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# PERFORMANCE EVALUATION OF ALTERNATIVE REFRIGERANTS

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## ABSTRACT

*The environmental problems of ozone depletion and global warming are of major concern in the world. Refrigeration and air-conditioning have been identified as major causes for ozone layer depletion and global warming. Thus, there is a great need to search for alternative refrigerants which can be used to replace the conventional CFC and HFC refrigerants used in the refrigeration and air-conditioning systems .This paper presents a detailed study on identifying various alternative refrigerants based on exergetic analysis of vapour compression refrigeration system. The alternative ecofriendly refrigerants for different systems like domestic refrigeration, air-conditioning and automobile air-conditioning have been proposed in this study.*

***Keywords:*** *Alternative refrigerants, Exergetic analysis, Global warming, Ozone depletion, Vapour compression refrigeration system.*

## I. INTRODUCTION

Refrigeration and Air-Conditioning now-a-days are more than just comfort. Today, with advancement in technology and change in climatic conditions of the earth's environment, refrigeration and air-conditioning have become a necessity. In good old days, the main purpose of refrigeration was to produce ice, which was used for cooling beverages, food preservation and refrigerated transport etc. Now we find various applications of refrigeration and air conditioning in all fields like food processing, preservation and distribution, power plants, vehicles and for commercial and residential comfort.

Refrigeration and air-conditioning have become very essential for mankind, without which the basic frame of the society will be adversely affected. Despite their inherent advantages refrigeration and air-conditioning contribute to the two major environmental problems: ozone layer depletion and global warming. Ozone depletion is caused by releasing refrigerants into the atmosphere. Global warming is increasing at high rate by emissions of carbon dioxide and methane resulting from human activity. Direct release of refrigerants accounts for only about 2% of total equivalent carbon dioxide release and carbon dioxide released by production of power to drive refrigerating systems is atleast ten times the direct effect of refrigerant emission. Therefore, refrigeration and air-conditioning accounts for about 20% of observed global warming. According to the terms of the Montreal Protocol, the manufacture, sale and use of chlorinated refrigerants were progressively phased out. Thus, refrigerants with high global warming potential (GWP) such as R-12, were replaced by compounds of lower GWP such as R-134a. The challenge now is to improve efficiency of systems, to reduce power consumption, to reduce leakage of refrigerants and to find ecofriendly refrigerants. The properties of few refrigerants are shown in Table 1.

Table 1.Properties of some refrigerants

| Refrigerants | Replaces | Molecular wt | Critical temp (°C) | ASHARAE Safety code | ODP | GWP |
|---|---|---|---|---|---|---|
| R12 | - | 120.93 | 112 | A1 | 0.82 | 10600 |
| R22 | - | 86.47 | 96.2 | A1 | 0.034 | 1700 |
| R502 | - | 111.64 | 80.7 | A1 | 0.221 | 4500 |
| R134a | R12 | 102.03 | 101.1 | A2 | 0.000 | 1300 |
| R404A | R502,R22 | 97.6 | 72.1 | A1 | 0.000 | 3800 |
| R407C | R22 | 86.2 | 87.3 | A1 | 0.000 | 1700 |
| R410A | R22 | 72.58 | 72.5 | A1 | 0.000 | 2000 |
| R417A | R22 | 106.75 | 89.9 | A1 | 0.000 | 2200 |
| R152a | R12,R134a | 66.05 | 113.3 | A3 | 0.000 | 120 |
| R600a | R12,R134a | 58.12 | 134.7 | A3 | 0.000 | 20 |

1.1. Exergy analysis of vapour compression refrigeration system

The vapour compression refrigeration systems release large amount of heat to the surroundings. The difference in temperatures between the system and the surroundings, gives rise to irreversibility. The efficiency of the vapour compression refrigeration system according to the first law of thermodynamics is usually measured in terms of coefficient of performance (COP). From the first law analysis the sources of thermodynamic losses in a thermodynamic cycle cannot be known. To identify and quantify the thermodynamic losses in a cycle second law of thermodynamics is used. The term exergy is defined as the maximum amount of work which can be produced by a system or a flow of matter or energy as it comes to equilibrium with a reference environment. A system in complete equilibrium with its environment does not have any exergy. Thermodynamic value of exergy can be used to assess and improve energy systems. The magnitude of exergy efficiency depends on the states of both the system and the environment. The decrease in environmental impact of a process indicates the increase of exergy efficiency.

