International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-04, Issue-07, Oct 2018

Exergy Analysis of a Vapour Compression Refrigeration System using R-134a and Hydrocarbon as Refrigerants

[1]Mukul Kumar, PG Scholar, Department of ME, BIT Sindri, Dhanbad, India

[2]R.K. Nayak, Assistant Professor, Department of ME, BIT Sindri, Dhanbad, India

[1]mukulmit2k11@gmail.com, [2]rajennayak4@gmail.com

Abstract - **Present study shows the effect of refrigerant variation on the performance of a simple Vapour Compression Refrigeration System. The analysis deals with the cooperative outcomes of exergy analysis of the present work. The main objective of this paper is to increase the performance by using two different refrigerants R134a and hydrocarbon. Exergy analysis is the effective tool for design and performance evaluation of Vapour Compression Refrigeration System. The considerable amount of energy produced in world is consumed by refrigerators. So, it's important to minimizing energy consumption of those devices. It is known that the Chlorofluorocarbon and Hydrochlorofluorocarbon refrigerants have been forbidden due to chlorine content and their high ODP (ozone depleting potential) and GWP (global warming potential). So, Hydrofluorocarbon refrigerants are widely used now a days. A no. of research paper has been presented on this area of research by replacing the refrigerants Chlorofluorocarbon and Hydrochlorofluorocarbon refrigerants with some other types of refrigerants. This paper deals with a comparative analysis of two refrigerants working in a one stage vapour compression refrigeration system. These refrigerants are: Tetrafluoroethane- R-134a and Hydrocarbon.**

Keywords — COP, Exergy Efficiency, Exergy destruction, R-134a and Hydrocarbon Refrigerants, VCR System

I. INTRODUCTION

The vapour compression refrigeration system (VCRS) is the most extensive system for a cold generation. This is used in domestic refrigerator, air conditioning, commercial refrigeration and industrial refrigeration. VCRS consume high energy. Thus, reduction in energy consumption is very important in VCR System [1]. Exergy analysis is real assessment of Vapour compression refrigerating system. Exergy (Available energy) is the maximum work that can be obtained till the system attains a dead state. Exergetic analysis combines the application of the first and second law of thermodynamic. This analysis helps to understand clearly irreversibility influences in thermodynamic process. It permits to identify and calculate various exergy losses in different components, such that we lead to improve thermodynamic efficiency and performance. The vapour compression refrigeration system (VCRS) is the most extensive system for a cold generation. This is used in domestic refrigerator, air conditioning, commercial refrigeration and industrial refrigeration. VCRS is most widely used in domestic and as well as large-scale approach to generating refrigerating effect. According to the Montreal protocol the refrigerant R-12 will be abandoned but due to high ODP and GWP level, R-134a possible substitute known.

Use of the refrigerants R502, R404A, and R507A computing coefficient of performance (COP), Exergy destruction, Exergetic efficiency of vapour compression refrigeration system. It concludes that the performance degradationof the evaporator has larger effect on the power consumption of the compressor but the performance degradation of the condenser has an overall larger effect on COP [2]. Study and investigate the performance analysis of vapour compression refrigeration system with zeotropic refrigerant R404a [3]. This paper presents the simulation result of vapour compression refrigeration system with R404A, 407C, 410A as refrigerants and conclude that the COP and exergetic efficiency of R407C are better than that of R404A and R410A. The ED of R410A is higher than that of R407C and R404A [4]. Energy (first law) 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. It does not provide information on how, where, and the amount of performance is degraded. As a complement to the present materials and energy balances, exergy calculations can provide increased and deeper insight into the process, as well as new unforeseen ideas for improvements [5].

 DOI : 10.18231/2454-9150.2018.0900

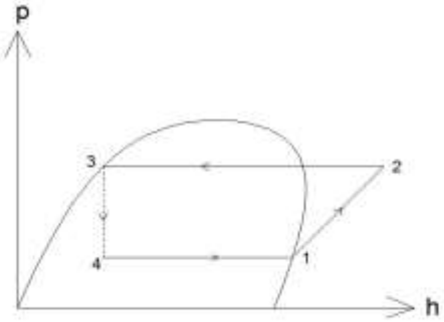

Fig. 1: p-h diagram of refrigeration cycle

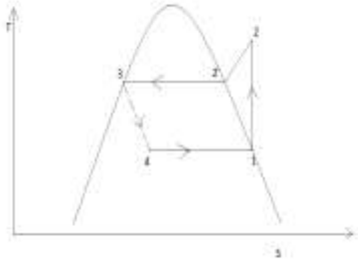

Fig. 2: t-s diagram of refrigeration cycle

In above diagram
Process 1-2 Isentropic or reversable adiabatic compression.
Process 2-3 Heat rejection at constant pressure.
Process 3-4 constant enthalpy expansion.
Process 4-1 Heat supply at constant pressure

