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EXERGY ANALYSIS OF VAPOUR COMPRESSOR REFRIGERATION SYSTEM USING ALTERNATIVE REFRIGERANTS-A REVIEW

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ABSTRACT

The objective of this paper is to presents review on the exergy analysis of vapour compression refrigeration system with using new refrigerants to replace CFCs and HCFCs. It is found that exergy analysis shows better and accurately location of inefficiency as compared to energy analysis. Exergy depends on the evaporator temperature, condenser temperature, degree of sub cooling and compressor pressure. The coefficient of performance (COP) and second law efficiency of the cycle increases, and exergy losses decreases with decreasing the temperature difference between the evaporator and refrigerated space and between condenser and outside air. It is also found that refrigerant should have low ODP and GWP. HC mixtures and R152a are the better substitutes to R12 in domestic refrigeration sector.R290, R1270, R290/R152a, R744 and HC/HFC mixtures are the long term substitutes for R22 in heat pump and in air conditioning system. In chiller application R11, R12 and R22 can be replaced by the R123

Keywords:-COP, exergy losses, second law efficiency, sub cooling, new refrigerants

INTRODUCTION

The first vapour compression refrigeration cycle was developed in 1834. There are the various applications where vapour compression refrigeration system is used such as in air conditioning units, domestic refrigerator and chiller unit etc. In this system working fluid used is known as refrigerant which is the medium of heat transfer. The first refrigerant used in vapour compression refrigeration system is sulfur dioxide which is highly flammable and toxic. In 1930 Freon group refrigerant was start in use in order to reduce the flammability and toxicity.

The properties of refrigerants their life time in the atmosphere, the time required to ascent into the stratosphere their distribution in that atmosphere and chances of bombardment by high energy photons which will further destroyed the ozone layer. Even percentage of CFC's in the stratosphere is too small but their capacity to destroy O_3layer is too large compared with CO_2.Thier lifetime is also considerable so their warming effect may take a few decades or even a century. Therefore, it is necessary to replace present conventional CFC refrigerants by some other refrigerants which will have less green house effect [17]. The commonly used refrigerants CFCs and HCFCs in many industrial and domestic applications are responsible to increase the ozone layer depletion and global warming. These refrigerants can be replaced by the new refrigerants such as R-134a, R-404a, R-407c, R-410a, R-290, and R-152a etc. and HC refrigerants which have zero ODP and low GWP in order to protect the environment [16].

The performance of the vapour compression refrigeration system can be calculated by two methods i.e. energy and exergy analysis. Energy analysis is based on the first law of the thermodynamic while exergy analysis based on the both first and second law of thermodynamic. The first law of the thermodynamic deals with quantity of energy and assert that energy cannot be created or destroyed, but it does not gives the information that how, where and how much the performance of the system degrade. Thus the second law of thermodynamic which deals with quality of energy is used to determine the performance degradation of the system. The second law of thermodynamic has proved to be a very powerful tool in the optimization of complex thermodynamic systems [8]. Basically in energy analysis calculate the work done by compressor (W), refrigerating effect (R_E), power per ton refrigeration(P/TR), volumetric refrigerating capacity (VCR) and coefficient of performance (COP)[2]. While exergy analysis discusses the exergy losses in each component of the system, exergy destruction ratio, efficiency defects, second law efficiency and also coefficient of performance(COP). On the basis of the study it found is that exergy analysis shows better and accurately locations of inefficiency as compared to energy analysis. It is also found that exergy depend on the evaporator temperature, condenser temperature, degree of sub cooling and compressor pressure. The evaporating and condenser temperature have strong effects on the exergy losses of the evaporator and condenser, and on the second law efficiency and COP of the cycle but little effect on the exergy losses in the compressor and expansion valve. If the temperature difference between the evaporator and refrigerated space & between condenser and outside air is increased then the exergy losses is also increased and COP and second law efficiency decreased [3, 10].

