Exergy Analysis Of Vapour Compression Refrigeration System By Using Ecofriendly Refrigerants

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Abstract*- In this work, the exergy performance assessment of a domestic refrigeration system has been theoretically assessed with R152a as an alternative refrigerant to R134a. The exergy performance assessment of the refrigerator was made for three condensing temperatures 40oC, 50oC and 60oC with evaporator temperatures between -50oC and 5oC.The assessment was made in terms of standard exergy performance parameters such as exergetic efficiency, exergy destructions, efficiency defect, exergy performance coefficient and EDR in the system. The overall efficiency defect in the refrigeration cycle working with R152a is consistently better than that of R134a. It has also been found that at higher evaporating temperatures, the exergy losses are maximal for the refrigerants in the four components. The results indicate that the exergetic efficiency for R152a is higher in comparison with R134a. The results confirmed that the new refrigerant is an exergy efficient and environment friendly alternative to R134a in domestic refrigerators.*

Keywords- R134a, R152a, domestic refrigeration system, exergy performance

I. INTRODUCTION

The continuous depletion of the ozone layer, which shields the earth's surface from UV radiation, has resulted in a series of international treaties demanding a gradual phase out of halogenated fluids. The chlorofluorocarbons (HCFCs) are bound to be prohibited in the near future. The HFCs (hydro fluorocarbons) are candidates for the definite substitution of both CFCs and HCFCs, as they do not contain chlorine. A further problem is the green house effect stemming from the infrared radiation capture by some components of the atmosphere. Human activities have considerably increased the concentration of green house gases (CFC, HCFC, CO2, methane, nitrous oxide) that determine the earth's surface and atmosphere warming that might adversely affect the natural eco system. Over the last hundred years, the mean temperatures have increased by 0.3-0.6^{o}c and doubling the amount of carbon dioxide in the atmosphere is likely to yield a further temperature increase from 1.5 to 4.5^{o}c. in particular it is well known that the green house effect resulting from an operating plant is not a secondary matter. Recent estimates indicate that the overall contribution both direct and indirect to the green house effect of HCFCs and CFCs exceeds 24%. So, the choice of the working fluids in the vapour compression plant must depend on both the absence of chlorine atoms in the molecule (ODP equal to zero) and their contribution to the green house effect (low GWP and high energy efficiency). The phase out of fully halogenated CFCs and the partially halogenated HCFCs is an irreversible process in the industrialized world but the problems of their replacement have been only partially solved.

Thermodynamic processes in refrigeration system release large amounts of heat to the environment. Heat transfer between the system and the surround environment takes place at a finite temperature difference, which is a major source of irreversibility for the cycle. Irreversibility causes the system performance to degrade. The losses in the cycle need to be evaluated considering individual thermodynamic processes that makeup the cycle. Energy analysis is still the most commonly used method in the analysis of thermal systems. The first law is concerned only with the conservation of energy and it gives no information on how where and how much the system performance is degraded. Exergy analysis is a powerful tool in the design optimization and performance evaluation of energy systems.

Montreal Protocol

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

1) Developed countries will phase out CFCs by 1996.
2) Developing countries will phase out CFCs by 2010 with freeze in 1999 and gradual reduction thereafter. Developed

countries will phase out HCFCs by 2030 while developing countries have been provided a grace period of ten years i.e. phase out by 2040.

3) Global warming is another serious issue. Some naturally occurring substances mainly cause this but CFCs have very large global warming potential. [1].

Chemically stable chlorofluorocarbon (CFC) refrigerant molecules remain for a very long time in the atmosphere. Therefore reach the ozone layer in the stratospheric area an energetic UV photon strikes the CFC molecule. The energy of the impact releases a chlorine atom, which is chemically very active and reacts with an ozone molecule. Through this interaction the ozone molecule is destroyed. This is a complicated chain reaction leading to the ozone hole. Health and environmental effects of ozone depletion can be multifarious. Because biological life on this planet evolved only after the ozone shield developed, enormous potential for harm exists if the shield is damaged.

The Global Warming Effect

The earth and its atmosphere get heated as they continuously receive suns energy in the form of high frequency radiation. Thus a delicate balance exists between the energy received and that returned to the outer space. The temperature of the earth depends on this. Many gases such as CO, methane (CH), NITROUS OXIDE (NO), various hydrocarbons, CFCs, HCFCs, HFCs, etc., are released by mankind due to various agricultural and industrial activities. These gases called green house gases act as a screen blocking out part of the infrared radiation of the earth towards outer space. Water vapour is also a powerful green house gas but is not harmful as it is condensable and cannot build up in the atmosphere. This is the reason that HFCs, even though are safe from the ozone depletion point of view are increasingly being blamed for contributing to the global warming. In fact man and animals emit significant amounts of GHGs due to their metabolic activity. Methane is a potent greenhouse gas produced by ruminant animals, such as dairy cows. Animal agriculture is responsible for more greenhouse gases than all of transportation.

Kyoto Protocol

Kyoto protocol aims at phasing out of substances that will lead to global warming. And R134a is used in domestic refrigerator and other vapour compression systems as it was identified as a replacement to CFC-12, keeping in view its zero ozone depleting potential. R134a has 1300 global warming potential per 100 year, which is very high. The sale of R134a reported to AFEAS 1970-2003 [2] is significantly increasing during the past two decades. The increased emission of R134a to the atmosphere are steadily increasing the concentration of green house gases via leaks and mostly, in an indirect way, via energetic performance of refrigeration plant. This will lead to adverse climatic problem. Hence, R134a is one of the six chemicals in the ―basket‖ that are to be phased out in the near future under Kyoto protocol.

