Comparison of Second Law Efficiency and Exergy Analysis of Refrigerants R-12, R-22, R-407C Influenced by Evaporator Temperature for Vapour Compression Refrigeration System

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Abstract – *An exergy analysis is usually done to improve the system and find out the sites of work lost. The sites having high exergy destruction indicates the scope of improvement in specific sites in order to achieve overall improved, efficient system. This research work investigates the losses involved in process and overall cycle due to irreversibility in vapour compression refrigeration system with evaporator temperature as influential parameter by exergy destruction and second law efficiency analysis. The present work analyzed the behaviour of three refrigerants R-12, R-22, and R-407C with variation of evaporator temperature. From exergy analysis, second law efficiency increases with evaporator temperature and exergy destruction decreases with increase in evaporator temperature and exergy loss for R-12 and R-22 are almost same but R-407C is maximum, exergetic efficiency is maximum for R-12 then R-22 and minimum for R-407C.*

Key Words: **Exergy Destruction, Work Lost, Irreversibility, Exergetic Efficiency, Second Law Efficiency, Vapour Compression, Refrigeration System.**

1.INTRODUCTION

As per the landmark agreement the 1987 Montreal Protocol which restrict the global production, consumption and emission of ozone depleting substance and also the 1997 Kyoto Protocol which implemented the 1992 UNFCCC to reduce greenhouse gas emissions. Along with the growing significance of environmental protection and energy conservation nowadays , the interest in rediscovering the alternative ecofriendly natural fluids have been revived .But still the synthetic fluids as HFCs dominate in practical domestic, commercial and industrial application . The HFCs are zero ozone depleting potential (ODP) but having strong global warming potential (GWP). In recent year, from across the globe dedicated regulation to actively phase out different HFCs have been scheduled. In china reduction of HFCs emission by 60% latest by Jan ,2030 and EUROPE completely restrict HFCs with GWP> 150 in mobile room air conditioning by Jan,2020 and with GWP>2500 in commercial refrigerator. USA already initiated the ban of HFCs in supermarket system in Jan, 2017.

Analysis of thermal systems is generally done by Energy method, but it does not provide the true picture of the degraded performance of system. Exergy analysis indicates that energy having quantity as well as quality. Energy analysis is concerned only with the conservation of energy, but exergy analysis shows true picture of efficiency in terms of exergetic or second law efficiency. An exergy analysis is usually done to improve the system and find out the sites of work lost. Exergy analysis of a refrigeration system can be applied by analyzing the components of the system separately. The sites having high exergy destruction indicates the scope of improvement in specific sites in order to achieve overall improved, efficient system.

Table 1: Nomenclature

T_c	Condenser temperature
COP	Coefficient of performance
$\dot{W}_c$	Power input to the compressor (kW)
$\dot{m}$	Mass flow rate of the refrigerant (kg/s)
h	Specific Enthalpy (kJ / kg)
$\dot{I}$	Exergy destruction (kW)
s	Specific entropy (kJ/kg-K)
h′	Actual specific enthalpy (kJ / kg)
s′	Actual specific entropy (kJ / kg -K)
$\dot{E}$	Exergy (kW)
$\dot{I}'$	Actual exergy destruction (kW)
W'_c	Actual compression work
T_0	Ambient temperature
η_{II}	Second law efficiency
T_e	Evaporator temperature

2. Literature review

Literature review covers from the basics extending to the developments and other investigations in VCRS reported by different researchers. The review is categorized into three different sections as given below:

- Exergy analysis
- Performance parameter
- Efficiency

2.1. Exergy analysis

Bolaji [1] investigated exergy analysis of domestic refrigerator with alternative refrigerants R-134a, R-152a compare with R-12 in this research overall efficiency of R-152a is found 41.5% at evaporator temperature -3^{0}C and overall efficiency defect is lower than R-134a. XU and Clodic [2] used an exergy analysis in vapour compression refrigeration system (VCRS) to investigate the performance between three refrigerants R-12, R-290 and R-134a. For freezer R-12 is better than R-134a & R-290 in terms of COP but for refrigerator of R-134a is almost efficient. Reddy et.al [3] conducted an exergy analysis of a VCRS with selected refrigerant and found that R-134a has better performance than R-407C in terms of exergy loss and COP. Lee et.al [4] did numerical analysis of exergy for air conditioning influenced by ambient temperature. They found that capillary has increasing exergy loss with respect to increasing ambient temperature out of four devices in air conditioning.