Exergy efficiency and Exergy destruction-
The second law efficiency or Exergy efficiency is defined as the ratio of Minimum available energy required for the cycle to Actual available energy consumed in the cycle. Is given by [6],

$$\eta_{II} = \frac{\text{Minimum available energy required for the cycle}}{\text{Actual available energy consumed in the cycle}}$$

$$(AE)_{actual} = w = \frac{RE}{COP_{ACTUAL}} \quad (1)$$

The minimum Available energy required for the same refrigerating effect RE is the work of a Carnot cycle operating between the same temperatures T_1 and T_2.
Thus,

$$(AE)_{minimum} = W_{carnot} = \frac{RE}{T1/(T2-T1)} \quad (2)$$

i.e, The second law efficiency of the refrigerator is,

$$\eta_{II} = \frac{\text{Minimum Available Energy}}{\text{Actual Available Energy}} = \frac{W_{CARNOT}}{W} = \frac{RE/W}{RE/W_{CARNOT}}$$

$$= \frac{COP_1}{COP_{CARNOT}} \quad (3)$$

i.e.-Second law efficiency also define as the ratio of Actual COP to Reversible or maximum COP.

Exergy destruction in each components: -

$ED_{EVAP.} = m(\psi_4 - \psi_1) + Q_{EVAP}(1 - T_0/T_{EVAP.})$

$= m((h_4 - T_0S_4) - (h_1 - T_0S_1)) + m(h_4 - h_1) \times (1 - T_0/T_{EVAP.})$

$ED_{COMP.} = m(\psi_1 - \psi_2) + W_C$

$= m((h_1 - T_0S_1) - (h_2 - T_0S_2)) + m(h_1 - h_2)$

$ED_{COND.} = m(\psi_2 - \psi_3) + Q_{COND.}(1 - T_0/T_{COND.})$

$= m((h_2 - T_0S_2) - (h_3 - T_0S_3)) + m(h_2 - h_3) \times (1 - T_0/T_{COND.})$

$ED_{Throttling} = m(\psi_3 - \psi_4)$

$= m((h_3 - T_0S_3) - (h_4 - T_0S_4)).$

II. FABRICATION OF EXPERIMENTAL SETUP

A pictorial diagram of VCR System consists Compressor, Condenser, Expansion valve and Evaporator is shown in fig. 3, Schematic diagram in fig.4.In this study, R 134A and Hydrocarbon is used as refrigerants in VCR system. Initially the refrigerant enters into the compressor, the purchased compressor is an oil- lubricated single stage reciprocating type and hermetically sealed. The Hermetic compressor have two advantage such as it minimizes leakage of refrigerant and has mechanism to cool the motor by using of the suction vapour flowing through the motor winding. Compressor increase both pressure and temperature of vapour refrigerant, then goes into the air-cooled condenser, and heat taken out from it and then it is condensed back again into the liquid state. As the refrigerant is under high pressure in condenser coil it moves to evaporator through capillary tube. Due to Refrigerant moves from condenser coil to capillary it experiences, change in pressure due to refrigerant movement from bigger diameter tube (condenser) to smaller diameter tube (capillary valve). The refrigerant under high pressure travels length of capillary tube with minimal pressure drop. The refrigerant exit from the expansion valve to evaporator (bigger diameter) this change in diameter drops the refrigerant pressure so, reducing it temperature. This low temperature refrigerant can now take in heat from room and boil. After refrigerant is allowed to pass through expansion valve, its pressure decreases and evaporation of the refrigerant will certainly occur in evaporator. In the evaporator liquid refrigerant absorb heat from cold chamber and get evaporated, it also offers a heat transfer surface area through which heat may move from the refrigerant space into the vaporising refrigerant.

