IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684, p-ISSN: 2320-334X.
PP 73- 77
www.iosrjournals.org

Exergy Analysis of R134a Based Vapour Compression Refrigeration Tutor

Pooja Yadav[1], Amit Sharma[2]
[1,2]*(Mechanical, DCRUST, Murthal, India)*

Abstract : *The paper presents the exergetic analysis of actual vapor compression refrigeration cycle. System discussed is R134a based vapour compression refrigeration tutor. Paper discusses the component's exergetic destruction and cycle's exergetic efficiency.*

Keywords: *Coefficient of performance; Exergy destruction; Exergetic efficiency*

I. INTRODUCTION

Over the last seven decades Chlorofluorocarbons (CFCs) have been used in refrigeration and air conditioning because of the favorable characteristics that they possess such as: low freezing point, non-flammability, non-toxicity and chemically stable behavior. But it has been recognized that the chlorine released from CFCs migrate to the stratosphere and destroys the ozone layer of the earth causing serious health problems[1]. In 1987 many countries across the world signed the Montreal Protocol, an international treaty to control those substances that deplete the ozone layer. Ozone depletion allows harmful ultraviolet rays from sun to enter the earth's atmosphere which leads to several diseases. According to the Montreal Protocol, 190 signatory countries have to phase out CFC's and other ozone depleting substances by 2010. According to this protocol all developed countries had to ban the use of all CFC's that were being used in refrigeration and air conditioning equipment till 1999. Due to global warming the temperature of the earth is increasing continuously which results in melting of glaciers at high speed which in turn leads to rise of water level in oceans affecting marine life and the coastal regions. Owing to its high ODP (=1) and GWP (=8500) [2] R12 has to be phased out. In India the manufacturing of new components using R12 has been banned since December 31, 2002. Till January 1, 2007 the country has achieved 85% reduction in CFC phase out. For domestic refrigeration R134a is a better substitute because of its similarity in thermodynamic properties to R12. R134a is having low ODP i.e. 0 and moderate GWP i.e. 1300 in comparison with R12 [3]. A comparison of performance between R12, R134a and R290 was carried out by Xu et al. They found the difference of performance was very small between R12 and R134a refrigerants [4]. Thermodynamic processes in refrigeration systems release huge amounts of energy in form of heat to the surroundings. Heat transfer from the system to the surroundings occurs at finite temperature difference which leads to irreversibility. System performance degrades due to irreversibility's. The losses in the thermodynamic processes that make up the cycle are calculated by considering them individual systems. Exergy analysis is best tool in evaluation of design, optimization and performance of energy systems. It helps in determining maximum performance of the systems and key points of exergy destruction. In case of complex systems component wise exergy analysis is performed. Potential improvement in the system can be obtained after calculating exergy destruction. There are various studies on the exergy analysis of refrigeration and other systems[1]. Venkataramana et al. has performed exergy analysis of an air conditioner containing refrigerant R22, substituted by R134a, R290, and R407. Results indicate that COP and exergy efficiency of R290 vapor compression refrigeration system (VCRS) is higher and the values for R407 and R134a VCRS were found to be lower in comparison of R22[5]. Chandrasekhran performed exergy analysis of vapor compression refrigeration system using R12 and R134a as refrigerants and concluded that COP increases when evaporator temperature increases for both refrigerants. COP of R134a is slightly higher at lower temperature and COP of R12 is higher at high evaporator temperature. Variation of exergetic efficiency of both refrigerants is similar to that of COP [6]. Shiva Reddy et al. has investigated the exergetic analysis of vapour compression refrigeration system with R134a, R143a, R152a, R404A, R407C, R410A, R502, and R507A. In this he studied that R134a performed better in all respect and R407 performed poor[7]. Bolaji et al. has performed design and performance evaluation of cooler refrigerating system working with R134a. Bolaji et al. checked the exergetic performance of domestic refrigerator using R12, R134a and R152a. The results showed that the average COP of R152a was nearly close to that of R12 and the highest efficiency defects were obtained using R134a as refrigerant[8].

Various studies reviewed focused on exergetic analysis of various systems. In this paper, exergetic analysis of vapour compression refrigeration test rig using R134a as refrigerant has been studied. This is a basic experiment performed in every engineering institute. The vapour compression refrigeration test rig is situated at

Refrigeration and Air conditioning Lab in the Mechanical Engineering Department of DCRUST, Murthal. This serves the purpose of demonstration of actual vapour compression refrigeration cycle. The test rig is around 10-15 years old and was R-12 operated. But according to Montreal Protocol R12 had to be phased out and therefore test rig was retrofitted with R134a refrigerant in 2010 [9]. System's component wise exergy destruction is presented and second law efficiency of system has been obtained.

