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COMPARATIVE STUDY OF EXERGY LOSS OF REFRIGERANTS DURING CONDENSATION PROCESS OF VCR CYCLE

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ABSTRACT

In this proposed work, analysis of change in exergy of various refrigerants who are having zero ozone depletion potential based on their properties is made by comparing the required outputs. The study is based on second law of thermodynamics in which the relation between exergy and Carnot COP of a VCR cycle is established to optimize the properties like pressure and temperatures of the specific system like condenser. The study was carried out with the starting point as the exit of compression process assuming condensation of the gaseous refrigerant without any pressure drop. Various values of change in exergy during condensation calculated for various temperatures, below saturation temperature ie. in sub cooled region of the liquid. The data plotted to obtain curves and mathematical model is proposed from data so obtained to calculate one parameter by just knowing the value of the other. Thus a relationship is establish between the degree of sub cool at the end of the condensation process to the exergy destruction for various refrigerants to compare outcome of results. In addition, a relationship between exergy drop and COP is established to optimize second law analysis of the system for different refrigerants for constant pressure condensation process in a vapour compression refrigerant cycle.

KEYWORDS: ODP, degree of sub cool, second law analysis, condensation, COP, refrigerants.

INTRODUCTION

Montreal protocol presented a list for the elimination of chlorine containing refrigerants, including R22. This traditional refrigerant has an ODP of 0.055. The deadline for the phase out of R22 in developed and developing countries is year 2020 and 2030, respectively[1]. In the interest of sustainable development, many attempts are made to replace traditional refrigerants with more efficient refrigerants with least possible ODP and global warming potential. Certainly the best solution to minimize ozone depletion is to use zero ODP products including zero ODP refrigerants. In this chain, theoretical assessment of the performance of R441a was done by C.Prabha et al [2] with standard parameters such as pressure ratio, volumetric cooling capacity (VCC), coefficient of performance (COP) and compressor input power. They obtained the results showing that the hydrocarbon refrigerant blend is suitable to be used as alternatives to R134 a as there is no mismatch in VCC. They also concluded that theoretically R441a has approximately the same VCC with about 5.2% higher COP at lower values of evaporator temperatures. Further they found that the compressor input power is also considerably reduced while using R441a. It was proved with the reported results that R441a is an energy efficient and environment friendly alternative to phase out R134 a in domestic refrigerators.

A computational model based on the exergy analysis presented by Recep Yumrutaş et al [3] to investigate the effects of the evaporating and condensing temperatures on the pressure losses, exergy losses, second law efficiency and coefficient of performance (COP) of a VCR cycle. They observed that the evaporating and condensing temperatures have strong effects on the exergy losses in the evaporator and condenser, on second law efficiency and COP. The integration of energy, entropy and exergy analysis can present a whole picture of the system performance. a number of applications of exergy analysis in hvac system have shown its effectiveness. Kanoglu et al. [4] analyzed an experimental open cycle desiccant cooling system and showed that the desiccant wheel has the greatest percentage of total exergy destruction followed by the heating system.

Although, alternative refrigerants are being attempted since the beginning of artificial refrigeration system, the attempts speeded up after the terms global warming potential (GWP) and ozone depletion potential (ODP) came into existence. Scientists and engineers worked very hard to get an efficient refrigerant at required pressure and temperature with least possible value of GWP and ODP. Akasaka R at el [5] quoting specific example of R134 a, mentioned that most of the refrigerants although having ODP very closed to zero, are responsible for global warming being high values of GWP. They stated that the refrigerant under study having ODP of 0.005 and GWP of 1300. The European Parliament published directives to ban all those refrigerants having GWP beyond 150 in mobile air. While testing various parameters for R134 yf at higher evaporation temperatures and lower condensation temperatures, Arif Amer et al [6] observed that R134 yf can be assumed to be a better choice for mobile air-conditioning systems in the point of view of exergetic performance. They also observed important differences between cycle efficiencies for hfo-1234yf and R134 a. However, the exergy destruction rate of the compressor obtained with HFO-1234yf is lower than calculated for R134a.According to exergy and energy analysis results obtained with this study, it can be evaluated that HFO1234yf is a good alternative to R134a. If flammability problem of the refrigerant is taken care, the refrigeration systems charged with HFO-1234yf can commonly be used in a refrigeration system.

