Jordan Journal of Energy
Volume1, Number 1, 2023

ISSN (Online): 2790-7678
ISSN (Print): 2790-766X

Jordan Journal of Energy (JJE)
Journal Homepage:ttp://dsr.mutah.edu.jo/index.php/jje
JJE an official peer review journal of Mutah University,

Experimental investigation of the effect of using different refrigerant gases on refrigerator performance

Saad S. Alrwashdeh[1], Handri Ammari[2] , Mahmoud Hammad[3], Heening Markotter[4]

[*1]Mechanical engineering department, Mutah University, Al-karak, Jordan
[1]saad.alrwashdeh@mutah.edu.jo
[2] Mechanical engineering department, Mutah University, Al-karak, Jordan
[2]hanamm@mutah.edu.jo
[3] Mechanical engineering department, Jordan University, Amman, Jordan
[3]mah_hamm@yahoo.com
[4] Mechanical engineering department, TU-Berlin, Berlin, Germany
[4]h.markotter@yahoo.com

Received: 2nd April, 2022 ; Accepted: 1st September, 2022

*Corresponding Author Email: saad.alrwashdeh@mutah.edu.jo (Saad S. Alrwashdeh)

ABSTRACT. An experimental study of the performance of a refrigerator using two refrigerants R-134a and R-410A has been conducted. The R-134a was the original design refrigerant, while the R-410A was the drop-in refrigerant. The study was performed on a small refrigerator charged with each refrigerant alone at nearly the same ambient conditions. Temperatures at various locations in the refrigeration system were measured using thermocouples during the running of the experiments, and the data collected were processed into performance refrigeration parameters. The results have indicated that both the refrigeration capacity and coefficient of performance were remarkably higher for the refrigerant R-410a by about 23 and 24%, respectively.

Keywords: Drop in- refrigerants, Office refrigerators, Performance comparison of refrigerants

1. Introduction.

Refrigerants are the working fluids in refrigeration systems that transfer heat from a lower temperature level to a higher temperature level. For several decades' chlorofluorocarbons (CFCs) were considered harmless refrigerants. The most widely used refrigerants were the R-12 and R-22, with R-12 being more common in automotive air conditioning and small refrigerators, and R-22 being used for residential and commercial air conditioning, refrigerators, and freezers. However, in the late twentieth century, ozone depletion and global warming have become dominant environmental issues. The 1987 Montreal Protocol and its amendments

(UNEP, 1987) and Kyoto 1997 Protocols gave a deadline to the use of chlorofluorocarbon (CFC) and hydrochlorofluorocarbon (HCFC) refrigerants, for they destroy the ozone layer. The chlorine atoms contained in CFC and HCFC refrigerants repeatedly combine with and break apart stratospheric ozone molecules, resulting in ozone depletion. The Protocols signed states that CFCs and HCFCs must be reduced and totally banned in the end of 2030.

The Ozone Depletion Potential (ODP) and Global Warming Potential (GWP) issues forced refrigeration engineers to develop alternative refrigerants as substitutes to CFCs and HCFCs. Environmentally benign, ‘natural’ refrigerants have attracted a considerable attention. The natural refrigerants are the naturally occurring substances, namely, ammonia, hydrocarbons (such as Propane and Butane), carbon dioxide, water, air, etc. These natural refrigerants have zero ODP, and the majority of them have zero GWP, and among them Carbon dioxide has many advantages [1], however some of them can be flammable and/or toxic [2].

Since the early 1996 HFCs (such as refrigerant R-134a) have obtained vital post as the most potential long-term alternatives to replace CFCs and/or HCFCs, and ever since they are widely applied to air-conditioning and heat pumping systems. However, in recent years, the international understanding on the global warming due to alternative refrigerants identifies the HFCs being among those which have considerable impact on the global warming. In accord with such understanding, developing new generation of promising alternative refrigerants that meet the criteria of low global warming besides zero ozone depletion potential is undertaken by researchers [3-9].

A promising alternative refrigerant to replace R134a is the zeotropic refrigerant R-410A as it may enhance the refrigeration cycle performance due to its promising thermophysical properties. However, although R-410A is of zero ODP, it has a high GWP, even higher than that of R-134a.
The goal of this work concentrates on investigating the performance of a small refrigerator with a drop-in refrigerant R-410A in place of the original refrigerant R-134a to examine the possibility of replacement [7, 10-13].

2. Components and Properties of R-410A and R-134a.

Refrigerant R-410A, known in the market as Puron, EcoFluor R-410A, and Genetron R-410A, is a zeotropic, mixture of R-32 (50%) and R-125 (50%) by weight. The blend R-410A is usually used as a refrigerant in air conditioning applications as a substitute to R-22. Whereas, refrigerant R-134a, also known as 1,1,1,2-Tetrafluoroethane Genetron 134a, Suva 134a, is an HFC refrigerant, widely used in household refrigerators and automobile air conditioners as a substitute to R-12 and R-22.

