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Refrigerants Retrofit as Alternative for R12 and R134a in Household Refrigerators

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Abstract

This paper deals simulation study to investigation for the exploring of environmentally friendly alternative refrigerants for the R-12 and R134a for low Global Warming Potential (GWP), negligible Ozone Depletion Potential (ODP) and a better Coefficient of Performance (COP).This investigation was achieved using a hydro fluoro-olefins-R1234yf, propane-R290 and isobutane-R600a refrigerants. The performance characteristics of household refrigerators were predicted using steady-state model under refrigeration capacity (200 W), constant evaporation temperature (-10 ° C) and condensation temperature (46 ° C). The results obtained showed that hydrocarbon (R600a) refrigerant had lower energy consumption values than among selected alternate refrigerants. The best COP was of R600a then R290, but the flammability issue of R290 and R600a determined usage them as alternative refrigerants. R1234yf which had higher energy consumption values and lower COP was chosen as the best substitute refrigerant due to its other excellent characteristics such as GWP≅4, zero ODP and low flammability. Thus, R1234yf of the alternative refrigerant deserves the best option to replace of R12 and R134a.

Keywords: alternative refrigerant; ODP; GWP; COP; P_{cp}; household refrigerator.

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1. Introduction

In recent past, CFCs (chlorofluorocarbon refrigerants) were used as working substances in a domestic refrigerator. CFCs contain chlorine atoms.CFCs are refrigerants that have been accountable for both environmental problems, ozone layer depletion (ODP) and global warming potential (GWP) under the Montreal protocol were abandoned. The Montreal Protocol regulates the production and use of ozone-depleting substances [1]. The HFCs refrigerants were candidate as substitutes to CFCs. HFCs contain no chlorine atoms in the molecule structure. It was developed to many long-term alternatives to CFCs because they have excellent thermodynamic properties similar to CFCs, but it has zero ODP. HFC- R134a (hydrofluorocarbon refrigerant) proposed as alternate working substance in a domestic refrigerator and other vapor compression systems to replace R12. Recently, it was observed that HFC134a refrigerants which contribute to raise the global warming because it contains fluorine in the molecule structure, so, HFC134a were considered a greenhouse gas due to their considerable effect on climate change which called greenhouse phenomenon, which has unpredictable consequences on earth's thermal balance such as a rise in ambient temperature. The GWP of the HFCs refrigerants is high [2]. Usually, release for each one kg of HFC gas contributes 1000-3000 times more to global warming than the release of one kg CO2. Several studies carried out to find substitutes which be eco-friendly refrigerants for replacement R-12 and R-134a and obtaining to best performance for parameters to reduce GWP and ODP. Consequently, Kyoto protocol established the phased out of R134a. Kyoto-protocol has been called for a reduction of greenhouse gases emissions that cause climate change. Thus, was provided with a powerful basis for the need to take over the use of natural refrigerants such as R600a and R290 refrigerant or their blends as a substitutes for the halocarbon refrigerants. Hydrocarbons as a refrigerant have many positive properties. The only disadvantage of HCs relative to other refrigerants, is flammability. One alternative option with low GWP being considered as an alternative to the R134a in domestic refrigerators is HFO-1234yf [3]. Household refrigerator sector pays particular attention to the use of R1234yf as an alternative to R134a because of similar thermal properties were proposed as a substitute [4].

