Thermodynamic Energy And Exergy Analysis For Refrigerator Performance Working With Alternative Refrigerants Mixture For R 134a

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Abstract-The refrigerant R134a widely used in refrigerating and air conditioning units .It has zero ozone depilation potential factor (ODP) but have 1300 global warming potential (GWP) and their interaction with heat radiation. It is necessary to minimize the global warming, by changing R134a with the ones that are not depleting the ozone layer and very little in Global Warming Potential (GWP).

In this paper, a new azeotropic refrigerant mixture of three refrigerants named R134a, R290 and R600a with four different mixing ratio of mass are used as an alternatives refrigerant to R134a . The theoretical model show that, all new refrigerant mixtures give higher refrigerating effect than that of R134a. Meanwhile experimental results revealed that the obtained COP by the new mixtures is less than that of R134a, and the most suitable refrigerant that can be used instead of R134a was Mix2.The COP of Mix2 is 8 % less than that of R134a at 24 □ room temperature.

key word :- refrigerant mixture, refrigerator, R134a

الخلاصة:
يستخدم مائع التثليج ١٣٤ بشكل واسع في التجميد ووحدات تكييف الهواء . ويمتاز هذا المائع بعدم امتلاكه اي تاثير على طبقة الاوزون لكن يمتلك ابتعاث حراري كامن يقدر ب (١٣٠٠GWP) . لذا من الضروري تقليل الاحتباس الحراري ، بتغير مائع التثليج ١٣٤ مع اخر لا يؤثر على طبقه الاوزون مع تاثير احتباس حراري قليل جدا.
في هذا البحث تم استخدام مائع جديد خليط من ثلاث موائعR134a و R290 و R600a بنسب خلط مختلفة كموئع بديلة للمائعR134a. بين التحليل النظري ان كل الموائع الخلائط تعطي تاثير تبريدي اعلى من المائع 134a.في غضون ذلك الجانب العملي بين ان معامل الاداء لموائع الخلائط اقل من مائع التثليج R134a ، كذلك مائع التثليج البديل الذي يمكن ان يستخدم بدلا عن R134a هو Mix2 . معامل الاداء للمائع Mix2 هو اقل ب ٨% من معامل المائع R134a في درجة حرارة الغرفة 24درجة سيليزية.

1. Introduction

R134a has been an incredibly useful refrigerant in many of refrigeration systems applications, such as refrigerator and freezer those used in houses and supermarkets. It has no effect on the Ozone Layer but its global warming potential is the highest when compared with other refrigerant. Because of the R134a has highest GWP of 1300a, Kyoto protocol recommended to phased out by the year 2015. The focus increasingly on the refrigerant impact on environment is inflamed claim for providing refrigeration systems that have best cooling behavior with little impact of global warming [1]. This is rousing the corporate of refrigeration to put environmentally friendly alternative refrigerants to the top of schedule of work. The choice of the perfect refrigerant does not exist. Coolant fluids are selected depending on their thermodynamic efficiency to extract heat and their safety in use. Hydrocarbons LPG (Liquefying Petroleum Gases) are efficient refrigeration fluids. However, they are very flammable, and potentially explosive. The using of isobutene and propane in refrigerators and freezers is allowed in 2011, by the Environmental Protection Agency issued [2].

