluoro methane (CBrF₃)
R-21 — Dichloromonofluoro methane (CHClF₂)
R-22 — Mono chlorodifluoro methane (CH₂F₂)
R-30 — Methylene-chloride (CH₂Cl₂)
R-32 — Difluoromethane (CH₃F)
R-40 — Methyl chloride (CH₃Cl)
R-41 — Methy fluoride (CH₃F)
R-100 — Ethyl chloride (C₂H₅Cl)
R-113 — Trichlorotrifluoroethane (C₃F₃Cl)
R-114 — Tetra-fluorodichloroethane (C₂F₆Cl₂)
R-125 — Pentfluoroethane (C₅F₁₂)
R-143a — Trifluoroeth (C₃H₃F₃)
R-152 — Difluoro-ethane (C₂H₆F₂)

- Azeotropes - The refrigerants belonging to this group consists of mixtures of different substances. These substances cannot be separated into components by distillations. They possess fixed thermodynamic properties and do not undergo any separation with changes in temperature and pressure. An azeotrope behaves like a simple substance. e.g. R500. It contains 73.8% of (R-12) and 26.2% of (R-152). Similarly R-134a h(Ref)= 148.4kJ/kg, and S (Ref)= 0.7967 Kj/kg.

R407C ( R-32/125/134a-23/25/52), R410A (R-32/125 - 50/50), R507A ( R-125/143a – 50/50).

Hydrocarbons- Most of the refrigerants of this group are organic compounds. Several Hydrocarbons are used successfully in commercial and industrial installations. Most of them possess satisfactory thermodynamic properties but are highly inflammable. Some of the important refrigerants of this group are:

R50 — Methane (CH₄)
R170— Ethane (C₂H₆)
R290— Propane (C₃H₈)
R600— Butane (C₄H₁₀)
R601— Isobutane [CH (CH₃)₂]

- Inorganic compounds—Before the introduction of hydrocarbon group these refrigerants were most commonly used for all purposes. The important refrigerants of this group are:

R717— Ammonia (NH₃)
R718— Water (H₂O)
R729— Air (mixture of O₂, N₂, CO₂ etc.)
R744— Carbon dioxide (CO₂)
R764— Sulphur dioxide (SO₂)

- Unsaturated organic compound. The refrigerants belonging to this group possess ethylene or propylene as their constituents. They are:

R1120 — Trichloroethylene (C₂H₃Cl₂)
R1130 — Dichlorethylene (C₂H₄Cl₂)
R1150 — Ethylene (C₂H₄)
R1270 — Propylene

B. Desirable properties of an ideal refrigerant:

An ideal refrigerant should possess the following properties:

1) Thermodynamic properties:

(1) Low boiling point
(2) Low freezing point
(3) Positive pressure in condenser and evaporator.
(4) High saturation temperature
(5) High latent heat of vaporization.

2) Chemical Properties:

(1) Non-toxicity
(2) Non-flammable and non-explosive
(3) Non-corrosiveness
(4) Chemical stability in reacting
(5) Non-irritating and odorless.

3) Physical Properties:

(1) Low specific volume of vapour
(2) Low specific heat
(3) High thermal conductivity
(4) Low viscosity
(5) High electrical insulation.

4) Other Properties:

(1) Ease of leakage location
(2) Availability and low cost
(3) Ease of handling
(4) High C.O.P.
(5) Low power consumption per TR
(6) Low pressure ratio and pressure difference

Some important properties (mentioned above) are discussed below:

- Freezing point - As the refrigerant must operate in the cycle above its freezing point, it is evident that the same for the refrigerant must be lower than system temperatures. It is found that except in the case of water for which the freezing point is 0°C, other refrigerants have reasonably low values. Water, therefore, can be used only in air-conditioning applications which are above 0°C.

- Condenser and evaporator pressures - The evaporating pressure should be as near atmospheric as possible. If it is too low, it would result in a large volume of the suction vapour. If it is too high, overall high pressures including condenser pressure would result necessitating stronger equipment and consequently higher cost. A positive pressure is required in order to eliminate the possibility of the
entry of air and moisture into the system. The normal boiling point of the refrigerant should, therefore, be lower than the refrigerant temperature.

