Exergy Analysis of domestic refrigerator 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 work 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.*

It has been ascertained that refrigerators are the devices that work virtually twelve months around the clock,therefore our scope of energy potency improvement initiates with the coining of latest term "exergy analysis" of the refrigerator. The new term introduced for refrigerator can be alone supported the properties of refrigerants utilized in this paper.

This paper is planned with an effort to pick the proper refrigerant for domestic refrigerator with given refrigeration capacity to improve the performance of a domestic refrigerator. For this purpose exergy analysis is finished with different refrigerants R12,R134a,R290,R600,R600a for computing COP,EDR ratio,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 cooling which is very essential in food preservation 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 so we reduce the power consumption. The quantitative 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 first law of thermodynamics is very common but it deals with conservation of energy hence it not tells where in the system irreversibility occur.

The analysis based on second law is better way as it deal 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.

The exergy analysis represents a good convenient standard to evaluate the maximum work obtainable from a given form of energy by bringing the system to the state of the surrounding environment and it plays a very important role in understanding the overall performance of whole system and its components [11]. This analysis also help in taking various decision regarding design parameter [12]. Many researcher have applied exergy studies in various thermodynamic process so as to describe the exergy analysis in simple and effective manner. Padilla et al [13] carried out the analysis and direct impact of replacement of R12 with zeotropic mixture R413A. By his analysis he concluded that the overall energy and exergy performance of the system

working with R413A is better than R12. Kumar et al [14] derive a method to deal with exergy analysis of vapour compression refrigeration system working with R11 and R12 as refrigerants.
In this study the main objective is to identify the amount and location of irreversibility within the cycle by exergy analysis by using different refrigerants.
Schematic diagram of vapour compression cycle is shown below

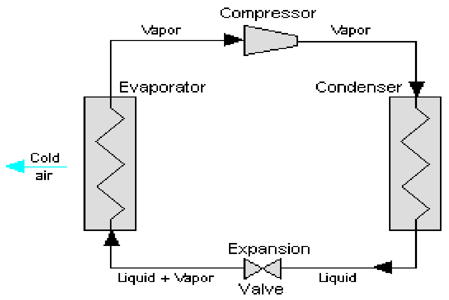

Fig 1 Component of vapour compression refrigeration system

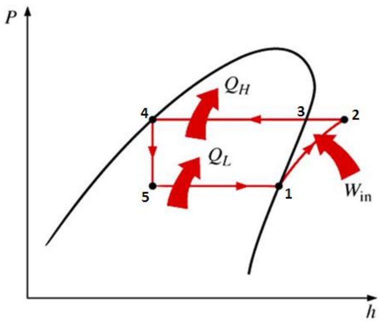

Fig 2 P-h Plot of Vapour compression cycle

The following p-h 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

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.

DOMESTIC REFRIGERATOR

A refrigerator is a famous household appliance that consists of a thermally insulated compartment and a heat pump which may be mechanical, electronic or chemical that transfers heat from the inside of the fridge to its external surrounding so that the inside space of the fridge can be cooled to a temperature below the ambient temperature of the room.Refrigeration is an essential food storage technology in developed countries. The lower temperature lowers the reproduction rate of bacteria, so that the refrigerator can reduce the rate of spoilage. A refrigerator maintains a temperature a few degrees above the freezing point of water. Promising temperature range for perishable food storage is 3 to 5 °C (37 to 41 °F).A similar device that can maintain a temperature below the freezing point of water is called a freezer. The refrigerator replaced the icebox, which had been a famous household appliance for almost a century and a half. For this reason, a refrigerator is usually referred to as an icebox in American usage.

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

Miguel Padilla et.al. has performed the exergy analysis of the impact of direct replacement R12 with the R143A on the performance of a domestic VCR system which was originally designed to work with R12. In a contorted condition at the condenser and evaporator.

Prateek D. Malwe et.al. works in the study of vapour compression system on the basis of exergy analysis and concluded by his study that the major part of exergy loss is coming from the irrerversibilites which is being generated in the system due to entropy generation and this has to be minimized in order to increase the performance of a particular system and also concluded that in among various component of vapour compression system, the compressor have lowest value of exergetic efficiency.

Min-Hsiung Yang et.al. works in the study of vapour compression refrigeration system by changing the evaporating and condensing temperature with superheating in evaporator to evaluate the performance of a system based on exergy analysis using the refrigerant R22, R134a, R410a and R417.They work on a numerical model to evaluate the performance enhancement and analyse the exergy destruction and finally conclude that the optimal degree of sub-cooling will be necessary.