The GWP depends on the following factors:

- The absorption of infrared radiation by a given species
- The spectral location of its absorbing wavelengths
- The atmospheric lifetime of the species

Thus a high GWP correlates with a large infrared absorption and a long atmospheric lifetime. The dependence of GWP on the wavelength of absorption is more complicated. Even if a gas absorbs radiation efficiently at a certain wavelength this may not affect its GWP much if the atmosphere already absorbs most radiation at that wavelength. A gas has the most effect if it absorbs in a window of wavelengths where the atmosphere is fairly transparent.

II. LITERATURE REVIEW

Reddy et al. [3] performed numerical analysis of vapour compression refrigeration system using R134a, R143a, R152a, R404A, R410A, R502 andR507A, and discussed the effect of evaporator temperature, degree of sub-cooling at condenser outlet ,superheating of evaporator outlet, vapour liquid heat exchanger effectiveness and degree of condenser temperature on COP and exergetic efficiency. They reported that evaporator and condenser temperature have significant effect on both COP and exergetic efficiency and also found that R134a has the better performance while R407C has poor performance in all respect.

Bolaji et al. [4] had done experimentally comparative analysis of R32, R152a and R134a refrigerants in vapour compression refrigerator and concluded that R32shows lowest performance whereas R134a and R152a showing nearly same performance but best performance was obtained of system using R152a.

B.O. Bolaji [5] discussed the process of selecting environmental-friendly refrigerants that have zero ozone depletion potential and low global warming potential. R23 and R32 from methane derivatives and R152a, R143a, R134a and R125 from ethane derivatives are the emerging refrigerants that are nontoxic, have low flammability and environmental-friendly. These refrigerants need theoretical and experimental analysis to investigate their performance in the system.

Bukola O. Balaji et al [6] investigated the exergetic performance of R12 and its substitute (R134a and R 152a) in the domestic refrigerator. R152a performed better than R134a in terms of COP, exergetic efficiency and efficiency defect as R12 substitute in domestic refrigeration system.

B.O Bolaji [7] performed experimental study of R152a and R32 to replace R134a in a domestic refrigerator. According to the result of the experiments, the average COP obtained using R152a is 4.7% higher than that of R134a.

Park et al [8] tested two pure hydrocarbons and seven mixtures composed of propylene, propane, HFC152a and dimethylether as an alternative to HCFC22 in residential air conditioners and heat pumps. Their experimental results show that the coefficient performance (COP) of this mixture was up to 5.7% higher than that of HFC22.

Selvaraju [9] et al. (2004) did the analysis of an ejector with environment friendly refrigerants. Comparison of performance of the system with environment friendly refrigerants (R134a, R152a, R290, R600a and R717) is made. Among the working fluids considered, the system with R134a gives better performance.

Sun D.W [10] et al. (1999) did comparative study of the performance of an ejector refrigeration cycle operating with various refrigerants. The results show that steam jet systems have very low coefficient of performance values, the system using R152a as refrigerant has better performance.

Ki-Jung Park [11] et al. analyzed performances of two pure hydrocarbons and seven mixtures composed of propylene, propane, R152a, and dimethylether were measured to substitute for R22 in residential air-conditioners and heat pumps at the evaporation and condensation temperatures of 7 °C and 45 °C, respectively. Test results show that the coefficient of performance of these mixtures is up to 5.7% higher than that of R22. Whereas propane showed 11.5% reduction in capacity, most of the fluids had a similar capacity to that of R22. For these fluids, compressor-discharge temperatures were reduced by 11–17 °C. For all fluids tested, the amount of charge was reduced by up to 55% as compared to R22. Overall, these fluids provide good performances with reasonable energy savings without any environmental problem and thus can be used as long-term alternatives for residential air-conditioning and heat-pumping applications.

Mao-Gang He[12] et al. analyzed that the R152a/R125 mixture in the composition of 0.85 mass fraction of R152a has a similar refrigeration performance with the existing refrigerant R12. Experimental research on the main refrigeration performances of domestic refrigerators was conducted, under the different proportions and charge amounts, when R152a/R125 is used to substitute R12 as a ‘‘drop-in’’ refrigerant. The experimental results indicate that R152a/R125 can be used to replace R12 as a new generation refrigerant of domestic refrigerators, because of its well environmentally acceptable properties and its favourable refrigeration performances.

A.S. Dalkilic [13] et al. studied the performance on a VCRS with refrigerant mixtures based on R134a, R152a, R32, R290, R1270, R600 and R600a was done for various ratios and their results are compared with R12, R22 and R134a as possible alternative replacements. The results showed that all of the alternative refrigerants investigated in the analysis have a slightly lower COP than R12, R22, and R134a for the condensation temperature of 50 °C and evaporating temperatures ranging between −30 °C and 10 °C. Refrigerant blends of R290/R600a (40/60 by wt. %) instead of R12 and R290/R1270 (20/80 by wt. %) instead of R22 are found to be replacement refrigerants among other alternatives.