Upon comparison of the thermodynamic properties given in Table 1, it is apparent that R-410A has better qualified properties at the level at which the refrigerant can be used than R-134a.

As for the physical properties of thermal conductivity, viscosity, specific heat, and vapor specific volume, R-410A has better physical properties than R-134a regarding heat transfer during the processes of the refrigeration cycle [14]. That is smaller size of components equipment can be used with R-410.

TABLE 1. Refrigerant Thermodynamic properties

Refrigerant No.	Name	Molecular Mass	Boiling point at pressure$_{atm}$, 1 bar abs	Freezing point at pressure$_{atm}$, 1 bar abs	Critical point		
					Temp (°C)	Pressure (kPa)	Specific volume (m^3/kg)
R-134a	Tetra -fluoroethane	102.03	-26.1	-96.67	101.1	4067.9	552
R-410A	R-32 Difluoromethane (50% weight), + R-125 Pentafluoroethane (50% weight)	72.6	-48.56	(-125) – (-103)	72.2	4757.38	–

As for the chemical properties, both refrigerants in concern are inflammable at normal the operating conditions. In general, R-410A should not be allowed to exist with air above atmospheric pressure or at high temperatures, or in an oxygen enriched environment.

Both of refrigerants; R-134a and R-410A are environment friendly as they don't contribute to ozone depletion (zero ODP). However, they both have a high global warming potential (1890 times the effect of carbon dioxide for R-410A, and 1300 for R-134a).

3. Experimental work and Procedure.

A small refrigerator of 250 W refrigeration capacity located at an engineering laboratory of the University of Jordan, the specifications of which are presented in Table 2, was used for carrying out the experiments. The refrigerator was originally charged with R-134a refrigerant, and then it was charged with drop-in refrigerant R-410A. The temperatures were taken using Copper-Constantan K-type thermocouples connected to the refrigerator components directly. They were placed along the refrigerator cycle. Time intervals were measured using a stopwatch. The refrigeration load was a mass of water. The experiments for both refrigerants were run at nearly the same weather conditions.

TABLE 2. Refrigerator specifications.

Total volume	155
Weight	38-35 kg
Rated voltage	220-240 V
Frequency	50 Hz
Rated input	110 watts
Rated Amperes	0.8 A
Net storage volume	130
Refrigerant used	R-134a
Compressor used	Panasonic 1 hp

The experimental procedure consisted of two parts; the first part was testing the influence of each refrigerant on the refrigerator performance by changing the evaporator temperature while holding the condenser temperature constant, and the second part on variable condenser temperature at constant evaporator temperature.

Variable evaporator readings were taken at normal working conditions of the refrigerator with nearly constant temperatures for the condenser. On the other hand, variable condenser readings were taken with maintaining the evaporator temperature nearly constant. The condenser temperature was changed using a water spray and a fan. The experiments were started with the original refrigerant, R-134a, and finished with the drop-in refrigerant, R-410A.

The temperatures measurements of refrigerator components during the experiments were collected and processed into a data processor concerning the performance of the refrigerator.

There were two sets of experiments. The first set of experiments were for a variable evaporator temperature at constant condenser temperature. The conditions when R-134a was used were; the evaporator temperature was varied from – 14.6 to –25.5°C (saturation pressures range between 100 to 170 kPa), whereas the condenser temperature was kept around 35°C (900 kPa pressure), the load was introduced to the evaporator space at 72.0°C, when the ambient temperature was about 11.6°C. The conditions when R-410a was used were; the evaporator temperature was varied from – 18.8 to –25.2°C, whereas the condenser temperature was kept around 38°C, the load was introduced to the evaporator space at 72.4°C, when the ambient temperature was about 13.0°C. The second set of experiments were for a variable condenser temperature at constant evaporator temperature. The conditions when R-134a was used were; the condenser temperature was varied from 41.4 to 46.5°C (saturation pressures range between 1000 to 1200 kPa), whereas the evaporator temperature was kept around – 19.2°C (135 kPa pressure), the load was introduced to the evaporator space at 12.0°C, when the ambient temperature was about 14.0°C. The conditions when R-410A was used were; the condenser temperature was varied from 40.5 to 47.2°C, whereas the evaporator temperature was kept around – 20.2°C, the load was introduced to the evaporator space at 7.0°C, when the ambient temperature was about 16.0°C.

Theoretical Analysis. The significant quantities of a standard vapor-compression cycle are; the work of compression, the heat rejection rate, the refrigeration effect and capacity, the mass rate of flow, and the coefficient of performance [15].

