Experimental Performance Investigation of Domestic Refrigerator Charged by R600a and R134a

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Abstract

The performance of vapor compression refrigeration (domestic refrigerator) charged with (R600a) and (R134a) was experimentally studied. A new Alternative refrigerant(R600a) suggested of the conventional (R134a).Various parameters were investigated such as refrigeration effect , pressure ratio , condenser heat rejection , evaporator capacity, RE and FE compartments temperatures .It is observed that replacing (R134a) with (R600a) was acceptable value specially by comparing conditions closely results .The minimum and maximum deviation in pressure ratio was about (8% to 23%), respectively, and the COP of (R600a) was less than the COP of (R134a) about (12%) .In spite of that, this reduction was considered acceptable due to ODP of (R600a) were zero and negligible by GWP.

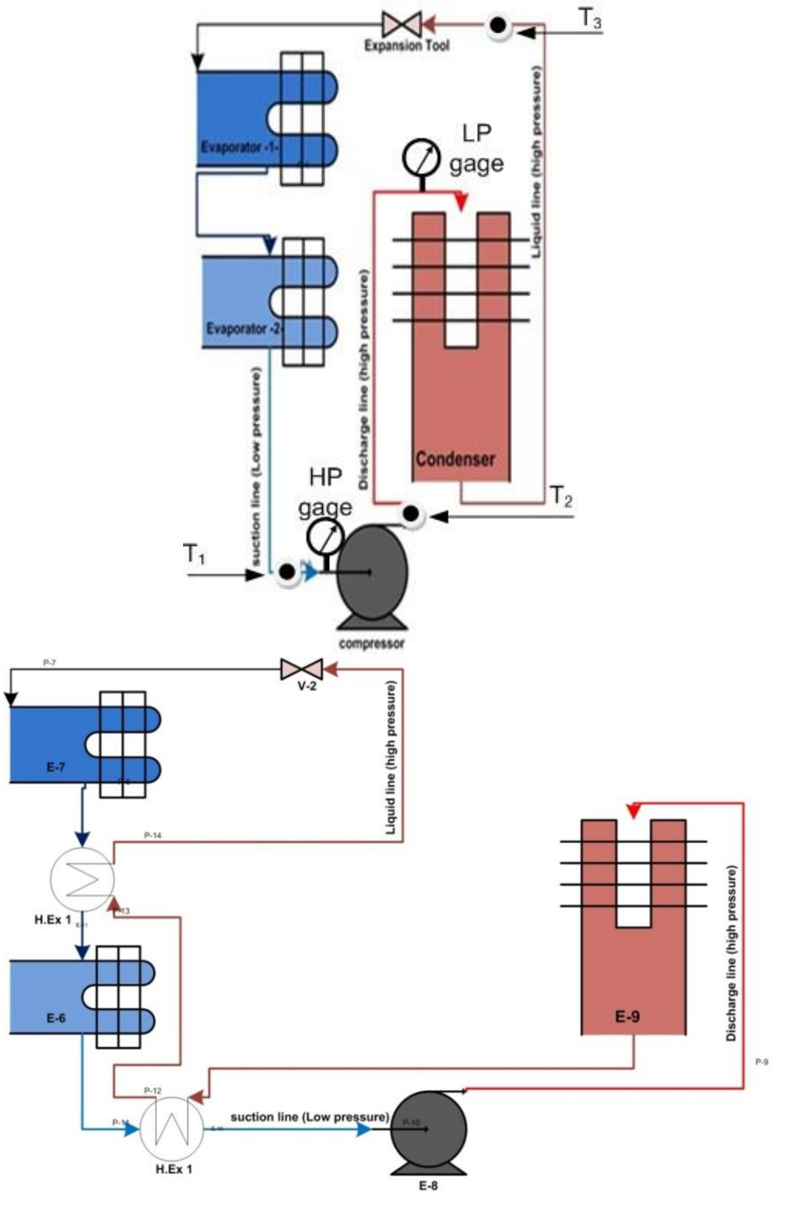
Keywords: VCR cycle performance, Alternative refrigerants, ODP, GWP.

