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Exergy Analysis of Vapor Compression Cycle

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Abstract: Refrigeration plays a very important role in industrial, domestic and commercial sectors for cooling, heating and food preserving applications. There are innumerable applications of such systems and they are the major consumer of electricity around the world. Energy consumption is directly proportional to the economic development of any nation, however this area is in great interest now because of increase in the cost of conventional fuels and environmental concerns globally. Due to the increasing energy demand, degradation of environment, global warming and depletion of ozone layer etc, there is urgent need of efficient energy utilization and waste heat recovery for useful applications. The researchers are concentrating on the alternate and environment friendly refrigerants, especially after the Kyoto and the Montreal protocols. However, in a quest to find out alternate and environment friendly refrigerants, the energy efficiency of the equipment having conventional refrigerants is also very important in the present age of competitive business community. The purpose of this project is : (1)To investigate exergy loss for each equipment in vapour compression refrigeration system & finding out the component in which the loss of available energy is more, (2)To provide alternate solution to improve the performance of vapor compression cycle. (3)To observe changes in exergy destruction w.r.t change in load.

Keywords: VCR system, Exergy Analysis, Exergy Destruction

I. INTRODUCTION

Air conditioning bears a huge cost because thermal comfort is very essential as far as domestic and industrial sectors are concerned. The big challenge is to use less energy for air conditioning applications in order to reduce the associated power consumption so as to make them more efficient and environmental friendly. The quantitative information is required to be obtained that will show the irreversibility of a process in all the components of any plant. In order to optimize their design, a thorough thermodynamic analysis is required. The analysis based on first law of thermodynamic is most commonly used in engineering applications, however, it is concerned only with law of conservation of energy and therefore it cannot show how and where irreversibility in the system or a process occurs. On the other hand, the analysis based on second law analysis is well known method being used to analyse all the thermodynamic cycles for better understanding and evaluation of irreversibility associated with any process. Unlike the first law (energy), the analysis based on second law analysis (exergy) determines the magnitude of irreversibility associated in a process qualitatively and thereby, provides an indication to point out the directions in which the engineers should concentrate more in order to improve the performance of this thermodynamic system.Thus, the aim of second law based analysis is to determine the exergy losses and to enhance the performance by changing the design parameters and hence, to reduce the cost of the refrigeration cycle.

II. LITERATURE RIVIEW

In 1987, Mastrullo conducted exergetic analysis of multi stage VCR systems using R12. Plant exergetic efficiencies, equipment irreversibility,and their sensitivity to main system parameters are evaluated for several typical component arrangements.The use of a flash tank for separation, desuperheater, and with a subcooling coil seemed the best solution.

In 2002, Aprea compared VCR systems with R22 and R407C on the base of exergetic analysis and found that the overall exergetic performance of the plant working with R22 is consistently better.

In 2003, Srinivasan at el, [37] carried out exergetic analysis of carbon dioxide VCR cycle using the new fundamental equation of state and prepared temperature v/s exergy chart and enthalpy v/s exergy chart. There exist upper and lower bounds for the high cycle pressure for a given set of evaporating and pre-throttling temperatures. The maximum possible exergetic efficiency for each case was determined. Empirical correlations for exergetic efficiency and COP, valid in the range of temperatures studied, are obtained and the exergy losses are quantified. In 2004, Fartaj et al. [38] analyzed transcritical CO_2 refrigeration cycle. By exergy loss analysis they showed that the compressor and the gas cooler exhibit the largest non-idealities within the system.

In 2009, Mafi exegetically analyzed the multistage cascade low temperature refrigeration systems having closed cycle propylene and ethylene systems, through exergy destruction method. Propylene refrigeration is utilized at several temperature levels to cool and heat the feed in the initial fractionation sections of the plant while the ethylene refrigeration is utilized at several temperature levels to cool the feed in the cryogenic section of the plant. The equations of exergy destruction and exergetic efficiency for the