Ki-Jung Park [14] et al. analyzed thermodynamic performance of two pure hydrocarbons and seven mixtures composed of propylene (R1270), propane (R290), R152a, and dimethylether (R170) was measured in an attempt to substitute R22 in residential air-conditioners. The pure and mixed refrigerants tested have GWP of 3–58 as compared to that of CO2 at the evaporation and condensation temperatures of 7 and 45 °C, respectively. Test results show that the COP of these mixtures is up to 5.7% higher than that of R22. Whereas propane showed 11.5% reduction in capacity, most of the fluids had the similar capacity to that of R22. Compressor discharge temperatures were reduced by 11–17 °C with these fluids. There was no problem found with mineral oil since the mixtures were mainly composed of hydrocarbons. The amount of charge was reduced up to 55% as compared to R22.

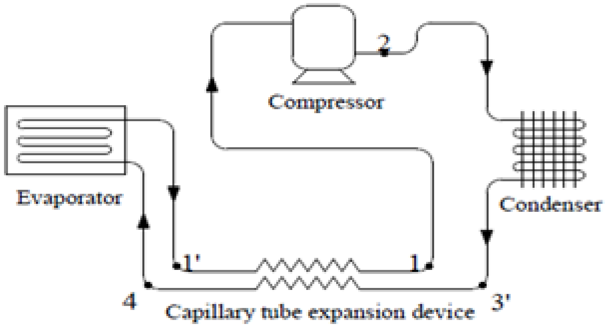
III. VAPOUR COMPRESSION REFRIGERATION

Out of all refrigeration systems, the vapour compression is the most important system from the view point of commercial and domestic utility. It is the most practical form of refrigeration. In this system the working fluid is vapour. It readily evaporates and condenses or changes alternately between the vapour and liquid phases without leaving the refrigerating plant. During evaporation, it absorbs heat from cold body. This heat is used as its latent heat for converting it from the liquid to vapour. In condensing or cooling or liquefying, it rejects heat to external body, thus creating 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 hot body or cooling medium. The principle upon which the vapour compression system works apply to all the vapour for which tables of thermodynamic properties are available.

Refrigeration System Components:

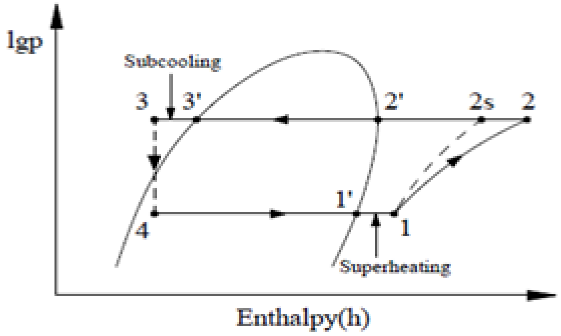
There are five basic components of a refrigeration system, these are:

- Compressor
- Condenser
- Expansion Valve
- Evaporator



shematic diagram of refrigerator cycle

Vapour Compression Refrigeration system



Pressure- Enthalpy Diagram

P-H diagram of VCR system

Compressor:

The purpose of the compressor is to draw the low temperature, low pressure vapour from the evaporator via the suction line. Once drawn, the vapour is compressed. When vapour is compressed it rises in temperature. Therefore the compressor transforms the vapour from a low temperature vapour to a high temperature vapour, in turn increasing the pressure. The vapour is then released from the compressor in to the discharge line.

Condenser:

The purpose of the condenser is to extract heat from the refrigerant to the outside air. The condenser is usually installed on the reinforced roof of the building, which enables the transfer of heat. Fans mounted above the condenser unit are used to draw air through the condenser coils. The temperature of the high pressure vapour determines the temperature at which the condensation begins. As heat has to flow from the condenser to the air, the condensation temperature must be higher than that of the air usually between - 12°C and -1°C. The high pressure vapour within the condenser is then cooled to the point where it becomes a liquid refrigerant once more, while retaining some heat. The liquid refrigerant then flows from the condenser in to the liquid line.

Expansion Valve:

Within the refrigeration system, the expansion valve is located at the end of the liquid line before the evaporator. The high pressure liquid reaches the expansion valve having come from the condenser. The valve then reduces the pressure of the refrigerant as it passes through the orifice which is located inside the valve. On reducing the pressure, the temperature of the refrigerant also decreases to a level below the surrounding air. This low pressure, low temperature liquid is then pumped in to the evaporator.

Evaporator:

The purpose of the evaporator is to remove unwanted heat from the product, via the liquid refrigerant. The liquid refrigerant contained within the evaporator is boiling at a low pressure. The level of this pressure is determined by two factors:

- The rate at which the heat is absorbed from the product to the liquid refrigerant in the evaporator.
- The rate at which the low-pressure vapour is removed from the evaporator by the compressor

To enable the transfer of heat, the temperature of the liquid refrigerant must be lower than the temperature of the product being cooled. Once transferred, the liquid refrigerant is drawn from the evaporator by the compressor via the suction line. When leaving the evaporator coil the liquid refrigerant is in vapour form.

IV. EXERGY ANALYSIS

Exergy analysis has two advantages over the conventional heat balance method for design and performance analysis of energy related systems. It provides a more accurate measurement of the actual inefficiencies in the system and the true location of these in efficiencies. In refrigeration cycle, with the heat balance analysis, it is not possible to find out the true losses. Exergy analysis is based on the assumption that there is an infinite equilibrium environment that ultimately surrounds all systems that are to be analyzed. The exergy or available energy of a system is the maximum work that could be derived if the system were allowed to come to equilibrium with the environment. It is a consequence of the second law of thermodynamics that the combined exergy of all systems can only decrease or remain unchanged. Unlike energy, exergy is not conserved, once it is lost, it is lost forever. In other words, exergy (quality) is degradable, while energy (quantity) is conserved. Exergy can be exchanged between systems, but if there are thermodynamic irreversibility's such as, friction or heat transfer with finite temperature differences, some of the potential for the production of work is destroyed. In all real processes, therefore, the total exergy of the system decreases.