- **Critical temperature and pressure** - For high C.O.P. the critical temperature should be very high so that the condenser temperature line on P-h diagram is far removed from the critical point. This ensures reasonable refrigerating effect as it is very small with the state of liquid before expansion near the critical point. The critical pressure should be low so as to give low condensing pressure.

- **Latent heat of vaporizations** - It should be as large as possible to reduce the weight of the refrigerant to be circulated in the system. This reduces initial cost of the refrigerant. The size of the system will also be small and hence low initial cost.

- **Toxicity** - Taking into consideration comparative hazard to life due to gases and vapours Underwriters laboratories have divided the compounds into six groups. Group six contains compounds with a very low degree of toxicity. It includes R12, R114, R13, etc. Group one, at the other end of the scale, includes the most toxic substances such as SO2. Ammonia is not used in comfort air-conditioning and in domestic refrigeration because of inflammability and toxicity.

- **Inflammability** - Hydrocarbons (e.g. methane, ethane etc.) are highly explosive and inflammable. Fluorocarbons are neither explosive nor inflammable. Ammonia is explosive in a mixture with air in concentration of 16 to 25% by volume of ammonia.

- **Volume of suction vapour** - The size of the compressor depends on the volume of suction vapour per unit (say per ton) of refrigeration. Reciprocating compressors are used with refrigerants with high pressures and small volumes of the suction vapour. Centrifugal or turbo-compressors are used with refrigerants with low pressures and large volumes of the suction vapour. A high volume flow rate for a given capacity is required for centrifugal compressors to permit flow passages of sufficient width to minimize drag and obtain high efficiency.

- **Thermal conductivity** - For a high heat transfer coefficient a high thermal conductivity is desirable. R22 has better heat transfer characteristics than R12; R21 is still better, R13 has poor heat transfer characteristics.

- **Viscosity** - For a high heat transfer co-efficient a low viscosity is desirable.

- **Leak tendency** - The refrigerants should have low leak tendency. The greatest drawback of fluorocarbons is the fact that they are odorless. This, at times, results in a complete loss of costly gas from leaks without being detected. An ammonia leak can be very easily detected by pungent odor.

- **Refrigerant cost** - The cost factor is only relevant to the extent of the price of the initial charge of the refrigerant which is very small compared to the total cost of the plant and its installation. The cost of losses due to leakage is also important. In small-capacity units requiring only a small charge of the refrigerant, the cost of refrigerant is immaterial. The cheapest refrigerant is Ammonia. R12 is slightly cheaper than R22. R12 and R22 have replaced ammonia in the dairy and frozen food industry (and even in cold storages) because of the tendency of ammonia to attack some food products.

  Co-efficient of performance and power per ton- Practically all common refrigerants have approximately same C.O.P. and power requirement.

- **Action with oil** - No chemical reaction between refrigerant and lubricating oil of the compressor should take place. Miscibility of the oil is quite important as some oil should be carried out of the compressor crankcase with the hot refrigerant vapour to lubricate the pistons and discharge valves properly.

- **Reaction with materials of construction** - While selecting a material to contain the refrigerant this material should be given a due consideration. Some metals are attacked by the refrigerants e.g. ammonia reacts with copper, brass or other cuprous alloys in the presence of water, therefore in ammonia systems the common metals used are iron and steel. Freon group does not react with steel, copper, brass, zinc, tin and aluminium but is corrosive to magnesium and aluminum having magnesium more than 2%. Freon group refrigerants tend to dissolve natural rubber in packing and gaskets but synthetic rubber such as neoprene are entirely suitable. The hydro generated hydrocarbons may react with zinc but not with copper, aluminium, iron and steel.