The vapour compression refrigeration cycle with liquid vapour heat exchanger including superheating, subcooling and pressure losses in evaporator and condenser is shown in Fig.1 (a) and (b).The first law, measures performance of the refrigeration cycle in terms of coefficient of performance (COP), which is defined as the net refrigeration effect produced per unit of work required.

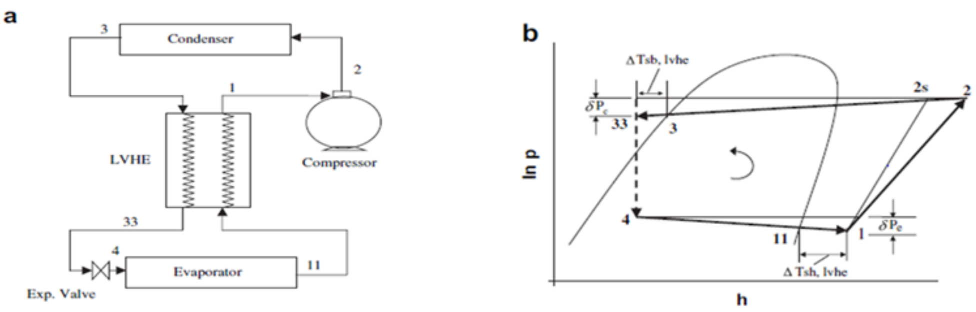


Fig.1 (a) schematic diagram of a vapour compression cycle with liquid vapour heat exchanger; (b) pressure enthalpy diagram of an actual vapour compression cycle with liquid vapour heat exchanger

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The second law of thermodynamics derives the concept of exergy, which always decreases due to thermodynamic irreversibility In exergetic analysis the performance of a system is measured by exergetic efficiency which is defined as the ratio of coefficient of performance of vapour compression cycle and the coefficient of performance of reversible refrigerator operating between the same temperatures [1].

## II. BACKGROUND WORK

Different researches contributed to the testing of new eco-friendly refrigerants which can replace the conventional CFC and HCFC refrigerants. Also, good amount of numerical and experimental work has been carried out on the exergetic analysis of alternative refrigerants.

Arora and Kaushik (2008) investigated an actual vapour compression refrigeration (VCR) cycle for exergy analysis. A computational model had been developed for computing coefficient of performance (COP), exergy destruction, exergetic efficiency and efficiency defects for R502, R404A and R507A. The investigation was done for evaporator and condenser temperatures in the range of -50°C to 0°C and 40°C to 55°C, respectively. The results indicated that COP and exergetic efficiency for R507A were better than that for R404A at condenser temperatures between 40°C and 55°C. However, both refrigerants showed 4 – 17% lower value of COP and exergetic efficiency in comparison to R502 for the condenser temperatures between 40°C and 55°C.

Reddy *et al.* (2012) dealt with the exergetic analysis of a vapour compression refrigeration system with selected refrigerants. Effects of condenser temperature, evaporator temperature, sub-cooling of condenser outlet, super-heating of evaporator out let and effectiveness of vapour liquid heat exchanger were computed. It was found that R134a showed better performance in all respect, whereas R407C refrigerant has poor performance.