Many study are adopted to get alternative refrigerant mixture .Mehmet KunduzIt et.al [3] studied exergy losses for vapour compression cycle, they found that the evaporating and condensing temperatures have more effects on the evaporator and condenser exergy losses, and on the exergetic efficiency and COP of the cycle with little effects on the losses exergy by the other components. and the decreasing in temperature difference between the evaporator and refrigerated space and between the condenser and outside air led to increase the COP of the system , decrease the exergetic efficiency, and decrease the total loss of exergy. M. A. Sattar et.al [4]check the performance of refrigerator working with Butane and Iso-butane as alternative refrigerant to R134a ,they found that the energy consumption for Butane and Iso-butane is less than that of R134a by 2% , 3% respectively at 28°C ambient temperature. Pooja Yadav et.al [5] perform an exergy analysis of actual vapor compression refrigeration cycle. System working with R134a based vapour compression refrigeration tutor, they observed that the maximum exergy destruction is in condenser. Bolaji et al. [6] used R12, R134a and R152a to check the exergetic performance of refrigerator. The results showed that the R152a has COP nearly close to that of R12 and R134a gives the highest efficiency defects. Selladurai et.al **[7]** checked the performance of domestic refrigerator by using R134a and R290/R600a mixture. They found that the mixture of R290/R600a obtained COP and exergetic efficiency more than R134a. As compared the compressor with other components, it gave maximum irreversibility. Wahid S. Mohammad et.al[8] investigate a theoretical and experimental work with two hydrocarbon refrigerant mixtures by different mixing ratio as a possible alternatives to R134a, ,they found that the mixture R290/R600 (60/40) % give higher cooling capacity, higher **COP**, lower power consumption and can be considered as alternative to replace R134a in domestic refrigeration system . Mahmood Mastani et.al [9] used R134a and R600a to perform exergy analysis for a refrigerator; they found that the maximum value of destructed exergy is from compressor. Mohammad Amir Khan[10]compared the performance of vapour compression cycle by using R152a, R290, R600, R600a, R123 and R717 with R134a by energy and exergy analysis. He found that the tested refrigerant had higher COP and exergetic efficiency than that of R134a. The current work is adopted for new mixture of three refrigerant named R134a, R290.and R600a,with four different mixing ratio,(70%R134a,20%R290,10%R600a),(70%R134a,10%R290,20%R600a),(50%R134a,20%R290,30%R600a),(60%R134a,20%R290,20%R600a), named Mix1, Mix2, Mix3 and Mix4 respectively. Table (1) showed the thermodynamic properties for this mixture.

2- Thermodynamic System Analysis:

2.1 Energy Analysis:-

The vapour compression cycle consist from: compressor, evaporator, condenser, and expansion valve. In an ideal refrigerator cycle there are four thermodynamic process Fig(1):

Adiabatic Compression (Process 1-2):

The amount of specific work done by compressor per unit mass of the refrigerant can be express regarding the change in enthalpy between State**1** and State **2**.

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

Constant Pressure Heat rejection (Process 2-3)

For the condenser the energy equation can be write as the enthalpies of refrigerant at the entrance and exit :

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

Adiabatic Throttling (Process 3-4)

For the capillary tube, the energy equation can be write as:

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

Constant Pressure heat addition (Process 4-1)

The amount of specific heat absorbed by evaporator can be find by evaluating the refrigerant enthalpies at the inlet and outlet

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

To get an indicted about the vapour compression cycle performance the coefficient of performance should be adopted ,which is the proportion of refrigerating effect to the work done by compressor, which used to give an

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

$$COP = \frac{h1 - h4}{h2 - h1} \tag{5}$$

2.2 Exergetic Analysis:

The method of exergy analysis get over many of the thermodynamic first law restrictions. Exergy analysis can give the energy quality quantify during heat transfer. The main objective of exergy technique is to give meaningful efficiencies, the causes and real ingredients of exergy losses.

For the main components, the equations of exergy rate can be write as follows [11]:-

-For Compressor

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

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

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

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

-For Condenser

$$\dot{m}_r\, ex_{in} = \dot{m}_r\, ex_{out} + Q_c\left(1 - \frac{To}{Tc}\right) + Ex_{dcon}$$

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

$$Ex_{dcon} = \dot{m}_r\, (h_2 - h_3 - T_o(s_2 - s_3)) - Q_c\left(1 - \frac{To}{Tc}\right) \tag{7}$$

-For capillary Tube

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

$Ex_{dexp} = \dot{m}_r\,(ex_{in} - ex_{out})$

$Ex_{dexp} = \dot{m}_r\,(h_3 - h_4 - T_o(s_3 - s_4))$ (8)

- For Evaporator

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

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

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

So the second law exergetic efficiency for refrigerator is the ratio of total output exergy to input exergy:-

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

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

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

$\eta_{exergetic} = 1 - \frac{EX_{DT}}{EX_{in}}$ (10)

Where:-

ex_{in} , ex_{out} is the exergy input and output respectively.

Ex_{dcop} , Ex_{dcon}, Ex_{dexp} ,Ex_{devp} is the destructed exergy in compressor, condenser, expansion valve and the evaporator respectively.

Qc, Qe= condenser heat rejected and evaporator heat absorbed .

$\dot{m}_r$ = rate of refrigerant mass flow.

Tc, Te and To= is the temperature of the condenser, the evaporator and ambient respectively.