Nowadays, In Iraq, the most commonly used refrigerants in the household refrigerator are the R12 and R134a, but both refrigerants cause the hazard environmental effects like GWP and ODP. Therefore, in order to protection environment must reduce and prevent the use of these refrigerants and replace them with new refrigerants be environmental friendly such as R1234yf, R290 and R600a research topic. The current simulation study carried out for a comprehensive comparison of R12 and R134a refrigerants with the selected substitute refrigerants R290, R600a and R1234yf based on the following criteria: coefficient of performance, power consumption, refrigeration effect, heat rejected in the condenser, specific work done at compressor, mass flow rate and heat transfer from condenser per unit mass of refrigerant. The performance of parameters was compared with those of CFC-12 and HFC-R134a refrigerants. Tashtoush, B. et, al. [5] Have been a performed experimental study on HC / HFC refrigerant mixtures as new alternative refrigerants to replace R12 in domestic refrigerators. The results indicate that a mixture propane /butane /HFC-R134a can be used in household refrigerators at the rate of charge to a 210 g to R12, without changing the lubricating oil of the compressor used with R12 systems. The possibility of using R-134a as an alternative refrigerant in R-12 systems without modification has been investigated. The only drawback to the use of R-134 as a retrofitting refrigerant was the compatibility of the new refrigerant with its equipment. Whereas, the only disadvantage when usage HCs is the flammability of the refrigerant which could be reduced and overcoming it by mixing HCs, R134a together. Wong wises, S., and Chimres, N. [6] Have been investigated experimentally using hydrocarbons such as propane, butane and isobutene and their mixtures in a household refrigerator to replace HFC-134a. The household refrigerator has been designed originally to works with R134a. The experiments for refrigerants were carried out at same conditions. The results reported that hydrocarbon mixtures, propane/butane (60/40 by wt. %) respectively, is good alternative refrigerant to replaces HFC-134a. Talib K. M. and Salam H. H. [7] Have investigation experimentally to test R134a and R600a/R290 mixture as new alternative refrigerants to replace R12 in domestic refrigerator-freezers. They changed the compressor size, length of the capillary tube, and the amount of the charge, for each refrigerant. The results showed the energy consumption increased about 7.5% when used R134a as an alternative refrigerant comparison to R12, with using polyol ester oil as lubrication oil. Also, showed when used R600a/R290 hydrocarbon mixture of (61 wt. %, 39 wt. %) respectively, the energy consumption lower than R12 about 4%, When running in a system with a mineral oil. Jwo, C. S. and his colleagues [8]they have an investigation to apply R-290 and R-600a hydrocarbon refrigerants mixtures, as an alternative refrigerant for R-134a and R12 for domestic refrigerators. During the test, the conventional R134a refrigerant was replaced by varied mass hydrocarbon refrigerant, which was mixed by R-290 and R600a with each 50% component ratio.

The results showed that refrigerating effect is improved by using hydrocarbon refrigerant. Furthermore, the total consumed energy is saved 4.4% and applied mass of refrigerant is reduced 40%. comparison the refrigerating effect and COP value for R-12, R-134a, and R-290/R-600a mixture as substitute refrigerant, it was found, that the use of R-290/R-600a with mass 90 g has best refrigerating behaviour for the utilized system and is reduced 40% in comparison with official 150g R-134a.

The total refrigerating behavior with R-290/R-600a is better than R-134a and total conserving energy is 4.4%.Leighton D.T. [9] investigated experimentally for study predictions the performance of household refrigerators using various refrigerant types as low GWP refrigerants such as R1234yf, R1234ze and R1234yf /R134a mixture .The investigation experimental were carried out of two states the first is Steady-state and the second transient thermodynamic models of the refrigeration system .It was found that the COP and evaporator capacity lower by about (8.9%,6.2%), respectively, when using R1234yf as a drop-in replacement for R134a. HFO-1234yf was found to be a suitable substitute with similar performance characteristics and low global warming potential. Kyle M. K. and his colleagues [10] Tested two various domestic refrigeration systems, Ref1 as a baseline and Ref2 as an advanced technology. Using R134a as baseline established and R1234yf, R1234ze as new substitute environmentally friendly refrigerants. In Ref1 and Ref2, R-1234yf had 2.7% and 1.3% higher energy consumption than R-134a, respectively, this encourages that R-1234yf is an appropriate drop-in to replace R134a in household refrigeration systems. Aprea, C. and his colleagues [11] have a comparative experimental analysis between HFC-134a, HFO-1234yf and a refrigerant mixture of HFC134a/HFO1234yf (10/90% wt.) in a domestic refrigerator. The tests accomplished after that added 10% of HFC134a to HFO1234yf. The experimental results reported that electrical energy consumption and the pull-down time reduced about (7.5%, 10%) and (-14%,-9%) comparison to HFC134a and HFO1234yf, respectively, during the pull-down tests. also, they showed HFC134a/HFO1234yf refrigerant mixture (10/90 by wt. %) can be considered as a good drop in of HFC134a in existing household refrigerators.