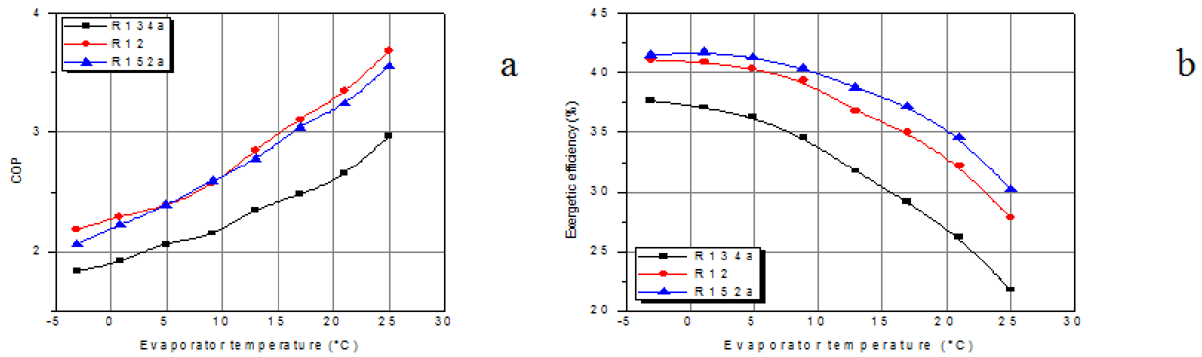


Fig.2 (a) Variation of cOP and (b) variation of exergitic efficiency with evaporator temperature.

Bolaji (2010) investigated the exergetic performance of a domestic refrigerator using two environment-friendly refrigerants (R134a and R152a) and compared with the performance of the system when R12 was used. The effect of evaporator temperature on the coefficient of performance (COP) and exergetic efficiency for R12, R134a and R152a is shown in Fig. 2(a) and 2(b). The results depicted that the average COP of R152a was very close to that of R12 with only 1.4% reduction, while 18.2% reduction was calculated for R134a in comparison with that of R12. Exergetic efficiency decreases with increase in evaporator temperature. Average exergetic efficiencies for R134a and R152a are 13.6% lower and 4.4% higher in comparison to that of R12, respectively. They concluded that R152a performed better than R134a in terms of COP, exergetic efficiency and efficiency defect as R12 substitute in domestic refrigeration system.

Anand and Tyagi (2012) presented a detailed experimental analysis of 2TR (ton of refrigeration) vapour compression refrigeration cycle for different percentage of refrigerant charge using exergy analysis. They developed an experimental setup and evaluated performance on different operating conditions using a test rig having R22 as working fluid. The coefficient of performance, exergy destruction, and exergetic efficiency for variable quantity of refrigerant had been calculated. The investigation had been done by using 2TR window air conditioner and the results indicated that the losses in the compressor are more pronounced, while the losses in the condenser are less pronounced as compared to other components, i.e., evaporator and expansion device. The total exergy destruction was highest when the system was 100% charged, whereas it was found to be least when the system was 25% charged. It was observed that the total exergy destruction was comparable when the system was 75 and 100% charged and least when the system was 25% charged because the evaporator temperature is very close to the reference temperature. The average COP was highest when the system was 50% charged and this is because of higher refrigerating effect and reduced compressor work. The exergy efficiency of the system varied from 3.5 to 45.9% which was mainly due to the variation of evaporator temperature.

Bhatkar *et al.* (2013) experimentally studied the popular refrigerants and gave recommendations for alternatives such as carbon dioxide, ammonia and hydrocarbons and new artificially created fluid, Hydro-Fluoro-Olefin 1234yf by DuPont and Honeywell which exhibit good thermo-physical and environmental properties and would be commercialized in the near future. They reported that considering global warming R 134a should be phased out and replaced by natural refrigerants such as ammonia, carbon dioxide and hydro carbons in vapour compression refrigeration system for sustainable environment. HFO-1234yf was also found suitable for refrigeration and air conditioning systems.

Khan *et al.* (2015) provided a detailed exergy analysis for theoretical vapour compression refrigeration cycle using R12, R22 and R134A. They concluded that the COP and exergetic efficiency of R12 were better than that of R22 and R134A. The EDR of R134A was higher than that of R22 and R12. This analysis was performed at condenser temperature on 40ºC and evaporator temperatures ranges from -10ºC to -40ºC. For all refrigerants R12, R22 and R134A COP and exergy efficiency increases with increase in degree of subcooling.