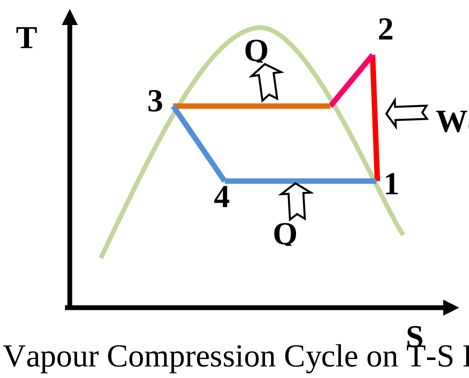


Fig (1) Vapour Compression Cycle on T-S Diagram[13

3- Methodology

In this work, all the equations related to both energy and exergy analysis and other properties of refrigerant mixtures are performed using Engineering Equation Solver Professional (EES)version 8.4, which is a powerful mathematical program developed by Dr. Sanford Klein of the University of Wisconsin (1992-2013). EES has a built-in thermodynamic and transport property relations, graphical skills, numerical integration, and various other useful mathematical functions, EES can fast solve scores of transcendental equations.

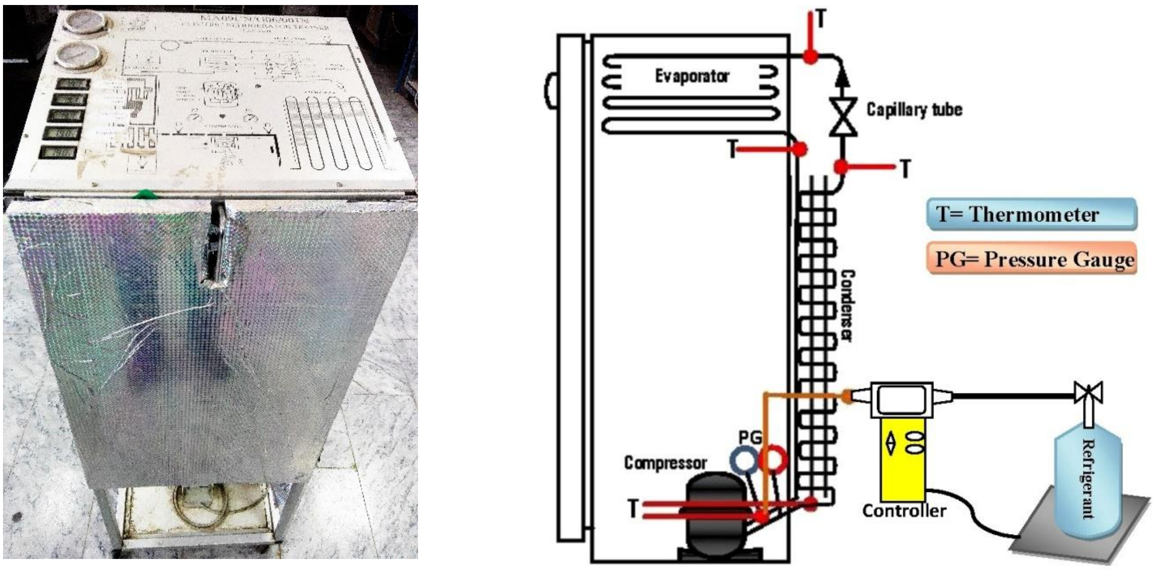
4-Experimental Work

4.1Test Rig :

To perform all the study tests a lab. refrigerator that is manufactured by Prodit Ltd is used (located in refrigeration laboratory of Basra engineering Technical College) which designed to work with R134a . The refrigerator consists of hermetic compressor, wire-tube air cooled condenser, capillary tube and plate type evaporator. The refrigerator supported with two pressure gauge, one connected on the suction side to measure the pressure of evaporator low pressure ,and another gauge is connected on the discharge side to measure the condenser pressure high pressure . Also the refrigerator have many digital thermometers to measure the temperature of refrigerant, which that attached to the inlets and outlets of the compressor, condenser and evaporator Fig (2).

4.2 **Refrigerant Charge Procedure** :

To charge R134a and its alternatives mixture into the refrigerator an electronic charging scale system has been used. That automatically charge the required amount of refrigerant with circumstantially. The charging scale device consists of a joystick with LCD, balancer, solenoid valve and charging hoses. The cylinder of charging was putted on the balancer. The refrigerant required amount is selected by joystick control panel. The outlet of the refrigerant cylinder is connected with the inlet of the electronic valve of charging scale by charging hose, and the outlet of electric valve was connected with service port of the refrigerator. Fig. (2) shows the test rig and procedure of refrigerant charging .

