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COMPARATIVE EXERGY ANALYSIS OF VAPOUR COMPRESSION REFRIGERATION SYSTEM USING R134A AND R290

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Abstract

In this research work Exergy analysis of VCR system is performed using an existing refrigerant R134a with an alternate refrigerant R290. R290 has very low GWP & ODP as compared to that of R134a. Hence its applicability in terms of exergy destruction is being studied. First and second laws of thermodynamics are used as tools for the analysis.

1. Introduction

Over the years refrigerants have been under scrutiny. The earliest recognized refrigerants like ammonia and carbon-dioxide were found to be harmful and therefore focus was shifted to first generation refrigerants which are chloroflurocarbons (CFCs) and Hydro-chloro-flurocarbons (HCFCs). They solved the problem of toxicity but had a limitation of being harmful for ozone layer. Further they were replaced by hydo-flurocarbons (HFCs), the second generation refrigerants [1]. Although they do not deplete ozone layer, they have serious potential of causing global warming. Keeping environment on top priority, refrigerants with zero ODP and low GWP are being sought for [1]. Propane (R290) is one such refrigerant which is environmentally suitable. Over the years much research has been carried out in order to find an alternate for R134a in VCR system (especially domestic refrigerator). Agrawal et al. [3] carried experimental study of domestic refrigerator using

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zeotropic blend of propane and butane. Jung et al. [4] tested mixture of propane and isobutene in domestic refrigerator. J Gill et al. [5] carried energy analysis of VCR system R134a and LPG. Kausik and Arora [6] conducted energy analysis of VCR system with R502, R404a and R507a.

These days exergy analysis is considered as a better tool for analysis as it tells about the degradation of quality of energy and also it identifies the region of exergy destruction in the system [2]. Therefore in this research work the authors carried out exergy analysis of R290 and its comparison with R134a.

2. Exergy Analysis

In VCR system there are generally four major components Evaporator, Compressor, Condenser and Expansion device. The electrical power is supplied to the compressor. On the other hand latent heat of vaporization is removed from evaporator and latent heat of condensation is dissipated by condenser. The schematic diagram represents processes 1-2, 2-3, 3-4, 4-1, which represent isentropic compression, condensation, throttling and vaporization of the refrigerant respectively. The equations for Exergy calculations are based on second law analysis [2]. Equations can be arranged as

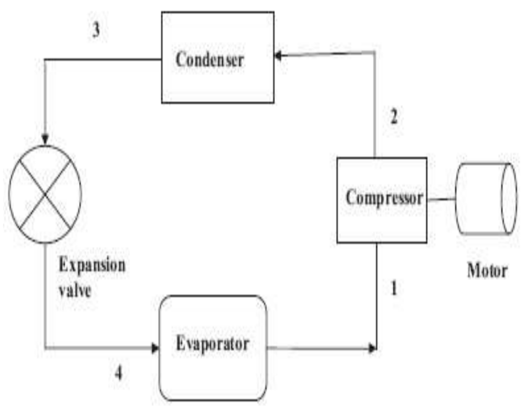

Figure 1. VCR system.

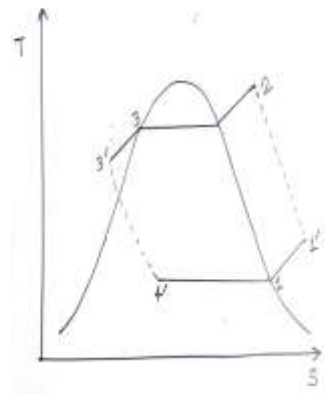

Figure 2. T-S Plot of VCR cycle.

For evaporator:

$$Q_{evap} = m(h_1' - h_2') \tag{1}$$

$$Iev = m\{(h_4' - h_1') - To(S_4 - S_1) + Q[1 - To/T_{ev}] \tag{2}$$

For compressor:

$$\text{Compressor work} = Wc = m(h_2 - h_1') \tag{3}$$

$$I_{comp} = m\{(h_1' - h_2) - To(S_1' - S_2')\} + W_{el}. \tag{4}$$

For condenser:

$$Q_{cond} = m(h_2 - h_3) \tag{5}$$

$$I_{cond} = m\{(h_2 - h_4) - To(S_2 - S_3) - Q_{cod}(1 - To/T_{cond})\}. \tag{6}$$