The work of compression, w, in kJ/kg, is the work required by the compressor, i.e.,

$$W = h_2 - h_1 \qquad (1)$$

where h_1 and h_2 are the enthalpies at inlet and exit of the compressor, respectively. The power consumed by the compressor, W, in kW, is given by,

$$W = \dot{m}\,(h_2 - h_1) \qquad (2)$$

where $\dot{m}$ is the mass rate of flow of the refrigerant.

The compressor isentropic efficiency, η_{is}, was calculated using the following equation,

$$\eta_{is} = (h_{2s} - h_1) / (h_2 - h_1) \qquad (3)$$

where h_{2s} is the enthalpy at the exit of the compressor after isentropic compression process. The heat rejection rate, Q_{out}, in kW, is the rate of heat rejected by the refrigerant, i.e.,

$$Q_{out} = \dot{m}\,(h_3 - h_2) \qquad (4)$$

where h_3 is the enthalpy at the exit of the condenser.

The refrigeration effect, q_{in}, in kJ/kg, is the heat absorbed by the refrigerant, i.e.,

$$q_{in} = h_1 - h_4 \qquad (5)$$

where h_4 is the enthalpy at the exit of the evaporator.

The refrigeration capacity, Q_{in}, in kW, is the rate of heat absorbed by the refrigerant, i.e.,

$$Q_{in} = \dot{m}\,(h_1 - h_4) \qquad (6)$$

The mass rate of flow of the refrigerant in kg/s is calculated from the following expression,

$$\dot{m} = [(mC\,\Delta T)_{water} + (mC\,\Delta T)_{container}] / [(\Delta h_1 - \Delta h_2)\times time] \qquad (7)$$

where m is the mass in kg, C is the specific heat in kJ/(kg.K), ΔT is the temperature difference in °C, and Δh_1 and Δh_2 are the enthalpy difference for the evaporator at exit and inlet during a given period of time, respectively. The mass of water and carton container were 0.5 and 0.2 kg, respectively. The C values for water and carton used were 4.186 and 2.5 kJ/(kg.K), respectively.

The coefficient of performance, COP, is given by,

$$COP = \text{Refrigeration capacity} / \text{Compressor power} = Q_{in}/W \qquad (8)$$

These quantities are controlled largely by the cycle suction and discharge pressures. For this work, these pressures were found by taking the temperatures of the middle condenser and evaporator inlet.

For R-134a, ASHRAE code was used, and the saturation pressures were found by interpolation within the data in the table of saturated pressures and temperatures, based on the thermocouples temperature readings that were placed at the middle of the condenser and the evaporator inlet. For R-410A, SUVA code was used, the saturation pressures were also found by interpolation as in the case of the original refrigerant. However, R-410A is a mixture of refrigerant fluids, and thus it has different pressures at each saturation temperature. But, for simplicity, the average pressure was taken for each state as the difference in pressure between the constituent refrigerants is small. That is,

$$Pavg = (P_l + P_g) / 2 \qquad (9)$$

where P_l and P_g are the pressures at the saturated liquid and vapor lines in kPa, respectively. As for the enthalpies at every state of both refrigerants, they were found using the EES (Engineering Equation Solver, commercial version 6.883-3D [09/01/03] software).

Results and Discussion. Comparison between the experimental results of the thermal performance tests performed on the refrigerator using the two refrigerants, R-134a and R-410A, under approximately similar conditions, was carried out and analyzed. The comparison was made for the two sets of experiments (variable evaporator temperature and variable condenser temperature) based on; power of the compressor, refrigeration capacity, heat rejection, coefficient of performance, and compressor isentropic efficiency.

Considering the variable evaporator temperature set of experiments first, Figs. 1 through 5 display the results for the two refrigerants. Figure 1 shows the effect of evaporating temperature on compressor's power. Although the results are scattered, the power consumption is a little lower for the refrigerant R-134a, taking into account that the compressor used was for R-134a.

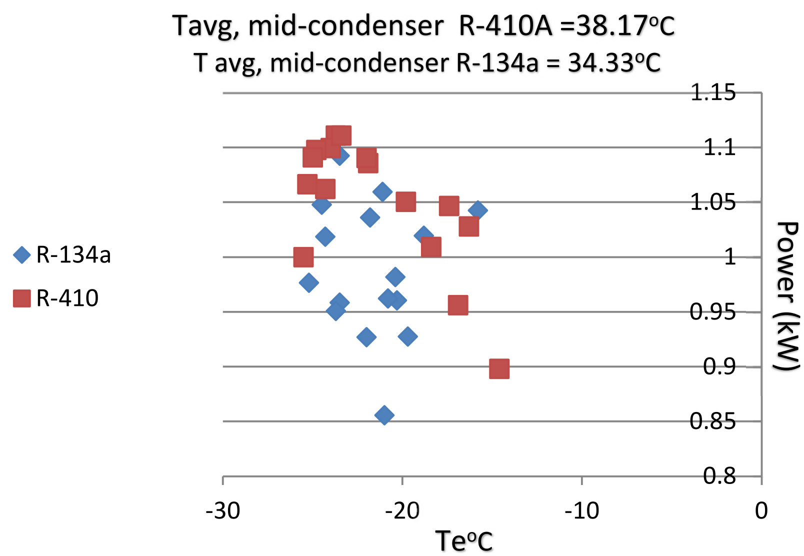

FIGURE.1. Effect of evaporator temperature on compressor power.