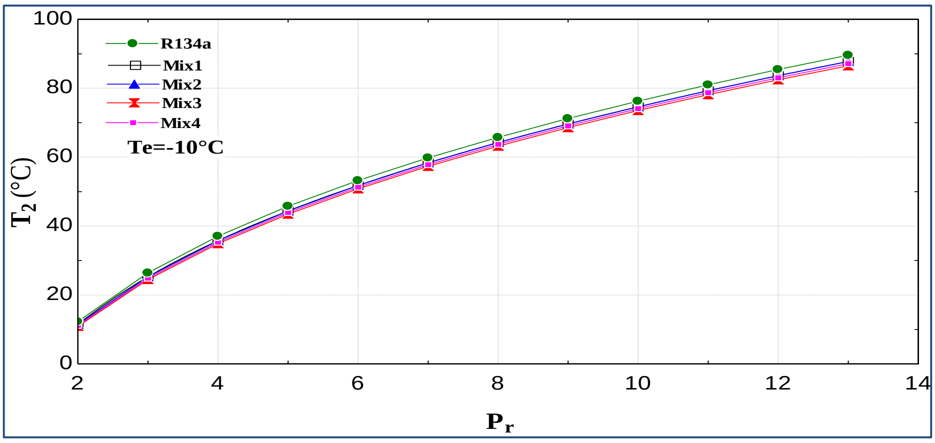


(A) **(B)**

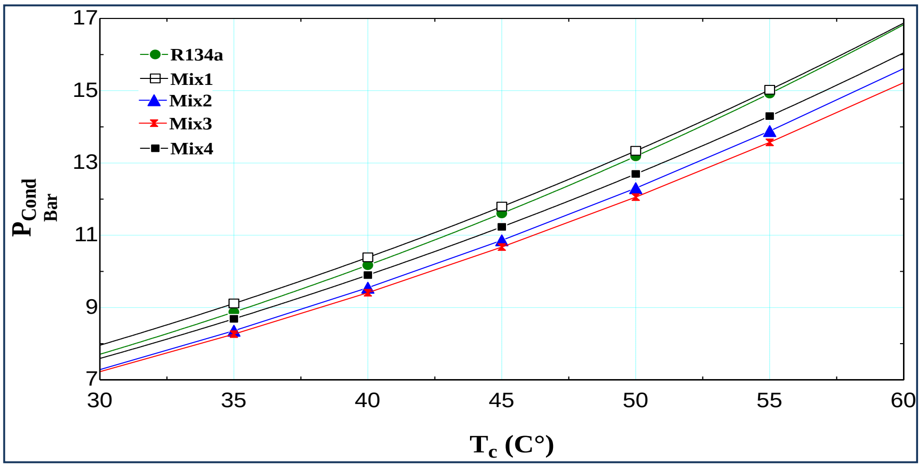
Fig (2) (A) Test Rig (B) Schematic Diagram of Charging Procedure

5-Result and Discussion:

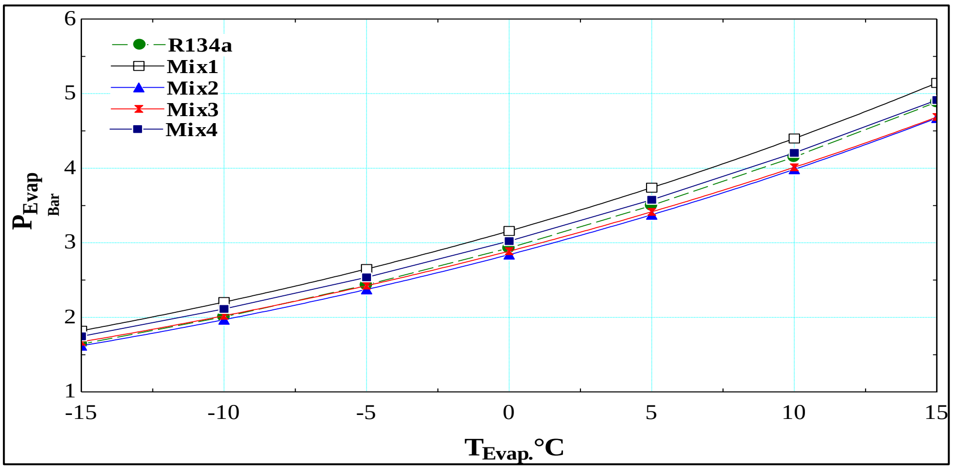
To perform all thermodynamic analysis for all tested refrigerant mixture, a comparison is adopted for compressor pressure ratio and maximum allowable temperature at compressor outlet (superheated region inlet for condenser). From Fig (3) at constant evaporation temperature, all tested refrigerant mixture give the same behavior of R134a. Since the maximum recommended pressure ratio for reciprocating compressor is six [13]; there for the maximum inlet condenser temperature is taken to be 55 ℃ for all next analysis. on the other hand when check the condenser pressure with different temperature ranged from 30 to 55℃ ; all refrigerant give a less reduction in pressure as compare to R134a Fig(4),Mix1=1.6 %,Mix2=6 %,Mix3=8 %and Mix4=3%. Where for the evaporator pressure the mixture provide the same behavior but with less increase and decrease from R134a pressure Fig(5). From this, the refrigerant mixture give a same behavior in condenser-evaporator pressure test with asymptotic pressure value.