C. **CFCs and ozone hole - a global problem**

1) **Function of Ozone Layer**

  The figure below exhibits various atmospheric layers with approximate thicknesses. Thermosphere layer varies from 4-8 Km (at -40°C) at the poles to about 16-18 km (at -80°C) at the equator. In this layer the temperature decreases with altitude at a rate of 1 C/165 m of distance, known as normal lapse rate. After this layer there is the stratosphere up to 50 km. In the stratosphere up to 40 km the concentration of ozone (a gas of three atoms of oxygen) is more. This layer is called ozonosphere or mesosphere. It absorbs Ultra-Violet (U.V.) rays coming from the sun and only the beneficial light and heat rays are allowed to reach the earth surface. Thus this layer forms a protective cover for all life on the earth i.e. it is an "Aanchal" of a mother to protect her children.
2) Causes of Ozone Hole
Throughout the history of mankind, there exist several examples of creation by man vitiating the atmosphere either knowingly or unknowingly. The effects of the same are realized later affecting the creator as well as nature. As for examples

Manufacture of automobiles and locomotives as well as their uses, installation and operation of thermal and nuclear power plants and chemical and refrigeration plants, yielding tremendous amount of polluting gases. Indiscriminate felling of trees, mining, big barrages, etc. leading to eco-imbalance.

Modernization of agriculture for large output and cities for better living causing several problems and Refrigeration and air conditioning for increased productivity and better quality of life. Though the above developments were brought by engineers, technocrats and industrialists for better products and services, developers have not been guiltless of creating continuously polluting environment over past 50 years, several governments and international bodies have shown their keen interest in protecting and finding the best solution to these problems. But the same have not rendered the satisfactory solution. In addition to pollution and eco-imbalance, the ozone hole has attracted rather bigger attention of the leading international bodies. The ozone hole has developed at the South Pole. Studies conducted at Antarctica lead to alarming results. Chlorine in CFCs molecules cause depletion of ozone. As CFCs molecules reach stratosphere, they are dissociated by the sunlight into active chlorine compounds which, in turn, attack ozone, generating a chain reaction. One molecule of CFC is thus sufficient to destroy many hundreds of ozone molecules.

3) Ozone Hole Form – A Global Concern
The chlorine or CFC molecules take about 25-30 years in reaching from the earth surface to ozonosphere. It means the ozone hole problem is due to release to such molecules around 1960’s. Since then the release of these molecules have gone to around 10-20 folds. It means the problem is expected to be rather more serious in the future.

Many International/National bodies have expressed their concern leading to several meetings of a large number of representatives of various countries—The Montreal Protocol in 1987 is an important step in this direction as 46 countries signed stipulating 50% reduction in CFCs by 1998. The Montreal Protocol in its condensed version consists of the following:
Production and consumption of the fully halogenated CFCs will be frozen to 1986 levels as of 1 January, 1989, the first reduction would take effect in 1993 reducing production and consumption to 80% of the 1986 levels and the next reduction would occur in 1998 with another 30% reduction, bringing about production and consumption to a total 50% of the 1986 levels.

The special issue of IIR, Paris gives exhaustive highlight on various measures for curbing CFC emission. The Environmental protection Agency (EPA) complied with the Montreal Protocol in formulating its rule. The ozone-Depletion Factor (ODF) has been given by the controlled chemicals weighted value as though R-134a does not contribute to ozone depletion, it adds to global warming by small value.

CFCs are used in various applications such as manufacture of foams, food treatment, aerosol, etc. in addition to refrigeration and air conditioning, [2]. Hence curbing the use of CFCs may jeopardize seriously the industrial development. However, various steps have been taken to develop ozone friendly substitutes to meet requirements for manufacture of other items.
D. Various Measures for Ozone Conservation

1) Direct Measures

This method envisages developing a technique to boost ozone molecule production at faster rate such that it may compensate the depleting ozone. To meet the challenge faced by the planet the suggested methods are.

Use of Radio-Waves to produce negative chlorine ions in the stratosphere plugging ozone holes with Balloons.

The former was suggested by Physicist, Alfred Wong of the University of California, Los Angeles. The negative chlorine ions do not destroy ozone. Thus by sending powerful radio-waves from the ground to upper atmosphere, surplus electrons may be created. These electrons when combine with neutral chlorine atoms, the latter becomes negatively ionized and thus becomes harmless to ozone. To have reasonably cost effective method, the solar energy may be utilized for this purpose.

