ARPN Journal of Engineering and Applied Sciences

EXERGY-ENERGY ANALYSIS OF LOW GLOBAL ALTERNATIVE REFRIGERANTS TO R22 FOR AIR-CONDITIONING APPLICATIONS

Mohammed A. Abdul Wahid and Ali Khalid Shaker Al-Sayyab
Basra Engineering Technical College Southern Technical University, Iraq
E-Mail: mohw2016@stu.edu.iq

ABSTRACT

In this study, a theoretical analysis is been carried for the application of the alternative refrigerant with low global warming to R22 in small air conditioning unit. The refrigerants investigation is R290, R600, R600a and R1270. The system mathematical models are running by using EES program .The results show that at any working condition the R600a give the identical performance to R22 and can be use in new units that required compressor modification. So the system with R1270 has less system performance reduction from R22 By 4.3% and can be used as retrofitting alternative refrigerant for current units without modification.

Keywords: Global refrigerants, air conditioning, exergetic analysis, compressor temperature.

NOMENCLATURE		
Symbols	**Description**	**Unit**
ODP	Ozone Depletion Potential	
GWP	Global Worming Potential	
COP	Coefficient Of Performance	
q_c	Heat rejected by condenser	kJ/kg
w_{scom}	Compressor Specific work	kJ/kg
q_e	Refrigerating effect	kJ/kg
h	Enthalpy of refrigerant	kJ/kg
S	Entropy of refrigerant	kJ/kg.k
Ex_d	The exergy destruction	kJ/kg
T0	Ambient air temperature	K
$\eta_{exergetic}$	Second law exergetic efficiency	
Q_c,	condenser heat rejected	kW
Q_e	evaporator heat absorbed respectively	kW
m_r	Refrigerant Mass Flow Rate	Kg/S
T_c	The Temperature Of The Condenser,	K
T_e	The Temperature Of The Evaporator	K
ex_{in}	Is The Exergy Input	
ex_{out}	The Exergy Output	

INTRODUCTION

The ozone layer is a region of Earth's stratosphere that absorbs most of the Sun's ultraviolet radiation. This layer is vital to human, animal, and plant to live on the Earth's surface. It was discovered at 1977's that the layer was susceptible to damage by emissions into the atmosphere of particular industrial chemicals, of which the most important was the family of chlorofluorocarbons (CFC) and Hydro chlorofluorocarbons (HCFC). The temperature of the Earth's has been increased about 1 degree Fahrenheit in the last century. Many researchers discovered that this increase is due to carbon dioxide with other greenhouse gases volumes increasing those emissions from fossil fuels burning or from air conditioning leakage. Scientists predict these changes will go on and will generate more severe weather in the future such as extreme heat. The changes of temperature connected with new spells of hot weather, leads air conditioners to working overtime to cooling buildings. Turning on the air conditioner that is demanded more energy additional carbon into the air mean that the earth will be pollute. The more active way to reduce the Carbone emissions and HCFC is by using more energy efficient air conditioners unit, which runs at less power with more ozone friendly refrigerant. The window type air conditioners (in Iraq) are widely used to cooling the house; this unit always used R22 as a working refrigerant, these refrigerants contained on chlorine that found to diffuse up into the stratosphere. The chlorine is representing the major causes of ozone layer destruction; the layer of ozone protects life on earth from excess ultraviolet light for this reason R22 is phase out by Montreal protocol [1]. Mehmet KunduzIt *et al* [2] study exergy losses for vapour compression cycle, they found that the exergy losses in the evaporator, condenser, the exergetic efficiency and COP of the cycle due to the evaporating, and condensing temperatures. However, there is a little effect on the losses exergy by the other components. Meanwhile, the temperature difference between the evaporator and refrigerated space and between the condenser and outside air decreased the COP of the system increase also decrease the exergetic efficiency, and decrease the total loss of exergy. Halimic *et al* [3] showed the largest cooling capacity of the refrigerants tested of R290 even higher than of R12 of the original refrigerant. Also showed that COP of system with R290 is identical to that of R12, it can be said that it represents an attractive alternative to existing CFCs in small domestic refrigerators. The original equipment would require a smaller capacity compressor than R12. M. A. Sattar *et al* [4] verify the performance of refrigerator working with Butane and Iso-butane as alternative refrigerant to R134a, and found that the energy consumption for Butane and Iso-butane at 28°C ambient temperature is less than that of R134a by 2%, 3% respectively. S. Venkataiah *et al* [5] evident that the analysis for air conditioning system of 1.5 TR with different alternative refrigerant to R22 (R134a, R404A, R407C, R410A, R507A, R290 and R600a). They deduced that the COP of the system with R600a highest than the COP of R22 and the rest of their tested refrigerants give lowest values of COP than of R22 .Then the system with R600a demanded more compressor displacement. Gaurav *et al* [6] Perform an experimental study for car air conditioning unit using R1234yf alternatively of R134a. They conclude that for the system with R1234yf the time of required cooling is 4% to 6% lesser than that with R134a. Vedat Oruc, Atilla G. Devecioglu [7] conducted an energy and exergy parameters analysis of R417A and R424A as alternative to R22. They carried out an experimentally study for a split-type air conditioner. The refrigerants of R417A and R424A are being smaller compared to R22 for the value of COP. Similarly, the use of R424A will be more suitable rather than R417A since COP values of R417A are lower about 5 .16% compared to R424A. They also found that R424A is more suitable than R417A as an alternative refrigerant to R22. Ankit Sethi *et al* [8] performed an experimental study of alternative refrigerant for R22 on split unit air conditioner using R444B and R407C. They obtained that R444B performance is similar to R22, and when compared to existing refrigerant like R407C, R444B is 5% more efficient across most of the operating range. R444B give identical refrigeration capacity to R22 and can be used as suitable alternative refrigerant to R22. Ali k. Shaker *et al* [9] carried out an experimental study to optimize the air conditioner performance by changing condenser circuit designs; the experimental showed that, the four-circuit condenser design with tube diameter of (5/16") gave 1.2 % increase in COP as compared to the base case of one circuit when retrofitted with R407C. This study deals with on climate friendly alternative refrigerant for R22 that named R1270, R290, R600 and R600a. Table (1) shows the thermodynamic properties for this refrigerant with R22.