Fig(3) Pressure ratio Vs condenser inlet temperature



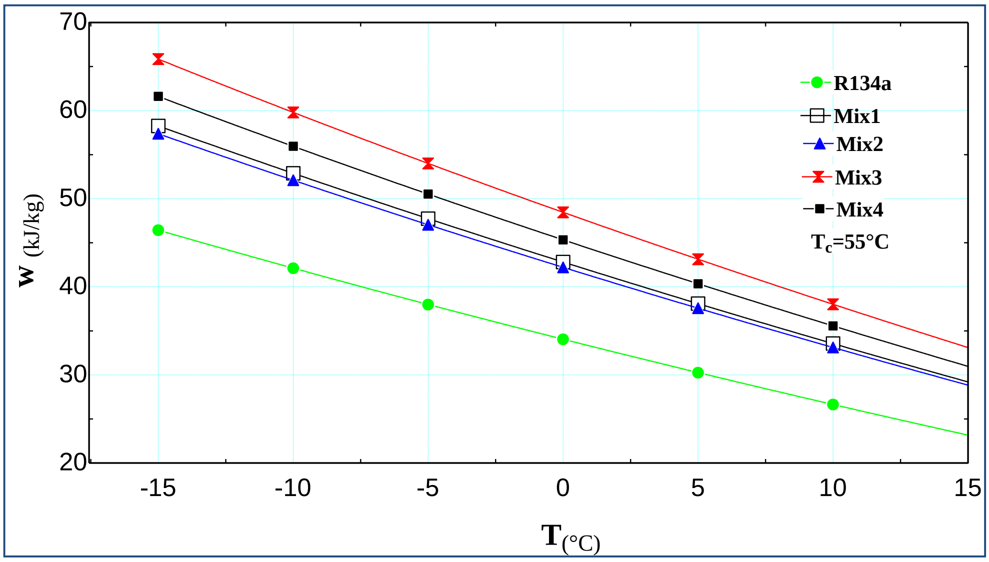
Fig(4) Condenser Pressure Vs condenser inlet temperature



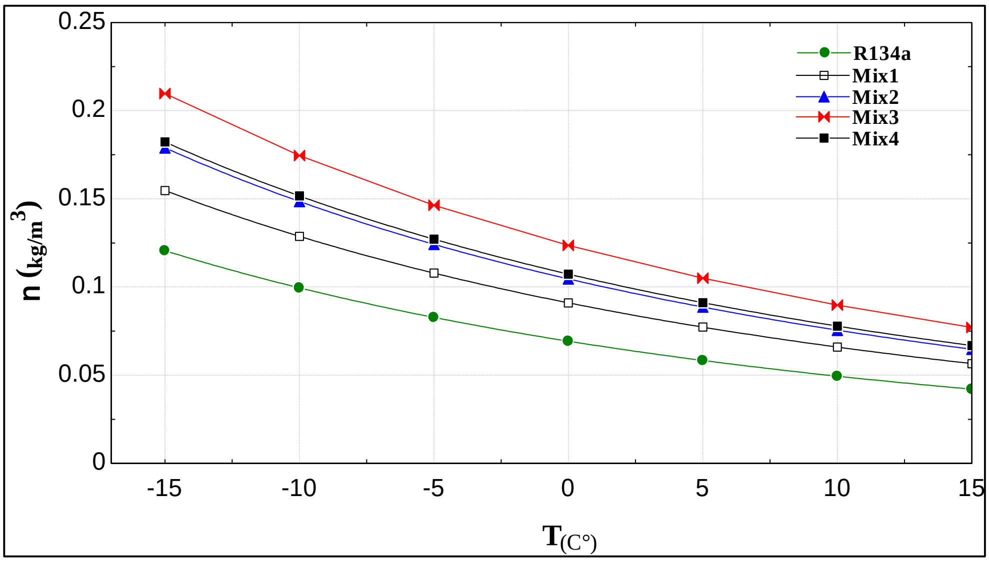
Fig(5) Evaporator Pressure Vs evaporation