II. EXERGY ANALYSIS

The exergy linked to a transfer or storage of energy is defined as the potential of maximum work. The exergy approach allows quantifying in a coherent way both the quantity and the quality of the different forms of energy considered. The concept of exergy presents the major advantages of efficiency definitions which are compatible with all cases of conversion of energy resources into energy services as heat and electricity, refrigeration, and heat pumps etc. [10]. Simplicity of operation of refrigeration test rig makes it fit for being used for academic purpose.

2.1 System Description

The Refrigeration test rig works on a simple vapour compression cycle and uses R134a as a refrigerant. The system is fabricated such that students can observe and study the working cycle, its component working and principle. The parts are arranged in such a fashion so that all parts are visible and working can be easily understood. Fig.1 shows the photograph of the system installed at RAC lab at DCRUST, Murthal.

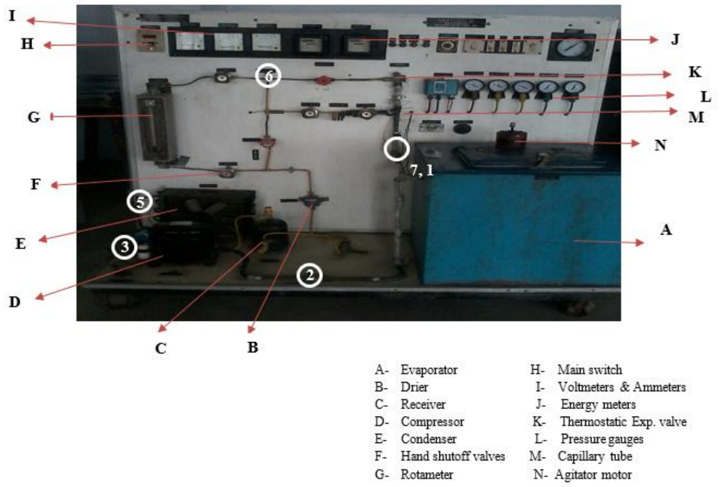

Fig.1. Vapour Compression Refrigeration Test Rig

A vapour compression refrigeration system mainly consists of components such as evaporator, compressor, condenser, expansion valve. These components are connected in a closed circuit through pipes that have heat transfer with the surroundings[11]. The process can be explained with the help of cycle in T-s diagram in fig.2. Table 1 summarizes the records of system based on various state points.

Table 1: Experimental results from vapour compression refrigeration test rig

State points	Description of state points	Pressure (bar)	Temperature (K)
1	Evaporator outlet	1.9	279.5
2	Compressor inlet	1.9	296.5
3	Compressor outlet	11	349
5	Condenser outlet	12.12	320
6	Before Expansion Valve	12.12	317
7	After Expansion Valve	2.4	279.5

The above experimental results have been taken from the project work of B.Tech students [9] and has been plotted on T-s chart in EES software in fig.2. At state 1, refrigerant leaves evaporator at a low pressure, low temperature saturated vapour and enters the suction pipe due to absence of proper insulation and length it allows heat transfer to take place from surroundings, which raises the temperature of refrigerant up to state 2. After that it enters into the compressor where both temperature and pressure increases. At state 3 it leaves the compressor at high pressure, high temperature, superheated vapour and enter the condenser where it reject heat to environment, during this heat transfer process pressure drop occurs. Refrigerant leaves the compressor at state 5 as high pressure, medium temperature, and saturated liquid. After that refrigerant subcools to state point 6. The expansion valve passes the high pressure liquid to low pressure liquid at constant enthalpy. At state 7 it leaves the expansion valve as a low temperature, low pressure and liquid-vapour mixture and enters the evaporator where it absorbs the heat, changed into saturated vapour, during this process again the pressure drops and the cycle is completed [9].