This paper presents the review of the performance analysis of the vapour compression refrigeration system using various refrigerants which are the substitutes of CFCs and HCFCs. It is found that exergy analysis shows better and accurately locations of inefficiency as compared to energy analysis. Exergy depend on the evaporator temperature, condenser temperature, degree of sub cooling and compressor pressure. It is also shows that refrigerant should have low ODP and GWP. Thus the refrigerants R-134a, R-404a, R-407c, R-410a, R-290, and R-152a and HC blends are consider.

Description of Cycle

A simple vapour compression refrigeration system consists of four basic components illustrated via, evaporator, compressor, condenser and expansion valve. These components connected in a closed loop through piping that has heat transfer with the surrounding as shown in fig.1. At state 1, refrigerant leaves the evaporator at a low pressure, low temperature, saturated vapour and enter the compressor through the suction line in which both temperature and pressure increased. This process can be shown in fig.2. At state 2, it leaves the compressor as a high pressure, high temperature, superheated vapour and enter the condenser where it reject heat to surrounding medium at constant pressure after undergoing heat transfer in the discharge line. Refrigerant leaves the condenser at state 3, as high pressure, medium temperature, saturated liquid and enters the expansion valve. The expansion valve allows to flowing the high pressure liquid at constant enthalpy from high pressure to low pressure. At state 4, it leaves the expansion valve as a low temperature, low pressure, and liquid-vapour mixture and enters the evaporator where it absorbs the heat at constant pressure, changed into saturated vapour and cycle is completed.

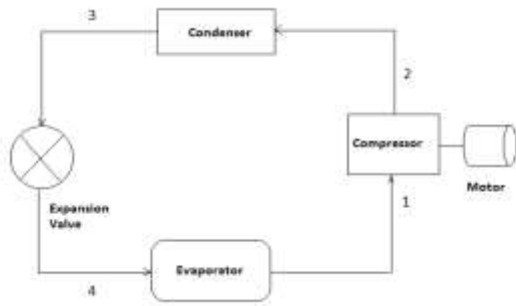

Fig.1. Schematic diagram of Simple Vapour Compression Refrigeration System

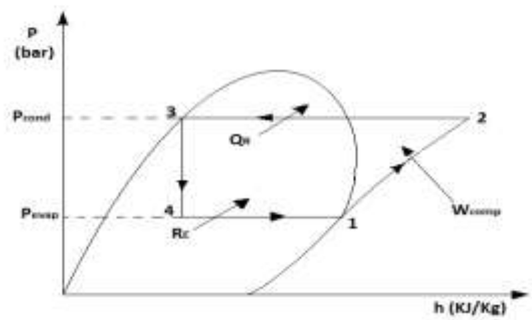

Fig.2 Pressure enthalpy diagram of vapour compression refrigeration cycle

Development of the System

As we know that COP and second law efficiency of the vapour compression refrigeration system can be increased by sub cooling. The sub cooling increases refrigerating capacity whereas there is no change in compressor work. As the COP of performance is the ratio of the refrigerating effect produced by evaporator to work done by compressor, hence COP increases. Vapour compression refrigeration cycle with liquid vapour heat exchanger including superheating and sub cooling as shown in fig.3.

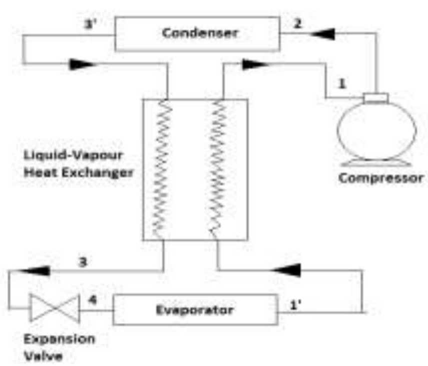

Fig. 3 Schematic diagram of vapour compressor refrigeration cycle with sub cooling and superheating in liquid vapour heat exchanger