For a specified system boundary a clear distinction can be made between exergy destruction and exergy loss. Exergy loss is exergy that is passed on to some other system often the environment and which cannot be considered useful in the context of the purpose of the system. The term exergy destruction is used when the potential for the production of work is destroyed within the system boundary. The exergy of a system is a co-property of the system and the environment. In exergy analysis of compressors the environment consists of the local surroundings of the compressor. These local surroundings are model as being in equilibrium and infinite. Given sufficient information, the exergy of all the systems can be determined at any time.

Thermodynamic analysis

A schematic diagram of a vapor compression refrigeration cycle used in domestic refrigerators and its pressure enthalpy diagram with liquid sub cooling and vapor superheating are depicted in the in Fig. 1 a and b, respectively. The domestic refrigerators are using capillary tube expansion device. Processes, 1-2, 2-3, 3-4 and 4-1 represent the various processes such as compression, condensation, expansion and evaporation, respectively. Processes 1-1′, and 3-3′ represent the superheating and sub-cooling processes, respectively. Points 1, 2, 3 and 4 represent the thermodynamic state of the refrigerant at compressor inlet (superheated vapor at evaporator pressure), compressor outlet (superheated vapor at condenser pressure), condenser outlet (sub cooled liquid at condenser pressure) and two phase fluid at evaporator pressure. The performance of the system is theoretically assessed in terms of exergy aspects based on the second law of thermodynamics.

The following assumptions are made based on the preliminary experiments with 180 liter domestic refrigerator using R134a.

i The compressor isentropic efficiency (η_{ise}) and volumetric efficiency (η_{vol}) are 0.75,
ii The compressor mechanical and motor efficiency are 0.85.
iii Compressor speed (N) is assumed as 2800 rpm,
iv Compressor stroke volume (V_{dis}) is 5 cm^3/rev.
vi Sub cooling and super heating are 5°C. The super heating and sub cooling take place in the evaporator and in the condenser, respectively and in the capillary tube.

The property values obtained from REFPROP have been used for predicting the performance of the refrigerator.

Coefficient of performance (COP)

On the basis of first law, the performance of refrigeration cycle is based on the coefficient of performance, which is defined as the ratio of net refrigerating effect (cooling/heating load) obtained per unit of power consumed. It is expressed as:

Coefficient of performance (COP)

COP is defined as the ratio of refrigeration effect to the compressor work for the VCR cycle.

$$COP = \frac{Refrigeration\ Effect}{Compressor\ work} \quad (1)$$

$$= Q_L/W$$

Isentropic efficiency,

$$\eta_{comp.} = \frac{W_{isen}}{W} = \frac{h_{2s}-h_1}{h_2-h_1} \quad (2)$$

<u>Compressor</u>:

$$\dot{E}_{x_{in}} - \dot{E}_{x_{out}} - \dot{E}_{x_{dest,1-2}} = 0$$
$$\dot{E}_{x_{dest,1-2}} = \dot{E}_{x_{in}} - \dot{E}_{x_{out}}$$
$$\dot{E}_{x_{dest,1-2}} = \dot{W} + \dot{E}_{x_1} - \dot{E}_{x_2}$$
$$\dot{E}_{x_{dest,1-2}} = \dot{W} - \Delta\dot{E}_{x_{12}}$$
$$\dot{E}_{x_{dest1-2}} = \dot{W} + m[(h_1 - h_2) - T_0(s_1 - s_2)]$$

(or)

$$\dot{E}_{x_{dest1-2}} = T_0\dot{s}_{gen_{1-2}} = \dot{m}T_0(s_2 - s_1)$$

$$\eta_{ex,comp} = \frac{W_{rev}}{W} = 1 - \frac{\dot{E}_{x_{dest,1-2}}}{W} \qquad (3)$$

<u>Condenser:</u>

$$\dot{E}_{x_{dest,2-3}} = \dot{E}_{x_{in}} - \dot{E}_{x_{out}}$$

$$\dot{E}_{x_{dest,2-3}} = \left(\dot{E}_{x_2} - \dot{E}_{x_3}\right) - \dot{E}_{x_{QH}}$$

$$= \dot{m}[(h_2 - h_3) - T_0(s_2 - s_3)] - \dot{Q}_H\left(1 - \frac{T_0}{T_H}\right)$$

(or)

$$\dot{E}_{x_{dest,2-3}} = T_0\dot{S}_{ger_{2-3}} = \dot{m}T_0\left(s_3 - s_2 + \frac{q_H}{T_H}\right)$$

$$\eta_{ex,cond} = \frac{\dot{E}_{x_{QH}}}{\dot{E}_{x_2} - \dot{E}_{x_3}} = \frac{Q_H\left(1 - \frac{T_0}{T_H}\right)}{\dot{m}[h_2 - h_3 - T_0(s_2 - s_3)]}$$

$$\eta_{ex,cond} = 1 - \frac{\dot{E}_{x_{dest2-3}}}{\dot{E}_{x_2} - \dot{E}_{x_3}} \qquad (4)$$

