Exergy Analysis of air conditioner by using alternate refrigerant

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Abstract - *In our daily life refrigeration has very important role mainly in industrial, domestic and commercial sector. This paper deals with study of vapour compression cycle based on exergy analysis so we know that, the amount of irreversibility in each component of vapour compression cycle and we also know the location where we get the maximum irreversibility in the vapour compression cycle. The primary objective is to study the various component separately and for this study we use the second law approach because the analysis based on first law of thermodynamics is very common and it deals with conservation of energy hence it not tells, where in the system irreversibility occur. For our study purpose we use the different refrigerant and we can also compare the different refrigerant so we know that, which refrigerant will perform better on the basis of exergy analysis. This paper is planned with an effort to pick the proper refrigerant for air conditioner with given evaporator and condenser temperature to improve the performance of a air conditioner. For this purpose exergy analysis is finished with different refrigerants R22,R134a,R290,R410a,R407c for computing COP, EDR, exergy efficiency and efficiency defect by EES (ENGINEERING EQUATION SOLVER).*

Key Words: Exergy, Exergy efficiency, Exergy destruction, EES (Engineering Equation Solver).

Nomenclature

T_o – Ambient temperature (K)
T_1 – Evaporator temperature(K)
T_2 – Compressor outlet temperature(K)
T_3 – Condenser temperature(K)
p_1 – Evaporator pressure(KPa)
p_2 – Condenser pressure(KPa)
h – Specific enthalpy (KJ/kg)
s – Specific entropy (KJ/kg k)
m – Mass flow rate (kg/s)
Q_e – Refrigeration capacity(KW)
W_c – Theoretical compressor work(KW)
W_a – Actual compressor work(KW)
Cop – Coefficient of performance
T_r – Refrigerated space temperature(K)
I_1 – Irreversibility in compressor(KW)
I_2 – Irreversibility in condenser(KW)
I_3 – Irreversibility in expansion valve(KW)
I_4 – Irreversibility in evaporator(KW)
I_t – Total Irreversibility in vapor compression refrigeration cycle(KW)
Eo – Product exergy rate(KW)
Ei – Fuel exergy rate(KW)
Eff – Exergy efficiency
EDR – Exergy destruction ratio
ED – Efficiency defect

1. INTRODUCTION

Refrigeration bears an enormous value due to thermal comfort which is very essential in residential area as well as in industrial sector. This system require energy for its functioning and our challenge is to use this system with less energy requirement. The information will be required to know where the more energy is lost or to know where is more irreversibility occur. For this a thermodynamic analysis is required.

The analysis based on second law is better way as it deals with evaluation of irreversibility in various thermodynamic process. It evaluate the magnitude of irreversibility associated in process qualitatively and point out the direction where we have to focus more in order to improve the performance of thermodynamic system.

Thermodynamic process which should be occur in vapour compression cycle, releases an enormous amount of heat to the environment and also the heat transfer which is going to be in the cycle, means in between the evaporator and refrigerated space and also in between the condenser and the surrounding will take place through a finite temperature difference and it should be a major cause which should be a responsible for irreversibility in the cycle (1).

Modern approach which is going to use for the study of vapour compression cycle is on the basis of exergy analysis, as it give information in a better way so we get better understanding of what should be occur in the process. The exergy analysis is a modern method uses the thermodynamic approach and comes as a useful and advance tool engineering process evaluation (2).

The conventional energy analysis which should be use various sector will not provide about the amount and the location where the energy is wasted in the cycle as it deals only with conservation of energy. On the other hand exergy calculation exergy calculation and exergy balance will provide better insight of the process and also we get the idea about the component in which the improvement should be required in the system(3). Dincer (4) will provide the

relationship in between the energy, exergy, environment and also about the energy making policy.
Schematic diagram of vapour compression cycle is shown below