Pottker *et al.* (2015) presented a theoretical study about the effect of condenser subcooling on the performance of vapour-compression systems. It was shown that, as condenser subcooling increases, the COP reaches a maximum Refrigerants with large latent heat of vaporization tend to benefit less from condenser subcooling. For an air conditioning system, results indicated that the R1234yf (8.4%) would benefit the most from condenser subcooling in comparison to R410A (7.0%), R134a (5.9%) and R717 (2.7%) due to its smaller latent heat of vaporization. The value of COP maximizing subcooling does not seem to be a strong function of thermodynamic properties.

In a numerical study by Yang and Yeh (2015) on vapour-compression refrigeration systems using R22, R134a, R410A, and R717 showed that low cooling water temperatures in the condenser significantly improved performance, heat transfer, and exergy destruction and enlarges the optimal degree of subcooling for a vapour-compression refrigeration system. The optimal degrees of subcooling for a vapour-compression refrigeration system occurred between $2^{o}$C and 6°C for initial cost saving and from $4^{o}$C to $7^{o}$C for total exergy destruction for R134a, R22, R410A, and R717.

IJARSE
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Yan *et al.* (2015) proposed a modified vapour-compression refrigeration cycle (MVRC) system which operates with the zeotropic mixture R290/R600a for domestic refrigerator-freezers. In the MVRC system, a phase separator was introduced to enhance the overall system performance. A theoretical energy and exergy analysis on the performance of the MVRC was carried out by developing mathematical model, and then the results were compared with that of the traditional vapour compression refrigeration cycle (TVRC) operating with the refrigerant R600a and the zeotropic mixture R290/ R600a, respectively. According to the simulation results of these two cycles, the MVRC gave the most excellent performances in the COP (coefficient of performance), the volumetric refrigeration capacity, the total exergy destruction and the exergetic efficiency under the same given operating conditions.

Mohanraj *et al.* (2008) theoretically assessed the possibility of using R152a and hydrocarbon refrigerants (such as R290, R1270, R600a, and R600) as alternatives to R134a in domestic refrigerators. The refrigerants were assessed over wider range of condensing and evaporator temperatures. The results showed that pure hydrocarbon refrigerants were not suitable to be used as alternatives to R134a due to their mismatch in Volumetric Cooling Capacity. Whereas, R152a had approximately the same Volumetric Cooling Capacity with about 9% higher coefficient of performance and lower values of operating pressure and compressor input power. They also found that the discharge temperature of R152a was higher than that of R134a by about 14–26 K. R152a is an energy-efficient and environment friendly alternative to phase out R134a in domestic refrigerators as reported by them.

The exergetic performance of vapour compression refrigeration cycle with two-stage and intercooler using refrigerants R507, R407c and R404a was analysed by Kilic (2012). The necessary thermodynamic values for analyses were calculated by Solkane program. The coefficient of performance, exergetic efficiency and total irreversibility rate of the system in the different operating conditions for these refrigerants were investigated. The coefficient of performance, exergetic efficiency and total irreversibility rate for alternative refrigerants were compared. The variation of exergetic efficiency with evaporator temperature is shown in Fig. 3(a). It was observed that COP increased when evaporator temperature was increased for all refrigerants and Fig. 3(b) shows that COP decreased when the condenser temperature increased. Obtained results depicted that COP and exergy efficiency of the system using R407c were better than the other refrigerants. It was noticed that the system using R507 refrigerant reaches the worst outcome in terms of total irreversibility rate. New ozone-friendly refrigerants such as R507, R407c and R404a could be used to replace CFCs and HCFCs were reported by them.