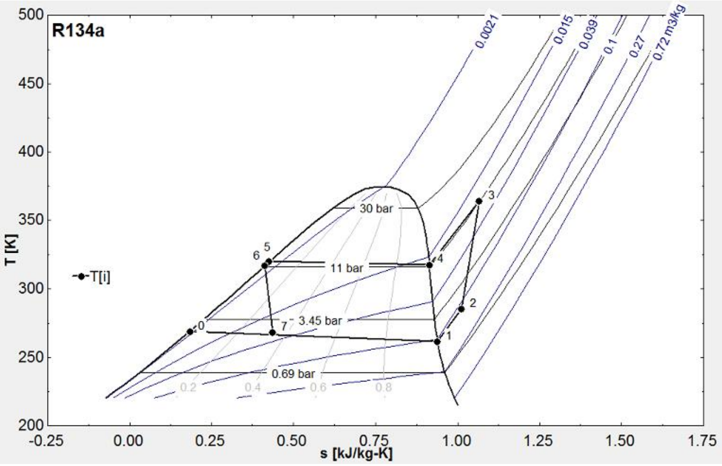

Fig.2. Temperature entropy diagram of vapour compression cycle

2.2 System Configuration

System specifications of refrigeration test rig with its components are summarized in Table 2.

Table 2: System configuration

S.No.	Parameters	Description
1.	Refrigerating Capacity	0.75 Ton
2.	Refrigerant	R134a
3.	Compressor	Hermetically Sealed Reciprocating Type (Single Power phase)
4.	Condenser	Air-cooled type
5.	Evaporator	Finned coils (Capacity 20 litres)
6.	Expansion Devices	Thermostatic expansion valve, Solenoid valve
7.	Pressure Guages	Discharge Pressure at compressor outlet, Condenser outlet, Liquid pressure before expansion valve, Suction pressure after expansion valve, Suction pressure at compressor inlet
8.	Voltmeter	0-300 V
9.	Ammeter	For Compressor: 0-10 A
10.	Power Meter	Two in number

1.3 Modelling of Components

The following assumptions are being observed for exergy analysis[7].

Table 3: Assumptions for exergy analysis

S.No.	Assumptions
1.	Mass flow rate is constant throughout, $\dot{m}$ = 1kg/s
2.	Kinetic and Potential energy changes are zero
3.	Isentropic efficiency of compressor is 0.85
4.	Mechanical efficiency of compressor is 0.9
5.	Steady state operations are considered in all components
6.	Pressure drops are negligible except condenser and evaporator

Exergy flow destruction in individual components is evaluated as follows [1, 6]:
Exergy of Compressor [7]
The irreversibility or exergy loss in compressor is presented as;

$$I_{dest\_c} = T_0 S_{gen} = \dot{m}_1(\psi_2 - \psi_3) + \dot{W}_c \quad (1)$$

$$I_{dest\_c} = \dot{m}_1 T_0 (s_3 - s_2) \quad (2)$$

Whereas W_c is power (W); $\dot{m}_1$ is mass flow rate of refrigerant (kg/s); ψ is flow exergy (kW); T_0 is the ambient temperature (K); S_{gen} is the entropy generation (kJ/K); I_{dest_c} is exergy destruction in compressor (kW); s is the specific entropy (kJ/kgK); T_0 is the dead state of the system (K).
Exergy of Condenser [7]
The irreversibility or the exergy loss in condenser is presented as;

$$I_{dest\_con} = T_0 S_{gen} = (\dot{m}_3((h_3 - h_5) - T_0(s_3 - s_5)) - Q_5(1 - \frac{T_0}{T_5}) \quad (3)$$

Where Q_5 heat transfer rate in condenser (kW); T_5 is the condenser outlet temperature (K); I_{dest_con} is the exergy destruction of condenser (kW).
Exergy of Expansion valve [7]
The exergy destruction in expansion valve is given by;

$$I_{dest\_\exp} = T_0 S_{gen} = \dot{m}_6((h_6 - h_7) - T_0(s_6 - s_7)) \quad (4)$$

Whereas $I_{dest\_\exp}$ is exergy destruction of expansion valve (kW).
Exergy of Evaporator [7]
The exergy destruction in evaporator is given by;

$$I_{dest\_eva} = T_0 S_{gen} = \dot{m}_7((h_1 - h_7) - T_0(s_1 - s_7)) - Q_7(1 - \frac{T_0}{T_7}) \quad (5)$$