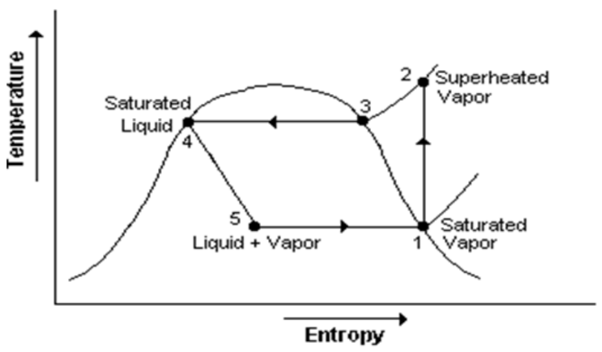

Fig 1 T-S Plot of Vapour compression cycle

The following T-S plot consist of four process:

•**Isentropic compression process**: The refrigerated vapour which is at low pressure is isentropically compressed to high pressure so the saturated refrigerant will convert into superheated vapour.
•**Constant pressure heat rejection process**: The superheated vapour enters the condenser so the high temperature refrigerant will reject the heat to the surrounding or the coolant in the condenser.
•**Isenthalpic expansion process**: The high temperature high pressure refrigerant vapour enters the expansion valve where the refrigerant will losses the pressure and convert into two phase mixture.
•**Constant pressure heat addition process:** Here the low pressure low temperature refrigerant will absorb the heat from refrigerated space so the two phase mixture will convert into saturated vapour.
Schematic diagram of various component of vapour compression refrigeration system

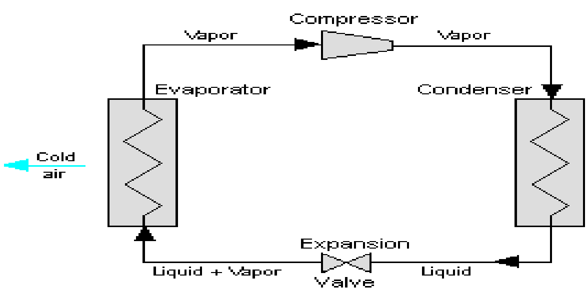

Fig 2 Component of vapour compression refrigeration system

The above figure has following main component:
Ø **Compressor:** The power to run the compressor is provided from the outside source and the refrigerant vapour which enters in the compressor is at low pressure and low temperature, so that after isentropic compression process it will convert into high pressure and high temperature refrigerant.
Ø **Condenser:** The superheated refrigerant enters at high temperature and it will rejects heat to the surrounding or to the coolant.
Ø **Expansion valve**: The high temperature saturated liquid will enter the expansion valve and will goes under isenthalpic process and convert into two phase mixture.
Ø **Evaporator**: The low pressure low temperature refrigerant will enters the evaporator and extracts the heat from refrigerated space so the two phase mixture will convert into the saturated vapour.
The main objective of this study is to judge the parameter related to exergy so we know in more detail about the location of irreversibility in various component by reviewing the various studies conducted on vapour compression cycle by various researchers.

AIR-CONDITIONING

It is defined as the process of treating the air so as, we have to regulate at same time its temperature, humidity, cleanliness and distribution to fulfill the requirements of the conditioned space. For higher level of comfort, the air in a room must be cooled or heated, humidified or dehumidified, pure and circulated.
The lowering or raising the temperature does not provide comfort in general to the machine or its components and living being in particular. In case of the machine components, along with the temperature, moisture content in the air has also to be controlled and for the comfort of human beings along with this two important parameter, air motion and cleanliness plays also a very important role. Air conditioning therefore is a broader aspect which looks into the simultaneous control all factors which are essential for the comfort of persons or animals or for the right performance of some industrial or scientific process.
So we can say that the air conditioning is a process of simultaneous control of temperature, moisture control in air, cleanliness and air motion.
The important actions concerned within the operation of an air-conditioning system are

a. Temperature control
b. Humidity control
c. Air filtering, improvement and purification
d. Air movement and circulation

Exergy

It is the maximum work which is obtainable by bringing a system into equilibrium with environment. System which is in equilibrium with environment having zero exergy because it has no ability to do work with respect to environment.

Exergy_analysis is a technique based on second law of thermodynamics. The fundamental of the exergy technique are developed by carnot in 1824 and clausius in 1865. The energy technique has gained more importance in various thermal process and plant system because the first law analysis is not sufficient to find out the amount and location of losses in the system. In such circumstances the exergy analysis is well suited to locate the system imperfection.