Figure. 2, and 3 gives the relation between the refrigeration capacity and the evaporating temperature. For both refrigerants, as the evaporating temperature increases, the refrigeration capacity increases. However, the increase in refrigeration capacity for R-410A is greater than that for R-134a by about 23%. As a result, the heat rejection rate is larger for R-410A as illustrated in Figure. 5.

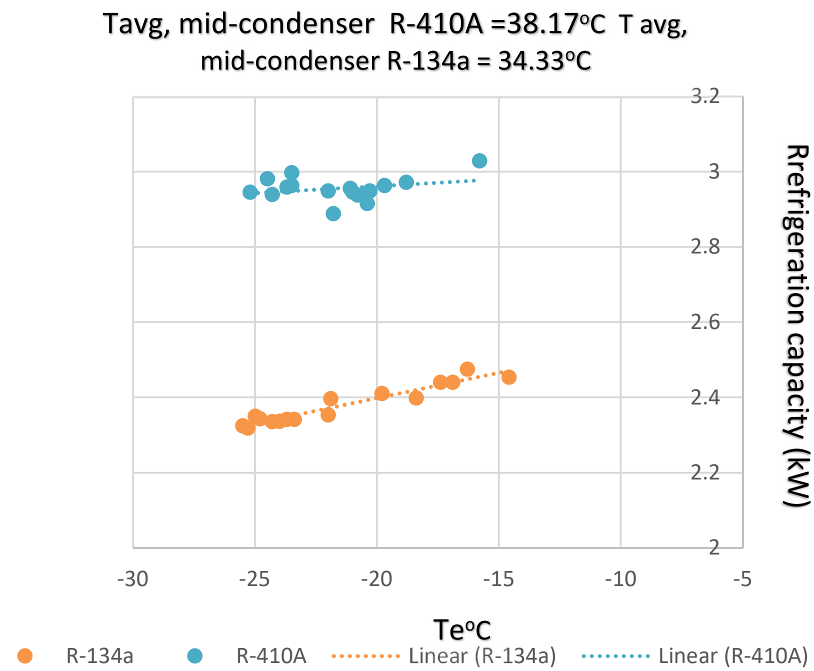

FIGURE. 2. Effect of evaporator temperature on refrigeration capacity.

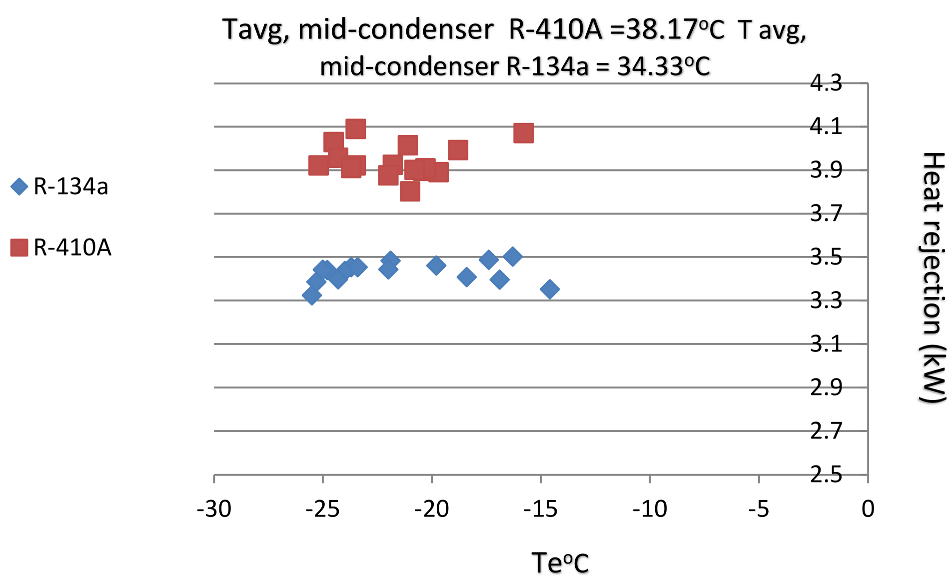

FIGURE. 3. Effect of evaporator temperature on heat rejection rate.