<u>Expansion valve:</u>

$$\dot{E}_{x_{dest3-4}} = \dot{E}_{x_{in}} - \dot{E}_{x_{out}}$$

$$\dot{E}_{x_{dest3-4}} = \dot{E}_{x_3} - \dot{E}_{x_4} = \dot{m}[(h_3 - h_4) - T_0(s_3 - s_4)]$$

$$\dot{E}_{x_{dest,3-4}} = T_0\dot{S}_{gen_{3-4}} = \dot{m}T_0(s_4 - s_3)$$

$$\eta_{exp.valve} = 1 - \frac{E_{x_{dest,3-4}}}{E_{x_3} - E_{x_4}} \qquad (5)$$

<u>Evaporator:</u>

$$\dot{E}_{x_{dest,4-1}} = \dot{E}_{x_{in}} - \dot{E}_{x_{out}}$$

$$\dot{E}_{x_{dest.4-1}} = -\dot{E}_{x_{QL}} + \dot{E}_{x_4} - \dot{E}_{x_1}$$

$$\dot{E}_{x_{dest,4-1}} = \left(\dot{E}_{x_4} - \dot{E}_{x_1}\right) - E_{x_{QL}}$$

$$= \dot{m}[(h_4 - h_1) - T_0(s_4 - s_1)] - [-Q_L(1 - \frac{T_0}{T_L})]$$

$$= \dot{m}[(h_4 - h_1) - T_0(s_4 - s_1)] + Q_L(1 - \frac{T_0}{T_L})$$

(Or)

$$\dot{E}_{x_{dest,4-1}} = T_0\dot{S}_{gen,4-1} = \dot{m}T_0\left(s_1 - s_4 - \frac{q_L}{T_L}\right)$$

$$\eta_{exs.\ Evp.} = \frac{\dot{E}_{x_{QL}}}{E_{x_4} - E_{x_1}} = \frac{-Q_L(1 - \frac{T_0}{T_L})}{\dot{m}[(h_4 - h_1) - T_0(s_4 - s_1)]}$$

$$= 1 - \frac{E_{x,dest4-1}}{E_{x_4} - E_{x_1}} \qquad (6)$$

Total exergy destruction in the cycle,

$$\dot{E}_{x_{dest\ total}} = \dot{E}_{x_{dest1-2}} + \dot{E}_{x_{dest2-3}} + \dot{E}_{x_{dest3-4}} + \dot{E}_{x_{dest4-1}}$$

$$\dot{E}_{x_{dest\ total}} = \dot{W} - \dot{E}_{x_{QL}} \qquad (7)$$

$$\dot{E}_{x_{QL}} = -Q_L\left(1 - \frac{T_0}{T_L}\right) \qquad (8)$$

$$\dot{W}_{min} = \dot{E}_{x_{QL}} \qquad (9)$$

The second law efficiency (or exergy efficiency) of cycle

$$\eta_{exergy} = \frac{E_{x_{QL}}}{W} = \frac{W_{min}}{W} = 1 - \frac{E_{x_{dest\ total}}}{W} \qquad (10)$$

Exergetic performance coefficient (EPC)

EPC gives information about the total exergy destruction rate (or loss rate of availability) in order to produce a certain amount of exergy output. The EPC objective function for a VCR system is defined as the ratio of exergy output to the total exergy destruction

.
$$EPC = \frac{\varepsilon}{1 - \varepsilon} \qquad (11)$$

Exergy Destruction Ratio (EDR)

Exergy Destruction Ratio is the ratio of the total exergy destruction in the system to the exergy in the product.

$$EDR = \frac{ED_{total}}{EP}(or)\left(\frac{1}{\eta_{ex.}} - 1\right) = \left(\frac{1-\varepsilon}{\varepsilon}\right) \qquad (12)$$

$$EP = Q_e\left|1 - \frac{T_o}{T_r}\right| \qquad (13)$$

Efficiency Defect

Efficiency defect is defined as the ratio between the exergy flow destroyed in each component and the exergy flow required to sustain the process.

$$\delta^i = \frac{\dot{X}_i}{Wc} \qquad (14)$$

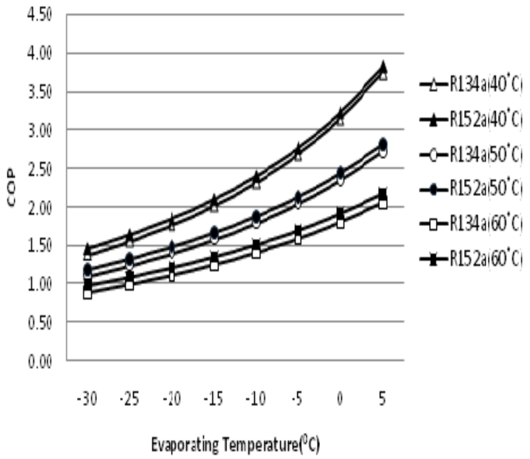
$$\Sigma\delta^i = \frac{\Sigma\dot{X}_i}{Wc} = \frac{\dot{X}_t}{Wc}$$

$$\eta_x = (1 - \Sigma\dot{X}_i)*100\% \qquad (15)$$

V. RESULTS AND DISCUSSIONS

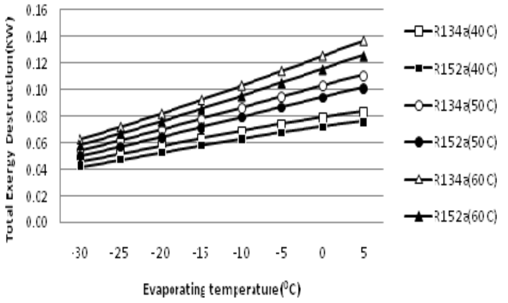
In this section, the exergy performance parameters are calculated from the results for the refrigerants using the different equations (1) - (15) and discussed. The comparison of Co efficient of performance (COP), exergy destruction, exergy efficiency, efficiency defect in different components, Exergy destruction ratio (EDR) and Exergy performance coefficient (EPC) are given below for R134a and R152a.