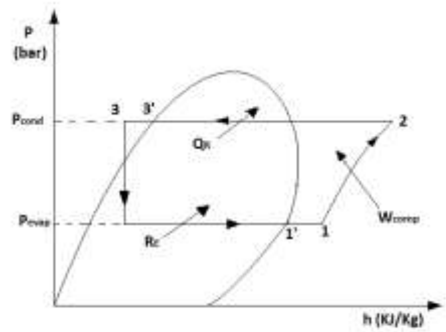

Fig. 4 ph diagram of vapour compressor refrigeration cycle with sub cooling and superheating in liquid vapour heat exchanger

From the analysis A.S. Dalkilic, S. Wongwises [2] shows that better performance obtained with sub cooling and superheating as compared to non sub cooling and non superheating condition. Akhilesh Arora, S.C. Kaushik [1] shows that exergy efficiency for 10℃ sub cooling is 14.9% for R404A and 14.8% for R507 at 40℃ condenser temperature and with decreasing the temperature differences between the evaporator and refrigerated space & between the condenser outside air COP and exergy efficiency increases, and exergy losses decreases.

LITERATURE REVIEW

- Recep Yumrutas, Mehmet Kunduz, Mehmet Kanoglu [3] investigated the performance of the refrigeration system using NH_3 as refrigerant based on the exergy analysis. It is found that the second law efficiency and COP increases & exergy losses decreases with decrease the temperature difference between evaporator and refrigerated space & between condenser and outside air.
- Arora and Kaushik [1] by using the computational model computing the coefficient of performance (COP), exergy destruction, Exergetic Efficiency and efficiency defects for R502, R404A and R507A. The evaporator and condenser temperature taken in the range of -50℃ to 0℃ and 40℃ to 55℃. The result indicates that R507A gives better performance as compared to R404A and R502A and it can be replace the R502 in future.
- A.S. Dalkilic, S. Wongwises [2] compare the performance of the vapour compression refrigeration

system with consider the superheating and sub cooling conditions and using refrigerant mixture based on HFC134a, HFC152a, HFC32, HC290, HC1270, HC600 and HC600a in different ratios. Their result compared with the R12, R22 and R134a and finally it is concluded that all the alternative refrigerant have slightly lower coefficient as compared to R12, R22 and R134a but refrigerant blends of HC290/HC600a(40/60 by wt. %) can be replace R12 and HC290/HC1270(20/80 by wt. %) can be replace R22.

- B.O. Bolaji [12]proposed the of study of R152a and R32 to replace R134a in a domestic refrigerator by experiment and their result shows that R152a can be replace R134a in domestic refrigerator.
- Bilal Ahmed Qureshi, Syed M. Zubair [4] theoretically investigated the performance degradation of the refrigeration system due to fouling conditions in air side. There are two sets of refrigerants consider1st set include the refrigerant R134a, R410A and R407C and shows that 134a always performs better and 2nd set include the refrigerants R717, R404A and R290 and shows that R717 always performs

better. It concluded that the performance degradation of the evaporator has larger effect on the power consumption of the compressor but the performance degradation of the condenser has an overall large effect on the COP.

- Miguel Padilla et.al. [5] Discuss the exergy analysis of R413A to replace R12 in domestic refrigerator by experimental. Total twelve tests performed (six tests for each refrigerant) and each test is depending on the fan velocity at condenser and evaporator. Better results obtained when fan velocity at evaporator is 0% and at condenser 100%.it gives the results that 413a gives better performance as compare to R12.

Effect of evaporator temperature

Evaporator temperature has a great effect on the performance of refrigeration system. The low quality refrigerant from expansion valve enters into evaporator where it absorbs the heat and changed into vapour. The temperature of the liquid refrigerant lower than the cooled space, therefore, refrigerant absorbs the heat. The heat transfer between the evaporator and cooled space increases with increase in evaporator temperature increases, consequently refrigerating effect increases and exergy losses decreases. V.P. Venkataramanamurthy et.al, [10] shows the comparison energy, exergy flow and second law efficiency analyses for R22, R436b in refrigeration cycles. Their result is shows that evaporating temperature has strong effects on the exergy flow losses.

