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First and second law analysis for alternate refrigerants used in VCR system: Literature review

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Abstract

Exergy analysis is a powerful tool in engineering which is outcome of second law of thermodynamics. It is accepted that the reversible machines are the most efficient machines and if energy losses are stopped completely, then the process approaches towards isentropic process. Exergy analysis also helps in taking account the important engineering decisions regarding design parameters of a system. Researchers carried out exergy studies of different thermal energy conversion systems describing various approach for exergy analysis and its usefulness in a more simple and effective manner. Many researchers, engineers and scientists calculated exergy change during a flow process theoretically and compared the data with practical process and reached to conclusion and optimized the properties and parameters to obtain required output and thus the efficiency.

Keywords: Refrigeration, Exergy Analysis, Reversibility, VCR cycle, Second law of Thermodynamics

Introduction

Every field of engineering depends solely and completely on power input, and thus the conversion of heat into work or vice versa. Most of engineers at some time or other time have been involved in the increasing the output in the limited value of input to a machine for the energy conversion. In every problem of this sort, more satisfactory solution can be withdrawn while taking purview fundamental concepts of engineering. Production Engineering, Mechanical Design, Fluid Mechanics and Thermal Engineering are the four major basic fields of Mechanical Engineering which play great role in building the equipments, machinery and power plants to make the human life considerable and comfortable. Thermodynamics, as basically applied to heat engines, was concerned with the thermal properties of their 'working materials' such as steam in an effort to increase the efficiency and power output of engines. Thermodynamics later expanded to the study of energy transfers in chemical processes and heat and work. At that time Thermodynamics was limited to the First law of Thermodynamics only which was expanded to the Second law of Thermodynamics and the Zeroth law thereafter. Entropy and reversibility is the outcome of the Second law of Thermodynamics. Refrigeration cycles are the major outcome of the Second law of Thermodynamics. Vapour Compression Refrigeration Systems are the most commonly used in almost all refrigeration systems. These systems belong to general class of vapour cycles, in which the working fluid, popularly known as ‘Refrigerant’ undergoes the change of phase at least one time during the cycle. The cycle on which the actual Vapour Compression Cycle works is Reversed Carnot Cycle, which is also called as Evans-Perkins Cycle.

The Exergy Analysis

Exergy analysis is widely accepted as a useful tool in obtaining the improved understanding of the overall performance of any system and its components as per Shah R [1]. Exergy analysis also helps in taking account the important engineering decisions regarding design parameters of a system. Researchers carried out exergy studies of different thermal energy conversion systems describing various approach for exergy analysis and its useful- ness in a more simple and effective manner. Experiments carried out by Zhao P.C [2] analyzed the exergy and the impact of direct replacement of R12 with zeotropic mixture R413A. The performance of a domestic vapor compression refrigeration system originally designed by Saiz Jabardo J.M [3] to work with R12 was evaluated using a simulated modeling. They concluded that the overall energy and exergy performance of this system working with R413A is better than that of R12.Tian C.Q, *et al* [4] derived a method to carry out the exergetic analysis of a vapor compression refrigeration system using R11 and R12 as refrigerants. The procedure to calculate various losses as well as coefficient of performance and exergetic efficiency of the cycle has been explained by proper example. The principles and methodologies of exergy analysis are well established by Dincer *et al* [5]. An exergy analysis is usually aimed to determine the maximum performance of the system and identify the sites of exergy destruction. Analyzing the components of the system separately can perform exergy analysis of a complex system. Identifying the main sites of exergy destruction shows the direction for potential improvements. Browne M. W, Bansal P. K, [6] did a detailed exergy analysis of an actual vapor compression refrigeration cycle. They developed a computational model to calculate the coefficient of performance, exergy destruction, exergy efficiency and the efficiency defects for R502, R404A and R507A for temperature in the range of -50°C to 0°C and condenser temperature range of 40°C to 55°C. They concluded that R507A is a better substitute to R502A than that of R404A. Torrella, *et al.* [7] studied the behavior of a two-stage compound compression cycle, with flash inter cooling with R22 using the exergy method and produced some useful conclusions.

Ding G. L, Zhang C. [8] asserts that conventional energy analysis, based on the first law of thermodynamics, evaluates energy mainly on its quantity but analysis that are based on second law considers not only the quality of energy but also quantity of energy. In this study, the main objective is to investigate the performance of a simple VCR system based on exergy analysis. The experimental analysis has been done on a 2TR window air conditioning system using R-22 as refrigerant. With the objective to find out the losses at different operating conditions for vapor compression cycle, exergy analysis has been done by varying the quantity of refrigerant charge. The system has been modified for experimental study to find the possible design conditions with the minimum exergy destruction. In the proposed study, the effects of temperature changes in the condenser and evaporator on the plant's irreversibility rate was determined. It is observed that the greater is the temperature difference between the condenser and the environment or between the evaporator and the cold room, the higher is the irreversibility rate. The analysis is performed by doing energy and exergy balances for the system. The properties of refrigerant at each state point are calculated using Forane software and the results are discussed.

Exergy Analysis of Alternate Refrigerants

While assessing the performance of a commercial vapour compression refrigeration plant, generally adopted for preservation of foodstuff, using R22 and its candidate substitute (R417A) as working fluids by Aprea and Renno [9] carried extensive experimentation. The working of the plant was regulated by on/off cycles of the compressor, operating at the working frequency of 50 Hz, imposed by the classical thermostatic control. The reported result indicated that the substitute refrigerant (R417A), which is a non azeotropic mixture and non-ozone depleting, can serve as a long term replacement for R22; it can be used in new and existing direct expansion R22 systems using traditional R22 lubricants. Also in their analysis, the best exergetic performances of R22 in comparison with those of R417A were determined in terms of the coefficient of performance, exergetic efficiency and exergy destroyed in the plant components.