The second method is proposed by a British Organization, Ozone Help (OH). It proposes to produce ozone in the upper atmosphere. The system known as “ozonator” consists of a solar powered machine attached to a big balloon. The machine is carried to a high altitude by balloons over Antarctica where the ozone depletion has reached its highest. The machine is about the size of a large microphone and generates a charge of more than 15,000 Volts. When this charge is emitted into atmosphere, it produces significant amount of ozone by converting oxygen of the air. The proposed method envisages to carrying 100 such ozonators powered 300 small solar panels per balloon.

2) Indirect Measures

This method proposes various measures to reduce the ozone depleting sources. They are:

Development of new refrigerants suitable for substitution of common CFCs [3]. Use of CFCs with relatively low ODP


a) Development of New Refrigerants

There are tremendous efforts put forth in this direction. Du Point Company has started up a small lot production facility to produce compound that replaces CFCs for use in refrigeration applications [3]. The plant located at the company’s chambers works in Deep-water. New Jersey, USA is producing HCP - 134 a. As it has no ozone depletion potential, this is earmarked to replace CFC-12, currently used for blowing agent and refrigerant in a large number of applications such as house hold refrigerators, window and automobile air conditioners etc.

The company has invested more than US $ 30 million in the alternative research since mid-1970 and over US $ 10 million in 1987 alone. It is expected that the successful adaptation to commercial facilities for customers could start up as early as 1992. The substitute for R-11 has been searched out by MAITLAND, Ont. Canada Du Pont Co. for production of R-123 (as substitute of R-11). Its ozone depletion potential is 98% less than that of R-1 1 and can be regarded as a reasonable tolerable/compromise substitute. R-123 has been tested for centrifugal liquid chillers and found “totally compatible” [4]. Figure 1.15 shows the variation in vapour pressures of new and existing refrigerants. The saturation pressures are almost the same for high pressure ranges. But in the low temperature ranges there is a significant deviation in the saturation pressure values. The capacity of the system gets reduced by 5-6%, being tolerably low in the light of serious problems resulting from ozone hole. But these refrigerants are about 3 to 4 times costlier than the existing costs. However, with increasing manufacturing facility, the cost is expected to come down to a reasonable value.

b) Use of Low ODP Value Refrigerants

It has been proposed to substitute R- 12 by a non-azeotropic mixture of R-22/R142b. Some compounds such as R-125 (CF3, CHF2), R-143a (CHF2 CF3, and R-152a (CH3CHF2) does not contain chlorine, but they are not used as refrigerant. The other refrigerants such as R-124 (CF3, CHFC1) and R-142b (CH3 CCIF) contain chlorine, but their ozone-depletion potential (ODP) is low. They can be better tried and used as refrigerant or as substitute for high ODP CFCs applications. The screw compressor using R-22 is available for large air-conditioning and heat pump applications. This type of machines should be preferred/recommended as far as possible in place R-11 and R-12 large air-conditioning plants as its ODP is just 0.05.

c) Use of Ammonia, Mixtures of Refrigerants and Water

In the light of gravity of problems due to ozone hole, ammonia has been suggested to be "an excellent alternative". It possesses almost all desirable properties such as high enthalpy of vaporization, COP, high refrigeration efficiency, large range of operating temperatures, low cost, available in abundance and, its leakage detection is very easy. It is not miscible in oil. Hence compressor lubrication will be quite effective. But ammonia is explosive in a mixture of air in the range of 17-29% by volume, but energy of reaction is small. In principle it, is possible NH3 compressor with less than half the cylinder volume of that require parable halo-carbon refrigerant in the same pressure range for refrigeration and even much less at higher temperatures heat pump usage. An advantage can be exploited to improve the energy efficiency. The high temperature range of R-717 allows its use right from low temperature to high temperature heat pump operation. The low molecular weight enthalpy of vaporization render small pipe dimensions for a given TR] much reduced cost of valves and fittings. Water is an excellent refrigerant for substitute of CFCs [3] because it has following characteristics:

Thermal stability at high temperature. Neither toxic nor flammable. Chemically inert at high temperature. High COP and outstandingly very high enthalpy of vaporization High coefficient of heat transfer, reduced size of heat exchange construction cost. No cost of refrigerant, no leakage problem on health or environ. Very low pressure system renders light components except corrosion, etc.