Effect of condenser temperature

Condenser temperature also greatly affects the COP, second law efficiency and exergy losses. With increasing the condenser temperature, COP and second law efficiency decreases, and the exergy losses increases because the temperature differences between the condenser and outside air increases. By using the computational model Recep Yumrutas [3] shows that COP and second law efficiency increases and total exergy losses decreases with increasing the temperature of evaporator and decrease temperature of the condenser.

Refrigerant

The working fluid used in refrigeration system for heat transfer is known as refrigerant which also affect the performance of the system. There are various CFCs and HCFCs refrigerant used in many industrial and domestic applications are responsible to increase the ozone layer depletion and global warming. According to Montreal Protocol (1987) the uses of CFCs have been banned in developed countries since 1996 and in developing countries since 2010. The HCFC will be banned on European countries in 2015 and practical use limit the year 2010.Generally, R12 was used as a refrigerant in refrigerator and R22 was used in air conditioning system which has higher COP as compared to other refrigerants. But both R12 and R22 was required to replace according to the Montreal Protocol because of high ODP and GWP. M. Mohanraj [16] studies the large number of theoretical and experimental world report and give the conclusion that HC mixtures and R152a are the better substitutes to R12 in domestic refrigeration sector.R290, R1270, R290/R152a, R744 and HC/HFC mixtures are the long term substitutes for R22 in heat and in air conditioning system. In chiller application R11, R12 and R22 can be replaced by the R123. There are the several theoretical and experimental investigation done for various alternative refrigerants can be seen in table 1

Table 1: Theoretical and experimental investigations for alternative refrigerant

Author	Analysis	Objective	Refrigerants	Results	Comments
Qureshi and Zubair [4]	Using EES Software	Performance degradation duo to fouling in a vapour compression refrigeration system.	R-134a, R-410A,R-407C, R-717, R-404A and R-290.	R-134a always performs better as compared to R-410A, R-407C &, R-717 always performs better as compared to R-404A and R-290.	Performance of the vapour compression refrigeration system degrades due to fouling effect.
Dalkilic and Wongwises [2]	Theoretical analysis	Performance comparison of vapour compression refrigeration system.	CFC12,CFC22,HFC134a & refrigerant mixture based on HFC134a, HFC152a, HFC 32, HC290, HC1270, HC 600 and HC 600a for various ratios.	Refrigerant blends of HC290/HC600a instead of CFC12 and HC290/HC1270 instead of CFC22 can be replaced.	Better performance obtained in superheating sub cooling condition.
B.O.Bolaji [12]	Experimental analysis	Study of R152a and R32 to replace R134a in a domestic refrigerator.	R152a, R134a and R32.	R152a can be replacing R134a in domestic refrigerator.	Domestic refrigerator is designed to work with R134a.
R. Flopis et.al. [11]	Experimental analysis	Energy analysis of two stage vapour compression refrigeration system	R-404A and R-507A.	R507 gives better result as compared to R404A.	Replace R-502, having ODP 0.221 & GWP 4500.
Venkataramanamurthy et.al. [10]	Experimental analysis	Analyze the system processes separately and to identify and quantify the sites having largest energy and exergy flow losses	R22 and R436b.	The second law efficiency and COP increases & exergy losses decreases with decrease the temperature difference between evaporator and refrigerated space & between condenser and outside air.	Evaporating temperature affects the exergy losses.
Arora and Kaushik [1]	Using EES Software. It's a computational program	Theoretical analysis of vapour compression refrigeration system	R-502, R-404A and R-507A.	R-507 is better substitute to R502A than R404A.	Evaporator and condenser temperature in the range of -50°C to 0°C & 40°C to 55°C.
Mani and Selladurai [13]	Experimental analysis	Experimental analysis of new refrigerant mixture to replace CFC12 and HFC134a.	CFC12, HFC134a and R290/R600a	R290/R600a mixture can be replaced for CFC12, HFC134a.	Vapour compres refrigeration system init designed to operate R12.
Miguel Padilla et. al. [5]	Experimental analysis	Exergy analysis of R413A to replace R12 in domestic refrigerator.	R413A and R12.	The overall energy and exergy performance of the system working with R413a is consistently better than that of R12.	Experimental test performs with consider various the fan velocity on evaporator and condenser.
Xuan and Chen [6]	Experimental study	Experimental study of HFC-161 mixture to replace R502 in vapour compression refrigeration system.	R-502, R-404A and R-507A and HFC-161 mixture.	HFC-161 new refrigerant can achieve a high level of COP and can be consider as a promising retrofit refrigerant to the latter.	Setup basically designed to use R404A.