5.1-Effect of evaporator temperature on compressor work:-

The compressor work for the tested refrigerant is adopted for evaporator temperature ranged (-15 □ to 15□) with steps of 5; and maximum condenser temperature of 55□ . From Fig (6) the compressor work of all tested refrigerant is decreased as the evaporation temperature increased due to saturation pressure rising that's lead to decreasing in to compressor pressure ratio and specific volume. also from Fig (6); the compressor work for mixture refrigerants are always greater than that of R134a; because of the refrigerant specific volume at the compressor inlet conditions is more than that of R134a for any evaporator temperature Fig(7). Therefor the compressor with current mixture required more work to give the same mass flow rate of R134a. So the compressor work increasing then that of R134a by 26%, 24%, 42 % and 33% for Mix1, Mix2, Mix3 and Mix4 respectively.



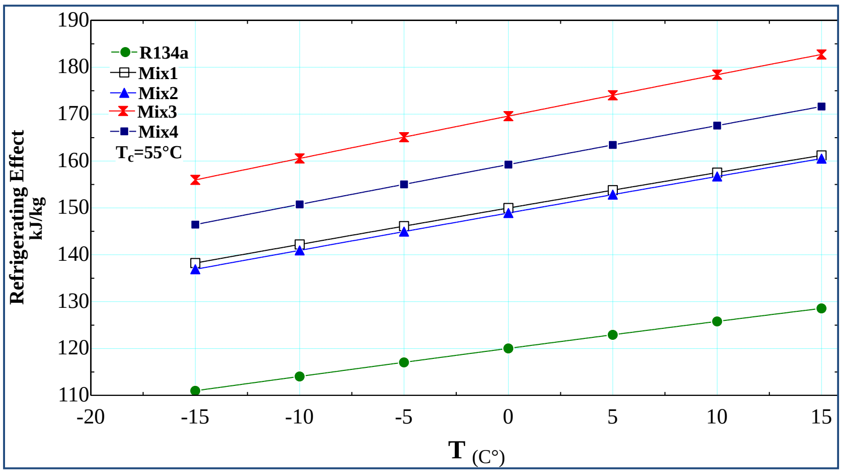
Fig(6) Compressor Work Vs Evaporator temperature



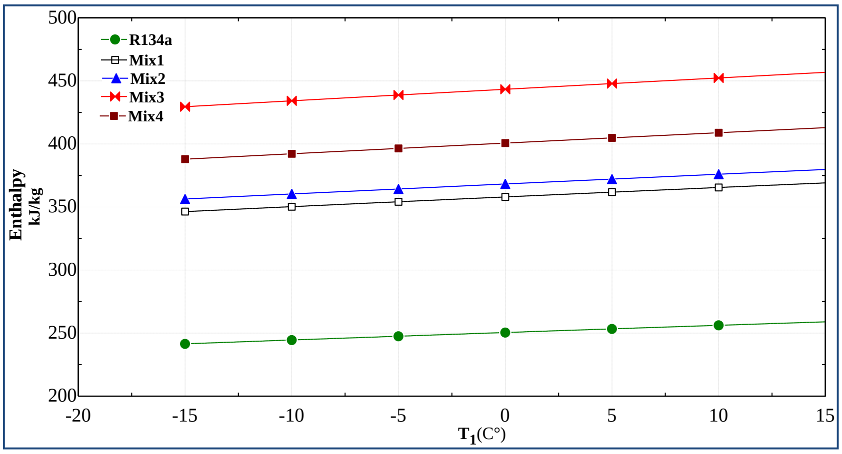
Fig(7) Specific volume Vs Evaporator temperature

5.2-Effect of evaporator temperature on refrigeration effect:

Fig(8) shows that as the evaporation temperature increased the refrigerant effect also increased, so all tested refrigerant mixture have the refrigerating effect more than that of R134a due to the enthalpy of the mixture is greater than that of R134a at same condition as shown in Fig(9). The refrigerating effect increasing is 25% 24% 41% and 33%, for Mix1,Mix2,Mix3 and Mix 4 respectively.