Nomenclature:

Symbol	Description	Symbol	Description
VCR	Vapor compression refrigeration	C.O.P	Coefficient of performance
NARMs	Non Azeotropic refrigeration mixtures	RE	Fresh food compartments
CFC	Chlorofluorocarbon	FE	Freezing compartment
ODP	Ozone depletion potential	HP, LP	High and low pressure
GWP	Global warming potential	Qc, Qe	Condenser and evaporator capacities
EER	Energy efficiency ratio	Wc	Compressor work

1- Introduction:

Vapor compression refrigeration (VCR) cycle is usually used for domestic refrigeration and air conditioning, chemical transportation applications and commercial industrial. For domestic applications (VCR) cycle contains double cabinets, one for cooling fresh food and second for freezing food. Complications occur in this system such as maintaining of different temperatures for the two capitates by single (VCR). For improving thermodynamic cycle efficiency with non-ozone depleting compounds is the use of Non Azeotropic Refrigerant Mixtures (NARMs). An early study in this area by Lorenz and Meutzner indicated significant performance gains in an experiment that utilized a NARM in a modified domestic refrigerator.[1] Lorenz and Meutzner (1975) invented a two series evaporator refrigeration cycle with two intercoolers using zeotropic refrigerant mixtures as shown in Figures (1-a) and (1- b).



- a -   - b -

Figure (1- a): Simple vapor compression refrigeration cycle;

Figure (1-b): Lorenz – Mutzner cycle with two in-between heat exchangers

Energy consumption is important considerable index for developing a refrigeration system using CFC alternatives in addition to the values of the ODP and GWP. Hydrocarbons are refineries production naturally after a percolation procedure. The environment properties are zero ODP and negligible GWP [2], Table (1) shows the environmental property data for hydrocarbon refrigerants and blends of current interest.

Table-1: Environmental data for hydrocarbon refrigerants [2].

Refrigerant	Atmospheric life	ODP	GWP
R 600 a	_	0	< 15
R290	_	0	< 15
Blend R6600a /R290	_	0	< 15

Most researchers noted that the energy efficiency ratio (EER) of the system would decrease for the normal refrigeration system when using CFC substitutes. **[3]** have reported the causes of a reduction in EER, which analyzed theoretically, and to improve EER by using a domestic refrigerator developed by charging it with a zeotropic mixture of RC22/R152a instead of the R12, This development resulted in an increase in EER by 6.5% compared with case of charging R12.

Hydrocarbons were used as refrigerants before the advent of CFCs, although in the open systems flammability was a drawback However, in hermetically sealed system, this problem was reduced to some extent.

Reinhard et.al [4], investigated the performance of hydrocarbon refrigerant mixture of R290/R600a in a VCR system, the 56%/44% mixture has a COP greater than that of R12. Mixture of (R290/R600a, 50:50wt %) has very similar saturation characteristics to R12.

2- Calculation equations and assumptions:

Many assumptions are considered in the calculations of the VCR cycle (domestic refrigerator): no heat gain or loss in suction (between evaporator to compressor), liquid line and discharge line pipe (between compressor to condenser) .In this work, the conditions are experimentally taken such as pressure in liquid, suction and discharge lines and their temperature, and compute enthalpies of all points for VCR cycle on p-h diagram

The coefficient of performance (COP) is the ratio of cooling capacity (refrigeration effect) to the required power (mechanical work of compressor) ; In order for calculating and comparing the coefficient of performance of a domestic refrigerator system, there is a need to calculate and evaluate the energy rejection from the system Qc and the power input compressor consumption in the process:

$$COP = \frac{RE}{W_{comp}} \quad \ldots\ldots\ldots\ldots (1)$$

Where RE is the cooling capacity and Wcomp is the input power required to drive the compressor. The energy balance of the evaporator gives [5]