ReepYumrutas et.al. has developed computational model based on the exergy analysis for the investigation of the effects of the evaporating temperature and condensing temperatures on the pressure losses, the exergy losses, the exergetic efficiency. He has also calculated the cop of vcr cycle

Gaurav et.al. has performed a comparison of energy and exergy analysis for R134a,R152a,R290,R600 and R600a in refrigerator by computing cop,edr,exergy efficiency and efficiency defect.He found that the efficiency defect is maximum in condenser and lowest in evaporator.

Mahmood Mastani Joybari et.al. perform experiment on domestic refrigerator based on exergy analysis and concluded that the compressor has higher exergy destruction among the other components.

E. Bilgen et.al. has performed an exergy analysis of heat pump-air conditioner system has been carried out by taking irreversibility due to heat transfer and friction. The coefficient of performance based on the first law of thermodynamics as a function of several parameters, their improved values, and the efficiency and coefficient of performance based on exergy analysis have been calculated.Based on the exergy analysis, a simulation program has been developed to simulate and evaluate experimental systems.

Md. Nawaz khan et.al. works in the study of vapour compression system based on energy and exergy analysis by using refrigerant R12, R134a and R22. They mainly focus on changes which occurs on exergy efficiency, cop, exergy destruction ratio due to working of a particular system on various evaporative temperature and all the equation which should be required for evaluation are developed for each component of vapour compression system.

Neera Jain et.al. works in the study of vapour compression system and there is study is based on exergy analysis so as to achieve better efficiency. They designed a model predictor controller so that through exergy analysis they minimize the exergy destruction and maximize the exergetic efficiency.

Hakan Caliskan et.al. deals with the two system which is able to be use for cooling purpose in building and mainly concentrate on dead state temperature so by varying the dead state temperature he compare the two system on basis of exergy analysis.

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 irreversibilities occur during a process.

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

Amir Fartaj et.al. uses the second law analysis approach so as to determine the irreversibility of individual component and its influence on the performance of CO2 refrigeration cycle and also to know the effectiveness of the various component of the system and the analysis reveals that the compressor will need more improvement so as to enhance the system performance.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.

Amir Fartaj et.al. uses the second law analysis approach so as to determine the irreversibility of individual component and its influence on the performance of CO2 refrigeration cycle and also to know the effectiveness of the various component of the system and the analysis reveals that the compressor will need more improvement so as to enhance the system performance.

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. Refrigerant used for analysis

The following refrigerants are used for exergy analysis of domestic refrigerator.

REFRIGERANTS	CHEMICAL FORMULA	NORMAL BOILING POINT(^{0}C)	CRITICAL TEMPERATURE (^{0}C)	GWP (PER 100 YEAR)
R12	CCl2F2	-26.07	111.97	2400
R134a(HFC)	CF3CH2F	-26.07	101.06	1300
R290(HC)	C3H8	-42.1	96.8	20
R600	C4H10	-0.56	153	20
R600a	(CH3)3CH	-11.67	135	20

3.2 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,

$$W_a = \frac{\text{Compressor Power}}{\text{mechanical efficiency}}$$

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,

$$I_4 = m*((h_5-h_1)-T_o*(s_5-s_1)) + Q_e*\left(1-\frac{To}{Tr}\right)$$

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

$$\text{Coefficient of performance} = \frac{\text{Heat addition in evaporator}}{\text{Actual Power}}$$

$$\text{Exergy efficiency} = \frac{Qe*(1-\frac{To}{Tr})}{Wel}$$

$$\text{Efficiencydefect}=\frac{\text{Exergy destruction of particular component}}{\text{Actual Power}}$$

$$\text{Exergy destruction ratio} = \frac{\text{Total Exergy destruction}}{\text{product exergy rate}}$$

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 = 0.015Kg/s
- Isentropic Efficiency of compressor = 80%
- Range of evaporator temperature is = -20^{0}C to 0^{0}C in the step of 2.22^{0}C
- Condenser temperature = 35^{0}C
- Dead state temperature = 25^{0}C
- Difference between evaporator temperature and space temperature is 10^{0}C
- 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