A little consideration will shows that refrigerant selected on the basis of their thermodynamic properties and also refrigerant should have low ODP and GWP. Properties of the possible future alternative refrigerants as shown table 2.

Table 2 Properties of the possible future alternatives refrigerants

Refrigerant	Name	Boiling Point	Critical Point	ODP	GWP
R-404A	R-125/R-143a/R-134a (44/52/4)	-47	73	0	3800
R- 407C	R-32/R-125/R-134a (23/25/52)	-44	87	0	1700
R-410A	R-32/R-125 (50/50)	-51	72	0	2000
R-413A	R-218/R-134a/R-600a (9/88/3)	-35	101	0	1900
R-507A	R-125/R-143a (50/50)	-47	71	0	3900
R-417A	R-125/R-134a/R-600 (46.6/50.0/3.4)	-43	90	0	2200
R-401A	R-22/R-152a/R-124 (53/13/34)	-31	78	0.037	1100
R-508A	R-23/R-116 (39/61)	-86	13	0	12000
R-134a	1,1,1,2-Tetrafluoroethane	-26	101	0	1300
R-134	1,1,2,2-Tetrafluoroethane	-23.0	119.0	0	1200
R-290	Propane	-42	97	0	20
R-717	Ammonia	-33	133		0
R-600a	Isobutene	-12	135		20
R-23	Trifluoromethane	-82.1	25.9	0	12000
R-32	Difluoromethane	-51.7	78.2	0	550
R-161	Fluor ethane	-37.1	102.2	0	12
R1-125	Pentafluoroethane	-48.1	66.2	0	3400
R-143a	1,1,1-Trifluoroethane	-47.2	72.9	0	4300
R-143	1,1,2-Trifluoroethane	5.0	156.7	0	300
R-152a	1,1-Difluoroethane	-24.0	113.3	0	120
R-236fa	1,1,1,3,3,3-Hexafluoropropane	-1.4	124.9	0	9400
R-218	Octafluoropropane	-36.6	71.9	0	8600
R-245fa	1,1,1,3,3-Pentafluoropropane	15.1	154.1	0	950

CONCLUSION

The exergy analysis shows better and accurate location of inefficiency as compared to energy analysis. Exergy losses depend on the evaporator temperature, condenser temperature, degree of sub cooling and compressor pressure. The coefficient of performance (COP) and second law efficiency increases, and exergy losses decreases with decreasing the temperature difference between the evaporator and refrigerated space and between condenser and outside air. This means that increase in condenser temperature and decrease in evaporator temperature, result in increase the exergy losses. It is also shows that selected refrigerant should have low ODP and GWP. R-134a, R-404a, R-407c, R-410a, R-290, and R-152a etc. and HC refrigerants (even these are flammable) can be selected because of low ODP and GWP. From studies M. Mohanraj [16] reported that HC mixtures and R152a are the better substitutes to R12 in domestic refrigeration sector.R290, R1270, R290/R152a, R744 and HC/HFC mixtures are the long term substitutes for R22 in heat and in air conditioning system. In chiller application R11, R12 and R22 can be replaced by the R123.

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