Expansion Device:

$$I_{\exp} = m(S_4 - S_3). \tag{7}$$

Total Destruction of exergy is given by

$$I_{Total} = I_{ev} + I_{Comp} + I_{cond} + I_{\exp}. \tag{8}$$

The above equations are used for calculating the exergy loss in VCR system for comparison of R134a and R 290 theoretically. There is one more analysis of R134ain which the theoretical analysis is compared with irreversibilities produced while operating the experimental setup with same refrigerant. When we go deep in the second law of thermodynamics we come across some comparison parameters like Energy Efficiency Ratio (EER), exergy efficiency second law efficiency η_{II}

EER =Exergy out per unit compressor work

$$\frac{h_1' - h_4}{Wc} \tag{9}$$

$$\text{Exergy Efficiency} = \frac{\psi_1' - \psi_4}{Wel} = \eta_x \tag{10}$$

Where $\psi = (h - h_0) - T_o(S - S_0)$

And

$$\eta_{II} = \frac{Qe}{Wc} \times \left(\frac{To}{Tc} - 1\right). \tag{11}$$

3. Results

As a result of application of above mentioned equations, the irreversibility produced in case of ideal and actual analysis using R134a is calculated. The irreversibilities in case of theoretical comparison of R134a and R290 is also obtained. These results are tabulated as follows

Table 1. Heat and Work interactions in various components of VCR system for both refrigerants.

	R134a Theoretical in KW	R134a Actual in KW	R290 Theoretical in KW
Qev	0.157	0.192	0.1579
Wc	0.0322	0.0496	0.0329
Wel	0.03975	0.0612	0.0406
Qcond	0.1897	0.2418	0.1909

Table 1 represents heat transfer in evaporator and condenser, and work consumed in compressor.

Table 2. Exergy destruction in all components of VCR system.

	R134a Theoretical in KW	R134a Actual in KW	R290 Theoretical in KW
Qev	-4.174×10^{-5}	-4.43×10^{-4}	1.939×10^{-4}
Wc	7.533×10^{-3}	2.44×10^{-2}	7.673×10^{-3}
Wel	$1.0.64 \times 10^{-4}$	1.292×10^{-5}	-3.39×10^{-4}
Qcond	7.619×10^{-3}	2.66×10^{-2}	7.55×10^{-3}

Table 2 represents irreversibilities generated in all four components of VCR system based on second law analysis.

Table 3. Performance parameters based on second law of Thermodynamics.

S. No	Refrigerant	η_x	COP	EER	η_{II}
1	R134a (T)	8.374	3.949	3475.72	55.77
2	R134a(A)	6.374	3.137	2751.79	44.24
3	R290	8.232	3.891	6398.27	54.89

Table 3 show performance parameters calculated using set of equations from.

The authors have also studied the comparison of COP variation for both the refrigerants against variation of evaporator and condenser temperature. The variation can be seen in the table and its pattern can be observed from the graph.

Table 4. Variation in COP with Change in Evaporator temperature (Te).

S.No	Tev in Kelvin	COP R134a	COP R290
1	270	4.7	3.72
2	271	4.85	3.952
3	272	5	4.01
4	273	5.17	4.109
5	274	5.34	4.23
6	275	5.52	4.2317
7	280	6.58	5.2

Table 4 represents COP variation with Te. Similarly Table 5 shows COP variation with condenser temperature T_{cond}.

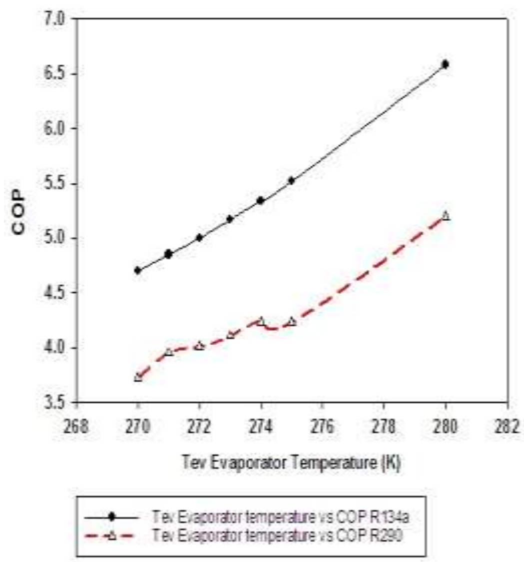

Figure 1. Variation of COP With evaporator temperature for R134a & R290.

It is seen in figure -1 that with increase in evaporator temperature, COP value for both the refrigerants increases which is in agreement with literature of refrigeration.

Table 5. Variation of COP with condenser temperature.