Figure 4 presents the relation between the coefficient of performance, COP, and the evaporating temperature. The figure indicates that as the evaporator temperature increases, the COP increases for both refrigerants, although the COP values are higher for R-410A by about 24% than for R-134a.

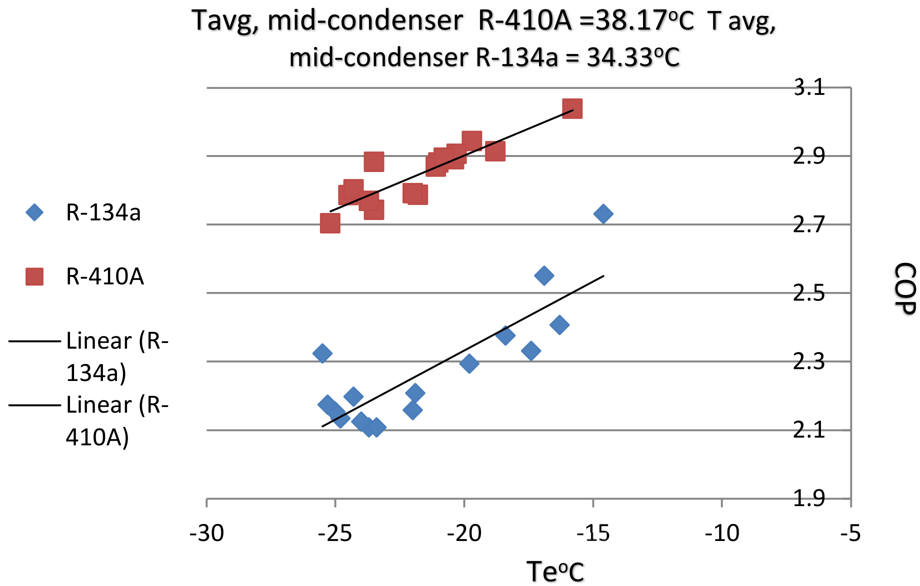

FIGURE. 4. Variation of coefficient of performance with evaporator temperature.

As for the isentropic efficiency of the compressor, it can be noticed from Fig. 5 that it is almost similar for both refrigerant, being around 85% ± 3%.

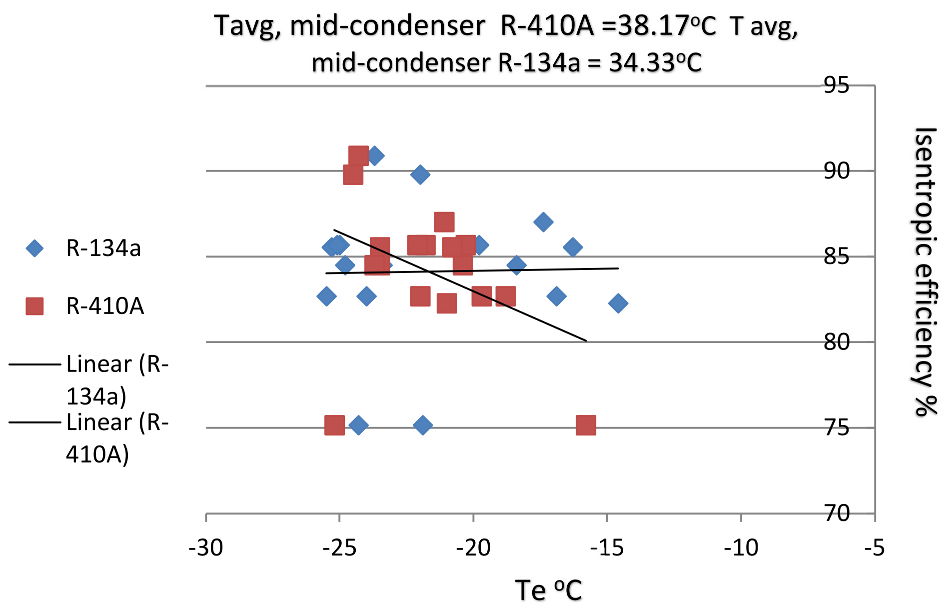

FIGURE. 5. Effect of evaporator temperature on compressor isentropic efficiency.

Figures 6 to 10 present the results of the second set of experiments where the condenser temperature is varied. Figure 6 display the effect of changing the condenser temperature on the compressor's power. The results indicate that the power consumption increases with the increase of the condensing temperature for both refrigerants, but it is lower for the refrigerant R-410A by about 3.5% than that of R-134a.