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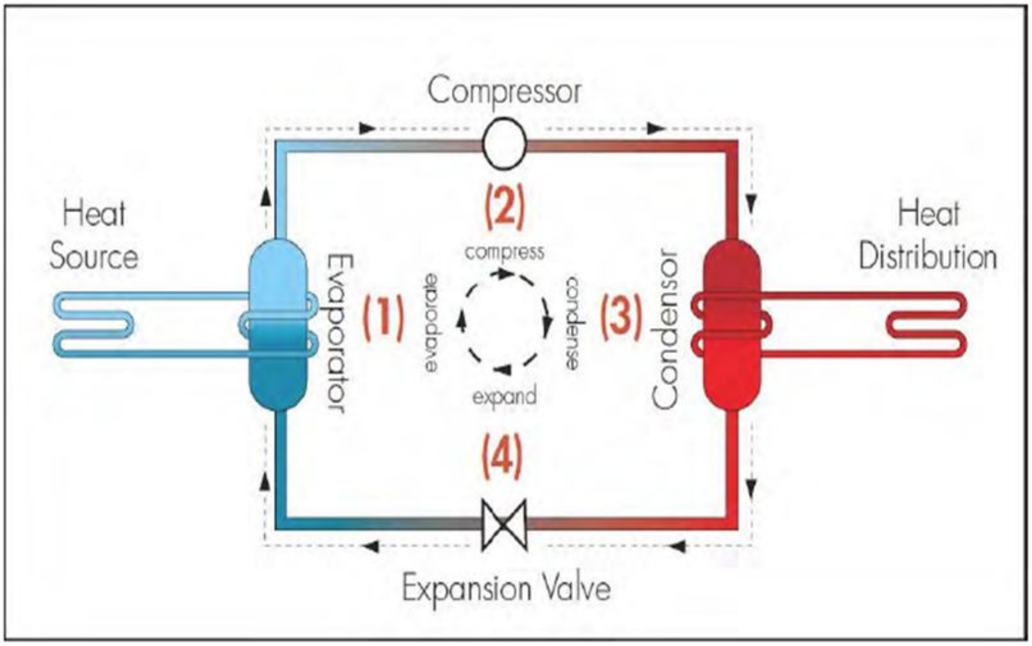
main system components such as heat exchangers, compressors and expansion valves are developed and combining them expression for minimum work requirement for the refrigeration systems is developed. It shows that the minimum work depends only on the properties of incoming and outgoing process streams cooled or heated with refrigeration system and the ambient temperature.

III.EXPERIMENTAL SETUP OF VCR SYSTEM

The system comprises of four components i.e. compressor, a capillary tube (expansion device), a condenser and an evaporator. Schematic diagram of vapor compression cycle is shown below,



A. System Configurations Of Experimental Setup Of Vcr System

TABLE I

Sr. no.	parameters	Description
1	Refrigerant Capacity	0.5 Ton
2	Refrigerant	R134a
3	Compressor	Hermetically Sealed Reciprocating Type
4	Condenser	Water Cooled Type
5	Evaporator	Water Cooled Type
6	Expansion device	Capillary Tube

B. Assumptions

1) Compressor process is assumed to be isentropic.
2) Mass flow rate is constant.
3) Atmospheric conditions are to be considered 101.325 kPa and 32 ◦C.
4) Steady state operations are considered in all the component.
5) Pressure drops are considered only in Evaporator and Condenser.

C. Abbreviations

h = Enthalpy
s = Entropy
x = Percentage of Moisture/Liquid
P = Pressure

T = Temperature
T0 = Environment Temperature = 305 K
(EXD)= Exergy Destruction or irreversibility

D. Readings

TABLE 2

Sr.no.	Massflow Rate(kg/s)		Pressure(psi)				Temperature(`C)			
	Condenser	Evaporator	Evaporator		Condenser		Evaporator		Condenser	
	m_e	m_c	In	Out	In	Out	In	Out	In	Out
1	0.0125	0.0056	32.5	33	235	230	23	-1	85	48
2	0.0124	0.005	37	35	250	245	24	5	89	54
3	0.0122	0.0048	37.5	37	255	250	24	4	92	56