$$RE = (h_1 - h_4) \quad \ldots\ldots\ldots\ldots (2)$$

$$q_{cond} = (h_2 - h_3) \quad \ldots\ldots\ldots\ldots (3)$$

$$w_{comp} = (h_2 - h_1) \quad \ldots\ldots\ldots\ldots (4)$$

Where q_{cond} is condenser heat rejection, h_1, h_2, h_3 and h_4 are enthalpies inlet compressor (outlet evaporator), outlet compressor (inlet condenser), outlet condenser (inlet expansion device) and outlet expansion device (inlet evaporator) respectively, taken into account the expansion in capillary tube is assumed as an isentropic process [5]:

$$(h_3 = h_4) \ldots\ldots (5)$$

The properties of all states above (h_1, h2, h3and h_4) recorded experimentally by using standard tables of both R600a and R134a (REF PRO) [6].

3- Test procedure and experiments:

A conventional domestic refrigerator was used to experts the performance of different refrigerants (R600a and R134a) by applying the results on p-h diagram [7] for both refrigerants (figure -2) and comparing the results.

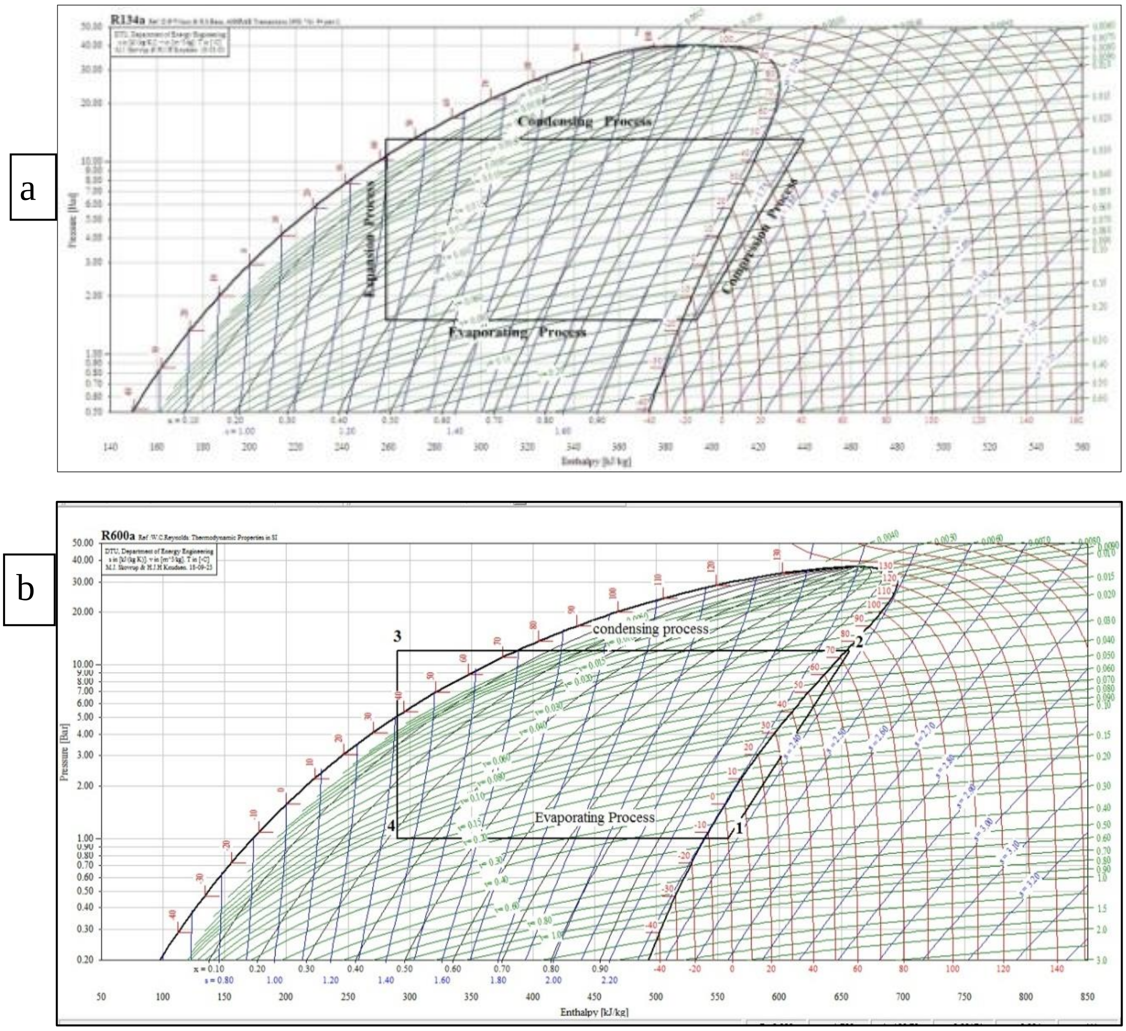
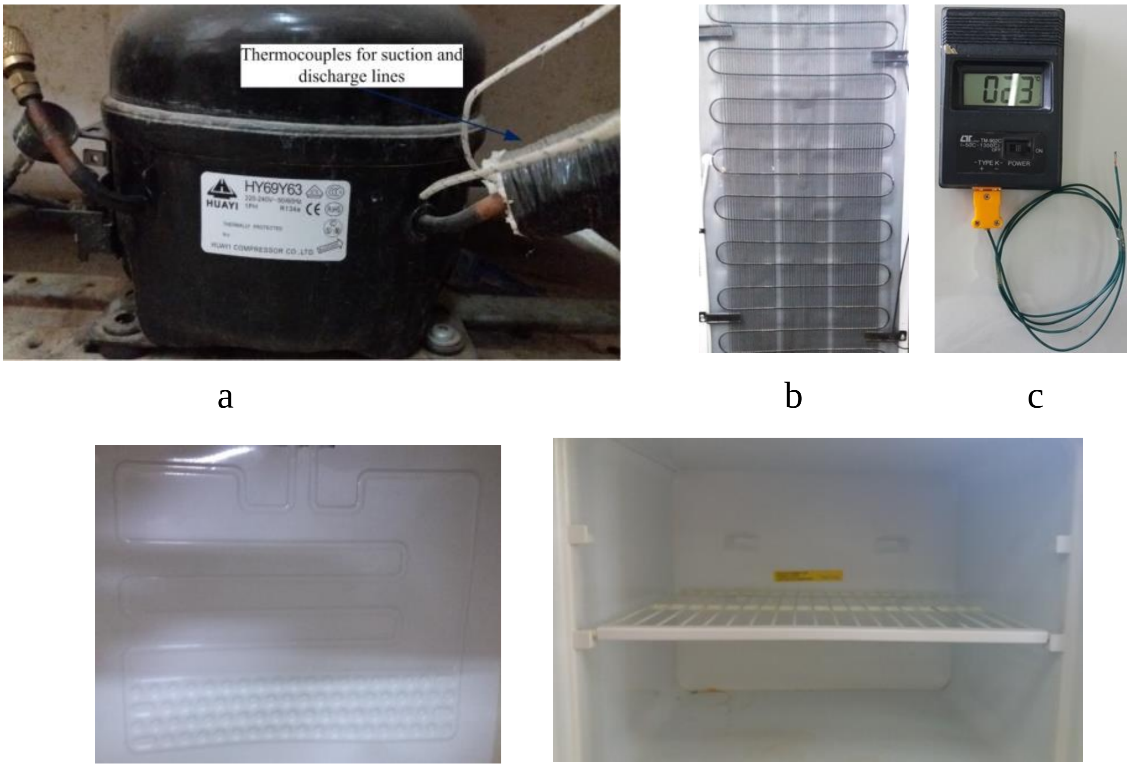


Figure (2) - : -a- (p-h) diagram for R134a, b – (p-h) diagram for R600a [6]

A reciprocating hermetic type compressor model of (HY69Y63 HUAYI Compressor company) shown in Figure 3 a below was used in this work; it was designed to work with R-134a refrigerant; since natural refrigerant (R600a) is one of the alternative refrigerant that this work going to expert it ; mineral oil must be used with this compressor [5].