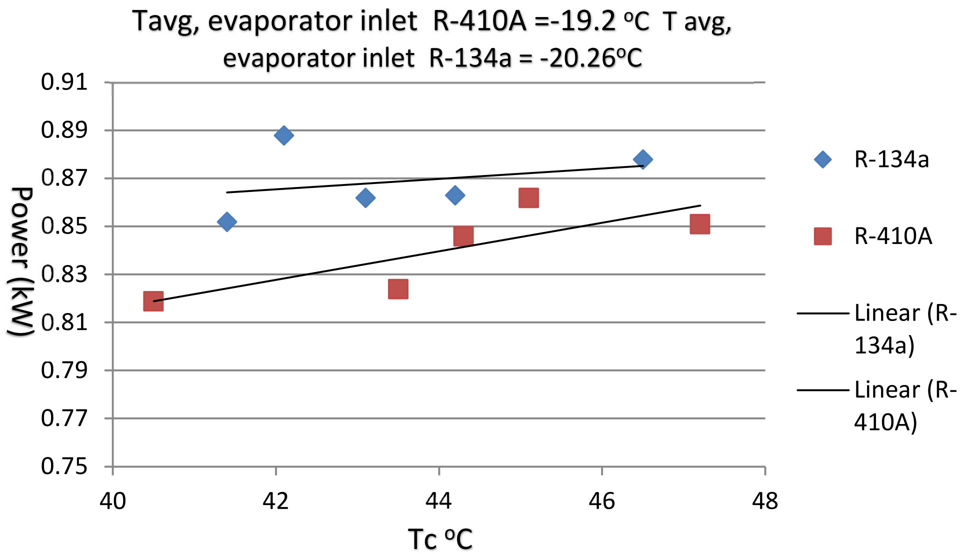

FIGURE. 6. Effect of condenser temperature on compressor power.

Figure 7 shows the influence of varying the condenser temperature on the refrigeration capacity. As one expects for both refrigerants, as the condensing temperature increases, the refrigeration capacity progressively decreases. The trend decrease in the refrigeration capacity for R-134a is lower than that for R-410A by about 3%. The power and refrigeration capacity variation with the condensing temperature results in a heat rejection rate slightly lower and steeper for R-134a than for R-410A as shown in Figure. 8.

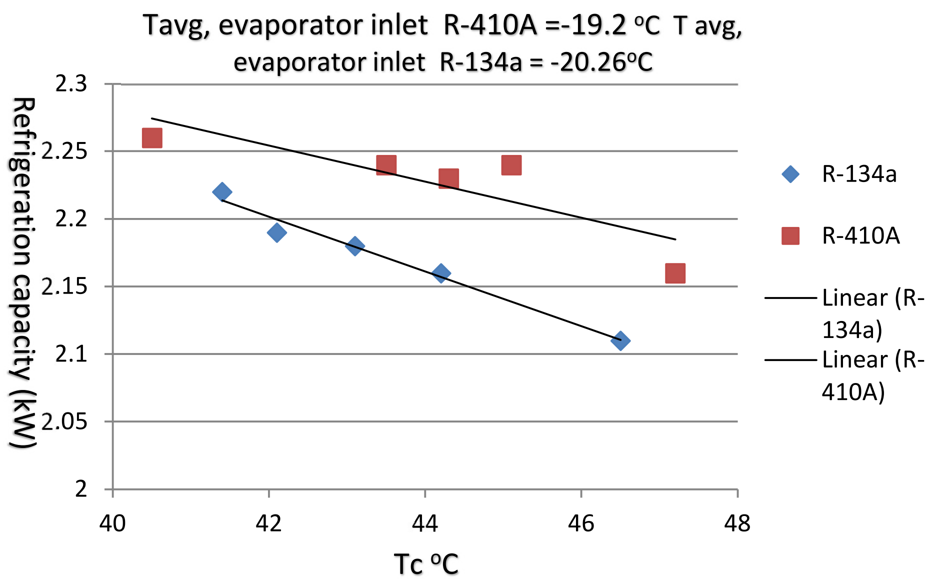

FIGURE. 7. Effect of condenser temperature on refrigeration capacity.