E. Plotted chart

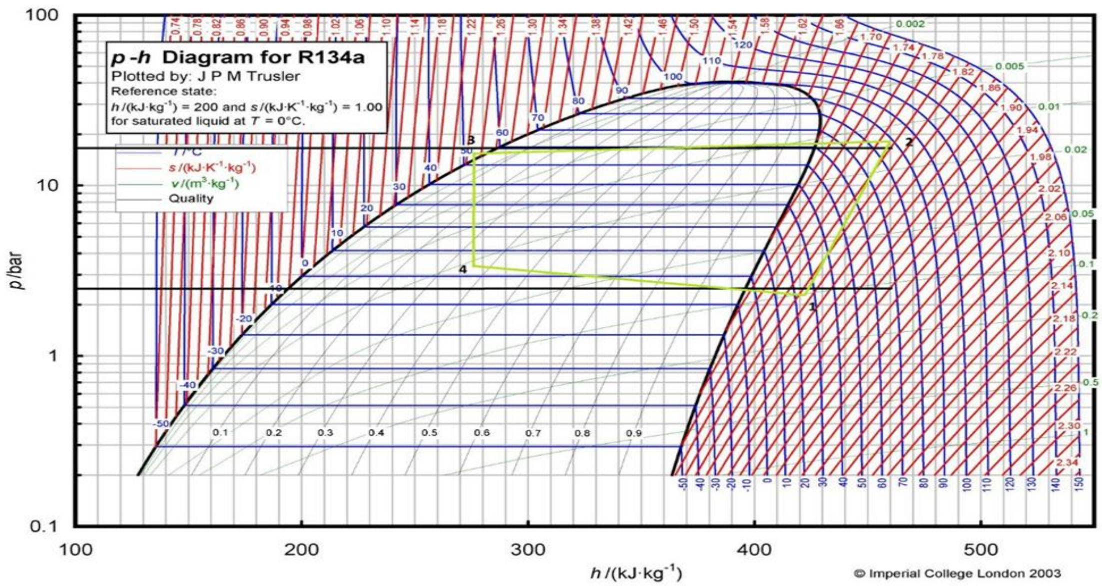


Fig. 1 p-h diagram for R134a

F. Calculation Table

TABLE 3

Sr.no.	Heat(kJ)		Entropy(kJ/kg.k)				Enthalpy(kJ/kg)			
	Q_e	Q_c	S_1	S_2	S_3	S_4	H_1	H_2	H_3	H_4
1	1.26	0.87	0.9299	1.013	0.463	0.4839	416	462	268	268
2	0.98	0.73	0.96	1.014	0.475	0.548	417	467	287	287
3	1.02	0.72	0.99	1.05	0.48	0.555	422	470	289	289

G. Sample Calculation

1) Compressor

$$(EX_d)_{comp} = Ex_1 + W_c - Ex_2$$

$$(EX_d)_{comp} = m_r[T_0(S_2 - S_1)]$$

$$= 1[(305)(1.014 - 0.96)]$$

$$= 16.72 \text{ kJ}$$

2) Condenser

$(EX_d)_{cond} = Ex_2 - Ex_3$

$(EX_d)_{cond} = m_r(H_2 - T_0S_2) - m_r(H_3 - T_0S_3) + Q_c(1 - T_0/T_r)$

$= 1[467 - (305)(1.014)] - 1[287 - (305)(0.475)] + [(0.73)(1 - 305/362)]$

$= 15.49$ kJ

3) Expansion device

$(EX_d)_{exp} = Ex_3 - Ex_4$

$(EX_d)_{exp} = m_r[T_0(S_2 - S_1)$

$= 1[305(1.014 - 0.475)]$

$= 22.26$ kJ

4) Evaporator

$(EX_d)_{evp} = Ex_4 + Q_e(1 - T_0/T_r) - Ex_1$

$= m_r(H_4 - T_0S_4) + Q_e(1 - T_0/T_r) - m_r(H_1 - T_0S_1)$

$= 1[287 - (305)(0.548)] + 0.98(1 - 305/278) - 1[417 - (305)(0.96)]$

$= -4.44$ kJ

H. Result Table

TABLE 4

	Exergy Destruction(kJ)			
Sr. No.	**Compressor**	**Condenser**	**Expansion Device**	**Evaporator**
1	25.34	12.11	6.37	-12.12
2	16.72	15.49	22.26	-4.44
3	12.20	13.131	22.87	-0.43