5.1Variation of Coefficient of performance On Evaporating Temperature



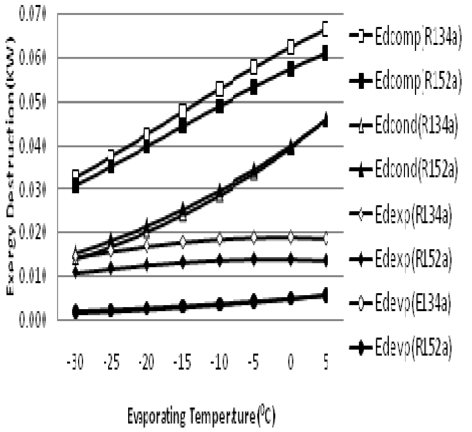
The COP of the two refrigerants is compared in Fig. 2. The COP of R152a is higher than that of R134a by about 3.60%, 5.78% and 8.62% at 40, 50 and 60°C, respectively due to its lower compressor power consumption and higher evaporator capacity. The COP of both R134a and R152a increases by about 132.58-171.51% with an increase in evaporator temperature from −30 to 5°C for the considered range of condensing temperatures.

5.2 Variation of Total Exergy Losses on Evaporating Temperature



Exergy loss increases as the temperature of the evaporator decreases as shown in Figure 3. Among the two refrigerants, R152a exhibits minimum exergy loss. The exergy loss is minimum at higher evaporating temperature, when compared to lower evaporating temperature. The average exergy loss for R152a is 8.15%, 7.82% and 7.30% at 40, 50 and 60°C, respectively lower than that of R134a. The exergy loss of both R134a and R152a decreases by about 80.85-118.49% with an increase in evaporator temperature from −30 to 5°C for the considered range of condensing temperatures

5.3 Variation of Exergy Losses on Evaporating Temperature in Different Components



Exergy losses in the individual components for Refrigerant R152a and R134a are shown in Figure 4 at condensing temperatures 40^0C, 50^0C and 60^0C respectively. Greater portion of exergy losses take place in the compressor. Evaporator has lower exergy losses compared to the other components.

5.4 Variation of Exergy Efficiency on Evaporating Temperature

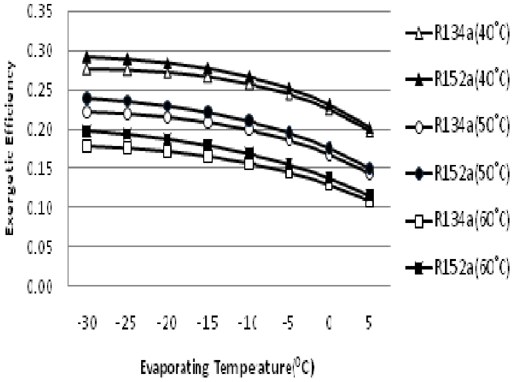


Figure 5 shows the effect of evaporator temperatures on exergetic efficiency (η_{ex}) with increases in evaporator temperature. Exergetic efficiency increases till the optimum evaporator temperature and beyond the optimum temperature decrease. The optimum evaporator is the temperature at which maximum exergetic efficiency is achieved. The increasing and decreasing of exergetic efficiency depends upon the two factors, first factor is the exergy of cooling effects i.e. Q_e (1-(T_o/T_e)). With increase in evaporator temperatures, Q_e increases while the term (1-(T_o/T_e)) reduces. Second factor is the compressor work required by compressor W which decreases with increase in evaporator temperature. The term Q_e and W have positive effect on increase of exergetic efficiency while the term (1-(T_o/T_e)) have negative effect on increase of exergetic efficiency. The combined effect of these two factors, increases exergetic efficiency increases till the optimum evaporator temperature and beyond the optimum temperature decrease. The average exergy efficiency for

R152a is 8.15%, 7.82% and 7.30% at 40, 50 and 60°C, respectively higher than that of R134a.The Exergy Efficiency of both R134a and R152a increases by about 40.09-72.28% with an increase in evaporator temperature from −30 to 5°C for the considered range of condensing temperatures

5.5 Variation of Total Exergy Losses on Condensing Temperature

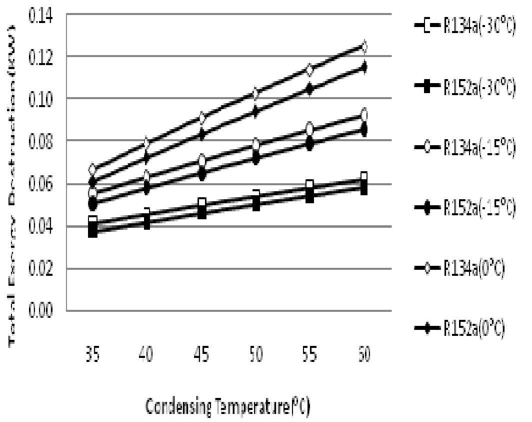
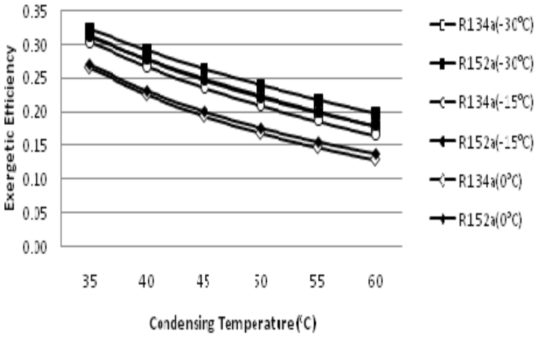