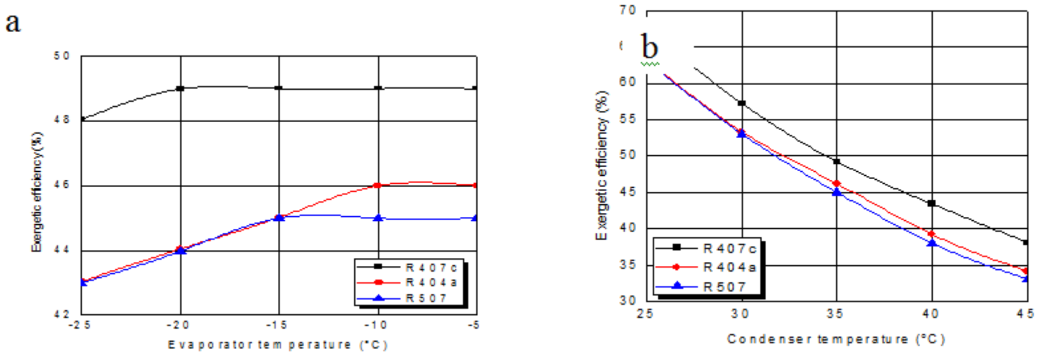


Fig.3 (a) Variation of exergetic efficiency with evaporator temperature (b) variation of exergetic efficiency with condenser temperature

Ahmed *et al.* (2012) compared the energetic and exergetic performances of a domestic refrigerator using pure butane and isobutane as refrigerants. The thermodynamic performances such as exergy destruction or losses, exergy efficiency, and coefficient of performances (COP) were investigated. These parameters were measured at varied operating conditions. They found that exergy loss and energy efficiencies of isobutane were found higher than that of R-134a in all operating conditions. The analysis showed that the performances of butane and isobutane as refrigerants were very near with HFC134a. It was also found that at higher evaporating temperatures, the exergy losses were minimal. They highlighted that the maximum exergy loss occurred in the compressor which was 69% of the whole losses in the system. Highest sustainability index was found for butane compared to that of R134a and R600a, respectively.

Wu *et al.* (2009) reported a ternary blend R152a/R125/R32 with a mass ratio of 48/18/34 as a potential alternative to R22. A computer code was developed with NIST REFPROP 7.0 for the comparative analysis of thermo physical properties and refrigerant performance of this new mixture and of R22. A drop-in test of this new mixture was performed in a domestic air-conditioner originally designed for R22. Both the calculation and experimental results showed that this new mixture could be regarded as a most likely drop-in substitute for R22 in many applications safely.

Jung *et al.* (1999) investigated thermodynamic performance of supplementary refrigerant mixtures for CFC12 used in existing automobile air-conditioners was examined. A thermodynamic computer analysis of an automobile air-conditioner was carried out for the initial screening of possible mixture candidates, and refrigerant mixtures composed of HCFC22,HFC134a, HCFC142b, RE170 (dimethylether), HC290 (propane), and HC600a (iso-butane) were proposed to supplement CFC12. They also manufactured a breadboard type refrigeration test facility to verify the performance of the alternative refrigerant mixtures. Test results showed that HFC134a/RE170mixture with zero ozone depletion potential is the best supplement to CFC12 as long term candidate. On the other hand, HCFC22/HFC134a/RE170 and HCFC22/HFC134a/HCFC142b mixtures were good only as short term supplementary alternatives since they contain HCFC22 as noted by them. They also reported that hydrocarbon mixture of HC290/HC600a showed a good performance but its use in existing automobile air-conditioners should be carefully considered due to its flammability.

Yataganbaba *et al.* (2012) investigated the exergy analysis on a two evaporator vapour compression refrigeration system using R1234yf, R1234ze and R134a as refrigerants. A computer code was developed by using Engineering Equation Solver to calculate exergy losses occurring in different system components, besides the exergy efficiency of the refrigeration cycle. They concluded that R1234ze was the best among considered refrigerants due to lower GWP and ODP values than R134a. The highest exergy efficiencies were obtained with R1234ze and R134a. They concluded that HFO-1234yf could be a good alternative to HFC-134a as a environmentally friendly refrigerant and could replace the conventional HFC-134a after having a slight modification in the design even though the values of performance parameters for HFO-1234yf are smaller than that of HFC-134a.