Fig. 3: Pictorial representation of experimental set up of VCR System

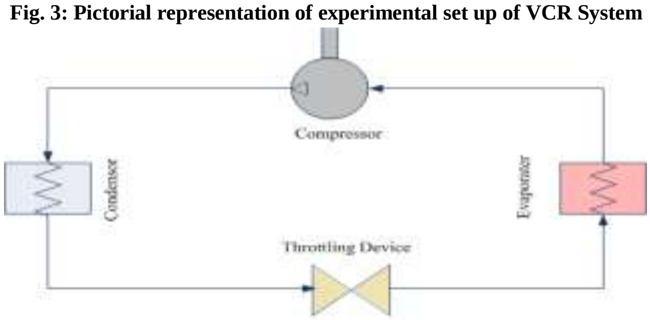

Fig. 4: Schematic diagram of Vapour compression refrigeration System

 DOI : 10.18231/2454-9150.2018.0900

III. DETAILS OF THE EXPERIMENTAL SETUP WITH PROCEDURE

A. Evaporator

Evaporator is a type of heat exchanger in which heat is absorb at constant pressure. Liquid Refrigerant absorbs heat from the evaporator chamber and gets evaporated, when a refrigerant is allowed to pass through expansion valve, its pressure decreases and evaporation of the refrigerant will be occurred. The evaporator has heat transfer surface area through which heat is remove from refrigerant space into the vaporizing refrigerant. An evaporator is any heat transfer surface in which a volatile liquid is vaporized for the purpose of removing heat from a refrigerated space and also, cooling its own coils. Evaporator is also called chiller, freezer, cooling coil depending upon its applications.

Fig. 5 Evaporator chamber in my experimental set up

B. Compressor

Compressor is a mechanical device, which is use to increase both pressure as well as temperature. It is generally used to handle saturated or superheated vapour. It increases pressure of refrigerant exit from the evaporator that means pulling the low temperature and pressure of saturated vapour and supplying high pressure and temperature towards the condenser. When compression put in, refrigerant vapour leaves the compressor at a varied pressure and also the excessive function used leads to superheating of the refrigerant vapour. The main objective of compressor is to recover the vapour which exit from the evaporator, and to increase heat range and pressure to single stage so that it could be became condensed with the obtainable condensing part.

Fig. 6: Compressor in my experimental set up

C. Condenser

It is a type of heat exchanger in which heat is rejected at constant pressure. High pressure and high temperature vapor which goes to the condenser has heat taken out of it and consequently it is condensed back again into the liquid state. The heat transmission channel can become water or air, the necessity is that, the temperature is usually lesser corresponding to pressure. The process of condenser is same as that of evaporator except opposite work.

Fig. 7 Condenser in my experimental set up

D. Expansion valve

Expansion valve is also known as throttling device-Flow through a restricted passage, partially open-wall, venturimeter or porous plug is known as throttling. Its results a decrease in pressure and process is irreversible adiabatic process. Expansion device is the refrigerant flow control valve. Used to lower the pressure to the equal level as that of the evaporating pressure, a device called expansion valve has to be placed to undertake this procedure or also called as throttling device or an expansion device. Because of the high pressure of the refrigerant is under in condenser coil it moves to evaporator through capillary.

Fig. 8: Expansion valve

III. RESULTS AND DISCUSSION

In order to describe the experimental outcomes, graphs are plotted between different parameters obtained from various number of observations.