Thermodynamic system analysis

Energy analysis

The Major four components of vapour compression cycle are: compressor, evaporator, condenser, and expansion valve [10]. Figure-1 shows the four thermodynamic processes in ideal refrigeration cycle:

The specific compressor work done can be found by

$$w_c = h_2 - h_1 \tag{1}$$

The specific heat rejected by condenser can be found by:

$$q_c = h_2 - h_3 \tag{2}$$

The capillary tube energy equation can be written as:

$$h_3 = h_4 \tag{3}$$

The system refrigerating effect can be found by

$$q_E = h_1 - h_4 \tag{4}$$

The coefficient of performance can give by

$$COP = \frac{\text{Heat absorbed by evaporator}}{\text{Compressor Work}}$$

$$COP = \frac{h_1 - h_4}{h_2 - h_1} \tag{5}$$

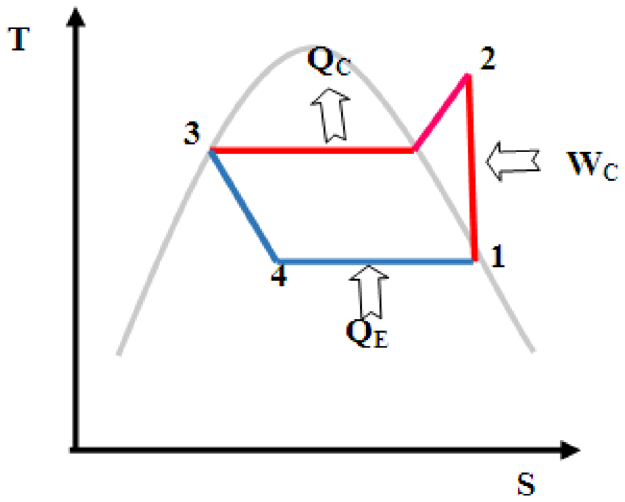

Figure-1. Process of vapour compression cycle on T-S diagram.