While developing various relationships between multiple parameters for alternate refrigerant R134 yf, Park and Jung [7] studied for nucleate boiling heat transfer coefficients of R134 yf. They investigated these coefficients for plain and low fin surface conditions. authors concluded that the nucleate boiling heat transfer coefficients of R134 yf are very similar to those of R134 a. While studying about the properties of 1234yF, Nielsen O J [8] stated that in response to concerns about the contribution of fluorocarbon refrigerants to global climate change, a new, more environmentally sustainable, refrigerant molecule has been developed and is being evaluated. This new molecule is the hydro fluoro olefin 2,3,3,3,-tetrafluoroprop-1-ene, or HFO-1234yf. The molecule has been shown to be stable inside refrigeration equipment, but to quickly decompose if accidentally released into the atmosphere. However, they also stated that conventional boiling correlations can be used for the design of evaporators and boilers with R134 yf .

Similarly, replacement of traditional refrigerants to attempt to minimize ODP and GWP dealt by many researchers all over the technological world. Weissler [9] stated that if a comparison is made between R134 a, R134 yf and R744 in the view point of global warming, it was observed that R134 yf has the lowest contribution to global warming. Because of the relatively low flammability limit and minimum ignition energy, some chemical companies proposed to use R134 yf to direct expansion refrigeration systems. However, safety class of R134 yf to be published is expected to be A2L The authors also concluded that almost all thermodynamic properties of R134 yf are lower than those of R134 a.

System Description

The system under study is condenser of a vapor compression system where refrigerant vapor enters the condenser at elevated pressure. After condensation it is further sub cooled to extract sensible heat from the available heat of the refrigerant. Although, condenser pressure is the matter of concern for a design engineer, the saturation temperature is the limiting factor at the designed pressure due to required heat transfer with the available cooling media. In the specific case of R 134 a, in Indian conditions, where cooling media is air, saturation temperature cannot be below 35^0 C even in the most favorable weather conditions.

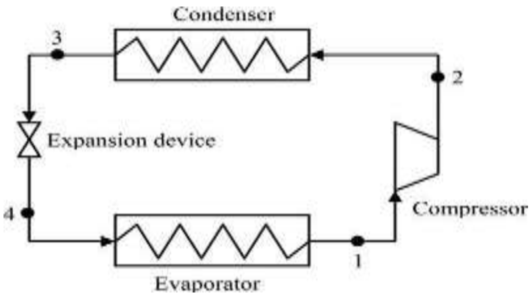


Fig 1 – vapor compression refrigeration system

The refrigeration cycle is shown in Fig 2 on h-s and in Fig 3 on T-s diagram separately with superheat of gases at the end of compression process at point 2 and leave sub cooled at the end of condensation process 2-5.

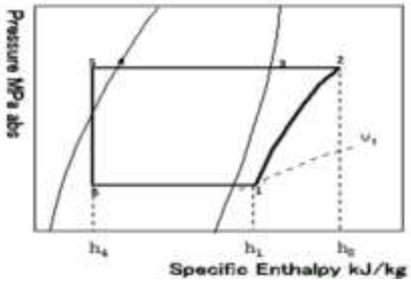


Fig 2 – P-h diagram for V C R Cycle

While dealing with different refrigerants to compare their performances in terms of COP or exergy analysis, it is not possible to show P-h diagram or T-s diagram on a common platform due to large variation in the saturation properties at the recommended pressure etc

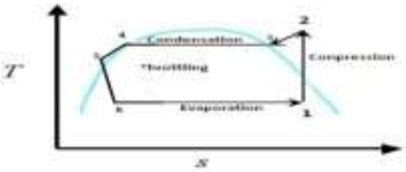


Fig 3 – T-s diagram for V C R Cycle

Some of the refrigerants, having zero ODP are considered for comparison of exergy change along with COP during VCR cycle. [10] The refrigerants, having no chlorine atom and having zero ODP are listed as under.

THERMODYNAMIC PROPERTIES OF REFRIGERANTS UNDER STUDY [11]

Number	**Chemical Formula**	**Molar Mass g/mol**	**Tc o C**	**Pc MPa**	**ODP**	**GWP**
152a	**CH_3CHF_2**	66.05	113	4.52	140	0
134a	**CH_2FCF_3**	102.03	102	4.06	1100	0
600a	**$(CH3)_3CH$**	58.1	135	3.62	4	0
R245fa	**CF3CH2CHF2**	134	154	3.61	1030	0

Table1

EXERGETIC ANALYSIS OF CONDENSATION PROCESS OF A VCR CYCLE:

Any refrigeration cycle includes various irreversible processes. As exergy or availability of a system at given state represents its maximum work potential, the exergy loss provides a very important criterion to evaluate the thermodynamic performance of a system . The second law of thermodynamics derives the concept of exergy, which always decreases due to thermodynamic irreversibility[12].