A two Plate – tube type evaporators used for this work shown in Figure 3 d and e below the 1st one for freezing compartment of the domestic refrigerator and the 2nd for the fresh food compartment.

Wire type, air cooled condenser (natural convection) shown in Figure 3b below was used to complete cycle, while the capillary tube (as expansion device) by 3 meters long and 2 mm inside Diameter .



a b c

d e

Figure (3): a: - compressor, b: - condenser, c: - reader and thermocouple, d: -RE and c: FE

4- Experiments Output Data:

The following parameters will be measured and studied during this work:

Experiments	C.O.P	RE(kJ/kg)	Wc (kJ/kg)	Qc (kJ/kg)	RE Temperature	FE Temperature
R600a						
R134a						

5- Results and discussion:

The variation of compressor pressure ratio for both refrigerant cycles is shown in figure (4), it can be seen from the figure that R-134a has high pressure ratio as compared with that for R-600a, this increases in pressure ratio due to that R-134a has high condensing pressure as compared with that for R-600a for a given saturation temperature. The figure shows that the unit reaches steady state at about 30 min. Although R-600a has low pressure ratio, but the compressor works with R-600a consumed more work as compared with that for R-134a as shown in figure (5), this is due to the high slope of entropy line for R-600a which leads to high work of compression. The figure shows that the both compressors showed increases in the work consumption after time 60 min. This is due to the increases in the ambient temperature, R-600a shows large increases in the work consumption, as mentioned before, and this is due to high slope of entropy line of R-134a which is affected by temperature difference significantly. As it is well known that the condenser holds the work consumed by the compressor, thus a more work consumption means a high heat rejected from the condenser. This phenomenon is reflected clearly on the heat rejection from the condenser as shown in figure (6). The figure shows that R-600a rejects more heat from condenser as compared with that for R-134a. The amount of heat rejection from the cycle increases with the time due to the increases in compressor work as mention before. Since the latent heat of evaporation of R-600a is more than that for R-134a at a given saturation temperature, thus the refrigeration effect of R-600a is more than that for R-134a as show in the figure, this condition is mentioned by H. Alan Fine [8].

The variation of Fresh food compartment (RE) and freezing food compartment (FE) temperatures for both refrigerants are shown in figure 7, it can be seen from the figure that R-134a gives a low FE temperature due to low saturation temperature for a given pressure as compared with that for R-600a. As R-134a absorbs more heat in FE compartment it temperature increases and reflects on the temperature of RE compartment, as shown in the figure. Thus the RE temperature for the cycle working with R-600a is less than that for R-134a. it can be seen from the figure that both FE and RE compartment temperatures reduced with the time due to the continuous absorbing of heat from both compartments. The improving in the refrigeration effect with low compressor work improve the cycle coefficient of performance (COP), as shown in figure (8), the figure shows that the cycle works with R-134a has a high COP as compared with that for R-600a. The cycle shows an improved in the cycle COP works with R-600a for the time extended from 20 to 60 min. this is due to the reduction in the compressor work as mentioned in figure (5). The cycle COP reduces with the time due to the increasing in the work consumed by the compressor for the mentioned period of time as shown in figure (5).