The main limitation of water as a refrigerant comes from its use above 4-5 °C and tremendously high specific volume. Even in this range there are many air-conditioning applications where it can be used as refrigerant using Waste heat from steel industry, biogas plants etc.

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It is an excellent working fluid for a closed heat cycle. Its performance index (PI) defined as $P = \frac{Q}{W}$ where $Q$ is the heat rejected in condensers/work input is found to be 5 for evaporator temperature of 110°C and condensing temperature of 155°C. This value can be increased significantly by improving the sealing and water injection system. The results have shown very encouraging performance for high temperature heat pump especially for chemical processes as well, and refer.

d) Mixed Refrigerants (Azeotrops)

Its use reduces the ozone depletion potential. As an example in place of R-12 a mixture 70% R-22 and 30% R-12 renders the ODP from 1 to about 0.34. Even this technique has got positional scope. In hybrid air-conditioning operation, this mixture has been tried. The performance of the system gave encouraging response.

IV. PROBLEM FORMULATION

The theoretical model has been proposed for thermal optimum analysis of traditional refrigerant with vapor compression refrigeration system, is presented. Such a system includes compressor, condenser, expansion device and evaporator. Evaporator and condenser temperatures, their heating surface areas (frontal surface area and number of tubes), centrifugal and axial fan powers, and compressor power are among the design variables.

To study the performance of the system under various situations, and implementing the optimization procedure, a simulation program including all thermal and geometrical parameters considering R410A(R-32/125 - 50/50), R507A (R-125/143a – 50/50), R407C R407C (R-32/125/134a-23/25/52) as refrigerants have been developed and compare the result from the ground level of R-22 refrigerants. The objective function for optimization has been designed to demonstrate refrigeration processes and to investigate the effects of different types of refrigerants on the performance of theoretical cycle of refrigeration with different conditions.

Refrigerant used for comparison: R22, R410A(R-32/125 -50/50), R507A (R-125/143a – 50/50), R407C (R-32/125/134a-23/25/52)

The performance of the refrigerators has been analyzed on the basis of following parameters:

- Coefficient of performance (COP)
- Evaporation Pressure
- Pressure Ratio
- Refrigerating Effect (RE)
- Isentropic Compression Work (W)
- Coefficient Of Performance (COP)
- Refrigeration Power
- Volumetric Refrigeration Capacity (VRC)
- Suction Vapour Flow Rate (SVFR)

A. For analytical analysis, conditions are sub-cooling and super-heating.

1) Temperature range:
- Evaporator temperature: -15 to 15 °C
- Condenser temperature: 50 °C (Constant)

B. Pressure range:
- Evaporator Pressure: 0.84 bar
- Condenser Pressure: 7.7 bar

C. Mathematical expressions for parameters are

1) Theoretical analysis

$$\text{COP} = \frac{h_1-h_4}{h_2-h_1}$$

$$\text{Pressure ratio} = \frac{P_{\text{cond}}}{P_{\text{evap}}}$$

$$\text{RE} = h_1-h_4 \text{ kJ/kg}$$

$$\text{W}_{\text{comp}} = h_2-h_1 \text{ kJ/kg}$$

$$\text{VRC} = p_1\cdot\text{RE} \text{ KJm}^{-3}$$

Power per ton of refrigeration (P/TR) = $3.5 * W_{\text{comp}} / \text{RE}$ (kWTR)

$$\text{SVFR} = \frac{1}{\rho_1} \cdot \text{RE} \text{ L/S}$$

2) Conditions:

- Superheating
  $$h_1 = h_1' + c_{pv} (\Delta T_s)$$
  $$h_2 = h_2' + c_{pv} (\Delta T_s)$$

- Sub-cooling
  $$h_3 = h_3' - c_{pv} (\Delta T_s)$$

V. RESULTS AND DISCUSSION

Some improvement can be done to enhance the performance of the VCRS system from the various performance parameters point of view by providing some alternative refrigerants (Like R-22, R410a etc).