2.2. Performance Parameter

Mahajan et.al [5] investigated the performance of HC-12a in domestic refrigerator and found out better performance than R-134a in terms of COP, compressor work, condenser heat rejection. Rocca et.al [6] showed the result of an experimental analysis comparing the performance of refrigerator operating with R-22 and its comparison with new HCF fluid R-417a, R-404a and R-407c.They verified that these HCFs are not efficient than R-22. VandaarKuzhali and Elansezhian [7] conducted an experimental research to reduce the usage of R-22 with hydrocarbon refrigeration mixtures (HCM) of R-22 and R-152a refrigerants in the ratio of 30:70, 50:50 and 70:30 by mass. The overall performance of HCM showed a long term substitute for R-22.

2.3. Efficiency

Naglakshmi and Yadav [8] conducted the experiment on test rig refrigerator with refrigerant R-12 and R-134a and found that COP of R-12 is greater than R-134a.Raj kumar and Gourav [9] investigated the performance analysis for R-600, R-600a,R-134a,R-152a, R-290 in domestic refrigerator. They found R-152a has highest COP and exergatic efficiency and R-600a has highest efficiency defect in compressor. Khalid [10] investigated the performance analysis of R-22 with R-407C, R-410a and R-417 and found that COP of R-417a is 12% higher than R-12 but R-407C and R-410a is 5% lowered than R-22.

3.Methodology

There are different methodologies to evaluate exergy destruction and second law efficiency is given below as:

- Simulation method
- Experimental method
- Analytical method

In the present analysis analytical method is used for VCR system with different refrigerants R-12, R-22, and R-407C using exergy destruction formula to analyze exergy destruction and exergetic efficiency (second law efficiency).

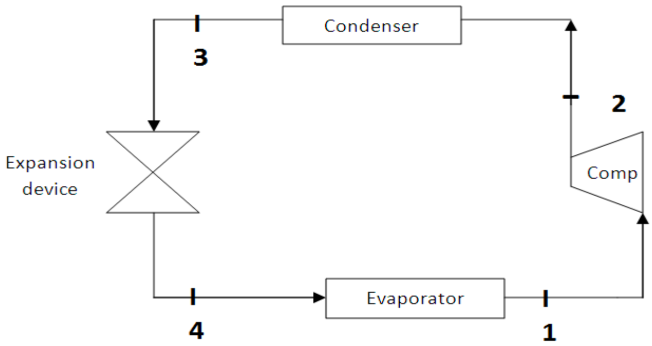

Fig.1. Block Diagram of Basic Vapour Compression

3.1. Cycle Description

It is irreversible cycle which is based on vapour compression refrigeration cycle which consists of four different processes. Block diagram shows the direction of refrigerant flow and four different components employed in different processes.

- Isentropic Process (1-2): The process 1 -2 is an isentropic process where refrigerant is sucked and compressed by compressor.
- Constant Pressure Heat Rejection Process (2-3): It is constant pressure process where compressed refrigerant is exchange heat with surrounding with the help of condenser.
- Isenthalpic Expansion Process (3-4): Here condensed refrigerant is gone through the throttling process which cools down refrigerant and then enters into the evaporator.
- Constant Pressure Heat Extraction Process (4-1): It is constant pressure process where refrigerant extracted heat from refrigerated space and after the evaporation of refrigerant in the evaporator, it is sucked by the compressor and whole process is repeated.

3.2. Refrigerants

For exergy analysis using three different refrigerants and *REFPROP* software for calculation of specified state point's properties of refrigerants.

- R-12
- R-22
- R-407C

3.3. Exergy Analysis

In this paper exergy destruction formula is employed for four main different component of vapour compression refrigeration cycle one by one. The applied vapour compression refrigeration system is defined to fit the following five assumptions.

3.3.1 Assumptions

The following assumptions are taken for exergy analysis in the vapour compression refrigeration system.

- Steady state, steady flow operation.
- Actual compression process.
- Isenthalpic expansion in throttling process.
- Pressure drops in the evaporator, condenser, and intersections is negligible
- kinetic and potential energy changes is negligible.

Table 2 shows design parameters of the applied system. Here evaporator temperature is taken as influential parameter for fixed condenser temperature of 313 K. Here evaporator temperature is varied from 248 K to 298 K and ambient temperature is taken as 298 K.

Table2: Design parameters of the applied vapour compression refrigeration system

Parameter	Value
Refrigeration capacity	3.51 kW
Condenser Temperature	313K
Evaporator Temperature Range	248K ~ 298K
Refrigerants	R-12 , R-22 , R-407C
Ambient Temperature	298K
Isothermal efficiency	85%
Mechanical efficiency	84%
Electrical efficiency	90%