Exergetic analysis

During heat transfer process to get quality quantify of energy the exergy analysis are used. The main purpose of exergy technique is to give meaningful efficiencies, the causes and real ingredients of exergy losses. The exergy rate equations of refrigeration system components can be writing as follows [11]:

For compressor

$$\dot{m}_r\, ex_{in} + W_{in} = \dot{m}_r\, ex_{out} + Ex_{dcom}$$

$$Ex_{dcom} = \dot{m}_r (ex_{in} - ex_{out}) + W_{in}$$

$$Ex_{dcom} = \dot{m}_r (h_1 - h_2 - T_o(s_1 - s_2)) + \dot{m}_r (h_2 - h_1)$$

VOL. 13, NO. 4, FEBRUARY 2018 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

$$Ex_{dcom} = \dot{m}_r T_o (s_2 - s_1) \quad (6)$$

For condenser

$$\dot{m}_r\, ex_{in} = \dot{m}_r\, ex_{out} + Q_c (1 - \frac{T_o}{T_c}) + Ex_{dcon}$$

$$Ex_{dcon} = \dot{m}_r (ex_{in} - ex_{out}) - Q_c \left(1 - \frac{T_o}{T_1}\right)$$

$$Ex_{dcon} = \dot{m}_r (h_2 - h_3 - T_o (s_2 - s_3)) - \left(1 - \frac{T_o}{T_c}\right) \quad (7)$$

For capillary tube

$$\dot{m}_r\, ex_{in} = \dot{m}_r\, ex_{out} + Ex_{d\exp}$$

$$Ex_{d\exp} = \dot{m}_r (ex_{in} - ex_{out})$$

$$Ex_{d\exp} = \dot{m}_r (h_3 - h_4 - T_o (s_3 - s_4)) \quad (8)$$

For evaporator

$$\dot{m}_r\, ex_{in} + Q_e \left(1 - \frac{T_o}{T_e}\right) = \dot{m}_r\, ex_{out} - Ex_{devp}$$

$$Ex_{devp} = \dot{m}_r (ex_{out} - ex_{in}) - Q_e \left(1 - \frac{T_o}{T_e}\right)$$

$$Ex_{devp} = \dot{m}_r (h_1 - h_4 - T_o (s_1 - s_4)) - Q_e \left(1 - \frac{T_o}{T_e}\right) \quad (9)$$

$$\eta_{\text{exergetic}} = \frac{\text{Exergy output}}{\text{Exergy input}}$$

$$Ex_{DT} = Ex_{in} - Ex_{out}$$

$$Ex_{out} = Ex_{in} - Ex_{DT}$$

$$\eta_{exergetic} = 1 - \frac{Ex_{DT}}{W_c} \quad (10)$$

RESULTS AND DISCUSSIONS

Effect of ambient air temperature on compressor work

Figure-2 explains the effect of ambient air temperature on compressor work for different refrigerants. First, the ambient air temperature is increased the compressor work increase. Because when the ambient air temperature is increased, the condenser temperature should be increased. Second, that will save the amount of heat rejected required, then the condenser pressure is increasing and increasing of compressor pressure ratio as shown in Figure-3, the compressor work is increased. Finally, the system with the refrigerant of R1270 required compressor work more than the system with R22.

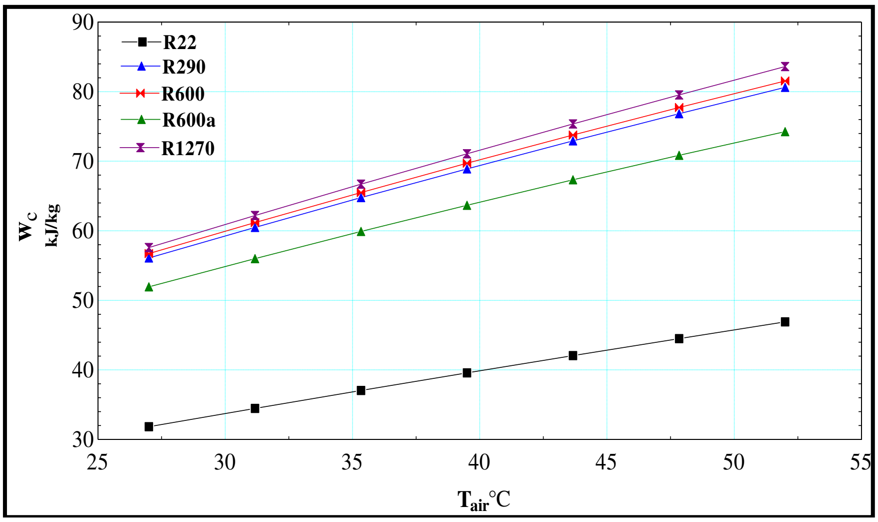

Figure-2. Compressor work vs ambient air temperature.