In this work, a new programing model has been proposed based upon the comparision and identifcation of HFC refrigerants to see the impact on GWP and ODP on the single stage vapour compression refrigeration system. R410A(R-32/125 -50/50), R507A (R-125/143a – 50/50), R407C (R-32/125/134a-23/25/52) are used as working fluid for comparison with conventional refrigerants R22 performance. The performance analysis has been carried out at different condensor and evopotrator temperature.

To perform these analysis frist of all thermal as well as physical properties has been identified to set the input parameters in analysing system. After setting the input parameters the number of input parameters has been identified from the theoritical point of view and converted into the program form in programing language. Analysis has been carried out and the result obtained is plotted to show the comparative study between the various alternative refrigerants on the basis of number of process parameters.

A. CASE-I: Without Superheating & Sub-Cooling

It shows the analytical analysis without superheating and subcooling for R-22,R407c, R410 a and R-507a.

The input parameters are :

1) Temperature range:

- Evaporator temperature: -15 to 15 °C
- Condenser temperature: 50 ° C (constant)

2) Pressure range:

- Evaporator Pressure: 1.03-2.18 bar; 0.84 -2 bar; 2.7-5.72 bar; 2.1- 4.96 bar
- Condenser Pressure: 7.7-12.17 bar; 7.7-13.17 bar; 18.77-30.51 bar; 16.25- 27.25 bar

So we have calculated COP, Evaporation Pressure ($P_{\text{evap}}$), Pressure Ratio, Refrigeration effect (RE), Isentropic Compression Work (W), Refrigeration Power, Volumetric

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Refrigeration Capacity (VRC), Suction Vapour Flow Rate (SVFR) for giving input parameters of R22, R410a(R-32/125 -50/50), R507a( R-125/143a – 50/50) and R407c( R-32/125/134a-23/25/52).

Fig. 5.1: COP vs. Evaporative Temperature at fixed condenser temperature (50°C).[25]

From the above curve it is observed that for a given condenser temperature $T_{\text{cond}}$, the COP increases with increasing $T_{\text{evap}}$.

But, for a given evaporator temperature $T_{\text{evap}}$ the COP decreases with increases in condenser temperature $T_{\text{cond}}$. Thus the work should have a reverse trend as compared to the COP.

The COP for R410a (R-32/125 -50/50) and R407c ( R-32/125/134a-23/25/52) for a given evaporator and condenser temperature are nearly same.

While the COP of R410a (R-32/125 -50/50) for the same set of temperatures is slightly higher.

However R410a and R407c can be used as a replacement refrigerant due to its eco-friendly properties.

Fig. 5.2: Evaporation pressure vs Evaporative Temperature at fixed condenser temperature (50°C). [25]

3) Evaporation Pressure:

Fig. 4.2 shows the plot in between evaporation pressure and evaporation temperature for listed refrigerants at constant condensation temperature. Evaporation pressure for R-410a (R-32/125 -50/50) is higher in comparison with other refrigerants.

a) Refrigerant:

R22, R410a(R-32/125 -50/50), R507a( R-125/143a – 50/50) and R407c( R-32/125/134a-23/25/52)

Fig. 5.3: Suction vapour flow rate vs. Evaporative Temperature at fixed condenser temperature (50°C).[25]

Suction Vapour Flow Rate plotted in between Suction Vapour Flow Rate and evaporation temperature for listed refrigerants at constant condensation temperature.

In this parameter R-407c (R-32/125/134a-23/25/52) plays significant role and provide excellent result.

Refrigerant: R22, R410a(R-32/125 -50/50), R507a( R-125/143a – 50/50) and R407c( R-32/125/134a-23/25/52)

Fig. 5.4: Refrigerating effect vs. Evaporative Temperature at fixed condenser temperature (50°C).[25]

4) Refrigeration Effect:

Fig. 4.4 shows the plot in between Refrigeration effect and evaporation temperature for listed refrigerants at constant condensation temperature.