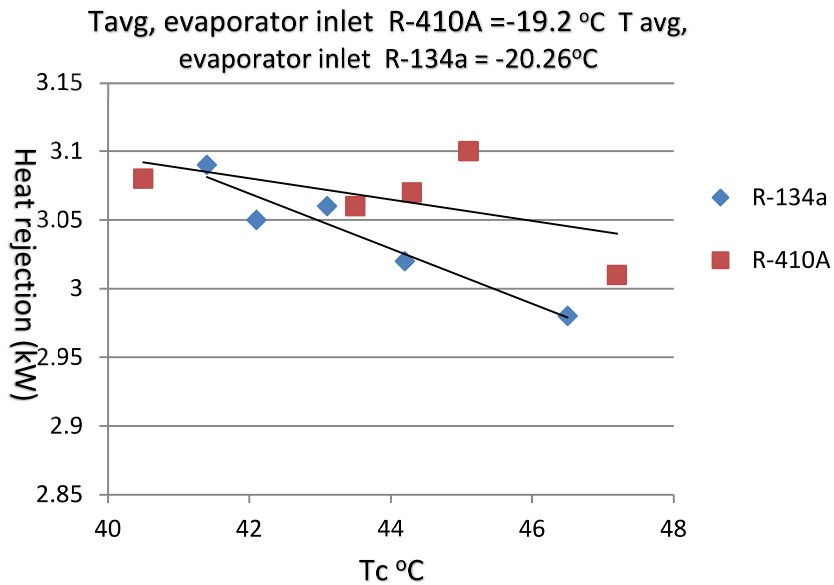

FIGURE. 8. Effect of condenser temperature on heat rejection rate.

The relation between the coefficient of performance, COP, and the condensing temperature is illustrated in Figure. 9. The figure indicates that as the condenser temperature increases, the COP decreases for both refrigerants. This is so since the refrigeration capacity decreases, and the compressor power increases with an increase in the condensing temperature. The COP values are higher for R-410A by about 7% than for R-134a.

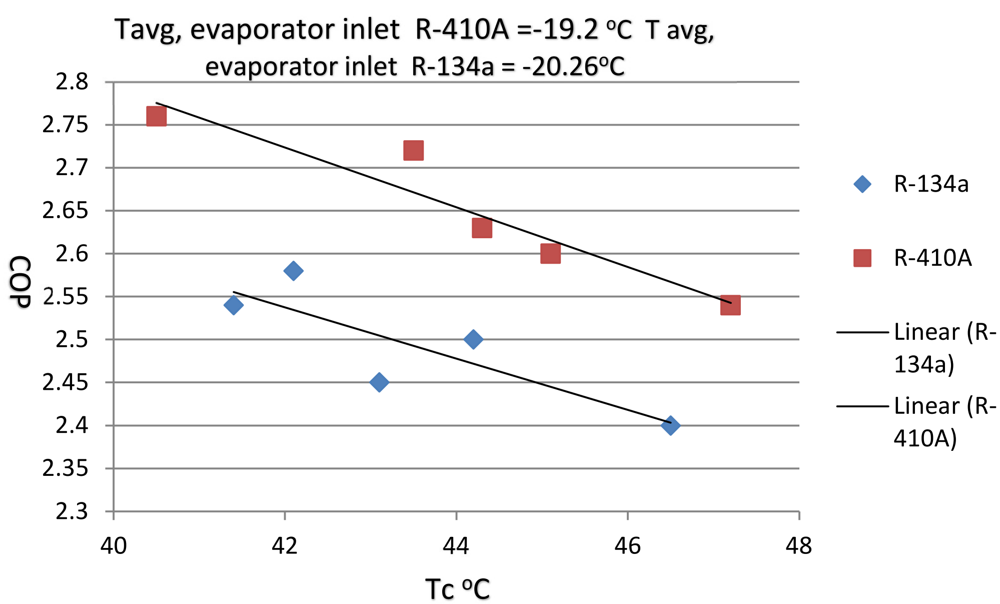

FIGURE. 9. Effect of condenser temperature on coefficient of performance.

The isentropic efficiency of the compressor is slightly higher for R-134a than R410A when the condensing temperature was changed as given in Figure. 10. Both trends of efficiencies are reduced with reduced condenser temperature.