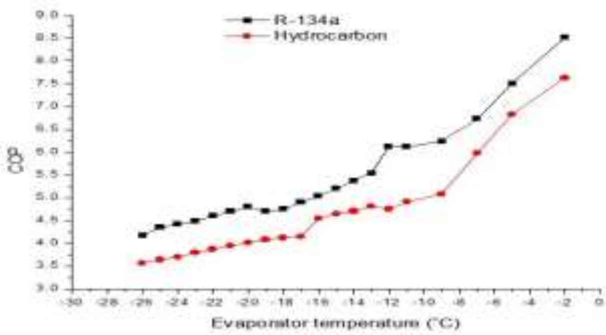

Fig. 8: Variation of COP with Evaporator Temperature

 DOI : 10.18231/2454-9150.2018.0900

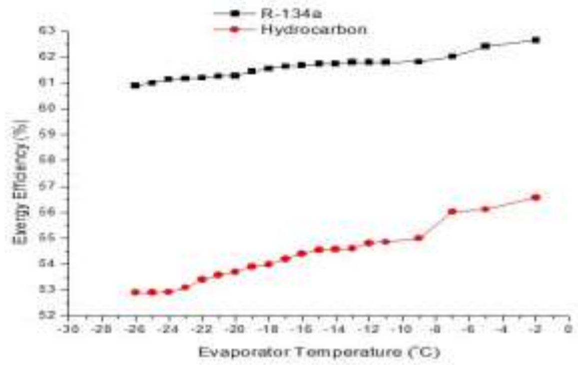

Fig. 9: Variation of Exergy Efficiency with Evaporator Temperature

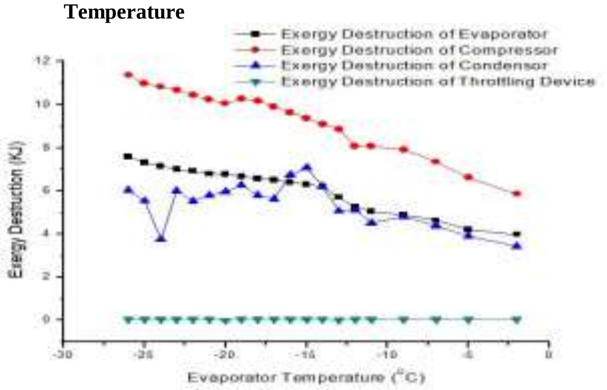

Fig. 10. Using R-134a Variation of ED with Evaporator Temperature

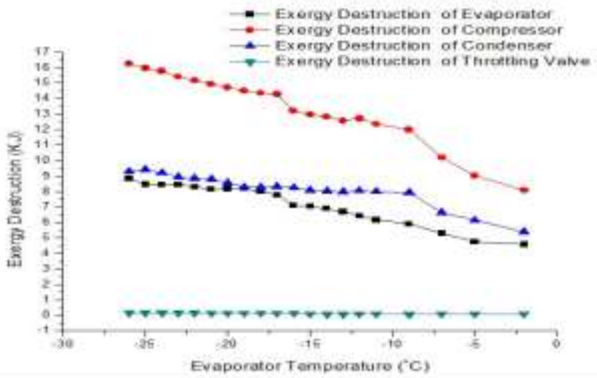

Fig. 11. Using Hydrocarbon Variation of ED with Evaporator Temperature

By adopting the procedure describe above the Exergy analysis of VCRS using R134A and Hydrocarbon as refrigerants, then experimentally evaluated with parameters such as compressor work input, refrigeration effect, COP, exergy efficiency. The exergy destruction of each components is also calculated.

- ❖ Fig. 8: shows the variation of COP with Evaporator Temperature. COP using refrigerant R134a is greater than Hydrocarbon. Trend of this graph is increasing continuously as increasing evaporator temperature, because as evap. temperature increase diff. bet. Condenser and evaporator temperature decrease so work input decrease and COP increases. Graph is approximate straight line because due to some environmental effect like surrounding temperature effected due to air velocity, heat losses etc.
- ❖ Fig. 9: shows the variation of Exergy efficiency with Evaporator Temperature. Exergy efficiency using refrigerant R-134a is greater than Hydrocarbon. Trend of this graph is increasing continuously as increasing evaporator temperature, because enthalpy of refrigerant increasing and work input is decreasing so, exergy efficiency increasing. Also graph is approximate straight line because due to some environmental effect like surrounding temperature effected due to air velocity, heat losses etc.
- ❖ Fig.10: shows the Using R-134a variation of Exergy destruction of evaporator, compressor, condenser and throttling valve with Evap. Temperature. Trend of this graph is approximately straight line and decreasing, The evaporating temperature increases heat transfer between the refrigerants enter into the evaporator tube and the refrigerating effect increase such that the exergy losses decrease. At higher evaporating temperature, exergy loss is lower compared to that of lower evaporating temperature. Exergy destruction represent rate of irreversibilities in that component. Compressor has greater effect on exergy destruction due to more irreversibility.
- ❖ Fig. 11: Same as above only difference is replace of Hydrocarbon in place of R-134a as refrigerant.

Comparison of performance using R-134a and Hydrocarbon as refrigerant, R134a has better performance than Hydrocarbon refrigerant also R134a is ecofriendly because of zero ODP and less GWP. So R134a is better refrigerant.