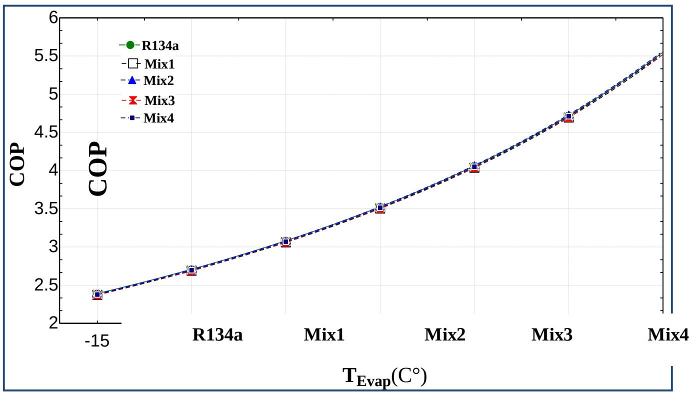
Fig(8) Refrigerating effect Vs Evaporator temperature



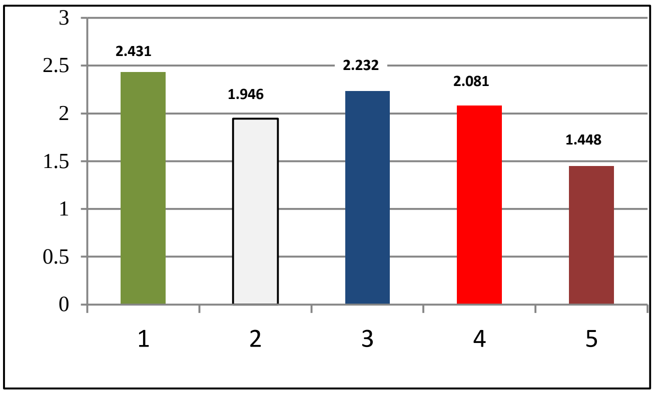
Fig(9) Refrigerant Enthalpy Vs Evaporator temperature

5.3-Effect of evaporator temperature on Coefficient of performance:

From Fig(10) the coefficient of performance for all tested refrigerants is increased with evaporator temperature rising due to the two reasons first one is the reduction in pressure ratio that's led to compressor work reducing ; and the last one is the refrigerating effect increasing. So the refrigerant mixture give closer value of COP to that of the R134a with reduction of 0.62% Mix1, 0.074% Mix2, 0.72% Mix3 and 0.35% for Mix4. On the other hand the experimental work Fig(11) shows the refrigerant mixtures give more reduction in COP than that of theoretical this due to the refrigerator is designed to work with R134a ,so the specific volume of gas state for mixture refrigerant is more than that of R134a Fig(7), which required more compressor work . The reduction in COP of experimental is 20 % Mix1, 8% Mix2, 14% Mix3 and 40% for Mix4.



Fig(10) COP Vs Evaporator Temperature



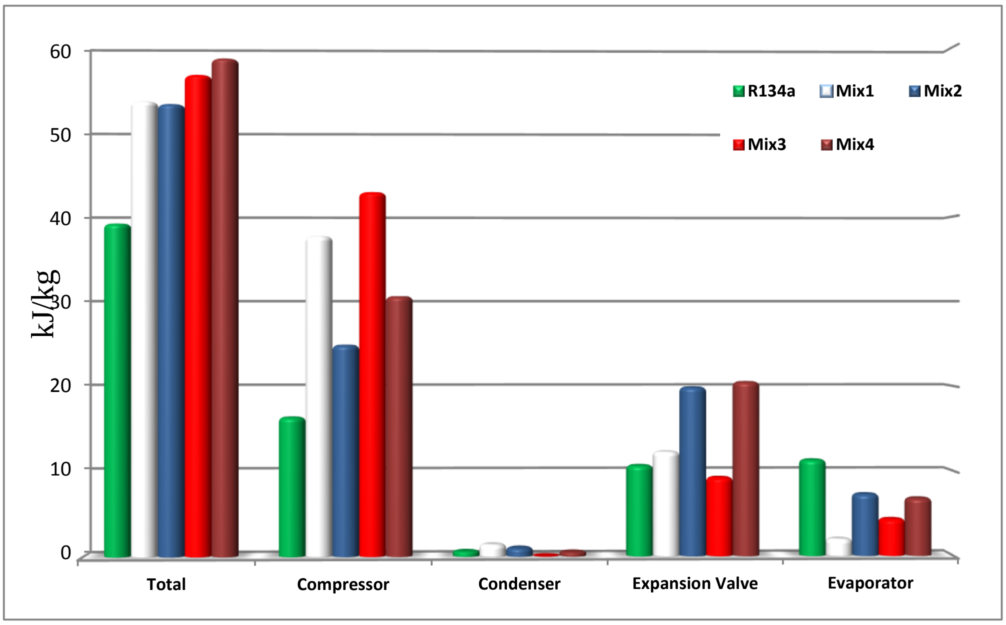
Fig(11) COP of Tested Refrigerants Experimental Work