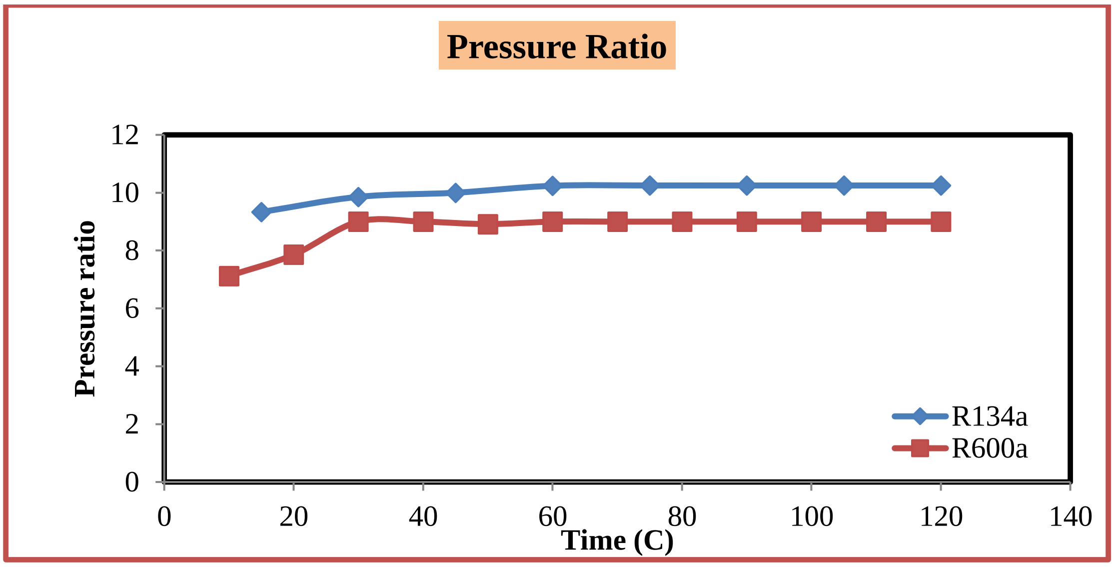


Figure (4): comparison of pressure ratio varies with operational time for both R134a and R-600a.

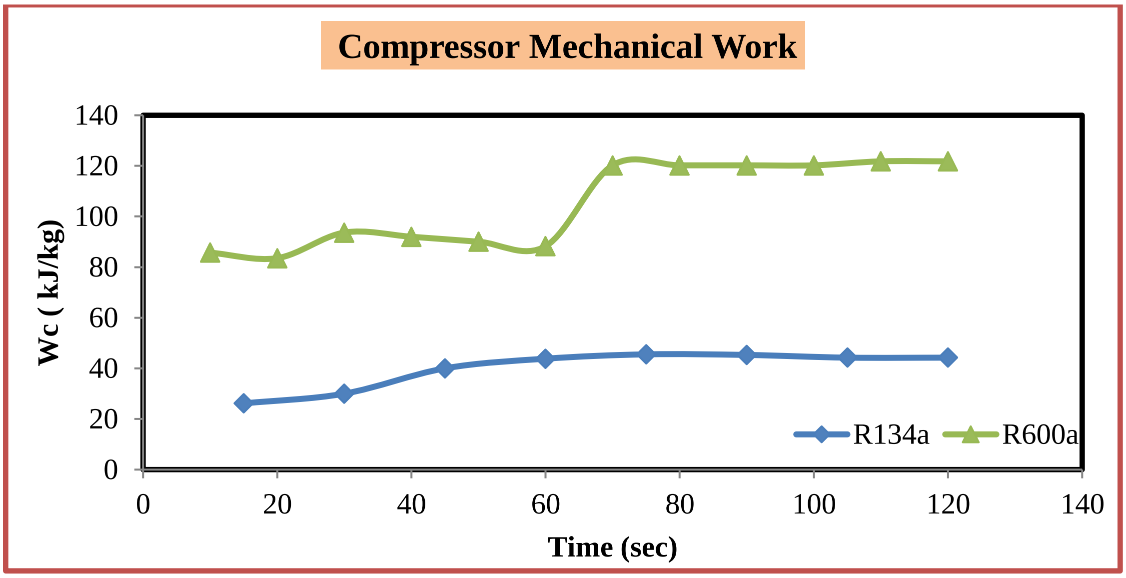


Figure (5): comparison of useful compressor work varies with operational time for both R134a and R-600a.