Whereas Q_7 heat transfer rate in evaporator (kW); T_7 is the temperature at exit of expansion valve (K); I_{dest_eva} is the exergy destruction in evaporator (kW).
Exergetic efficiency of system [1]
The total exergy destruction rate (X_t) is given by;

$$X_t = I_{dest\_c} + I_{dest\_con} + I_{dest\_\exp} + I_{dest\_eva} \quad (6)$$

The overall system exergetic efficiency is the ratio of exergy output (X_{out}) to exergy input (X_{in});

$$\eta_{\text{exergetic}} = \frac{\text{Exergy output}}{\text{Exergy input}} \quad (7)$$

$$\eta_{exergetic} = (\frac{X_{out}}{X_{in}}) \times 100\% \quad (8)$$

$$X_{out} = X_{in} - X_t \quad (9)$$

Whereas $\eta_{\text{exergetic}}$ is the exergetic efficiency of the whole actual vapour compression cycle.
Exergy input to the system is supplied through the compressor work. Therefore

$$X_{in} = \dot{W}_c \quad (10)$$

$$\eta_{exergetic} = (1 - \frac{X_t}{\dot{W}_c}) \times 100\% \quad (11)$$

The energetic efficiency of the system is given by;

$$COP = \frac{(h_1 - h_7)}{(h_3 - h_2)} \times \eta_{isen} \times \eta_m \text{ [7]} \quad (12)$$

Where η_{isen} is the isentropic efficiency, η_m is the mechanical efficiency and h is the enthalpy in (kJ/kg) at different state points of cycle.

Table 4: The exergy destruction of every component of the tutor is given in following table

Component	Exergy destruction (kW)
Compressor	14.212
Condenser	29.32
Expansion Valve	3.57
Evaporator	-7.80

III. Results, Discussion and Conclusions

The second law of thermodynamics is a powerful optimization tool of thermodynamic systems. In this paper, we examine the performance of refrigeration tutor in light of second law of thermodynamics. We discuss the exergy destruction, which is the wasted work potential during a process as a result of irreversibilities. Component's exergy destruction as per model presented in section II is presented in Table 4. From the calculations we observed that maximum destruction is in condenser. The exergetic efficiency of the whole system can be calculated by using equations (6), (7), (8), (9), (10) and (11) as follows:

$$\eta_{exergetic} = 35.23\% \qquad (13)$$

From equation (12) COP of the system is given by

$$COP = 3.19 \qquad (14)$$

In future, work could be performed on calculating the exergetic efficiency of an individual component and how the exergetic efficiency varies by use of alternative refrigerants.

References

[1] B. O. Bolaji, "Exergetic Performance of a Domestic refrigerator using R12 and its Alternative Refrigerants," *Eng. Sci. Technol.*, vol. 5, no. 4, pp. 435–446, 2010.

[2] O. L. Protection, O. Science, C. I. O. Substances, C. I. Substances, T. Area, and C. Name, "Class I Ozone-depleting Substances," 2014. [Online]. Available: Class I Ozone-depleting Substances Science Ozone Layer Protection %. [Accessed: 11-Jul-2014].

[3] B. Tashtoush, M. Tahat, and M. A. Shudeifat, "Experimental study of new refrigerant mixtures to replace R12 in domestic refrigerators," vol. 22, pp. 495–506, 2002.

[4] X. Xu, "Exergy Analysis on a Vapor Compression Refrigerating System Using R12 , R134a and R290 as Refrigerants," *Refrig. Air Cond.*, 1992.

[5] V. M. V. Padmanabhan and S. K. Palanisamy, "Exergy efficiency and irreversibility comparison of R22, R134a, R290 and R407C to replace R22 in an air conditioning system," *J. Mech. Sci. Technol.*, vol. 27, no. 3, pp. 917–926, Mar. 2013.

[6] M. Chandrasekharan, "Exergy Analysis of Vapor Compression Refrigeration System Using R12 and R134a as Refrigerants," vol. 2, no. July, pp. 134–139, 2014.

[7] 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," *Clean Technol. Environ. Policy*, vol. 14, pp. 47–53, 2012.

[8] B. O. Bolaji and Z. Huan, "Thermodynamic analysis of hydrocarbon refrigerants in a sub-cooling refrigeration system," vol. 1, no. June, pp. 317–333, 2013.

[9] P. Bansal, A. Aggarwal, R. Verma, and Y. Kumar, "Upgradation and Simulation of Refrigeration Test Rig," DCRUST,Murthal, 2010.

[10] F. Daniel, "exergy Geneva Law." [Online]. Available: http://leni.epfl.ch/files/content/sites/leni/files/pdf/exergy Geneva Law.pdf. [Accessed: 02-Mar-2015].

[11] J. Soni, "Exergy Analysis of Vapour Compression Refrigeration System with Using R- 407C and R-410A," vol. 1, no. 7, pp. 1–12, 2012.