Soni and Gupta (2012) performed a theoretical study of a vapour compression refrigeration system with refrigerants R-407C and R-410A. A computational model based on energy and exergy analysis was presented for the investigation of the effects of evaporating temperatures, degree of subcooling, dead state temperatures and effectiveness of the heat exchanger on the coefficient of performance, second law efficiency and exergy destruction ratio of the vapour compression refrigeration cycle. The COP and exergetic efficiency of R-407C are better than that of R-410A. For both refrigerants i.e. R-407C and R-410A, COP and exergy efficiency improved by sub cooling of high pressure condensed liquid refrigerant as shown in Fig. 4. The total increase in exergetic efficiency for R-407C was 7.02% for 10°C subcooling and for R-410A is 8.01% for 10°C.

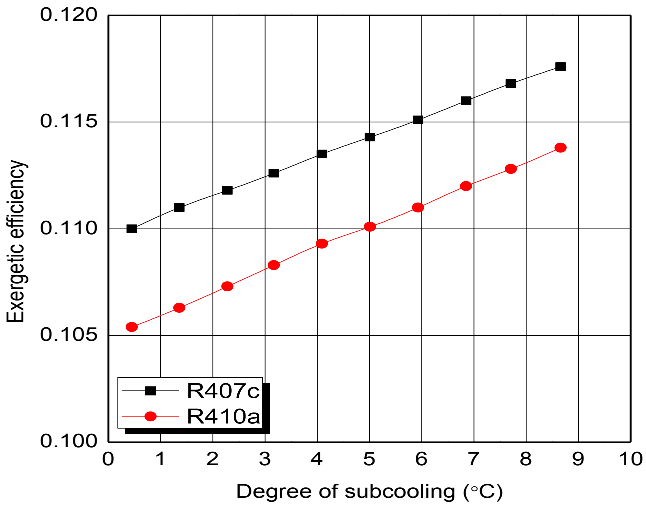


Fig. 4.Effect of degree of subcooling on coefficient of

A theoretical study by Dalkilic and Wongwises (2012) on a traditional vapour-compression refrigeration system with refrigerant mixtures based on HFC134a, HFC152a, HFC32, HC290, HC1270, HC600, and HC600a for various ratios was carried out and their results were compared with CFC12, CFC22, and HFC134a as possible alternative replacements They found that all of the alternative refrigerants investigated in the analysis showed slightly lower performance coefficient (COP) than CFC12, CFC22, and HFC134a for the condensation temperature of 50 °C and evaporating temperatures ranging between −30 °C and 10 °C. Refrigerant blends of HC290/HC600a (40/ 60 by wt.%) instead of CFC12 and HC290/HC1270 (20/80 by wt.%) instead of CFC22 were found to be replacement refrigerants among other alternatives as reported by them.

Lugo *et al.* (2002) presented an easy-to-use and accurate method to calculate some of the thermo physical properties of aqueous solutions which are used as secondary refrigerants. This method is based on the correction of the ideal behaviour of aqueous solutions by excess functions. This method allows to determine the following properties: freezing points, densities, heat capacities, thermal conductivities and dynamic viscosities. As an illustration, it is applied to aqueous solutions of (i) ethyl alcohol, (ii) ammonia, (iii) sodium chloride, (iv) ethylene glycol and (iii) propylene glycol. The approach involved, based on excess functions, is quite straightforward since it generally requires only one interaction coefficient to account for non-ideal behaviour; the model can be applied to other aqueous solutions as long as a database covering the whole domain corresponding to the first eutectic point is available. If the approach involved here is applied to different aqueous solutions, it will be possible to compare the properties of different secondary refrigerants in order to choose the more convenient one for a given application.