Effect of ambient air temperature on condenser heat rejection

Figure-4 shows the condensing temperature has increased the heat rejected through condenser decrease for all refrigerants studied. This is due the condensing temperature increased the latent heat of vaporization decrease for all refrigerants studied as shown in Figure-5.

ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

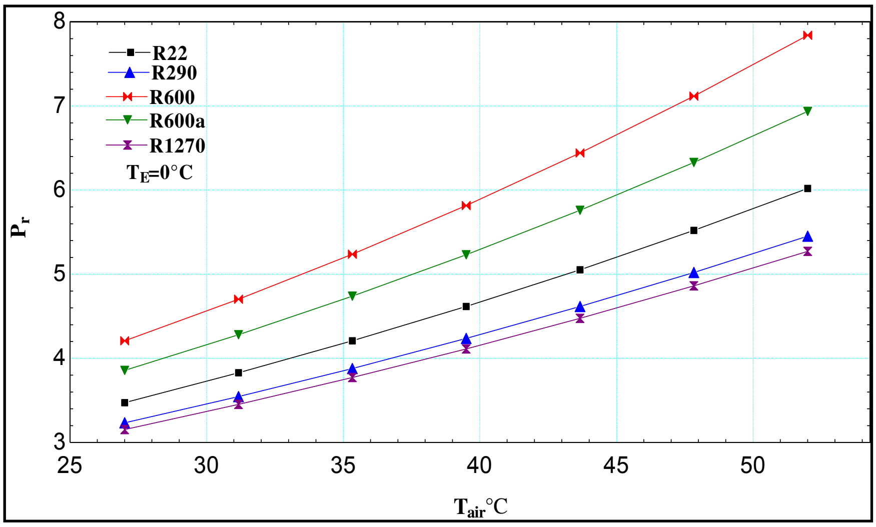

Figure-3. Compressor pressure ratio vs ambient air.

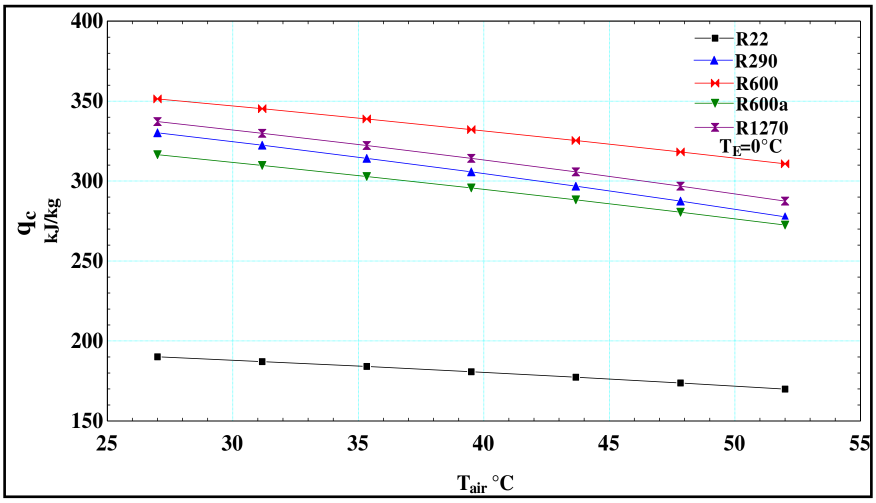

Figure-4. Condenser heat rejection vs ambient air.

