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Exergy Analysis of a Chilling Plant – A Review

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ABSTRACT
Exergy analysis is widely used in the design, simulation and performance analysis of various types of engineering applications in comparison with energy analysis. Energy analysis presents only quantities results while exergy analysis presents qualitative results about actual energy consumption. This paper emphasizes review of open literature related to the application of exergy analysis in various engineering application since its development. It has been found that application of exergy analysis in vapour compression refrigeration system has been increased in last decade only.
Keywords – Energy, Exergy, Exergy Analysis, Vapour Compression Refrigeration System, Chilling Plant

I. INTRODUCTION

The term Exergy was published for the first time by Rant in 1956, and refers to the Greek words ex (external) and ergos (work). Another term describing the same is Available Energy or simply Availability. The term Exergy is related to Ideal Work and Exergy Losses relate to Lost Work. Recently, exergy analysis method has been widely used in the design, simulation and performance assessment of various types of systems for identifying losses and in-efficiencies. Exergy is defined as the maximum work that may be achieved by bringing a system into equilibrium with its environment. First law of thermodynamic only deals with the quality of energy, while exergy deals with both quality and quantity. Every system not in equilibrium with its environment has some quantity of exergy, while a system that is in equilibrium with its environment has, by definition, zero exergy since it has no ability to do work with respect to its environment.

A chilling Plant works on VCRS that cools Air/Water, creating a more comfortable environment. Chillers are also used to provide process cooling to equipment in an effort to maximize productivity. Chillers circulate chilled water to process unit in order to transfer heat from process to water. This water then returns to the evaporator side of the chiller where the heat is passed from the water to a liquid refrigerant. The refrigerant leaves the evaporator as a cold vapor and enters the compressor where it is compressed into a hot vapor. Upon leaving the compressor, the vapor enters the condenser side of the chiller where heat is transferred from the refrigerant to the air side of the condenser where it is circulated to an open surrounding environment for the final removal of heat.

II. LITERATURE REVIEW

The detailed review of literature related to the inception, development, and various application of exergy analysis has been carried by Enrico S. et**.** al.[1].

The review is divided into following sub groups.
(1) Conceptual literature in line with Exergy.
(2) Inception of "Exergy"
(3) Development of Exergy
(4) Expertise phase of Exergy
(5) Application of exergy analysis in various fields.

Number of literatures published in the sub group number 1 to 4 is presented in Table 1.1 while the application of exergy analysis in various engineering field is tabulated in Table 1.2.

Sub Group	Duration of Year	Number of Research Papers Published
Conceptual Literature in line of Exergy	1824-1952	33
Inception of Exergy	1953	1
Development of Exergy analysis	1954-1970	71
Expertise Phase of Exergy	After 1970	292

Table 1.1 Development Scenario of Exergy

Type of Engineering Applications of exergy analysis	Number of Research Papers Published				
	1931-1960	1961-1980	1981-2000	2001-2010	2011-2014
Steam Power Cycles	2	4	5	5	-
Gas Turbine Cycles	-	4	6	9	-
Renewable Energy Cycles	-	-	4	1	-
Combined & Cogeneration Cycles	-	9	20	11	-
Heat exchangers & Heat Networking	1	5	18	8	-
Cryogenics	4	15	14	12	-
Chemical Processes	3	10	15	11	-
Distillation & Desalination	1	6	15	8	-
Industrial & Agricultural Systems	2	6	22	8	-
Environmental Appli.	-	8	21	12	-
VCRS	-	-	-	5	8

Table 1.2 Application of Exergy Analysis

From Table 1.1, it is found that, exergy analysis has grown from child to adult from 1824 to till date and scientists and researchers are enjoying the fruitful results of expertise in the field of Exergy analysis. From Table 1.2, it is clear that, since its development, exergy analysis has been widely used in most of the engineering applications. The study of exergy analysis related to VCRS has been increased in last decade only.

Other literatures related exergy analysis is presented in the following section.

Amir V et al. [2] have 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. [3] 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. [4] 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. [5] 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.[6] 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 °Cto 0°Cand 40 °C to 55°C, 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. The conclusions of the present analysis are summarized below.

- COP and exergetic efficiency for R507A are better than that for R404A at condenser temperatures between 40^{O}C and 55^{O}C. However, both refrigerants show 4–17% lower value of COP and exergetic efficiency in comparison to R502 for the condenser temperatures between 40^{O}C and 55^{O}C.

- The worst component from the viewpoint of irreversibility or exergy destruction is condenser followed by compressor, throttle valve and evaporator, respectively. The most efficient component is liquid vapour heat exchanger. The summation of efficiency defects for R507A is less than R404A for condenser temperatures between 40 ℃ and 55℃.

Rahim K.J et al. [7] 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 [8] 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. [9] 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. [10] 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. After the successful investigation of the HC as a refrigerant on the basis of performance, the following conclusions can be drawn based on the results obtained:

- Exergy loss for butane and isobutene are less than that of the refrigerant R134a in the present test unit. In the higher evaporating temperature exergy loss is decreased for all refrigerants.
- Exergy efficiency is also higher for butane compared to that of isobutene and R-134a as refrigerants.
- Exergy loss in the compressor is higher than that in the other parts of the system i.e. up to 69% of the total exergy loss occurs in the compressor.
- The co-efficient of performances for butane and isobutene are comparable with that of R134a.
- Exergy loss increases with the increase of condenser temperature. Its higher for butane compared that of R134a and iso butane.

Camelia S et al. [11] 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 manner for five refrigerants (R22, R134a, R717, R507a, R404a) proving a different behavior and thus bringing important information about system optimization when working with a specific refrigerant.

Vaibhav J et al. [12] investigated thermodynamic analysis of R134a, R410a, R407c and M20 in comparison to R22. In the present research study a refrigerant property dependent thermodynamic model of a simple reciprocating system, which can simulate the performance of actual system as closely as possible, has been used to compare the characteristics of various refrigerants. From the comparison of performance parameters it can be concluded that R407C is a potential HFC refrigerant replacement for new and existing systems presently using R22 with minimum investment and efforts.

Jyoti S et al. [13] Presented a theoretical performance study of a vapour compression refrigeration system with refrigerants R-407C and R-410A. 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.

Ratnesh S et al.[14] 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 [15] 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. [16] has 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.

III. CONCLUSION

In this paper, review of exergy analysis method has been studied since then when the word “exergy” was not in use. From the review it is clear that application of exergy in various fields are on its peak. The literature related to exergy analysis of VCRS is available since last decade only and particular for chilling plant is rare. Thus, it seems that there is scope of application of exergy analysis in chilling plant for analyzing its performance.

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