2. Type of refrigerants used in household refrigerators

Refrigerants are working fluids in refrigeration and air-conditioning systems. The refrigerant absorbs the heat from the space to be cooled through the evaporator and then reject it to the outside through the condenser. The refrigerants used and the alternative refrigerants must meet many requirements, the following features are considered as major standards in the selection of proper refrigerants such as environmental safety ,Chemical stability, Satisfactory thermal and physical properties, high latent heat of vaporization, Low cost, no corrosiveness, non-toxicity, Short atmospheric lifetimes, non-explosive, and Non-flammable [12] .Unfortunately, there are no long-term refrigerants have all of these properties that fully meet these requirements, but at least both Eco-friendly and energy-efficient. There are different types of refrigerants which are described as followings.

2.1. CFCs, R-12: Dichlorodifluoromethane

CFCs are fully halogenated. This means that there are no hydrogen atoms, only halogens (chlorine, fluorine, bromine, etc.). They are stable, allowing them to reach the stratosphere without too many problems. It contributes to the destruction of the ozone layer. This is R-12.

2.2. HFCs, 1, 1, 1, 2-Tetrafluoroethane (R134a)

R-134a is an HFC-based refrigerant are molecules composed of carbon, fluorine and hydrogen. It is no contain chlorine atoms. Thus, they do not have influence of the ozone layer. R134a has GWP extremely high. Hence, need to replace it because of their effect in the climate change [13].

2.3. Hydrocarbons (HC)

Natural refrigerants refer to all non-synthetic natural materials. It can be drawn directly from the environment, including hydrocarbons (HC) propane (R290) and isobutene (R600a). Natural refrigerants are low global warming potential because they can easily be absorbed by nature. HCs have good thermodynamic properties and heat transfer performance, zero ODP and GWP near the unit, but are dangerous because of their flammability. Flammable gasses are common in many technical applications and do not cause many problems when observing simple precautions. Another area where propane could be a substitute for R-12 in the future refrigerators and freezers.

2.4. HFO, 2, 3, 3, 3-tetrafluoroprop-1-ene (R1234yf)

R1234yf Is the new refrigerant developed by Honeywell and DuPont together, has been considered as a possible alternative and promising drop-in replacement for R134a In the old and modern automobiles, will become a necessity for the near future [14].

It is a worldwide industry accepted solution for a low GWP refrigerant. The biggest benefit of the new refrigerant is that it breaks down faster in the atmosphere than the R-134a.

Table 1: Thermodynamic properties of R12 and Its Alternative Refrigerants

	Refrigerants				
Trade name	R12	R134a	R600a	R290	R1234yf
Chemical formula	CF2Cl2	CH2FCF3	C4H10	C3H8	CH2CFCF3
Lubricant	mineral oil	Polyester	mineral oil	mineral oil	Polyester
Normal boiling point(0C)	-29.8	-26.1	-11.73	-42.1	-30
Critical pressure(bar)	41.15	40.59	3.65	4.247	35.76
Critical temperature(0C)	112	101.1	134.7	96.86	95
Critical density(Kg/m3)	558	511.9	224.4	218.5	489
Molecular weight(Kg/Kmol)	120.93	102.02	58.12	44.096	114.04
Latent heat of evaporation (kJ/kg)	165.1	215.9	386	425.59	163.39

3. Environmental impacts

Halogenated refrigerants are considered for refrigeration, air conditioning, and other long-term uses. Halogenated refrigerants are a family of chemical compounds derived from hydrocarbons (methane and ethane) by replacing chlorine and hydrogen fluoride atoms. Chlorine and fluorine emissions in halogenated refrigerants are responsible for major environmental impacts that have serious implications for the future development of refrigeration-based industries**.** The environmental impact (ozone depletion potential and global warming potential) of selected refrigerants represented in table 2.

Table 2: Environmental impact of selected refrigerants

	Type	ODP	GWP
R12	CFC	1	8500
R134a	HCFC	0	1300
R290	HC (Natural)	0	3.3
R600a	HC (Natural)	0	4
R1234yf	HFO	0	4

3.1. Ozone Depleting Potential (ODP)

ODP is considered as the first main environmental impacts resulting by refrigeration-based industries due to daily human activity and chemical industrial substances which are releasing into the atmosphere layers [15]. The ODP is a number that indicates the amount of ozone depletion in the atmosphere due to a substance. The ODP is the ratio of the chemical effect on ozone to the effect of a similar mass of R-11. Thus, the ODP of R-11, which is in CFC group, has been accepted as 1 and used as a reference value. The stratospheric ozone layer which protects the earth's surface from direct UV rays. Decrease or removal of this layer which functions as a filter against harmful ultra-violet rays can damage life on earth profoundly.