Figure 6 shows that the exergy losses are increased with the increase of condensing temperature for all the refrigerants. It is obvious because higher the temperature difference between the ambient and the component the higher the exergy losses. Availability of work is also increased. The average exergy loss for R152a is 7.02%, 7.80% and 8.46% at 40, 50 and 60°C, respectively lower than that of R134a. The exergy loss of both R134a and R152a increases by about 53.30-90.34% with an increase in condenser temperature from 35 to 60°C for the considered range of evaporating temperatures

5.6 Variation of Exergy Efficiency on Condensing Temperature



It is observed that with the increase of condensing temperature, irreversibility also increases for all the refrigerants. Variation of exergetic efficiency with condenser temperature for R152a compared with R134a is shown in Fig.7. The average exergy Efficiency for R152a is 6.98%, 5.28% and 3.85% at 40, 50 and 60°C, respectively higher than that of R134a. Exergetic efficiency decreases with increase in condenser temperature. The Exergy efficiency of both R134a and R152a increases by about 63.12-105.98% with an increase in condenser temperature from 35 to 60°C for the considered range of evaporating temperatures

5.7 Variation of Efficiency Defect in Compressor

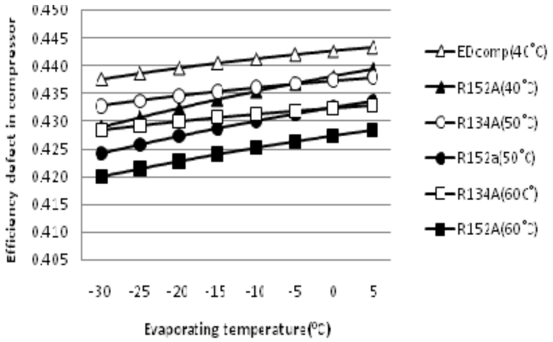


Figure 8 shows the comparison of efficiency defect in compressor for R134a with R152a varying evaporator temperature. As shown in the figure, the efficiency defect in compressor decreases with decrease in evaporator temperature exemption for R134a. The result obtained shows that the average efficiency defect in compressor is 1.41%, 1.48% and 1.50% at 40, 50 and 60°C, respectively lower for R152a respectively in comparison with that of R134a. The Efficiency defect in compressor of both R134a and R152a decreases by about 1.04-2.42% with an increase in evaporator temperature from −30 to 5°C for the considered range of condensing temperatures

5.8Variation of Efficiency Defect in Condenser

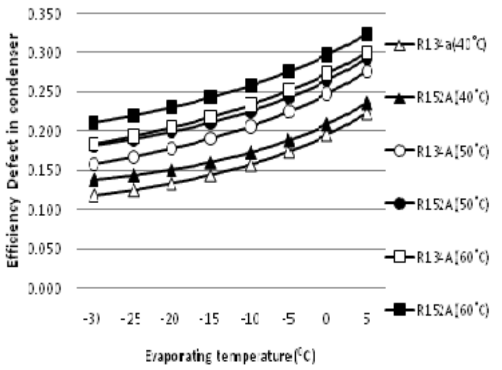


Figure 9 shows the variation of efficiency defect in condenser with evaporator temperature for R134a and R152a. As shown in the figure, efficiency defect in condenser decreases with increase in evaporator temperature. The result obtained showed that the average efficiency defect in condenser is 10.78%, 10.30% and 11.36% at 40, 50 and 60°C, respectively higher for R152a in comparison with that of R134a. The Efficiency defect in condenser of both R134a and R152a increases by about 53.06-90.55% with an increase in evaporator temperature from −30 to 5°C for the considered range of condensing temperatures

5.9 Variation of Efficiency Defect in Expansion Valve

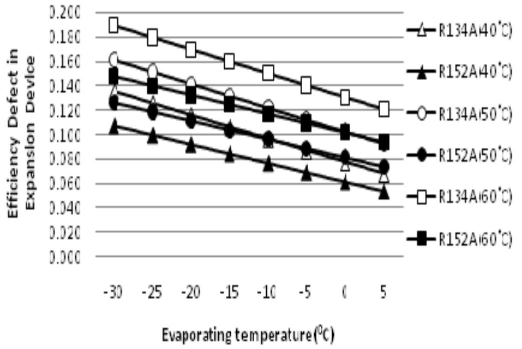


Figure 10 shows the variation of efficiency defect in expansion valve with evaporator temperature for R134a R152a. As revealed in the figure, efficiency defect in expansion valve decreases with increase in evaporator temperature. The result obtained showed that the average efficiency defect in expansion valve is 21.21%, 22.71% and 22.52% at 40, 50 and 60°C, lower for R152a respectively in comparison with that of R134a.The Efficiency defect in Expansion valve of both R134a and R152a increases by about 56.31-100.34% with an increase in evaporator temperature from −30 to 5°C for the considered range of condensing temperatures.