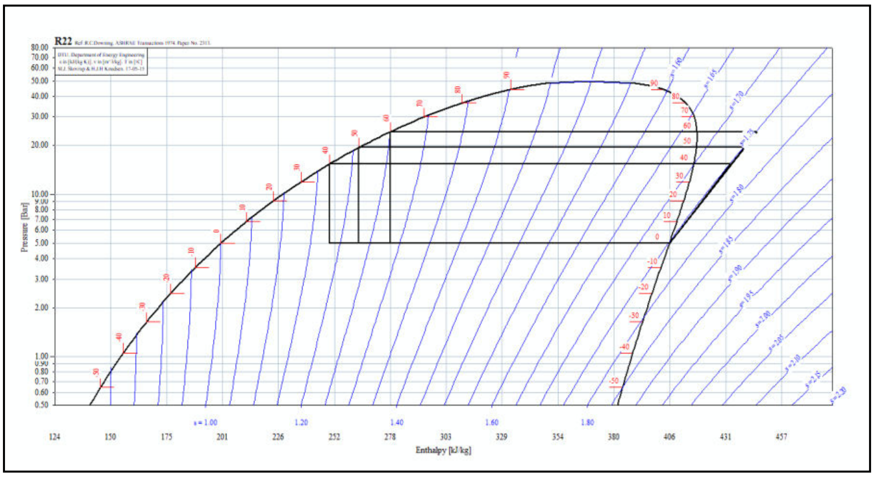

Figure-5. Condenser two phase rejon vs ambient air.

Effect of ambient air temperature on refrigerating effect

Figure-6 manifests the refrigerant effect decreased with increasing of the ambient temperature for all refrigerants tests. Due to the ambient air temperature increased the condenser heat rejection decrease then reduces the amount of sub-cooled degree. Meanwhile, the portion of vapor increases and reduce the amount of latent

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

heat. The refrigerant effect of refrigerant R600 is the highest of other and is more than the refrigerant R22 by 46%.

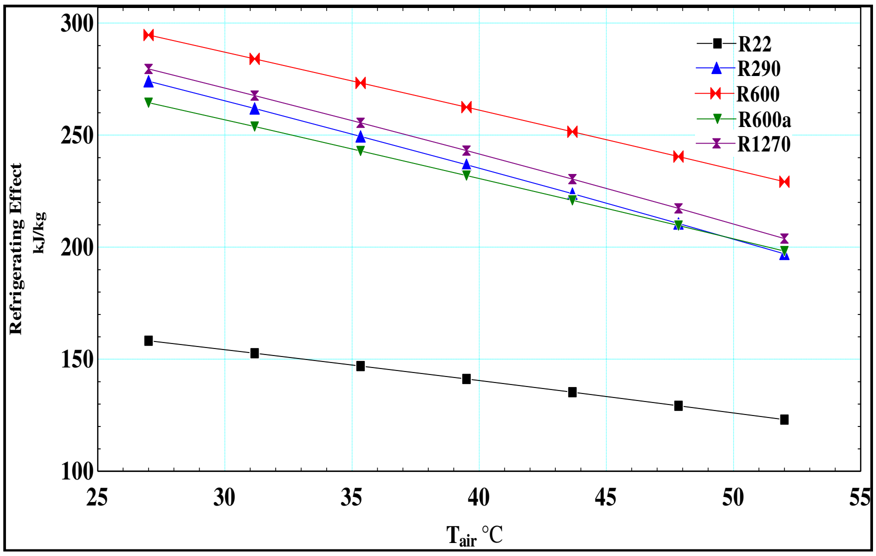

Figure-6. Refrigerating effect vs ambient air temperature.

Effect of ambient air temperature on coefficient of performance

The coefficient of performance is depending on the refrigerant effect and compressor work. Figure-7 shows the coefficient of performance for all refrigerant tests decreased with the increase of the ambient temperature. Because the increase of ambient temperature the compressor work will increase. From equation that is calculate the value of COP, the denominator is represented by the compressor work and the numerator is represented by refrigerating effect. The compressor work is increased and the refrigerating effect decreased as the increase of the ambient air temperature, so the COP decrease. At any ambient air temperature the R290 give identical performance to R22, so R600 give the highest cop with 5.7 % higher than of R22.