4. Exergy Analysis

4.1. Exergy of Compressor

Applying exergy balance equation-

$\dot{E}_1 + \dot{W}_c = \dot{E}_2 + \dot{I}_{12}$

$\dot{I}_{12} = (\dot{E}_1 - \dot{E}_2) + \dot{W}_c$

$= \dot{m}*(h_1 - T_0 s_1) - \dot{m}(h_2 - T_0 s_2) + \dot{W}_c$

$= \dot{m}*\{(h_1 - h_2) + T_0 (s_2 - s_1)\} + \dot{W}_c$

Here process is isentropic i.e. $s_1 = s_2$

$\dot{I}_{12} = \dot{m}*\{(h_1 - h_2)\} + \dot{W}_c$

For actual cycle,

$\eta_{isen} = 0.85$

$\eta_{mech} = 0.84$

$\eta_{elect} = 0.9$

Considering mechanical and electrical exergy loss,

$\dot{I}_{(mech, elec)} = \dot{W}_e' - \dot{W}_c$

$= \dot{W}_e' - \eta_{mech} * \eta_{elect} * \dot{W}_e'$

$= (1 - \eta_{mech} * \eta_{elect}) * \dot{W}_e'$

$\dot{E}_1 + \dot{W}_e' = \dot{E}'_2 + \dot{I}'_{12}$

$\dot{I}'_{12} = (\dot{E}_1 - \dot{E}'_2) + \dot{W}_e'$

$\dot{I}'_{12} = \dot{m} \{ (h_1 - h'_2) + T_0 (S'_2 - S_1) \} + \dot{W}_e'$

4.2. Exergy of condenser

$\dot{E}_2 = \dot{E}_3$ + Exergy due to heat loss to the surrounding + $\dot{I}_{23}$

Exergy due to heat loss to the surrounding $= Q_c*(1-T_0/T)$

Since surrounding is assumed to be at dead state i.e. $T = T_0$

Exergy due to heat loss to the surrounding = 0.

$\dot{I}_{23} = \dot{E}_2 - \dot{E}_3 = \dot{m} *\{(h_2 - h_3) + T_0 (s_3 - s_2)\}$

4.3. Exergy of Throttle Valve

$\dot{E}_3 = \dot{E}_4 + \dot{I}_{34}$

$\dot{I}_{34} = \dot{E}_3 - \dot{E}_4$

$\dot{I}_{34} = \dot{m} *\{(h_3 - h_4) + T_0 (s_4 - s_3)\}$

Since it is an isenthalpic process, i.e. $h_3 = h_4$

$\dot{I}_{34} = \dot{m}^*\{T_0 (s_4 - s_3)\}$

4.4. Exergy of Evaporator

$\dot{E}_4 + Q_e^*(1-T_0/T_r) = \dot{E}_1 + \dot{I}_{41}$

$\dot{I}_{41} = \dot{E}_4 - \dot{E}_1 + Q_e^*(1-T_0/T_r)$

Here, $T_0 > T_r$

So, the term $Q_e^*(1-T_0/T_r)$ gives negative value, it means exergy of the system decreases and we have to supply external exergy in terms of compressor work.

Total exergy destruction (I_{total}) is given by,

$I_{total} = I_{evap} + I_{comp} + I_{cond} + I_{throt}$

Second Law efficiency (Exergetic efficiency) of the system is the ratio of actual COP to ideal COP

$\eta_{II} = COP_{actual} / COP_{ideal}$.

$$COP_{actual} = \frac{\text{(Refrigeration capacity)}}{\text{Actual compressor work}}$$

$$= \text{(Refrigeration capacity)} / \dot{W}_e'$$

$$COP_{ideal} = \frac{Te}{(Tc - Te)}$$

5.Result

From exergy analysis of VCRS for three different refrigerants, results discussed in terms of second law efficiency vs. evaporator temperature and exergy destruction of the system vs. evaporator temperature as given in graph 5.2 and 5.3 respectively.

5.1. Result table

The following table shows total exergy destruction and second law efficiency of the system for given refrigerant at fixed condenser temperature and varied evaporator temperature from 248 K to 298 K.

Table 3: Calculated value of I_{total} and η_{II}

Refrigerants	R-134a		R-12		R-22	
Temperature range $T_E \rightarrow T_C$ (K)	I_{total} (Kw)	η_{II}	I_{total} (Kw)	η_{II}	I_{total} (Kw)	η_{II}
248→313	1.443	0.398	1.226	0.444	1.217	0.444
258→313	1.116	0.421	0.995	0.467	0.957	0.464
268→313	0.854	0.442	0.716	0.497	0.743	0.483
278→313	0.639	0.463	0.560	0.509	0.567	0.503
288→313	0.467	0.485	0.530	0.530	0.424	0.522
298→313	0.327	0.506	0.552	0.552	0.305	0.543