IV. Conclusion

- ❖ Exergy analysis is a technique to present the process and this further aid in reducing the thermodynamic losses occurring in the process. So, it is an important tool in explaining the various energy flows in a process and in the final run helps to reduce losses occurring in the system.
- ❖ In this system comprises of four components i.e. compressor, a capillary tube (expansion valve), a condenser and an evaporator. The maximum exergy loses occurred in compressor among the components of the vapor compressor refrigeration system.
- ❖ It is observe that COP and Exergy efficiency of VCR System is greater in case of using R134a refrigerant rather than Hydrocarbon refrigerant.
- ❖ Some of the researcher using Hydrocarbon and its blend generally show the better performance according to energy and exergy efficiency of the system. So, the choice of the hydrocarbons and their blend. But due to flammability issue hydrocarbon cannot be used alone in the industrial sectors.
- ❖ R134a is best according to zero ODP and low GWP and also better performance than Hydrocarbon.

Future Scope

There are many works can be done for improving Vapour compression refrigeration System, in place of traditional refrigerant, Nano refrigerant can be used to improvement of

 DOI : 10.18231/2454-9150.2018.0900

Vapour compression refrigeration System. Also using and comparison some other refrigerants which have less ODP and GDP.

Appendix

LIST OF ABBREVIATIONS USED

T_1 = Inlet Temperature of Compressor ℃.
T_2 = Exit temperature of compressor ℃
T_3 = Exit Temperature of Condenser ℃
T_4 = Inlet Temperature of Evaporator ℃

T_0 = Atmospheric Temperature℃
$T_{evap.}$ = Evaporator Temperature. ℃
h_1 = Specific enthalpy at inlet to compressor (KJ/kg)
h_2 = Specific enthalpy at exit of compressor (KJ/kg)
h_3 = Specific enthalpy at exit of condenser (KJ/Kg)
h_4 = Specific enthalpy at inlet to evaporator (KJ/Kg)
s_1 = Specific entropy at inlet to compressor (kJ/kgk)
s_2 = Specific enthalpy at exit of compressor (kJ/kgk)
s_3 = Specific enthalpy at exit of condenser (KJ/kgk)
s_4 = Specific enthalpy at inlet to evaporator (KJ/kgk)
m = mass of refrigerant in kg.
COP = Coefficient of performance
C_{Pv} = Specific Heat of vapour refrigerant KJ/KgK
RE = Refrigeration Effect
W = Work input (KJ)
ED = Exergy destruction (KJ)
Ψ = Available energy
h_{II} = Second law efficiency or Exergy efficiency

REFERENCES

[1] K. Harby, Gebaly, D.R. Koura, N.S. Hassan, M.S, 2016. Performance improvement of vapour compression cooling systems using evaporative condenser an overview. Renewable Sustain. Energy Rev. 58, 347–360.

[2] A. Arora, S.C. Kaushik, "Theoretical analysis of a vapour compression refrigeration system with R502, R404A and R507A", International Journal of Refrigeration 31, 998 – 1005, 2008

[3] Jerald L, and Kumaran S. (2014), "Investigations on the performance of Vapour Compression System Retrofitted with Zeotropic Refrigerant R404A", American Journal of Environmental Science, Volume 10.pp.35-43.

[4] J. Soni and R. C Gupta. (2013), "Performance Analysis of Vapour Compression Refrigeration System with R404A, R407C AND R410A", Int. J. Mech. Eng. & Rob. Res., Vol.2.

[5] Saidur R, Masjuki HH, Jamaluddin My. An application of energy and exergy analysis in residential sector in Malaysia. Energy Policy 2007; 35:1050–63.

[6] P.K Nag "Thermo dynamics", by Tata McGraw-Hill Publishing Company Limited, 7 West Patel Nagar, New Delhi 110008; 231-235

[7] Yumrutas V.P and Kumar S.P, (2010),"Experimental Comparative Energy, Exergy Flow and Second Law Efficiency Analysis of R22, R436 Vapour Compression Refrigeration Cycles", International Journal of science and Technology vol.2.

[8] R.J Greco, R, Llopis, E, Torrella (2004), "Analysis of the variation mechanism in the main energetic parameters in a single-stage vapour compression system with R22,R407,NGL and LPG", Int J Applied Thermal Engineering, pp.167-176

[9] J.S Fernandez, Seara, J. Sieres and Manual Vazquez (2006) Compression-Absorption cascade refrigeration system Applied Thermal Engineering Vol. 26pp: 502-512

[10] Jelinek M. (2012):Performance of a triple ,pressure level absorption/ compression Cycle Applied Thermal Engineering Vol 42,pp :2-5

 DOI : 10.18231/2454-9150.2018.0900