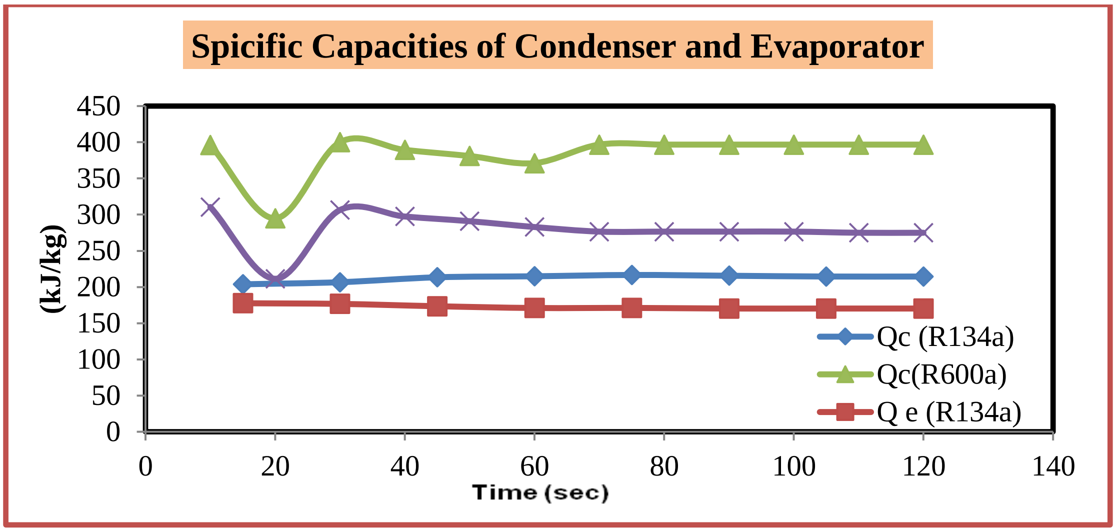


Figure (6): comparisons of condenser and evaporator capacities varies with operational time for both R134a and R-600a refrigerants.

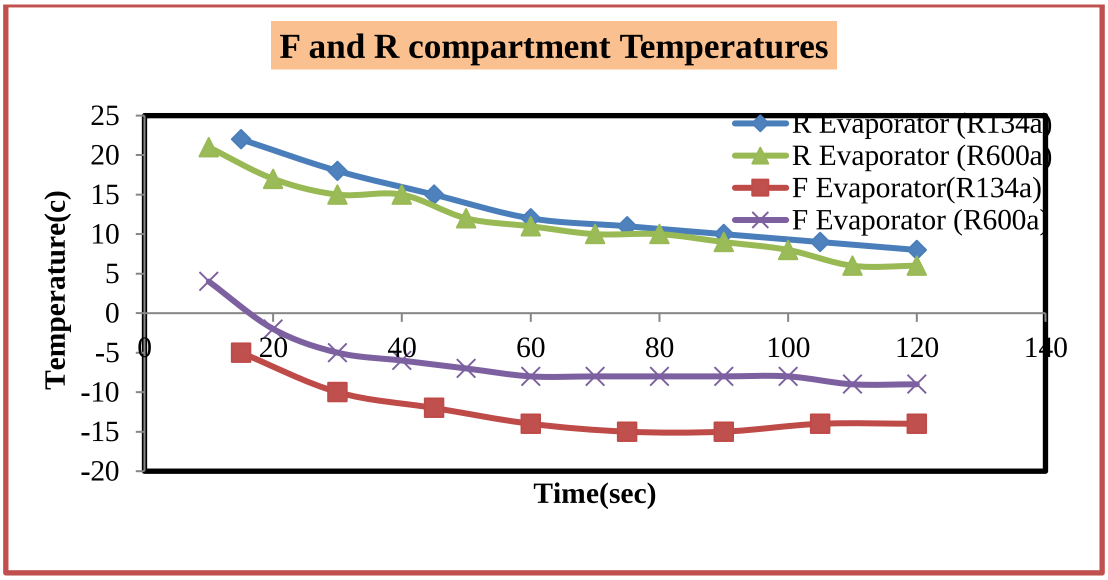


Figure (7): comparisons of R and F evaporator Temperatures varies with operational time for both R134a and R-600a.