5.2. Variation of exergy destruction with Evaporator temperature

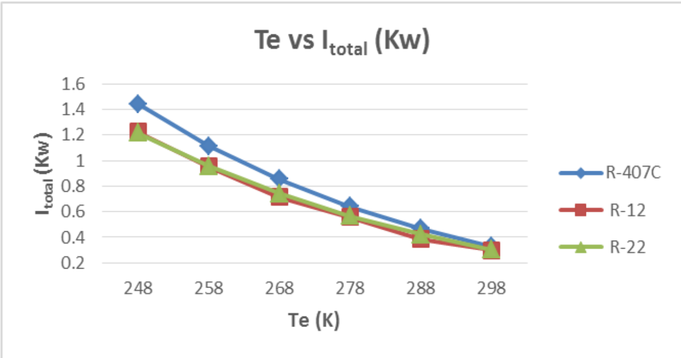

Fig.2. Variation of exergy destruction with evaporator temperature

5.3. Variation of second law efficiency with Evaporator temperature

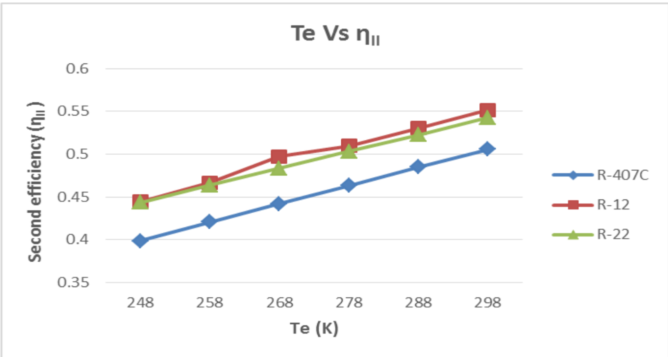

Fig.3. Variation of second law efficiency with evaporator temperature

6. CONCLUSIONS

Based on the results, the following conclusions have been arrived at:

- As the evaporator temperature increases there is gradual decrease in exergy destruction of the system for given refrigerant from graph in figure 5.2.
- From result table5.1 exergy loss for R-12 and R-22 are almost same but R-407C is maximum.
- From graph in Fig. 5.3 show that second law efficiency increases with evaporator temperature.
- Exergetic efficiency is maximum for R-12 then R-22 and minimum for R-407C.
- Exergy destruction is maximum at - ve temperature of evaporator for refrigerant R-407C but at near ambient condition it is almost same for all three refrigerants from graph in Fig. 5.2.

REFERENCES

[1] Bukola O. Bolaji "Exergetic performance of a domestic refrigerator using R-12 and its alternative refrigerants" journal of engineering science and technology , december 2010 , vol. 5(4), pp. 435–446 .

[2] Xu, X. And Clodic, D., "Exergy analysis on a vapor compression refrigerating system using R-12, R-134a and R-290 as refrigerants" (1992). International Refrigeration And Air Conditioning Conference. paper 160. http://docs.lib.purdue.edu/iracc/160.

[3] V. S. 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," (2012) Clean Technol. Environ. Policy, vol. 14, pp. 47–53.

[4] Jing-Nang Lee, Chien-Chih Chen and Chen-Ching Ting," Numerical Analysis of Exergy for Air-Conditioning Influenced by Ambient Temperature",International Journal of Engineering and Technology Innovation,(2014) vol. 4, no. 3, pp. 152-160.

[5].Rajanikant Y. Mahajan 1 , Sanjaykumar A. Borikar ,"Performance Evaluation of Domestic Refrigerator Using Hc- 12a Refrigerant as an Alternative Refrigerant to R12 And R134a" . The International Journal Of Engineering And Science (IJES), (2014), Volume-03, Issue-10, Page- 26-37

[6]L A ROCCA, V., Messineo, A., & CLOTH, D.. " An experimental study of a refrigerating plant When replacing R22 with HFCs refrigerants". (2011), In Proceedings of the XIV European Conference "The Latest Technologies in Air Conditioning and Refrigeration Industry". Milan.

[7] S. Vandaarkuzhali,R. Elansezhian ," Investigation of R152a/R22 mixture in air conditioning system", Current Trends in Engineering and Technology (ICCTET), 2014 2nd International Conference IEEE, Coimbatore, India.

[8] K. Nagalakshmi , G. Marurhiprasad Yadav, "The Design and Performance Analysis of Refrigeration System Using R12 & R134a Refrigerants", ISSN : 2248-9622, Vol. 4, Issue 2(Version 1), February 2014, pp.638-643

[9].Gaurav , Raj Kumar, "Performance Analysis of Household Refrigerator with Alternate Refrigerants", International Journal of Innovative Research in Science, Engineering and Technology , April 2014, ISSN: 2319-8753, Vol. 3, Issue 4

[10] Khalid, M.A. (2006). "Comparison of performance analysis of R22 and its alternate". 11th HVACR Conference, Krachi, 56-67.