S.No.	Tcond in Kelvin	COP R134a	COP R290
1	311	5.47	4.36
2	312	5.3	4.22
3	313	5.14	4.09
4	314	5	4.01
5	315	4.85	3.95
6	316	4.69	3.88
7	317	4.55	3.78

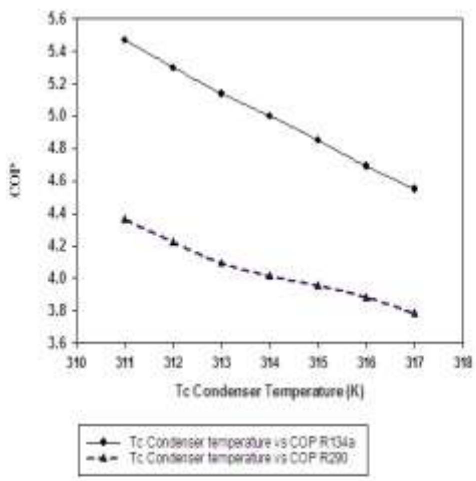

Figure 2. Variation of COP With condenser temperature for R134a & R290.

Figure 2 represents that with increase in condenser temperature COP for both the refrigerants decreases.

4. Conclusions

In this communication Exergy analysis of vapour compression is carried out for existing refrigerant R134a and its suggested alternate R290. The following conclusions are drawn from the study.

• Electrical work and compressor work consumed by R290 is slightly on higher side as compared to R134a for same temperature range of evaporator and condenser. R290 consumes 2.174% more compressor power and 2.138% more electrical power when compared with R134a.

• For the same temperature difference of evaporator and condenser R290 removes 0.573% more heat as compared to R134a.

• Exergy destruction is 0.905% less in case of R290 when compared with exergy destruction of R134a.

• Compressor is found to be the major contributor in exergy destruction for both refrigerants.

• COP of VCR with R290 is 1.468% less than that of R134a.

Hence it can be inferred that propane when seen in terms of irreversibility generation is a good potential alternate for R134a. Although COP of VCR using R290 is less that R134a, still the difference is marginal.

References

[1] United Nations Environmental Programme, Montreal Protocol on substances that deplete the ozone layer, Final act. New York: United Nations; 1987.

[2] J. U Ahmed, R. Saidur and S. S. Masjuki, A review on exergy analysis of vapor compression refrigeration system, Renewable and Sustainable Energy Reviews 2011

[3] M. A. Sattar, R. Saidur and H. Masjuki, Butane, isobutane and their mixture as an alternative to R134a in domestic refrigerator, Int. J. of World Mechanical and Materials Engineering 2007;29: 223-228.

[4] N. Agrawal and S. Patil, Experimental Studies of a Domestic Refrigerator Using R290/R600a Zeotropic Blends, Energy Procedia 109 (2017), 425-430.

[5] J. Gill and J. Singh, Energy analysis of vapor compression refrigeration system using mixture of R134a and LPG as refrigerant, Int. J . of Refrigeration, 2017.

[6] A. Arora and S. C. Kaushik, Theoretical analysis of vapour compression refrigeration system with R502, R404A and R507A, International Journal of Refrigeration 3I (2008), 998-1005.

[7] C. S. Chaudhari and S. N. Sapali, Performance investigation of natural refrigerant R290 as a substitute to R22 in refrigeration systems, Int. conference on RAAR 2016, Energy Procedia 109 (2017), 346-352.

[8] N. D. Shikalgar and S. N. Sapali, Energy and exergy analysis of a domestic refrigerator: Approaching a sustainable refrigerator, Journal of Thermal Engineering 5 (2019), 469-481.

[9] P. K. Nag, Engineering Thermodynamics, 2e McGraw Hill education India, 2015.

[10] Y. A. Cengel and M. A. Boles, Thermodynamics: An engineering approach, McGraw Hill, New York, 1988.

[11] C. P. Arora, Refrigeration and air conditioning, McGraw Hill Education, India, 2015.

[12] R. Yumrutas, M. Kunduz and M. Kanoglu, Exergy analysis of VCR system, Exergy, an International Journal 2 (2002), 266-272.

[13] D. C. Anta and L. N Antres, Thermodynamic screening of alternate refrigerants for R290 &R600a, Results in Thermal Engineering, 2019.

[14] A. Maiorino, C. Aprea, M.G. Del Duca, R. Llopis, D. Sánchez and R. Cabello, R-152a as an alternative refrigerant to R-134a in domestic refrigerators: An experimental analysis, International Journal of Refrigeration 96 (2018), 106-116.