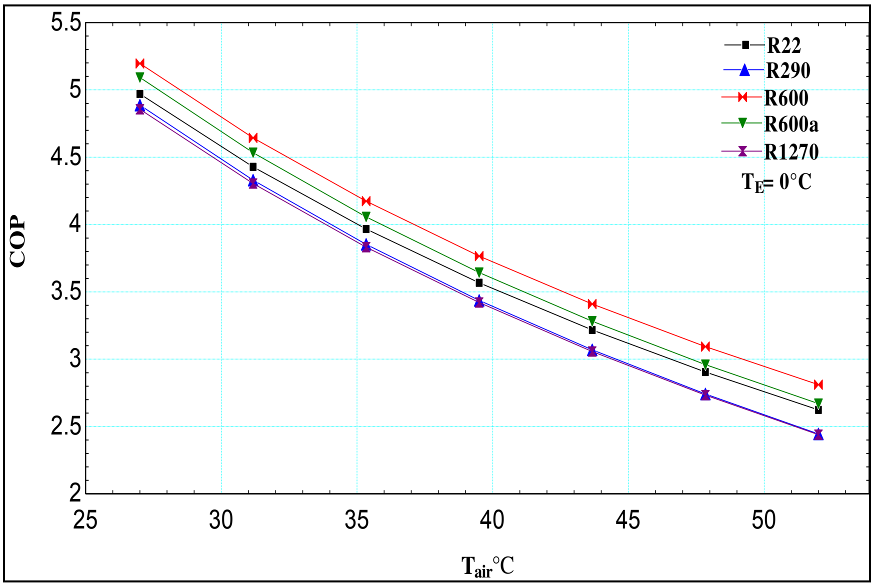

Figure-7. COP vs ambient air temperature.

Exergy distraction and exergy efficiency

From Figure-8 total exergy destruction of all the tested refrigerants are higher than of R22, so the compressor is represent the major exergy destruction. so as the condensing temperature increase the exergy efficiency will decrease Figure-9, as a result of the pressure ratio increasing so compressor work.the exergy efficiency of refrigerant R290 and R1270 is than of R22, while R600a and R600 have highest from R22.

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

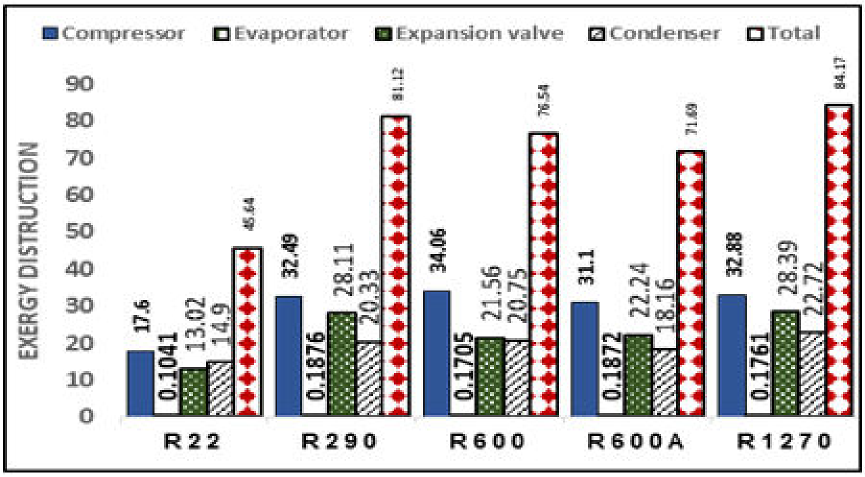

Figure-8. Exergy distraction vs studied refrigerants.

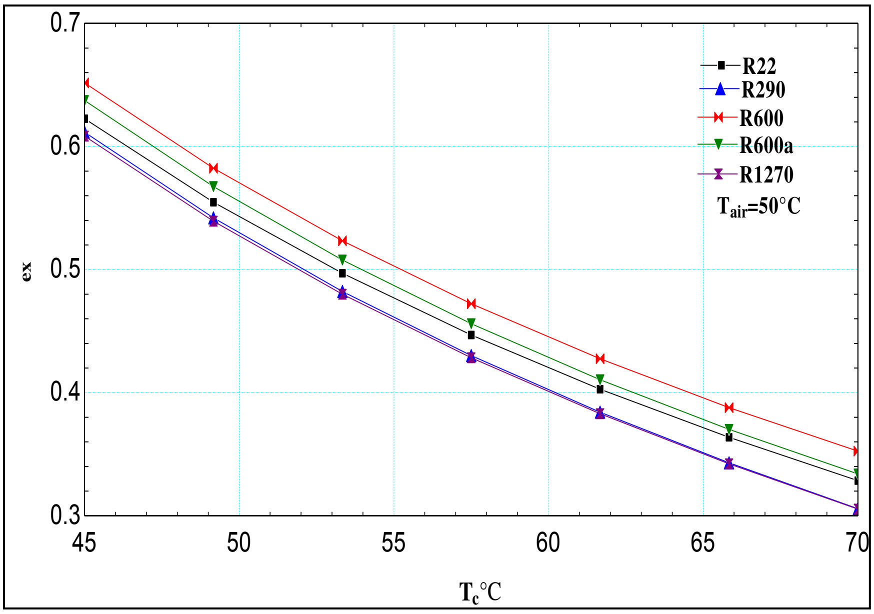

Figure-9. Exergy efficiency vs ambient air temperature.