3.2. Global warming potential (GWP)

The second major environmental impact is GWP, which is due to the absorption of infrared emissions from the earth, causing an increase in global earth surface temperature. GWP is a number that indicates the amount of global warming caused by a substance. GWP is the ratio of warming caused by a substance to warming caused by a similar mass of carbon dioxide. Thus, the global warming potential for CO2 is 1.0.The use of refrigerant high-GWP is not recommended because it stimulates the formation of serum gas and increases global warming. The GWP is based on infrared absorption of the refrigerant, a gas lifetime in the atmosphere, and the selected time frame. Thus, the same gas can have different GWP for different time frames with 100 years normally used as the standard time frame.

4. Performance parameter analysis

For accomplished simulate of vapour compression refrigerator system (domestic refrigerator), taken into account a number of assumptions are:

- Steady state condition.
- The sub cooling degree for baselines is 6°C.
- No heat losses and no heat gain from or to the system.
- No pressure loss through pipelines.

The coefficient of performance (COP) relates the cooling capacity to the required power and indicates the overall power consumption for the desired load. In order to compare the coefficient of performance of a household refrigerator system, there is need to calculate and evaluate the energy extracted from the cooling system Q_0 and the power input compressor consumption in the process;

$$COP = \frac{\dot{Q}_0}{P_{CP}} \qquad (1)$$

Where $\dot{Q}_0$ the cooling capacity and Win is is the input power required to drive the compressor. The energy balance of the evaporator gives:

$$\dot{Q}_0 = \dot{m}_0 \cdot q_0 \quad (2)$$

Where q_0 the heat transfer to evaporator per unit is mass of refrigerant; $\dot{m}_0$ is the mass flow rate (kg/s) at the evaporator.

$$q_0 = h_2 - h_6 \quad (3)$$

Where h_6 is the enthalpy of refrigerant at the inlet of evaporator (kJ/kg).

h_2 Is the enthalpy of refrigerant at the outlet of evaporator (kJ/kg).

The actual specific enthalpy of the superheated refrigerant vapour at the compressor exit h_2 which can be calculated using energy balance equation between superheated and sub cooling at heat exchanger region shown down:

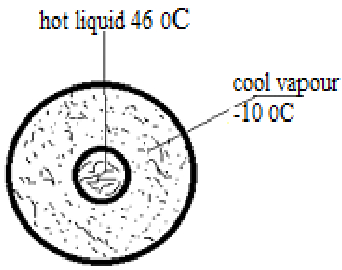

Figure 1: Cross section of the internal heat exchanger for the supposed domestic refrigerator.

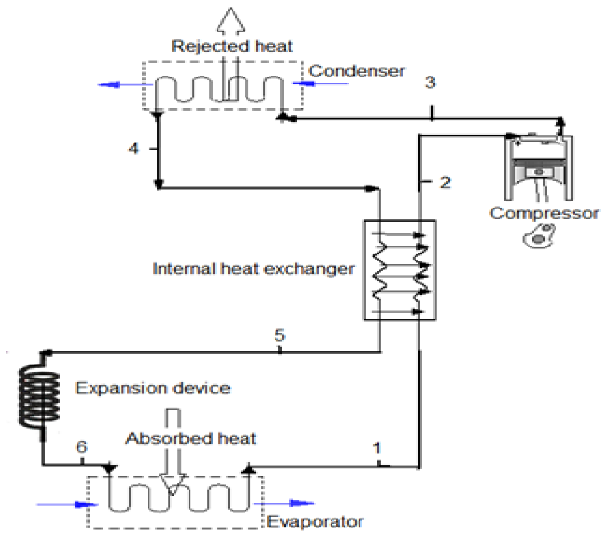

Figure 2: Shows internal heat exchanger in vapour compression refrigeration system.

$$Q_{12} = Q_{45}$$

$$\dot{m}_0 \cdot (h_2 - h_1) = \dot{m}_{cd} \cdot (h_5 - h_4) \qquad (4)$$

Since the mass flow rate of the cooling medium is fixed as that:

$$\dot{m}_0 = \dot{m}_{cd}$$

Consequently, the value of enthalpy at the end of the internal heat exchanger shown in Fig. 1 and Fig.2 above, can be calculated from the following equation:

$$h_2 = h_1 \cdot (h_5 - h_4) \qquad (5)$$

The compressor input power on the refrigerant is calculated by the following equation;

$$P_{cp} = \dot{m}_0 \cdot (h_3 - h_2) \qquad (6)$$

Where h_3 is the enthalpy of the refrigerant at the outlet of the compressor (kJ/kg).