Why Exergy Analysis

Conventional thermodynamics analysis is based primarily on first law of thermodynamics which state the principle of conservation of energy.

An energy analysis of an energy-conversion system is basically an accounting of the energies coming into it and exiting it. Efficiency are often evaluated as ratio of energy quantities, and are often used to assess and compare various system. For example Power Plant, thermal storage, heaters and refrigerators are often compared based on energy efficiency.

Exergy analysis allows several of the shortcomings of energy analysis to be overcome. Exergy method which is based on the second law of thermodynamics and is useful in identifying the cause, location and magnitude of process irreversibility. The exergy related to an exergy amount would be a quantitative assessment of its usefulness or quality. Exergy analysis acknowledges that the, though energy cannot be created nor be destroyed, it is degraded in quality, eventually reaching a state during which it's in complete equilibrium with the environment and hence of no more use for performing tasks.

2. Literature Review

Mehul Tandel et.al. works in the study of window air conditioning and complete there study based on exergy analysis by using refrigerant R22 and R407C. They perform study on a experimental setup and complete their study by evaluating the different parameter by running the system at various condition and finally obtained a result that the exergy destruction will be highest in compressor when the system will be working on its highest exergetic efficiency.

Mohan Chandrasekharan works in the study of vapour compression refrigeration system by using the method exergy analysis and perform his analysis by using the refrigerant R12 and R134a. For obtaining the result he use the computational model so that he compare the two refrigerant based on exergy analysis by evaluating the parameter like exergy efficiency, coefficient of performance and study the effect which should be occur in this parameter by changing the operating condition like evaporating temperature and also by degree of sub-cooling.

Recep Yumrutas et.al. works in the study of vapour compression refrigeration system by using a computational model and perform study on the basis of exergy analysis. In this paper we get the point that by changing the evaporating and condensing temperature there will be little changes occur in exergy loss in evaporator and expansion valve as compare to compressor and condenser of vapour compression cycle and by changing this parameter we also see the effect which occur in coefficient of performance, exergy loss and second law efficiency.

J U Ahamed et.al. study in the field of exergy analysis in various sector where vapour compression refrigeration is used. He analyze the refrigerant R407a, R600a, R410a, and R134a with respect to the exergy efficiency and found that the major part of exergy loss occur in compressor of vapour compression refrigeration system and also found that the exergy will depend on environment temperature, evaporating temperature, condensing temperature, subcooling.

Ma. Guadalupe Alpuche et.al. perform the exergy analysis at different temperature and relative humidity condition and see the effect of air cooling desiccant system in the interior of building while reaching the thermal comfort condition.

B. N. Taufiq et.al. use the exergy method to find out the overall and individual component efficiencies and he find out the thermodynamic losses which occur in various component and through this he describe the modeling and optimization of cooling system in building.

Miguel Padilla et.al. focus on exergy analysis in domestic vapour compression refrigeration system and analyze the effect of direct replacement of R12 with zeotropic mixture R413A on performance of domestic vapour compression refrigeration system. All the factors are evaluated on exergy basis which have effect on performance of this system.

Jun Lan Yang et.al. perform the comparative study on transcritical carbon dioxide refrigeration cycle with throttling valve and with an expander and find out the amount and location of irreversibility by method of exergy analysis.

Ren Chengqin et.al. mainly discuss the principle of exergy analysis in heating ventilation and air conditioning application and used this principle to find out the performance of different evaporative scheme and also concluded that the selection of dead state is very important in calculation of exergy analysis in heating ventilation and air conditioning application.

Akhilesh Arora et.al. works in a numeric al model for vapour compression refrigeration system and by use of various refrigerant they perform the study based on exergy analysis and concluded that the increase in the dead state temperature will decreases the exergy destruction ratio and also show the positive effect in exergy efficiency.

Abdullah Yildiz et.al. works in the field of space heating problem in building and give the information that the energy conservation concept is not sufficient for understanding the important aspect of energy utilization process thus he uses the method of exergy analysis based on first and second law of thermodynamics for better understanding of energy flow in building.