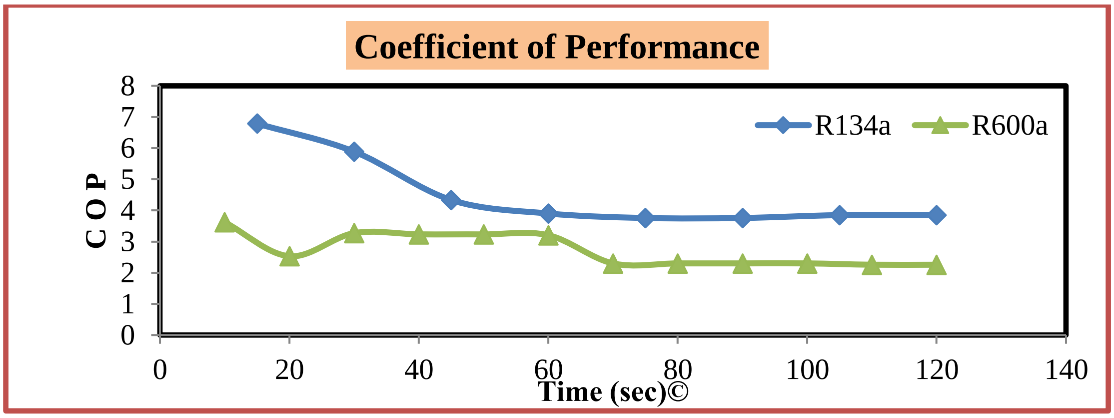


Figure (8): comparison of coefficient of performance varies with operational time for both R134a and R-600a.

6- Conclusions:

1- R-134a consumed less compressor work as compared with that for R-600a, this conditions reflects negatively on the COP cycle.
2- From the environment view point and according to the EPA's announcement the chosen date for mandatory R-134a phase out is the year 2020[9], and the degradation of HFO R1234yf – which is widely used in mobile air-conditioning systems – into trifluoroacetic acid (TFA; the atmospheric by-product of HFOs) could contaminate the water supply as TFAs cannot be removed after contamination has taken place [10].
3- So the use of HC-600a is promising because low global warming effects and ozone depletion number.

CONFLICT OF INTERESTS.

- There are no conflicts of interest.

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التحقيق العملي لأداء ثلاجة منزلية مشحونة بغازي التبريد R600a وR134a

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الخلاصة

تمت دراسة اداء منظومة تبريد تعمل بانضغاط البخار (ثلاجة منزلية) شحنت بمائعي التبريد (R600a) و (R134a) دراسة عملية. وتم اقتراح مائع التبريد (R600a) كمائع بديل عن مائع التبريد التقليدي (R134a)، وكان التحقيق العملي لعدة عوامل تشغيلية مؤثرة للمنظومة مثل: التاثير التبريدي للمبخر (RE)ونسبة الانضغاط (Pr) وكمية الحرارة الملفوظة في المكثف (q_{cond}) ودرجة حرارة المبخر المخصص للتجميد (FE) ودرجة حرارة المبخر الثانوي المخصص للتبريد (RE). وقد تبين من النتائج التي تم الحصول عليها ان استبدال (R134a) بــ (R600a) مقبول و منطقي خاصة بقارنة النتائج و السلوك المتشابة للمائعين بدراسة العوامل المشار اليها اعلاه .اعظم وادنى تفاوت في نسبة الانضغاط كان يتراوح بين (8%) الى (23%) على التوالي، بينما معامل اداء المنظومة (COP) للمائع (R600a) كان اقل من (COP) للمائع (R134a) بمقدار (12%) تقريبا وبالرغم من وجود أختلاف بين المائعين لكن يمكن اعتبار نتائج (R600a) مقبولة واعتباره بديلا ناجحا للمائع (R134) كون (ODP) له تعادل صفرا و(GWP) قليلة جدا يمكن اهمالها وهذان المؤشران مهمين جدا للبيئة والحفاظ على معدل درجة الحرارة والمناخ .

الكلمات الدالة: – اداء دورة التبريد الانضغاطية VCR، موائع التبريد البديلة، ODP،GWP .