The heat rejected in the condenser to the surroundings is expressed as:

$$Q_{cd} = \dot{m}_{cd} \cdot q_{cd} \qquad (7)$$

Where q_{cd} is heat transfer from condenser per unit mass of refrigerant, Calculate by:

$$q_{cd} = h_3 - h_5 \qquad (8)$$

The specific work performed by the compressor for each 1 kg of cooling fluid, which represents the difference between the enthalpy at the input and the compressor output, respectively.

Can be illustrated by the following equation:

$$W_{in} = h_3 - h_2 \qquad (9)$$

Where W_{in} is the specific work done by kJ/kg.

5. Results and discussions

In this study, a comparison of refrigerants performance parameters (COPs, compressor input powers, specific work done, the refrigeration effect, the condenser heat dissipated amass flow rates) for the selected substitute refrigerants based to baseline refrigerants were discussed by the refrigerator.

This research deals refrigerants R290, R600a and R1234yf to evaluate their feasibility for replacing R12 and HFC-134a in the household refrigerator by comparing the relevant parameters. The standard operating conditions are assumed for the household refrigerator. The calculations are performed at a condensing temperature of 42°C and an evaporating temperature of -10°C. The liquid is sub cooling of 6°C in the condenser. Based on these operating conditions, theoretical results of performance parameters in the household refrigerator were determined by using EES software. The results are shown in Figure 3 to Figure 9.The results of performance parameters of refrigerants discussed down.

5.1. Coefficient of performance

A comparison of the coefficient of performance of domestic refrigerators working with various refrigerants namely R12, R134a, propane (R290), isobutene (R600a) and the HFO (R1234yf) can be concluded from Figure 3. The COP of R600a are closer to that of R12.The lowest COP was when to use R1234yf, at same standard operating conditions .The COP of isobutane among substitutes refrigerants is the best.This means that the isobutane is a suitable replacement for R12 and R134a over the considered range of operating conditions. While the COP for the hydrocarbon propane is slightly lower than that for R134a, but must to taken into account the flammability issue of hydrocarbon refrigerants. This means that the R1234yf is the best alternative refrigerant for R12 and R134a although, that is lower COP. The COP is drawn to different refrigerants on the same graph. Results are shown in Figure. 10 which exhibits a gradual increase in the COP of various refrigerants, which indicates that pure commercial isobutane as an alternative refrigerant give the highest COP about (3%) comparison to R134a, but it was slightly lower than R12 ,while, pure R1234yf and propane R290 give lowest COP about (9.38%,6.5%) and (4.94%,1.93%) comprasion with R12 and R134a , respectively.

Figure 3: Shows the COP of R12 and R134a comparison with alternative refrigerants.

5.2. The refrigeration effect

The refrigeration effect is the main purpose of the refrigeration system. The refrigerant effect of the local refrigerator using R-134a and R12 was considered as the standard refrigerant and refrigeration effect of alternative refrigerants was compared. The results indicate that refrigeration effect was significantly higher when used R290 and R600a as working fluid than R12 and R134a.while R1234yf had lowest refrigeration effect comparison with all other refrigerants. The q_0 of R12 and R134a comparison with alternative refrigerants was represented in figure 4.

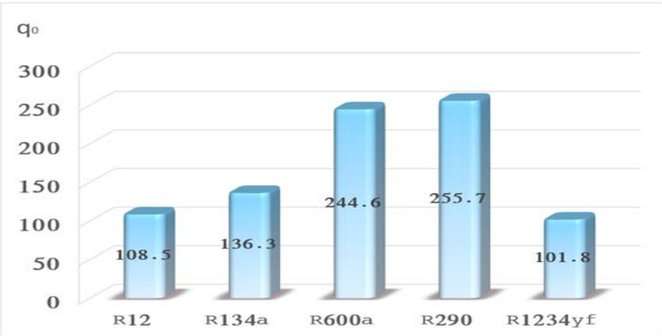

Figure 4: Shows the q_0 of R12 and R134a comparison with alternative refrigerants

5.3. Specific work done (Win)

Figure 5, shows the specific work done of the compressor of refrigerants used into investigation study. The results showed that the specific work which is the difference in the enthalpy between the input of the compressor(suction line) and the compressor output (discharge) are significantly high for the hydrocarbon refrigerants (R290, R600a) as alternative refrigerants comparison to R12, R134a. The specific work of the alternate R1234yf is significantly less than other substitute’s refrigerants.