From the graph it’s clear that R-410a (R-32/125 -50/50) shows significant results as compare to other refrigerants.

a) Refrigerant:

R22, R410a(R-32/125 -50/50), R507a( R-125/143a – 50/50) and R407c( R-32/125/134a-23/25/52)

b) Parameter:

Isentropic compression work, kJ kg⁻¹

Evaporator temperature : -15 to 15 °C

Condenser temperature : 50 ° C
Performance Analysis of Vapour Compression Refrigeration system by using Azeotrops

Considering the comparison of performance coefficients (COP) and pressure ratios of the tested refrigerants and also the main Environmental impacts of ozone layer depletion (ODP) and global warming, refrigerant R410A and R407C are found to be the most suitable alternatives refrigerants to R22. R410a has slightly lower coefficient of performance (COP), higher refrigerating capacity than R22. Considering the comparison of performance coefficients (COP) and pressure ratios of the tested refrigerants and also the main Environmental impacts of ozone layer depletion and global warming, refrigerant R410A and R407C are found to be the most suitable alternatives refrigerants to R22. R410a and R407c have environmental properties friendly to climate. Both have zero ODP (ozone depleting potential) & GWP (global warming potential) and global warming, refrigerant R410A and R407C are found to be the most suitable alternatives refrigerants to R22. R410a and R407c have environmental properties friendly to climate. Both have zero ODP (ozone depleting potential) & GWP (global warming potential) and also physical properties and thermodynamic performance parameters (COP, Evaporation pressure, Pressure ratio, Refrigeration effect, Isentropic Compression work, Power per ton of Refrigeration, Volumetric Refrigeration Capacity, SVFR) have been calculated by using various refrigerants in single stage vapour compression refrigeration system (0.5 TR cooling capacity) at various condenser and evaporator temperature. The various thermodynamic performance parameters of all alternate refrigerants R22, R410a (R-32/125 -50/50), R507a (R-125/134a – 50/50) and R407c (R-32/125/134a-23/25/52) in single stage vapour compression refrigeration system. The various curves are plotted.

1) Co-efficient of performance (COP):
Fig 4.1 shows the curve for COP vs. T_\text{evap} was plotted. From the Figs it is observed that for a given condenser temperature Tcond, the COP increases with increasing T_\text{evap}. But, for a given evaporator temperature Tevap the COP decreases with increased condenser temperature Tcond. Thus the work should have a reverse trend as compared to the COP. These results are as expected, because the COP= h1-h4/h2-h1, it is obvious that the COP increases with increasing evaporator temperatures, and decreasing condenser temperature.

The COP for R410a (R-32/125 -50/50) and R407c (R-32/125/134a-23/25/52) for a given evaporator and condenser temperature are nearly same while the COP of R410a (R-32/125 -50/50)for the same set of temperatures is slightly higher. However R410a and R407c can be used as a replacement refrigerant due to its eco-friendly properties (It does not have any Ozone depleting Cl atoms) at a small loss of performance from the thermodynamic point of view.

Evaporation Pressure: It shows the plot in between evaporation pressure and evaporation temperature for listed refrigerants at constant condensation temperature. Evaporation pressure for R-410a (R-32/125 -50/50) is higher in comparison with other refrigerants.

Pressure Ratio: Fig. shows the plot in between pressure ratio and evaporation temperature for listed refrigerants at constant condensation temperature. Pressure ratio for all refrigerants are having almost same value in all evaporating temperature.

Refrigeration Effect: Fig. shows the plot in between Refrigeration effect and evaporation temperature for listed refrigerants at constant condensation temperature. From the graph it’s clear that R-410a (R-32/125 -50/50) shows significant results as compare to other refrigerants.

Isentropic Compression Work: Fig. shows the plot in between Isentropic Compression Work and evaporation temperature for listed refrigerants at constant condensation temperature. Again the refrigerant R-410a (R-32/125 -50/50) and R-407c shows significant results from the replacement point of view.