5.10 Variation of Efficiency Defect in Evaporator

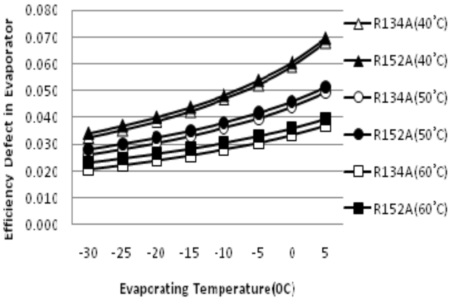


Figure 11 shows the variation of efficiency defect in evaporator with evaporator temperature for R134a and R152a. This figure revealed that the efficiency defect in evaporator decreases with decrease in evaporator temperature. The results obtained showed that the average efficiency defects in evaporator are 5.09%, 7.52% and 10.66% at 40, 50 and 60°C, respectively higher for R152a in comparison with that of R134a. As shown in Fig.12, the overall efficiency defect in evaporator is marginal in comparison with those of other components in the system (Figs.9, 10 and 11). Transferring heat at lower temperature difference can further reduce the efficiency defect in the evaporator .The Efficiency defect in Evaporator of both R134a and R152a increases by about 70.04-109.08% with an increase in evaporator temperature from −30 to 5°C for the considered range of condensing temperatures

5.11 Variation of Exergy Destruction Ratio on Evaporating Temperature

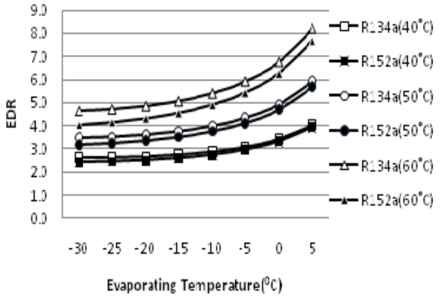


Figure 12 shows the variation of Exergy Destruction Ratio (EDR) with varying evaporator temperature for R134a and R152a. The figure shows that the EDR decreases with increase in evaporator temperature. The trend is similar for all the analyzed refrigerants. The results obtained showed that the average EDR for R152a is 8.15%, 7.82% and 7.30% at 40, 50 and 60°C, respectively lower in comparison to R134a. The Exergy destruction Ratio of both R134a and R152a decreases by about 55.49-90.17% with an increase in evaporator temperature from −30 to 5°C for the considered range of condensing temperatures.

5.12 Variation of Exergy Performance Coefficient on Evaporating Temperature

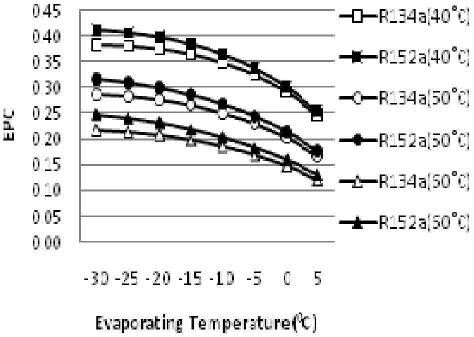


Figure 13 shows the variation of Exergy Performance Coefficient (EPC) with varying evaporator temperature for R134a and R152a. The figure shows that the EPC decreases with increase in evaporator temperature. The results obtained showed that the average EPC for R152a is 4.94%, 7.37% and

10.43% at 40, 50 and 60°C, respectively higher in comparison to R134a. The Exergy Performance Coefficient of both R134a and R152a decreases by about 55.49-90.17% with an increase in evaporator temperature from −30 to 5°C for the considered range of condensing temperatures

VI. .CONCLUSION

The following conclusions can be drawn from the result and discussion:

- R152a has the highest value of coefficient of performance by 4.65%, 7.15% and 10.52% at 40°C, 50^0C and 60^0C respectively in comparison to R134a.
- R152a has the highest value of exergetic efficiency by 4.62%, 7.15% and 7.18% at 40^0C, 50^0C and 60^0C respectively in comparison to R134a.
- R152a has the lower value of Exergy Destruction Ratio by 6.00%, 8.40% and 11.33% at 40^0C, 50^0C and 60^0C respectively in comparison to R134a.
- R152a has the highest value of EPC by 6.43%, 9.26% and 12.94% at 40^0C, 50^0C and 60^0C respectively in comparison to R134a.
- R152a has the lowest value of Total Exergy Destruction than R134a by 7.45%, 7.18% and 6.73% at 40^0C, 50^0C and 60^0C respectively.
- R152a has the lowest value of exergy destruction in Compressor and Expansion device than R134a.
- R152a has the highest value of exergy destruction than R134a in condenser and evaporator.
- R152a has the lowest value of Efficiency defect in compressor by 1.72%, 1.76% and 1.77% at 40^0C, 50^0C and 60^0C respectively in comparison to R134a.
- R152a has the highest value of Efficiency defect in condenser by 15.34%, 13.22% and 13.50% at 40^0C, 50^0C and 60^0C respectively in comparison to R134a.
- R152a has the lowest value of Efficiency defect in throttle valve by 21.22%, 21.61% and 22.25% at 40^0C, 50^0C and 60^0C respectively in comparison to R134a.
- R152a has the highest value of Efficiency defect in evaporator by 4.93%, 7.55% and 11.07% at 40^0C, 50^0C and 60^0C respectively in comparison to R134a.

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