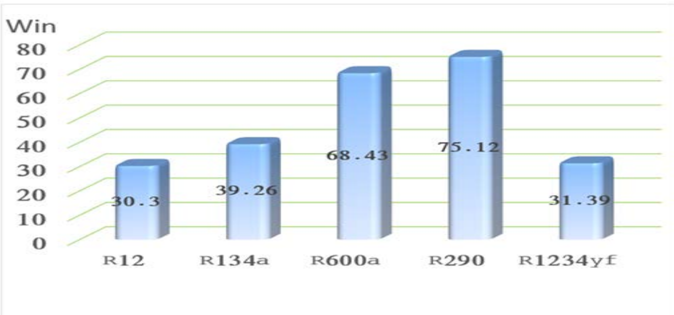

Figure 5: Shows the specific work Win of R12 and R134a comparison with alernative refrigerants**.**

5.4. Heat transfer from condenser per unit mass of refrigerantq_{cd} .

It presents the amount of heat dissipated to the outside surrounding by the condenser per 1 kg of the cooling medium. The results showed that R290 and R600a they have highest heat dissipated compared with R12 and R134a respectively. While R1234yf it has the lowest heat dissipated for each 1 kg of the cooling medium.

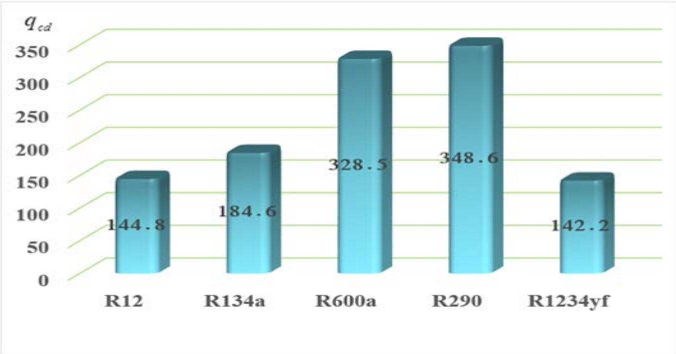

Figure 6: Shows the q_{cd} of R12and R134a comparison with alternative refrigerants.

5.5. Consumption input power

Compressor is the most component of the domestic refrigerator that consumes electrical energy. The results showed that the energy consumed in the used compressors in domestic refrigerators higher by about (10.35%, 6.98%) than R12 and higher than R134a by about (5.19%, 1.98%) when using R1234yf and R290 as a replacement for R12 and R134a, respectively.

Figure 7: Shows the consumption input power of R12and R134a comparison with alternative refrigerators

The energy consumption of R600a refrigerant refrigerator was achieved lower by nearly 2.88% compared with those of refrigerator R134a. While it is slightly less than R12. The results showed that R600a has the least energy consumption among all the refrigerants. This means that the best consumption of energy will be in the case use of R600a as a working fluid comparison to other refrigerants. This means reducing the indirect environmental effects resulting from the high energy consumption of household refrigerators compressors which cause raise the earth's temperature so called global warming. Also, observed that the value of compressor input power for R1234yf is higher than the other refrigerants.

5.6. The condenser heat dissipated

Figure 8 shows the different investigated refrigerants. The condenser heat dissipated increases with change refrigerant. R1234yf, R600a and R290 have highest condenser heat dissipated about (4.6%, 0.599%, 2.1%) comparison of R12. Whereas, R1234yf and R290 have value higher about (3.1%, 0.62%) than R134a, respectively. Also, observed that R600a has condenser heat dissipated lower than of R134a about (0.886%).This means that R1234yf has best condenser heat dissipated among all substitute refrigerants.

Figure8: Shows the Q_{cd} of R12and R134a comparison with alternative refrigerants

5.7. Mass flow rate

Figure 9 shows the mass flow rate of various refrigerants. The results presented that increased the mass flow rate of the compressor, causing compressor work to increase slowly. It can be seen that R290 and R600a exhibit a lower mass flow rate than R12, while R1234yf has the highest mass flow rate than all refrigerants. This reflects the effect of the mass flow rate of the consumption of energy in the compressors. The increase in the mass flow rate leads to increase consumption of energy in the compressor.