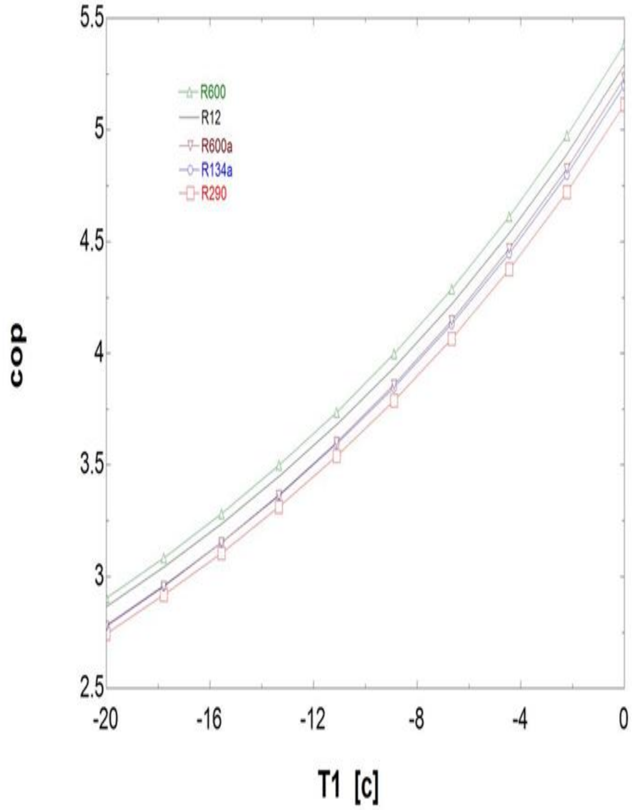

Fig 3 Evaporator temperature and coefficient of performance

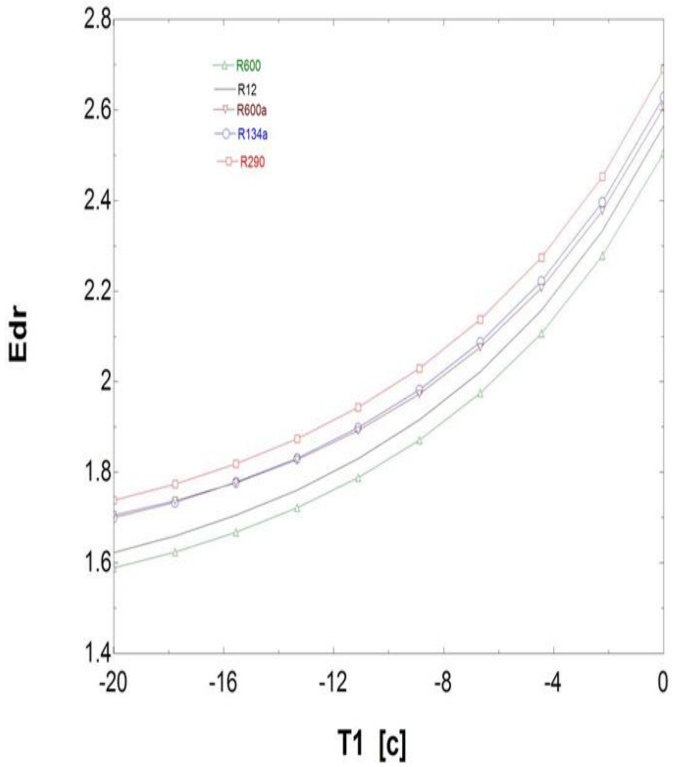

Fig 4 Evaporator temperature and Exergy destruction ratio

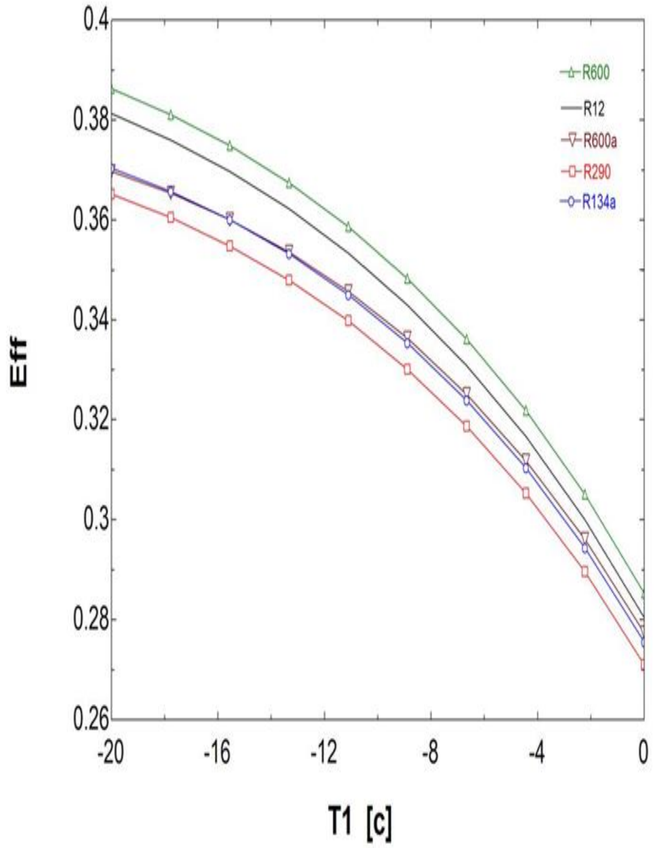

Fig 5 Evaporator temperature and Exergy efficiency

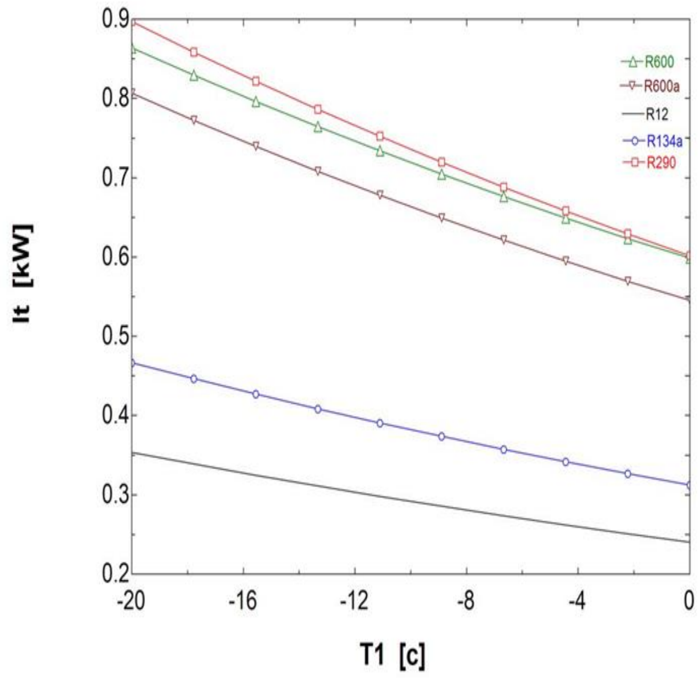

Fig 6 Evaporator temperature and Total irreversibility

5. CONCLUSION

The following conclusion can be drawn from analysis

- R600 shows highest value of coefficient of performance among R12,R134a,R290,R600a,R600.After R600,R12 shows good result with respect to coefficient of performance.After R12,R600a with a slight advantage over R134a show satisfactory cop value.Also COP value is increasing as the evaporator temperature is increasing.
- As the evaporator temperature increases, the exergy destruction ratio increase which is not good for a refrigeration system, so the refrigerant should have less value of exergy destruction ratio, so as per this criteria the refrigerant R600 shows better result and after that R12 is showing better performance followed by R600a,R134a,R290.
- As evaporator temperature increases the exergy efficiency decreases because the product exergy rate decreases as the evaporator temperature increases. So as per exergy efficiency criteria refrigerant R600 shows best result among R12,R134a,R290,R600a,R600 and it gives high value of exergy efficiency at low value of evaporator temperature. After R600, R12,R600a,R134a show good result as per exergy efficiency followed by R290 at last.
- As the evaporator temperature increases, the value of total irreversibility decreases and the refrigerant R290 shows the highest value of total irreversibility among R12,R134a,R290,R600a,R600.
- Among all refrigerants R12,R134a,R290,R600a,R600,Irreversibility is highest in compressor.
- As the evaporator temperature increases the irreversibility in compressor decreases and as per this criteria the refrigerant R12 shows best result among R12,R134a,R290,R600a,R600 and R600 shows a highest value of irreversibility in compressor.
- As the evaporator temperature increases the irreversibility in condenser decreases and as per this criteria the refrigerant R12 shows best result followed by R134a,R600a,R290,R600.
- As the evaporator temperature increases the irreversibility in expansion valve decreases and as per this criteria the refrigerant R12 shows best result followed by R134a,R600,R600a,R290.
- As the evaporator temperature increases the irreversibility in evaporator decreases

slowly.The refrigerant R12 shows best result followed by R134a,R600a, R290,R600.

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