Rahim K.J *et al.* [10] submitted Energy, Exergy and Thermo economics Analysis of Water Chiller Cooler for Gas Turbines In- take Air Cooling. In the present study, the performance of a cooling system that consists of a chilled water external loop coupled to the GT entrance is investigated. An objective of the present study is to assess the importance of using a coupled thermo-economics analysis in the selections of the cooling sys- tem and operation parameters. In the present study, the profitability resulting from cooling the intake air is calculated for electricity rates between 0.07 and 0.15 $/kWh and a payback period of 3 years. Cash flow analysis of the GT power plant in the city of Yanbu shows a potential for increasing the output power of the plant and increased revenues. Bukola O.B [11] presents experimental results of investigation of effects of sub-cooling on the performance of four ozone-friend- ly alternative refrigerants (R32, R152a, R143a, and R134a) in a domestic refrigeration system. The study was performed using a system designed for R12 with the aim of finding a drop-in re- placement for the refrigerant. Ust Y *et al*. [12] analyzed exegetic performance coefficient criterion for a vapour compression refrigeration system for different refrigerants. This analysis has been carried out using the refrigerants R32, R410A, R143A, R404A and R125. The COP at maximum EPC condition for the refrigerant R125 is bigger than the other refrigerants studied in this paper. According to the results, the refrigerant R32 shows the best performance in terms of EPC among the other refrigerants (R410A, R143A, R404A and R125). Ahamed J.U *et al.* [13] worked on exergy analysis in various usable sectors where vapour compression refrigeration systems are used. Exergy losses, exergy efficiency, second law efficiency and irreversibility of the system components as well as of the whole system are measured. In the vapour compression system, R134a, R290 and R600a are considered as refrigerants. Exergy parameters in the compressor, evaporator, condenser and expansion devices are calculated and analyzed. Exergy losses depend on evaporator temperatures, condensing temperature, refrigerants and ambient temperature. Most of the exergy losses occur in the condenser. Expansion device has the lowest losses. Exergy parameters are compared for different operating temperatures. It is found that hydrocarbons (R600a) have 50% higher exergy efficiency than R134a. Mixture of hydrocarbons also shows the best performance based on the exergy analysis. Camelia S *et al*. [14] work on a comparative analysis of the refrigerant effect on the operation and performances of a one stage vapour compression refrigeration system. The paper presented proposed an analysis model for comparing the operation of a VCR System with different refrigerants, from performances point of view and from limitations in terms of compression ratio. This paper presents a comparative analysis of five refrigerants working in a one stage VCRS with sub cooling and superheating. While comparing exergy loss of various refrigerants during condensation process of VCR cycle, Shreekant Tare *et al.* [15] plotted various parameter and optimized the data which are outcome of second law,

Traditional Refrigerants v/s Untraditional Refrigerants

Based on the exergy analysis, exergy destruction rates were estimated for each component of the system in a comparative refrigerant systems. Ratnesh S *et al*. [16] investigated a domestic refrigerator designed to work with R-134a to assess the possibility of using a mixture of propane and isobutene. The performance of the refrigerator using azeotropic mixture as refrigerants was investigated and compared with the performance of refrigerator when R-134, R12, R22, R290, R600a is used as a refrigerant. It has been found from the calculations that mixture of propane and isobutene (mint gas) is producing better results than other refrigerants.

Average refrigeration capacities of R152a and R134a were 2.6% higher and 3.4% lower than that of R12, respectively, while average capacities of R143a and R32 were 22.4% and 31.3% lower than that of R12, respectively. Also, the results obtained showed that as the degree of sub-cooling increases, the pressure ratio reduces, while both the refrigerant mass flow rate and the coefficient of performance (COP) increase. The COPs of R152a and R134a obtained at various degrees of sub-cooling are close to that of R12, while significant deviations in COPs of R32 and R143a were obtained when compared with that of R12. The overall assessment of the results showed that R152a and R134a refrigerants had the most similar performance characteristics to R12, with R152a having a slightly better performance, while the performances of R32 and R143a were significantly lower than that of R12.Jyoti S *et al.* [17] resented a theoretical performance study of a vapour compression refrigeration system with refrigerants R-407C and R-410A. It was a novel approach as all the refrigerants dealt in this study were having zero ODP and exergy was compromised with ozone depletion potential of the refrigerants. A computational model based on energy and exergy analysis is presented for the investigation. The exergetic efficiency of R-407C is 2.5-5.1% higher than R410A for considered range of dead state temperatures. A theoretical investigation showed that better performances of R-407C in comparisons with R-410A.

R.S.Mishra [18] presents methods for improving first law and second law efficiency have using new refrigerants: R134a, R290, R600a, R1234yf, R502, R404a and R152a and R12, R502. For exergy and energy analysis six type of vapour compression refrigeration system have been considered with using eco-friendly refrigerants with multi-evaporators, multiple compressors and multiple expansion valve with parallel and series with inter cooling and flash chambers. Numerical computational model have been carried out for the system. Performance of the system using R600 and R152a nearly matching same values under the accuracy of 5 % can be used in the system and difficulties detected with R600, R290 and R600a having flammable problems therefore safety measures are required using these refrigerants, therefore R134a is recommended for practical and commercial applications. Naushad A.A *et al.* [19] conducted theoretical exergy analysis of HFO-1234yf and HFO-1234ze, both ultra-low Global Warming Potential(GWP) and zero Ozone Depletion Potential(ODP) refrigerants in simple vapour compression refrigeration system and comparison of their results with HFC-134a refrigerant as possible alternative replacements in Automotive air-conditioning and stationary refrigeration is presented. Results obtained indicate that HFO-1234yf and HFO-1234ze can be good replacement of R-134a.X.

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