COP = Heat absorbed during evaporation process / Work done during compression process
= $(h_1-h_5) / (h_2-h_1)$ ………..(a)

The exergy balance for the condensation process $\dot{m}(\Psi_2-\Psi_4) = \sum(1- T_0/T_k) Q_k-T_0S_{gen}$ where Qk is the heat lost ….(b)

Thus assuming $\dot{m} = 1$ kg/s, $d\Psi= [(h_2-h_3)+(h_3-h_4)+(h_4-h_5)]-T_0[(s_2-s_3)+(s_3-s_4)+(s_4-s_5)]$ ………..(c)

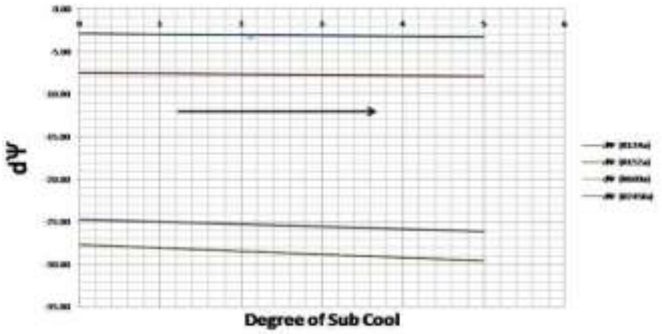
Gives $d\Psi= (h_2-h_5)-T_0(s_2-s_5)$ ………(e) [13]

ASSUMPTIONS

(a) Refrigerant gases leave compressor in superheated conditions and at a constant pressure of 800 kPa.
(b) Entire condensation process held at constant pressure . Friction inside the heat exchanger is assumed to be negligible .
(c) Mass of the refrigerant under circulation is unity.
(d) Mass flow in the condenser is a continuous flow and the process is study flow process.
(e) Condenser is an infinite sink.
(f) Condensation process is reversible.
(g) Ambient temperatureT_0 is considered to be at 300 K.
(h) To calculate COP of the cycle, evaporator pressure is considered to be atmospheric pressure at 101kPa.
(i) Vapor leaving evaporator at dry and saturated state.
(j) Only thermodynamic properties of the refrigerants are considered.

RESULT AND DISCUSSION

Exergy lost during condensation of the refrigerant at elevated constant pressure plotted versus various degree of sub cool. The results plotted on graph No 1 for various refrigerants.



Degree of Sub Cool v/s Exergy Loss for the refrigerants under study.

Graph 1

It is obvious from the graph that more the liquid refrigerant loses the temperature in the condenser below saturation temperature, exergy lost more and more linearly. Looking towards the straight line nature of all the graphs, equations for various straight lines can be formed as under.

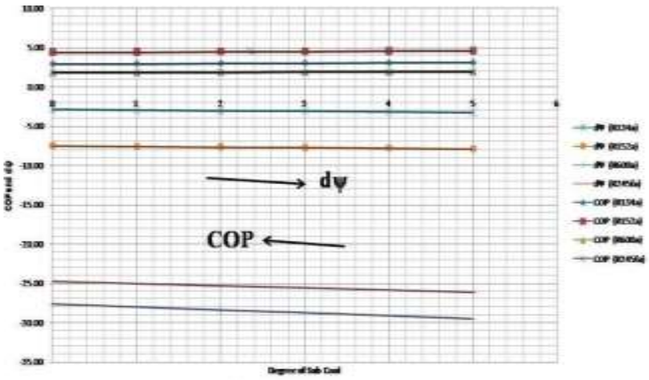
R134a	**y = -0.075x - 2.864**
R152a	**y = -0.077x - 7.487**
R600a	**y = -0.38x - 27.64**

R245fa	**y = 0.028x - 24.73**

Table2

Where y represents the loss of exergy (kJ/kg) and x represents the degree of sub cool. The relationship can easily be extended for interpolated or extrapolated values for different refrigerants.

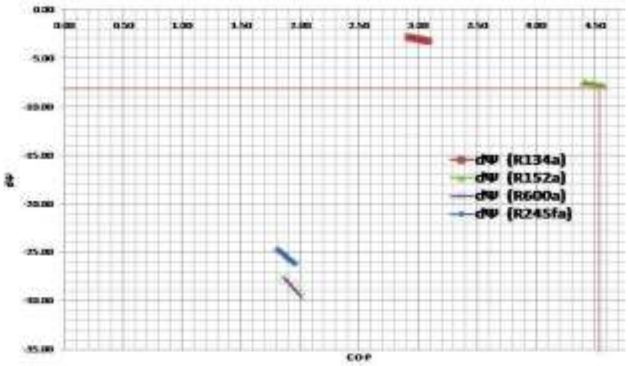
Further the linear relationship between COP and exergy loss is seen in Graph 2 .It is linear and a relation similar to table No. 1 can be established between COP and exergy loss, irrespective of degree of sub cool. However the values of slope (m) and intercept (C) will be different for different refrigerants.