Table-1. Results accumulated.

Refrigerant	R22	R 290	R1270	R600	R600a
Name		Propane	Propylene	butane	Isobutane
Formula	$CHClF_2$	C_3H_8	$C_3 H_6$	C_4H_8	(CH_3) 3 CH
Critical temperature °C	96.15	96.7	92.42	114.9	135
Critical pressure(bar)	49.9	42.5	46.65	40.1	36.45
Molecular weight in kg/kmol	86.47	44.1	42.08	58.12	58.1
Normal boiling point in °C	–40.81	-42.1	-47.72	-7.31	-11.6
Vapor Specific volume m^3/kg at 5°C	0.0481	0.4188	0.08277	0.3683	0.3561
h_{fg} at 1 bar in kJ/kg	234.1	426.1	439.5	385.1	366.2
GWP 100 years	1810	8	2	8	8
ODP	0.055	0	0	0	0

CONCLUSIONS

The preceding results of current study, the following conclusions can be listed:

a) The air conditioning system with R1270 required more compressor work than of R22.
b) The major exergy destruction component in the refrigeration cycle will represented by compressor.
c) The refrigerant R290 and R1270 give identical exergy efficiency behavior and lower exergy efficiency of R22, while R600a and R600 have highest exergy efficiency from R22.
d) At any ambient air temperature the system working the R290 give identical performance to R22, so R600 give the highest cop with 5.7 % higher than of R22.
e) At any working condition, the R600 can using as the best low global warming alternative refrigerant to R22 with modification in compressor displacement.
f) At any working condition, the R1270 can using as the best low global warming retrofitting alternative refrigerant to R22 without modification in compressor displacement with 4.3 % performance reduction.

REFERENCES

[1] The Montreal Protocol, http://ec.europa.eu.

[2] Mehmet Kunduz, Recep Yumruta, Mehmet. 2002. Exergy analysis of vapor compression refrigeration systems, an International Journal of Exergy. pp. 266-272.

[3] Halimic D., Ross B., Agnew A., Anderson I., Pott A. 2003. Comparison of the operating performance of alternative refrigerants. Applied Thermal Engineering. 23: 1441-1451.

[4] M. A. Sattar, R. Saidur, and H. H. Masjuk. 2007. Performance investigation of domestic refrigerator using pure hydrocarbons and blends of hydrocarbons as refrigerants. World Academy of Science, Engineering and Technology.

[5] S. Venkataiah and G. Venkata Rao. 2014. Analysis of Alternative Refrigerants to R22 for Air-Conditioning Applications at Various Evaporating Temperatures. Journal of Engineering Research and Applications. 4(3): 39-46

[6] Gaurav and Raj Kumar. 2015. Sustainability of Automobile Air Conditioning System Using Refrigerant R1234yf Instead of R134a, International Journal of Automotive Engineering. 5(3).

[7] Vedat Oruc, Atilla G. Devecioglu, Thermodynamic performance of air conditioners working with R417A and R424A as alternatives to R22 ,International journal of refrigeration 55 (2015).

[8] Ankit Sethi, Elizabet Vera Becerra, Samuel Yana Motta, Mark Spatz. 2015. Low GWP R22 replacement for air conditioning in high ambient conditions. International journal. 57: 26-34.

[9] Abdul Hadi N. Khalifa,Johain J. Faraj and Ali Khalid. Shaker. 2017. Performance study on a window type air conditioner condenser using alternative refrigerant R407C, engineering journal. 21(1).

[10] 2012. Refrigeration and Air conditioning, P.L. Ballaney, fifteenth edition.

[11] 2015. Exergy Analysis of Heating Refrigerating and Air Conditioning, Ibrahim Dincer and Marc A. Rosen. Elsevier Inc.

[12] G. Wall. Exergy a useful concept, Ph.D. Thesis, Chalmers University of Technology, Goteborg, Sweeden, 2009, pp 1-19.Engineering Equation Solver EES, V 10.115 .