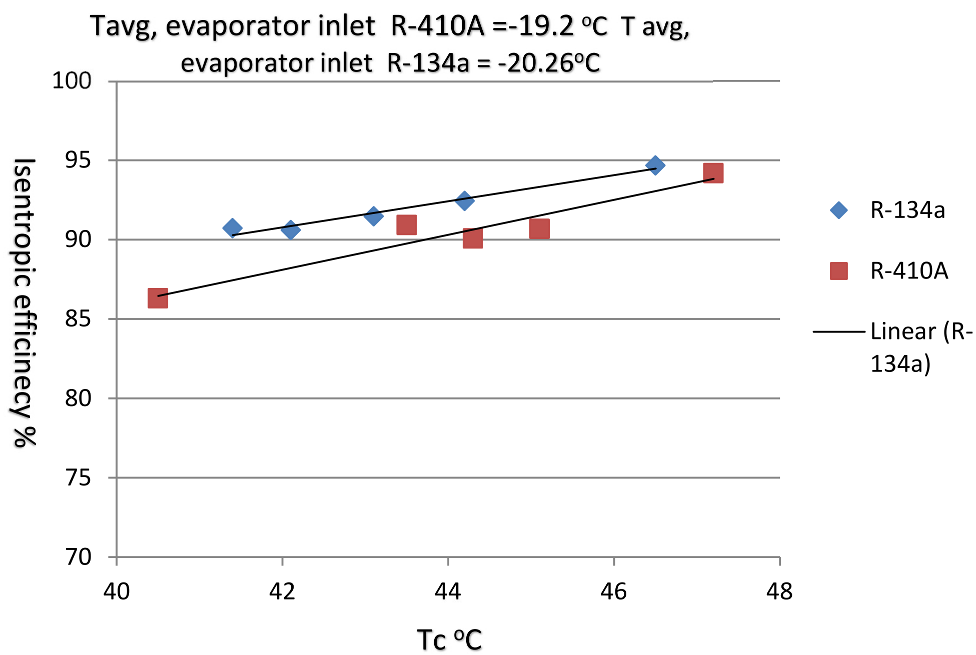

FIGURE. 10. Effect of condenser temperature on compressor isentropic efficiency.

Conclusions. This experimental study was carried on a small refrigerator to study the performance of the refrigerator using each of two refrigerants R-134a and R-410A. The test results have provided the following conclusive remarks:

- The power consumption was slightly lower when R-134a was used when the evaporator temperature was varied. On the other hand, it was the other way round when the condenser temperature was varied.
- The refrigeration capacity was higher by about 23% for R-410A when the evaporator temperature was varied.
- The heat rejection was higher when R-410A was used at both sets of experiments.
- The COP of the refrigerator was higher by about 24% for R-410A when the evaporator temperature was varied.

The isentropic efficiency, however, was generally slightly higher when R-134a was used, not forgetting that the compressor used was an R-134a compressor.

In general, the results indicate the possibility of dropping in refrigerant R-410A in place of refrigerant R-134a with a remarkable improvement in the coefficient of performance.

REFERENCES

[1] Adriansyah, W., Combined AC-HWH System for Indonesian Climate Condition. Bali Indonesia, 2003. FTEC.
[2] Yoon, S.H., et al., Characteristics of evaporative heat transfer and pressure drop of carbon dioxide and correlation development. International Journal of Refrigeration, 2004. 27(2): p. 111-119.
[3] Fatouh, M. and M. El Kafafy, Assessment of propane/commercial butane mixtures as possible alternatives to R134a in domestic refrigerators. Energy Conversion and Management, 2006. 47(15): p. 2644-2658.
[4] Bolaji, B.O., Performance investigation of ozone-friendly R404A and R507 refrigerants as alternatives to R22 in a window air-conditioner. Energy and Buildings, 2011. 43(11): p. 3139-3143.
[5] Kazakov, A., M.O. McLinden, and M. Frenkel, Computational Design of New Refrigerant Fluids Based on Environmental, Safety, and Thermodynamic Characteristics. Industrial & Engineering Chemistry Research, 2012. 51(38): p. 12537-12548.
[6] Barta, R.B., D. Ziviani, and E.A. Groll, Experimental analyses of different control strategies of an R-410A split-system heat pump by employing a turbomachinery expansion recovery device. International Journal of Refrigeration, 2020. 112: p. 189-200.
[7] Kaew-On, J. and S. Wongwises, Experimental investigation of evaporation heat transfer coefficient and pressure drop of R-410A in a multiport mini-channel. International Journal of Refrigeration, 2009. 32(1): p. 124-137.
[8] Markötter, H., et al., Morphology correction technique for tomographic in-situ and operando studies in energy research. Journal of Power Sources, 2019. 414: p. 8-12.
[9] Saraireh, M.A., F.M. Alsaraireh, and S.S. Alrwashdeh, Investigation of heat transfer for staggered and in-line tubes. International Journal of Mechanical Engineering and Technology, 2017. 8(11): p. 476-483.
[10] Román, A., et al., Measurement of the void fraction and maximum dry angle using electrical capacitance tomography applied to a 7 mm tube with R-134a. International Journal of Refrigeration, 2018. 95: p. 122-132.
[11] Pamitran, A.S., et al., Forced convective boiling heat transfer of R-410A in horizontal minichannels. International Journal of Refrigeration, 2007. 30(1): p. 155-165.
[12] Mateu-Royo, C., et al., Comparative analysis of HFO-1234ze(E) and R-515B as low GWP alternatives to HFC-134a in moderately high temperature heat pumps. International Journal of Refrigeration, 2021. 124: p. 197-206.
[13] Göbel, M., et al., Transient limiting current measurements for characterization of gas diffusion layers. Journal of Power Sources, 2018. 402: p. 237-245.
[14] fundamentals, A.S.o.H.R.a.A.C.E.h.o., ASHREA 1993, Atlanta
[15] Jones, W.F.S.a.J.W., Refrigeration and Air Conditioning. 1982: McGraw –Hill, New York.