Sieres *et al.* (2012) presented a hybrid formulation for the calculation of thermodynamic properties of pure refrigerants and refrigerant mixtures. Explicit formulations were obtained to model some properties that are used to predict other thermodynamic properties through differentiation, which assures a fast and stable calculation. As an example the equations for R1234yf and R407C were presented in the paper. The source data for regressing was obtained from REFPROP 9.0. The accuracy of the thermodynamic properties formulae was satisfactory for applications in which computation speed and stability are preferred rather than accuracy. It was shown that the deviations of the calculated thermal properties were always low and within the uncertainties of the source data used for regression and accuracy evaluation. Each refrigerant and thermodynamic property is treated in a similar way, so the method can be easily programmed and extended to other refrigerants.

Sozen *et al*. (2009) proposed a new approach (artificial neural network, ANN) to determine of thermodynamic properties of an environmentally friendly alternative refrigerant (R407c) for both saturated liquid–vapour region (wet vapour) and superheated vapour region. In this study, an ANN based methodology for the calculation of thermodynamic properties of new ozone-friendly refrigerant R407c has been put forward. This work clearly showed that, for the calculation of thermodynamic properties of refrigerant mixtures, the ANNs may be employed. With the formulas obtained the user may use such results without a system running the relevant ANN Software. In other words, they may be put in a spreadsheet application to provide useful results. With the empirical formulae obtained from the ANN, the interval values have been calculated correctly.

## III. OBSERVATIONS

The following observations were noted from this review on the exergetic analysis of the vapour compression refrigeration system using alternative refrigerants.

i. R1234ze had both the low ODP and GWP and could be used to replace R134a.It was found that the values of performance parameters for HFO-1234yf were smaller than that of HFC-134a, but the difference was small, so it could be a good alternative to HFC-134a because of its environmentally friendly properties.

ii. The COP and exergetic efficiency of R-407C were found to be better than that of R-410A. For both refrigerants i.e. R-407C and R-410A, COP and exergy efficiency improved by sub cooling of high pressure condensed liquid refrigerant and the total increase in exergetic efficiency of 7.02% for R-407C and 8.01% for R-410A for 10℃ subcooling was observed.

iii. The performances of butane and isobutane as refrigerants were found to be similar to HFC134a. . Highest sustainability index was found for butane compared to that of R134a and R600a, respectively.

iv. Refrigerant blends of HC290/HC600a (40/ 60 by wt.%) instead of CFC12 and HC290/HC1270 (20/80 by wt.%) instead of CFC22 were identified to be replacement refrigerants.

v. Various methods like hybrid formulation method, method based on correction of ideal behaviour of aqueous solutions by excess function, Artificial Neural Network (ANN) used to determine the properties of refrigerants for both saturated liquid-vapour region and superheated vapour region were discussed for calculating the thermodynamic properties for different refrigerants.

## IV. CONCLUSIONS

The following conclusions had been drawn at the end of this study.

i. R152a could be used to replace the conventional R12 refrigerant in domestic refrigeration systems.

ii. HFC134a/RE170 mixture with zero ozone depletion potential could be the best long term supplement for CFC12 used in automobile air-conditioners.

iii. HFO1234yf could be used as an alternative for the most used R134a and was found suitable for refrigeration and air conditioning systems.

## REFERENCES


[1] Akhilesh Arora and S.C. Kaushik, Theoretical analysis of a vapour compression refrigeration system with R502, R404A and R507A, International Journal of Refrigeration, 31, 2008, 998-1

[2] V. Siva Reddy, N. L. Panwar and S. C. Kaushik, Exergetic analysis of a vapour compression refrigeration system with R134a, R143a, R152a, R404A, R407C, R410A, R502 and R507A, Clean Technology Environmental Policy, 14, 2012, 47–53.

[3] Bukola O. Bolaji, Exergetic performance of a domestic refrigerator using R12 and its alternative refrigerants, Journal of Engineering Science and Technology, vol. 5, 2010, no. 4: 435 – 446.

[4] S. Anand and S. K. Tyagi, Exergy analysis and experimental study of a vapour compression refrigeration cycle Journal of Thermal Analysis and Calorimetry, 110, 2012, 961–971.