Power per Ton of Refrigeration: Fig. shows the plot in between Power per Ton of Refrigeration and evaporation temperature for listed refrigerants at constant condensation temperature. From the plot it can be concluded that R-507a (R-125/143a – 50/50) and R-407c (R-32/125/134a-23/25/52) showing significant results as compare to other refrigerants.

Volumetric Refrigeration Capacity: It shows the plot in between Volumetric Refrigeration Capacity and evaporation temperature for listed refrigerants at constant condensation temperature. Drastic excellent results are obtained for R-410a (R-32/125 -50/50) refrigerant as compare to others.

Suction Vapour Flow Rate: It shows the plot in between Suction Vapour Flow Rate and evaporation temperature for listed refrigerants at constant condensation temperature. In this parameter R-407c (R-32/125/134a-23/25/52) plays significant role and provide excellent result.

VI. CONCLUSION AND FUTURE SCOPE

Based on the thermodynamic study & numerical calculation following conclusion have been drawn for Refrigerant R407C (R-32/125/134a-23/25/52), R410A (R-32/125 -50/50), R507A (R-125/143a – 50/50).

The result obtained showed that R410a and R407c have physical properties and thermodynamic Performance similar to R22. R410a has slightly lower coefficient of performance (COP), higher refrigerating capacity than R22. Considering the comparison of performance coefficients (COP) and pressure ratios of the tested refrigerants and also the main Environmental impacts of ozone layer depletion and global warming, refrigerant R410A and R407C are found to be the most suitable alternatives refrigerants to R22. R410a and R407c have environmental properties friendly to climate. Both have zero ODP (ozone depleting potential) & GWP (global warming potential) Therefore R-407 C and R- 410 A can be used as alternative...
to refrigerant R-22. COP of R410a is nearly closed to R22 in both cases with superheating & sub-cooling. This indicates that it may be a good substitute of R22. Refrigeration effect of R410a is higher than R22. Its value is nearly closed to R22 at medium evaporator temperature (about 15°C), it increase sharply (Tevap = -15°C). This shows that R410a is best suitable only for medium temperature refrigeration system. Work of compressor by using R410a & R-407c is much closer to R22 in both cases with & without superheating & sub-cooling. This indicates that both may be considered good substitute for R22. Refrigerating effect per kg of refrigerant of R410a is much higher as compared to R22. This will reduced the mass flow rate of refrigerant for 1 ton refrigerating effect. Thus, it will reduce the cost of the system. Heat rejected in the condenser is decreased in both alternative refrigerants (R410a & R407c). Hence, load on condenser will decrease & life of condenser will increased. Due to lesser amount of heat to be rejected use same condenser, the condensing temperature & pressure & hence discharge temperature will be lowered. The discharge temperature influences the stability of the lubricant & compressor components. The discharge temperature of this alternative refrigerant R410a is founds to be closed to R22. This means the longer compressor life time can be expected & no major change is required in the compressor. Comparing all results it appears that R-410a is the best substitute choice for R-22.

B. Future Scope

After performing comparative study some replaceable refrigerants has been found for R22, but not satisfying each and every constrained. So future analysis can be focused on the numbers of Azeotrope’s. Practical validation of the proposed refrigerants is still remained, so future work can be focus on practical work. The performance can also be carried out using Heat exchanger at the inlet and out of the compressor, considering Sub cooling at the high pressure and superheating at the low pressure of Refrigerants. Stakeholders in the refrigeration & air-conditioning industry now face the challenge & opportunity to address the requirement of the Montreal protocol & Kyoto protocol in the professional manner by selecting a low or zero ozone depleting refrigerants with a minimal global warming potential, without compromising system reliability, energy consumption or safety. All new refrigerants analysis in this report are alternatives to R22 with no major drawback & it is recommended in future and also supported by a broad base of service capability & experience. The challenge therefore is to developed acceptable plans the lead directly to environmentally acceptable long-term solutions, with time frames that are consistent with international organizations.

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