5.4-Effect of refrigerant type on exergy distraction of refrigerator components:

The idiom exergy is Greek world where ex (out or outer) and ergon (force or work), (ex = external, ergos = work. energy: en = internal). This concept first appears in 1824 by Carnot [11].

Thermodynamic exergy analysis is based on the thermodynamic second law, that gives a substitutional and highlight of assessing and comparing processes and systems rationally and meaningfully. In particular, exergy analysis yields efficiencies that provide a real measure of how nearly actual performance approaches the ideal and identifies more clearly than energy analysis the causes and locations of thermodynamic losses. Consequently, exergy analysis can assist in improving and optimising designs.

Fig(12) shows the rates of exergy destruction of the tested refrigerants for the system component. It can one observe that Mix4 give the greater destruction of exergy where Mix2 give the lowest one of mixture and the greater components exergy destruction is for the compressor with Mix3,



Fig(12) Exergy Destruction For Tested Refrigerants

6-Conclution

A computational model based on thermodynamic energy and exergy analysis with experimental work are presented for the investigation of the best alternative refrigerant for R134a working in refrigerator. After the successful investigation on the performance of the new refrigerant mixture as alternative refrigerant, the following conclusions based on the results obtained can be list below:

1. The compressor work of all tested refrigerant is decreased as the evaporation temperature increased, due to saturation pressure rising that's lead to the compressor pressure ratio and specific volume of compressor inlet decreasing.
2. The tested refrigerant required more work than that of R134a, So the compressor with Mix1 needed 26.14% more than R134a, with Mix2 required 23.98%, with Mix3 required 42.33% and with Mix4 required 33.15%.
3. The theoretical model show that the refrigerant mixtures give closer value of COP to that of R134a with reduction of 0. 6284% Mix1, 0. 0739% Mix2, 0.7189% Mix3 and 0.3497% for Mix4, where in experimental work all refrigerant give reduction more than that of theoretical model because of the refrigerator is design to work with R134a.
4. The compressor represents the higher exergy destruction components for all tested refrigerants where the condenser represent the lower exergy destruction components.
5. The refrigerator with Mix4 give the greater exergy destruction where with Mix2 give the lowest one of mixture.
6. The Mix2 refrigerant is the best from other proven refrigerant as the alternative refrigerant to R134a with COP reduction of 8.18% and GWP of 910.9 , table (1).
7. The tested refrigerant can be used as the alternative refrigerant with less modification on capillary tube size.

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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_{dcom}	The exergy destruction of compressor	kJ/kg
To	Room temperature	K
Tc	Condensing Temperature	K
ex_{in}	exergy input	kJ/kg
ex_{out}	exergy output	kJ/kg
$\eta_{exergetic}$	Second law efficiency	

Table(1) Properties of Alternative Refrigerant Mixture to R134a

Refrigerant	R 134a	Mix1	Mix2	Mix3	Mix4
Mixing ratio	%100	70%R134a,20%R290 ,10%R600a	70%R134a,10%R290 , 20%R600a	50%R134a,20%R290 , 30%R600a	60%R134a,20%R290, 20%R600a
Critical temperature in °C	101	107.4	103.6	110.3	106.9
Critical pressure (bar)	42.4	39.95	40.55	39.73	40.14
Molecular weight kg/kmol	102	86.05	87.46	75.87	81.66
boiling point in °C at 1.0135 bar	-26.5	-24.84	-27.86	-25.01	-26.44
Vapor Specific volume m^3/kg	0.1925	0.2663	0.2291	0.3104	0.2697
h_{fg} at -25 °C kJ/kg	216	267.8	270.6	303.1	286.8
GWP 100 years	1300	910.9	910.9	651.5	781.5
ODP	0	0	0	0	0