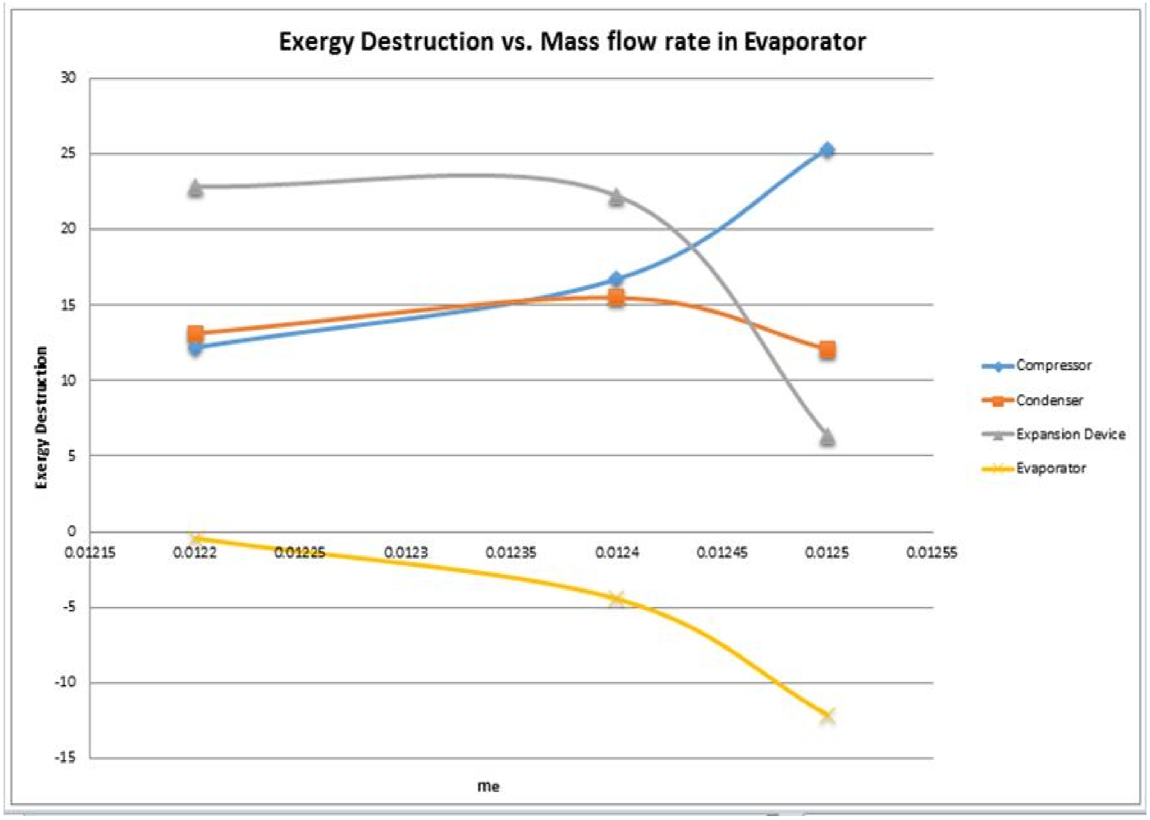


Fig. 2 Exergy Destruction vs. Mass flow rate in Evaporator

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IV. CONCLUSIONS

Exergy analysis is a technique to present the process and this further aid in reducing the thermodynamic losses occurring in the process. This 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 experimental study, a window air conditioning system based on vapor compression cycle is modified for experimental analysis. The system comprises of four components i.e. compressor, a capillary tube (expansion device), a condenser and an evaporator based on the experiment testing following conclusions are drawn:

1) With increase in mass flow rate, irreversibility in Evaporator as well as expansion valve, decreases.
2) High Mass flow rate is not favourable for compressor efficiency.
3) Maximum Destruction of Exergy is founded in Throttling or Expansion device for small rate of cooling water mass in the Experimental VCR setup. It is highly irreversible process for that condition. It may be because system error.
4) For various mass flow rate exergy destruction is different leading from throttle device to compressor.
5) Although the quantity of refrigerant charged do affect the exergy losses but the maximum losses in major cases are in the compressor. This is attributed to the frictional losses and losses due to wire drawing effect during suction and delivery of the refrigerant. This will augment the study of tribology to exactly study the friction characteristics and also the design aspects needs to be improved to reduce the wire drawing effect to have efficient compressor.
6) It is observed that the total exergy destruction is comparable when the system is 75% and 100% charged and it is least when the system is 25% charged because the evaporator temperature is very close to the reference temperature.
7) The average coefficient of performance is highest when the system is 50% charged and this is because of higher refrigerating effect and reduced compressor work.
8) The exergy efficiency of the system varies from 3.5% to 45.9% which is mainly due to the variation of evaporator temperature.
9) The average values of the system exergy efficiency are more when the system is 100% charged. These values show that the overall exergy performance is better when the system is fully charged but the compressor work is the highest in this case and the COP is also less as compared to other situations. When the actual requirements are less the system should be operated with variable refrigerant flow so as to achieve optimum balance between the exergy efficiency and energy saving.