[5] V. W. Bhatkar, V. M. Kriplani and G. K. Awari, Alternative refrigerants in vapour compression refrigeration cycle for sustainable environment: a review of recent research International Journal of Environmental Science and Technology, 10, 2013, 871–880.

[6] Md. Nawaz Khan, Md. Mamoon Khan, Mohd. Ashar and Aasim Zafar Khan, Energy and Exergy Analysis of Vapour Compression Refrigeration System with R12, R22 and R134a, International Journal of Emerging Technology and Advanced Engineering, issue 3 volume 5, 2015, ISSN 2250-2459.

[7] Gustavo Pottker and Pega Hrnjak, Effect of the condenser subcooling on the performance of vapour compression systems International Journal of Refrigeration, 50, 2015, 156-164.

[8] Min-Hsiung Yang and Rong-Hua Yeh, Performance and exergy destruction analyses of optimal subcooling for vapor-compression refrigeration systems, International Journal of Heat and Mass Transfer, 87, 2015, 1-10.

[9] Gang Yan, Chengfeng Cui and Jianlin Yu, Energy and exergy analysis of zeotropic mixture R290/R600a vapour-compression refrigeration cycle with separation condensation, International Journal of Refrigeration, 53, 2015, 155-162.

[10] M. Mohanraj, S. Jayaraj and C. Muraleedharan, Comparative assessment of environment-friendly alternatives to R134a in domestic refrigerators, Energy Efficiency, 1, 2008, 189–19.8.

[11] Bayram Kilic, Exergy analysis of vapour compression refrigeration cycle with two-stage and intercooler, Heat Mass Transfer, Springer-Verlag, 48, 2012, 1207–1217.

[12] J. U. Ahamed, R. Saidur, H. H. Masjuki and M. A. Sattar, An analysis of energy, exergy, and sustainable development of a vapor compression refrigeration system using hydrocarbon, International Journal of Green Energy, 9:7, 2012, 702-717.

[13] Jiangtao Wu, Yingjie Chu, Jing hu and Zhigang Liu, Performance of mixture refrigerant r152a/r125/r32 in domestic air-conditioner, International Journal of Refrigeration, 32, 2009, 1059-1057.

[14] Dongsoo Jung, Bongjin Park and Hyunchul Lee, Evaluation of supplementary/ retro®t refrigerants for automobile air-conditioners charged with CFC12, International Journal of Refrigeration,22, 1999, 558-568.

[15] Alptug Yataganbaba, Ali Kilicarslan and Irfan Kurtbas, Exergy analysis of R1234yf and R1234ze as R134a replacements in a two evaporator vapour compression refrigeration system, International Journal of Refrigeration, 60, 2012, 26-37.

[16] R.C. Gupta and Jyoti Soni, Exergy analysis of vapour compression refrigeration system with using R-407c andRr-410a International Journal of Engineering Research & Technology, vol. 1 issue 7, 2012, issn: 2278-0181.

[17] A.S. Dalkilic and S. Wongwises, A performance comparison of vapour-compression refrigeration system using various alternative refrigerants, International Communications in Heat and Mass Transfer, 37, 2012, 1340-1349.

[18] R. Lugo, Fournaison J.M. Chourot and J. Guilpart, An excess function method to model the thermophysical properties of one-phase secondary refrigerants, International Journal of Refrigeration, 25, 2002, 916-923.

[19] Jaime Sieres, Fernando Varas and Jose Antonio Martinez-Suareza, Hybrid formulation for fast explicit calculation of thermodynamic properties of refrigerants, International Journal of Refrigeration, 35, 2012, 1021-1034.

[20] Adnan Sozen, Erolarcaklioglu, Tayfun Menlik and Mehmet Ozalp, Determination of thermodynamic properties of an alternative refrigerant(R407c) using artificial neural network, Expert Systems with Applications, 36, 2009, 4346-4356.