Degree of Sub Cool v/s Exergy Loss & COP for the refrigerants

Graph 2

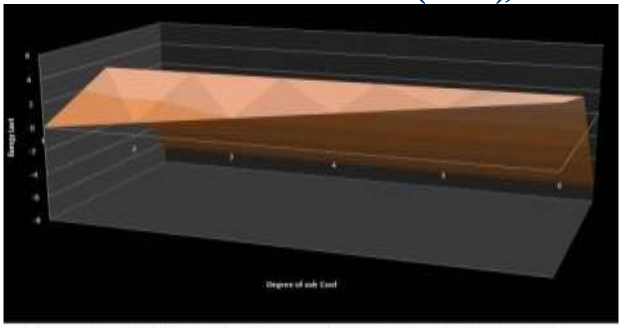
Graph 3 represents direct relationship between COP and exergy lost. While analyzing the graph it is observed that although R134 a seem to be an attractive refrigerant due to the least value of exergy lost, its COP would be limiting factor compared to R152a, whose COP can be considered to be the highest amongst the selected refrigerants. Other two refrigerants like R600a and R245 fa due to poor COP and high exergy lost would be the last choice for the researchers



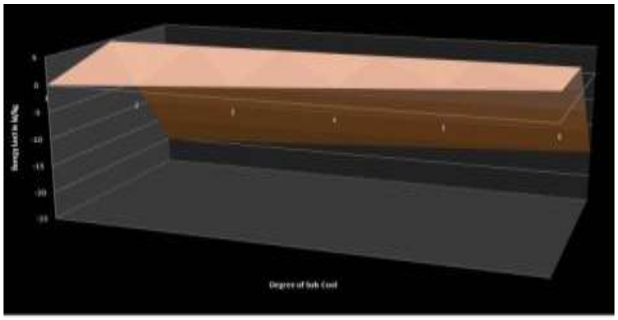
COP v/s Exergy Loss for the refrigerants under study.

Graph 3

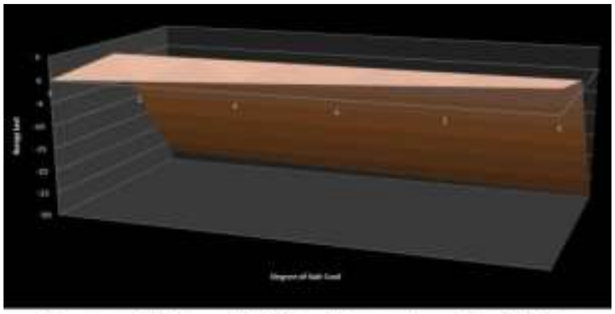
The combined 3dimensional graphs showing degree of sub cool on X-axis, Exergy lost on Y-axis and COP on Z-axis can be plotted for individual refrigerant as per graph number 4 to 7.



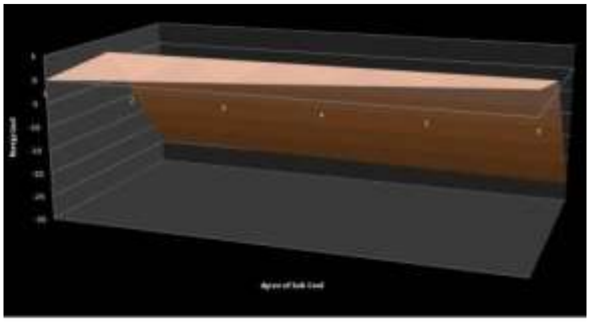
Degree of Sub cool, COP and Exergy Loss for R134a
Graph 4



Degree of Sub cool, COP and Exergy Loss for R152a
Graph 5



Degree of Sub cool, COP and Exergy Loss for R 600a
Graph 6



Degree of Sub cool, COP and Exergy Loss for R 245fa
Graph 7

Although the nature of all the 3D graphs seem to be the same for all the refrigerants, the topmost quadrilateral area is different for different refrigerants which shows that although degree of sub cool at some constant pressure is same, exergy COP relation is different for different refrigerants.

CONCLUSION

In this paper, Exergy loss during condensation process for four refrigerants R134a, R152a, R600a and R245fa analyzed with reference to second law of thermodynamics. Exergy loss calculated during the condensation process for different degree of sub cool keeping the condenser and evaporator pressure constant. Graphs plotted between exergy loss, COP and degree of sub cool and analyzed the nature of curves obtained. It is observed that more and more exergy is lost linearly with degree of sub cool. Also exergy is lost by the refrigerant linearly irrespective of degree of sub cool with increase of COP. It is also concluded that out of the four refrigerants, R152fa has got the best possible combination of COP and exergy lost compared to others within the pre decided temperature and pressure range.

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