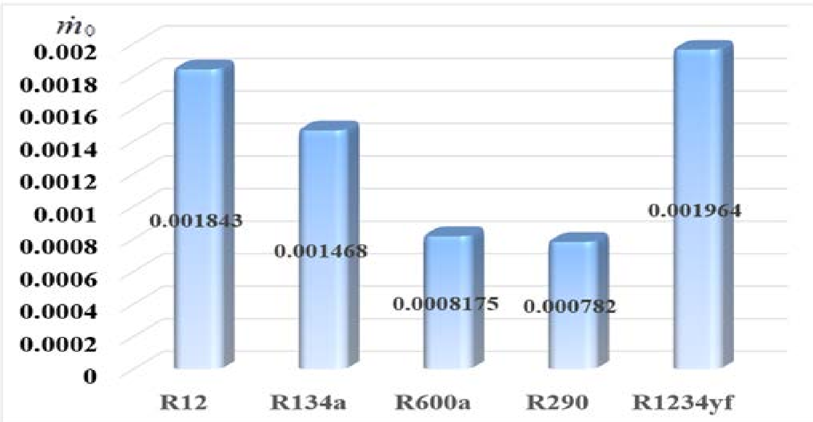

Figure 9: Shows the $\dot{m}_0$ of R12 and R134a comparison with alternative refrigerants.

6. Conclusion

In this theoretical study, appropriate environmental solutions in one than refrigeration applications (household refrigerator) in Iraq were investigated. Household refrigerator is one of a Vapour compression refrigeration systems which used the refrigerants as working fluids.

The refrigerants are responsible for two main environmental problems have emerged: atmospheric ozone-destroying and global warming. Since the ozone depleting substances have almost disappeared in developed countries, but it still using in developing countries like Iraq. Greenhouse gases emission which resulted than used synthetic refrigerants present currently is a major concern, such as CFCs and HFCs that extensively employed in refrigeration systems. The study simulates the environmental friendliness refrigerants, COPs, safe and available cost-effective refrigerants as a replacement to CFC12 and HFC134a in household refrigeration systems. After investigation of the performance of variety refrigerants, the following conclusions can be drawn on the basis of the results obtained. It was observed that:

- Natural refrigerants R290, R600a showed better performance than industrial refrigerants.
- The results found out that the first and most convenient option to replace R12 and R134a for a household refrigerator is the HFO-1234yf, Due to the flammability issues associated with R290 and R600a, the GWP issues of R134a and the ODP issues of R12.
- The inferred that the significantly lower GWP of R123yf and its similar thermodynamic properties when using R1234yf as a replacement refrigerant of R12 and R134a will be allowing to meet the environmental regulations and environmental impact to be reduced.
- The most powerful alternative refrigerant was HC-R600a, which was evaluated as a direct alternative to HFC-134a and R12, with similar performance characteristics and COP higher about (3%) comparison to R134a, while it was slightly lower than R12, in the investigation unit used (household refrigerator) but the only drawback which facing used this refrigerant is flammability.
- Refrigerating effect of R290 was higher than all other refrigerants in the same conditions.
- Specific work done of R290 refrigerant was higher than all other selected refrigerants.
- Heat transfer from condenser per unit mass of refrigerants R290 was higher than all other selected refrigerants.
- Consumption input power of R600a was lower than other selected refrigerants.
- The condenser heat dissipated was higher than other selected refrigerants.
- Mass flow rate of R290 was lower than all other refrigerants.

Thus the results prove that the hydrocarbon refrigerant R600a gives best performance than all other selected refrigerants in the domestic refrigeration system and the R600a gives the best result for replacement refrigerant in existing machines, designed for CFCs and HFCs, but the concern due to flammability issue became only drawback which facing use HCs refrigerants as replacements of R12 and R134a then found that the best choice to replace R12 and R134a into currently applications, will be R1234yf. R1234yf have many properties which make it the better substitute refrigerant to old refrigerants such as zero ODP, negligible GWP and very low flammability, which made it meeting the environmental requirement and the international regulations about climate change and protection ozone layer.

7. Recommendations

The authors recommend using the refrigerants retrofit to reduce the environmental influences that resulting by using old refrigerants such as R12 and R134a.

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