Pooja Yadav et.al. perform the study of exergy analysis of actual vapour compression refrigeration cycle using the refrigerant R134a and perform study on exergy destruction which is unused work potential which occur during a process due to the irreversibility occur during a process.

C. Aprea et.al. perform exergy analysis of vapour compression plant by substitution of R22 with zeotropic mixture of R407C and compare the exergy loss of both refrigerant by performing test on experimental setup. In this paper the individual component has analyze based on exergy so as to determine the component which contribute most for the decrease of exergy performance of refrigerant R407C.

3. Methodology

Exergy analysis is a technique that is based on the second law of thermodynamics and it also uses the conservation of mass and energy principles for the analysis, design and improvement of the system. Many engineers and scientist advised that the thermodynamic performance of a system is best evaluated by doing an exergy analysis additionally to or in situ of place of standard energy analysis because exergy analysis appears to provide more insights and to be more useful in furthering efficiency improvements efforts than energy analysis.

3.1 Theoretical Formulation

For analyzing the vapour compression system on the basis of exergy analysis we need some mathematical relation. Through mathematical relation we find out the exergy loss in various component and also compare the different refrigerant on the basis of different exergy parameter. For theoretical formulation we need some assumptions which are as follow:

- Steady state condition
- Neglect the exergy associate with the heat transfer in the condenser
- Neglect the kinetic energy losses
- Neglect the potential energy losses
- Pressure losses in condenser and evaporator is neglected
- Isentropic efficiency will be 100%
- Mechanical efficiency will be 80%

Mathematical equation for different component of vapour compression refrigeration system on the basis of exergy analysis (30)
Specific exergy for any particular state is given as
= $(h-h_o)-T_o*(s-s_o)$

Compressor
Actual Power,

W_a =compressor power/mechanical efficiency

Compressor power = $m*(h_2 - h_1)$

Exergy destruction, $I_1 = m*((h_1 - h_2)-T_o*(s_1-s_2)) + W_a$

Condenser

Exergy destruction, $I_2 = m*((h_2 - h_4)-T_o*(s_2-s_4))$

Expansion valve

Exergy destruction, $I_3 = m*T_o*(s_5-s_4)$

As $h_5 = h_4$

Evaporator

Heat addition = $Q_e = m*(h_1- h_5)$

Exergy destruction,

$I_4 = m*((h_5-h_1)-T_o*(s_5-s_1)) + Q_e*(1-T_o/T_r)$

Where T_r =Te + 10^0C

Total Exergy destruction = Sum of exergy destruction of all components

Itotal, $I_t = I_1 + I_2 + I_3 + I_4$

Product exergy rate = $Q_e*(1-T_o/T_r)$

Fuel exergy rate = W_a

Coefficient of performance

= Heat addition in evaporator/Actual power

Exergy efficiency =$(Q_e*(1-T_o/T_r))/ W_a$

Efficiency defect

=Exergy destruction of particular component/Actual power

Exergy destruction ratio

=Total exergy destruction/Product exergy rate

From this analysis we find out the location where more irreversibility occur so we work on that area to improve the performance of the system by reducing the losses.

4. Result

Design assumed for analysis

- Mass flow rate of refrigerant is = 0.05Kg/s
- Isentropic Efficiency of compressor = 80%
- Range of evaporator temperature is = 0^0C to 15^0C in the step of 1.667^0C
- Condenser temperature = 50^0C
- Dead state temperature = 40^0C
- Difference between evaporator temperature and space temperature is 10^0C
- Thermal exergy loss in condenser is neglected as the boundary of the condenser is assumed to be at the environment temperature

The following graph is to be drawn with the help of Engineering Equation Solver by varying the evaporating temperature