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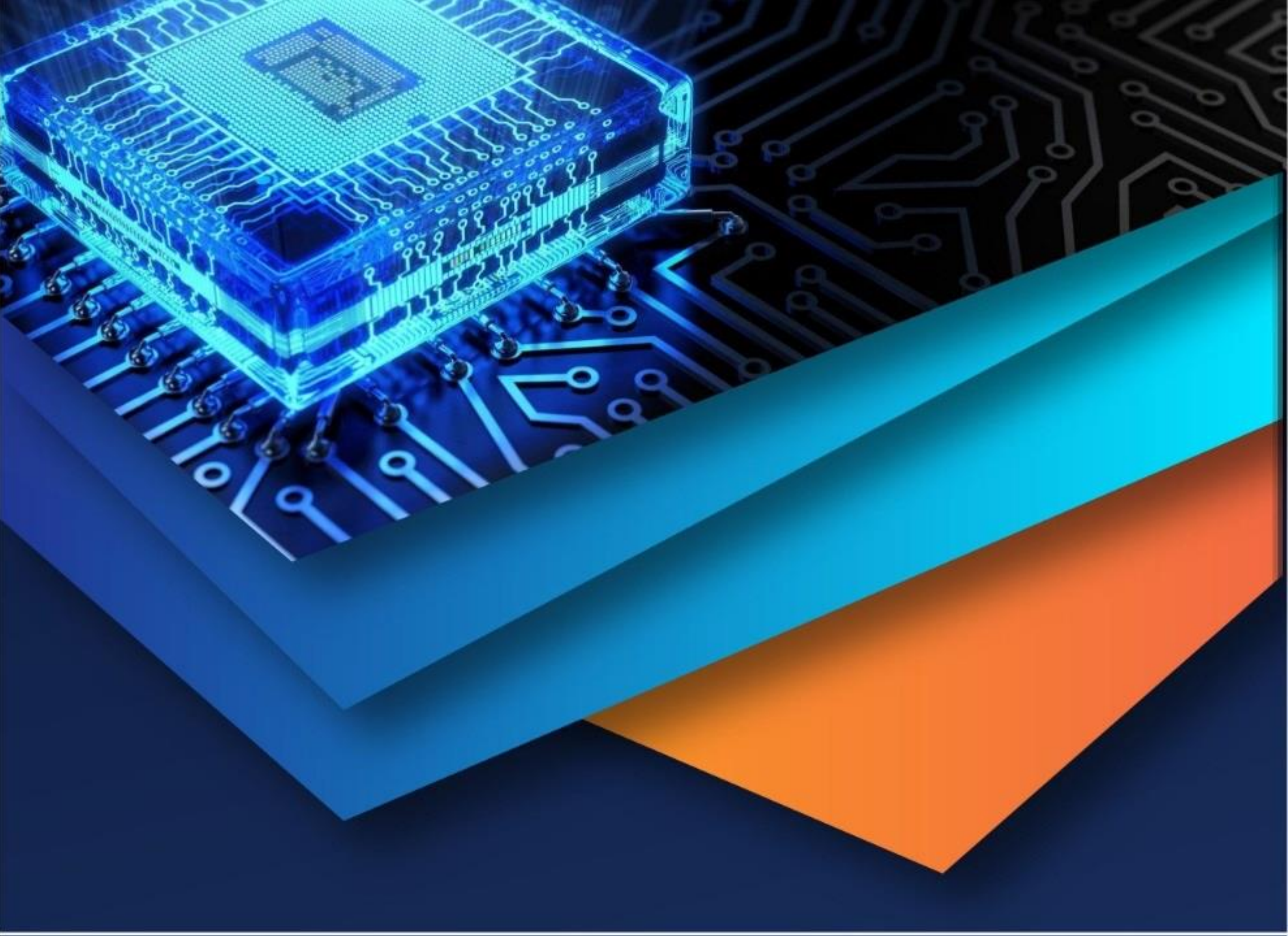

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