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Exergy Analysis and Irreversibility Applied to Vapour Compression Refrigeration System: Literature Review

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ABSTRACT

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 In every problem of this sort, more satisfactory solution can be withdrawn while taking purview fundamental concepts of engineering.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 there after. 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. To analyze and enhance the net output of the complete cycle, it is essential to find the natural upper limit for the performance of the cycle. This limit is set by completely reversible cycle.

KEYWORDS :

Analysis of First and Second law applied to VCR System :

The analysis based on first law of thermodynamic is most commonly used in engineering applications; however, it does not 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 analyze all the thermodynamic cycles for better understanding and evaluation of irreversibility associated with any process. Unlike the first law [energy], Ding. G.L. Zhang. C.L made the analysis on the basis of second law [exergy] to determine the magnitude of irreversibility associated in a process qualitatively and thereby, provided an indication to point out the directions in which the engineers should concentrate more in order to improve the performance of this thermodynamic system [1-2]. 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 as mentioned by Murphy W.E [3].

A lot of studies on the performance evaluation and optimization have been carried out experimentally and theoretically are available in the literature from 1991 onwards. Pfafferott T carried out studies on the refrigeration systems show that the performance analysis of refrigeration systems were investigated based on first law of thermodynamics. However, this approach is of limited use in view of the fact that the actual energetic losses are difficult to make out because the first law deals with the quantity of energy and not the quality of energy [4]. In order to calculate the actual losses due to irreversibility in the process, exergy analysis based on second law of thermodynamics is the proper tool as mentioned by J Kim S.O [5]. **D. Li, Groll E.A** [6] on critical analysis mentioned that exergy utilizes exergetic efficiency criterion taking into account all the losses appearing in a system, for measuring the actual performance.

The 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** [7]. 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. Experiments carried out by **Zhao P.C** [8] analysed 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** [9] 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 [10] 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. **Browne M. W, Bansal P. K,** [11] 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** [12] 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. [13] 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 :
Torrella and J.A. Larumbe [14] described a Second Law Analysis based on experimental data of a two-stage vapour compression facility driven by a compound compressor for medium and low-capacity refrigeration applications, which operates with the most usual inter-stage configurations [direct liquid injection and subcooler]. The experimental analysis performed for an evaporating temperature range between]36ºC and]20ºC and for a condensing temperature range between 30ºC and 47ºC using the refrigerant R-404A. They compared the final results with energy analysis from previous works. Additionally, a new criterion of equivalence between the simple vapour compression cycle and the two-stage compression cycle given by the researchers.

Amir V et al. [15] studied on exergy concept and it's characteristic. Here author had introduced the detail information about exergy and also describe about exergy losses, entropy and energy in thermodynamic systems. Here, author had define dead state, surroundings, immediate surroundings, environment and different forms of exergy. In this paper the concept of exergy and its characteristic and application in various fields has been discussed. And different forms of exergy have been derived. Also a brief comparison between energy and exergy analysis has been done.

Yunus A et al. [16] describe that At present day also human ,tend to judge things on the basis of their quantity rather than quality, and perceive bigger things as being better, stronger, and more competitive. Assessments made on the basis of quantity only (the first law) may be grossly inadequate and misleading. When two companies merge, for example, we expect the joint company to be more productive and more dominant in a competitive world, and when two states or countries merge, we expect the new union to be stronger. But experience shows that often this is not the case, confirming the phrase "bigger is not necessarily better". In thermodynamics, this is analogous to a system with a larger energy content not necessarily having a larger exergy content or work potential. so requirement of exergy analyses to know how effectively useful energy converted into useful work.Aprea C et al. [17] presented the experimental studies of performances of a vapour compression refrigeration plant using as working fluids R22 and its substitute R417A (R125/R134a/R600, 46.6/50/3.4% in mass). This type of plant is applied to a commercially available cold store, generally adopted for preservation of foodstuff. The experimental analysis had allowed the determination of the best energetic performances of R22 in comparison with those of R417A in terms of the coefficient of performance, exergetic efficiency, exergy destroyed in the plant components and other variables characterizing the refrigeration plant performance.

Guiyin F et al. [18] has investigated Exergy analysis of a dual mode refrigeration system for ice storage air conditioning. Here, dual mode refrigeration system consists of conventional air conditioning operation unit and the ice storage operation unit. The refrigeration system studied is a dual-mode refrigeration cycle process. This indicates that the refrigeration system operates not only in conventional air conditioning mode during daytime, but also in ice storage mode during nighttime. . The results show that the exergy efficiency of the refrigeration system in ice storage operating mode is 17.63% lower than that of the refrigeration system in air conditioning operating mode.Akhilesh A et al.[19] presented a detailed exergy analysis of an actual vapour compression refrigeration (VCR) cycle. A computational model has been developed for computing coefficient of performance (COP), exergy destruction, exergetic efficiency and efficiency defects for R502, R404A and R507A. The present investigation has been done for evaporator and condenser temperatures in the range of 50 to 0 and 40 to 55 , respectively. The results indicate that R507A is a better substitute to R502 than R404A.The efficiency defect in condenser is highest, and lowest in liquid vapour heat exchanger for the refrigerants considered. In this communication, an extensive energy and exergy analysis of R502, R404A and R507A in an actual vapour compression cycle have been presented. Xu and D. Clodic [20] experimented the exergy losses in various conditions for different refrigerants. The authors tabulated the data as under.

Parameters		R12	R134A	R290
T cond	^{0}C	57.4	54.1	48.3
P cand	bar	14.4	14.6	16.5
Tin evap	^{0}C	-21.3	-17.7	-17.8
Pin evap	bar	1.43	1.46	2.62
Tout evap	^{0}C	-19.6	-17.1	-14.9
Pout evap	bar	1.42	1.35	2.43

Table 1 Operating parameters of 3 refrigerators

	R12		R134a		R290	
	Exergy loss (W)	%	Exergy loss (W)	%	Exergy loss (W)	%
Condenser	4.60	6.57	3.67	5.62	2.76	3.78
Subcooler	2.75	3.92	2.08	2.97	2.3	3.28
Capillary	0.06	0.08	0.03	0.04	0.05	0.07
Evaporator	6.67	9.52	5.37	7.70	5.43	7.43
Compression	55.98	79.9	58.65	84.03	62.44	85.43
Total	70.05	100	69.79	100	73.08	100

Table 2 Exergy losses in refrigerator components

Alternate Refrigerants and Exergy Analysis :
Rahim K.J et al. [21] had submitted Energy, Exergy and Thermo economics Analysis of Water Chiller Cooler for Gas Turbines Intake 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 system 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 [22] presents experimental results of investigation of effects of sub-cooling on the performance of four ozone-friendly 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 replacement for the refrigerant. 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.

Ust Y et al. [23] has analyzed exegetic performance coefficient criterion for a vapour compression refrigeration system for different refrigerant. 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. [24] 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. [25] work on a comparative analysis of the refrigerant effect on the operation and performances of a one stage vapour compression refrigeration system. the paper is to present and propose 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. 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.[26] 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 azotropic 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.

R.S.Mishra [27] 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 intrercooling 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. [28] 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.

Conclusion :

Exergy analysis which is outcome of second law of thermodynamics is an important tool to compare the performance of thermodynamic systems. Engineers and scientists all over the globe are trying hard to enhance the system performance and optimize the parameters. As refrigeration system is also a thermodynamic system, its COP enhancement is being attempted by optimization of pressure, flow rate, refrigerant properties etc and it is a continuous process started in the eighth decade of last century.

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