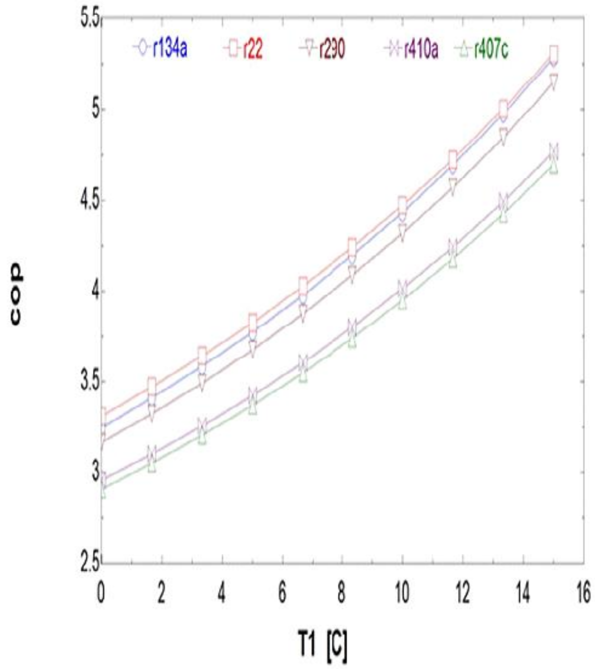

Fig 3 Evaporator temperature and coefficient of performance

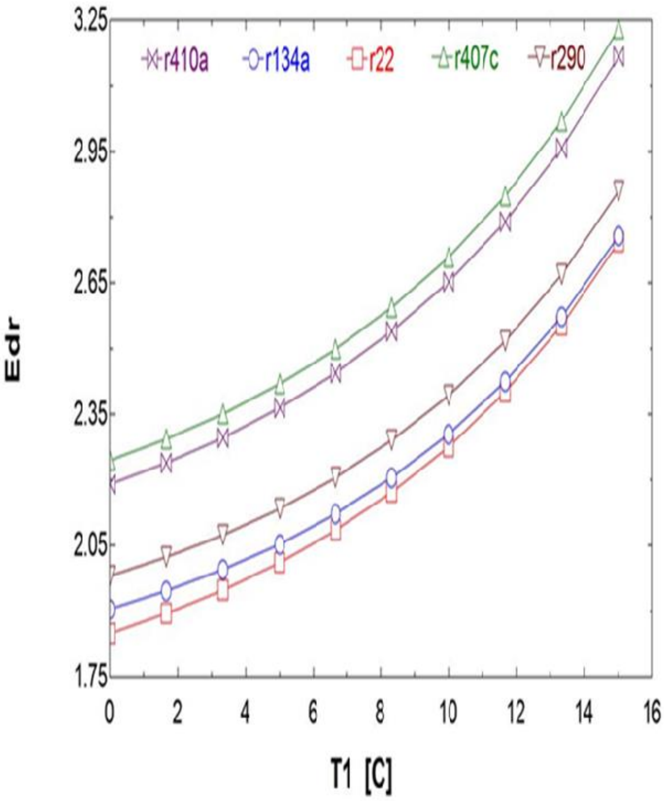

Fig 4 Evaporator temperature and Exergy destruction ratio

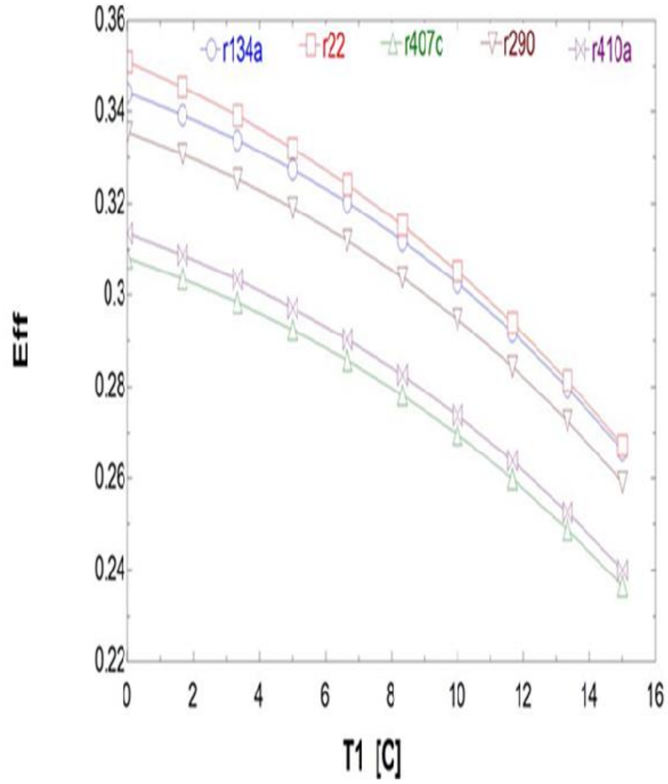

Fig 5 Evaporator temperature and Exergy efficiency

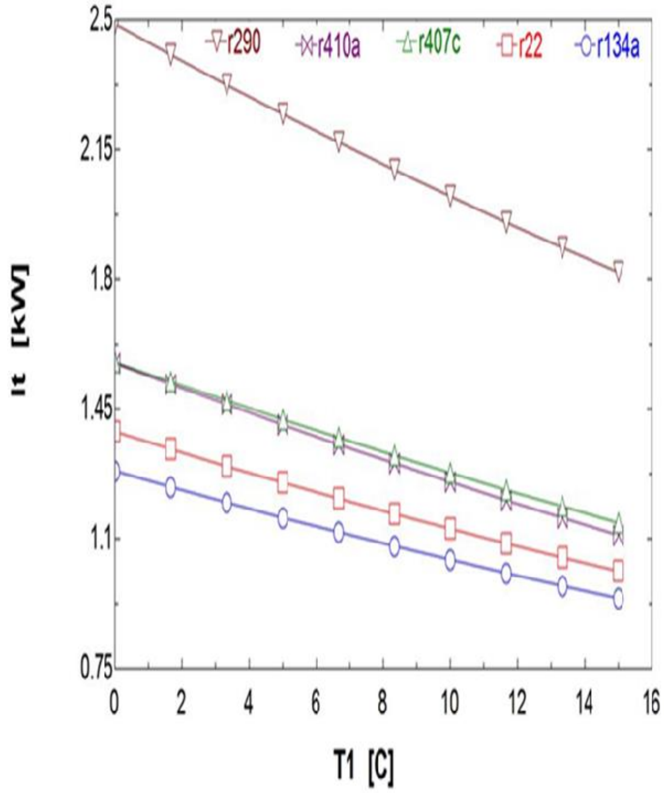

Fig 6 Evaporator temperature and Total irreversibility

5. CONCLUSION

The following conclusion can be drawn from analysis

- R22 shows higher value of coefficient of performance and also as the evaporator temperature will increases its value also increases. After R22, R134a shows good result with respect to coefficient of performance.
- As the evaporator temperature increases, the exergy destruction ratio increase which is not good for a refrigeration system, so the refrigerant which has less value of exergy destruction ratio, so as per this criteria the refrigerant R22 shows better result and after that R134a will shows better performance.
- As evaporator temperature increases the exergy efficiency will decreases because the product exergy rate decreases as the evaporator temperature increases. So as per exergy efficiency criteria refrigerant R22 shows better result and it give high value of exergy efficiency at low value of evaporator temperature. After R22, R134a shows good result as per exergy efficiency.
- As the evaporator temperature increases, the value of total irreversibility decreases and the refrigerant R290 shows the higher value of irreversibility and R134a shows less value of irreversibility.
- In case of refrigerant R134a, R290 and R410a the irreversibility is highest in compressor where as in case of R22 condenser shows higher value of irreversibility and in R407c evaporator shows higher value of irreversibility.
- As the evaporator temperature increases the irreversibility in compressor decreases and as per this criteria the refrigerant R134a shows good result and R290 shows a higher value of irreversibility in compressor.
- As the evaporator temperature increases the irreversibility in condenser decreases and as per this criteria the refrigerant R407c shows good result and R290 give high value of irreversibility.
- As the evaporator temperature increases the irreversibility in expansion valve decreases and as per this criteria the refrigerant R22 shows good result upto 9^0C and after that R407c shows good result. The refrigerant R134a shows good result as per irreversibility in evaporator and R407c gives higher value of irreversibility in evaporator.

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