Evaluation of low GWP refrigerants as alternatives for R134a in a vapor compression refrigeration cycle under varying operating conditions

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ABSTRACT

The present work is a numerical comparative study for low GWP refrigerants based on R161, R152a, R1234ze(e) and R1234yf as a substitute for R134a in a vapor compression refrigeration cycle under varying operating conditions. A computational model is developed by engineering equation solver software (EES). The effects of degree of subcooling, superheating, evaporating and condensing temperatures on the main performance parameters in term of mass flow rate of refrigerant, pressure ratio, volumetric cooling capacity, compressor input power and coefficient of performance are computed for selected refrigerants. The performance results are compared with respect to R134a. The results indicated that the coefficient of performance for R152a is slightly better than the other refrigerants under various operating conditions. The refrigerant R1234ze(e) has approximately the same COP and VCC of R134a and it has the lowest compressor input power and TEWI value over the four compared low GWP refrigerants.

Keywords: Low GWP refrigerants, Vapor compression Refrigeration cycle, Operating conditions, Main performance parameters, TEWI.

الخلاصة:

البحث الحالي هو دراسة عددية لمقارنة اداء موائع التثليج ذات احتباس حراري منخفض مثل R161, R152a, R1234yf و R1234ze(e) كبدائل لمائع التثليج R134a بدورة التثليج الانضغاطية البخارية عند درجات حرارة التشغيلية مختلفة. تم اجراء الحسابات باستخدام برنامج (EES) لمحاكاة منظومات التثليج ولموائع التثليج المختارة. إنّ الهدفَ الأساسي للدراسةِ الحاليةِ هو دراسة تأثيرمختلف الشروط التشغيلية مثل درجات حرارة التبريد الفائق و التحميص و درجات المبخر والمكثف على متغيرات أداءِ الدورةَ والتي هي الكتلة الجريانية لمائع التثليج ومعامل الاداء وسعة التثليج الحجمية و قدرة الضاغط. كذلك تم مقارنة متغيرات الاداء لهذه الموائع مع متغيرات الاداء لمائع التثليج R134a. النتائج بينت ان معامل اداء لمائع R152a اعلى بقليل اذا ما قورن ببقية الموائع الاخرى عند مختلف درجات حرارة التشغيلية. كذلك بينت النتائج ان المائع R1234ze(e) يملك معامل اداء و سعة تثليج حجمية مشابهة لمائع التثليج R134a بينما يمتلك من جهة اخرى اوطا قدرة داخلة للضاغط و كذلك اوطا التأثير الحراري المكافئ الكليّ(TEWI) مقارنة ببقية الموائع.

الكلمات المفتاحية : – موائع ذات احتباس حراري منخفض،دورة التثليج الانضغاطية البخارية، الشروط التشغلية، متغيرات الاداء الرئيسية، التأثير الحراري المكافئ الكليّ.

Nomenclature

B	carbon dioxide emission factor
C	Compressor volumetric clearance ratio;
E	Energy consumption (kWh)
H	Enthalpy (kJ/kg)
l	Leakage rate per year (%)
m	Refrigerant mass (kg)
$\dot{m}$	Refrigerant mass flow rate (kg/h)
n	Adiabatic index (n=Cp/Cv)
N	Compressor speed (rpm)
p	Pressure (bar)
P_r	Pressure ratio
$\dot{Q}$	Heat transfer rate (kW)
S_l	Service life of refrigeration system (years)
T	Temperature(°C)
v	Specific volume at compressor suction (m^3/kg)
V	Volume (m^3)
$\dot{W}$	Compressor power (kW)

Greek symbols

η	Efficiency

Subscripts

c	condenser
d	displacement
e	evaporator
I	input
is	isentropic
r	refrigerant
v	volumetric

Abbreviations

CFC	Chlorofluorocarbon
COP	Coefficient of performance
EES	Engineering Equation Solver
EOS	Equation Of State
GWP	Global Warming Impact (CO_2=1)
HC	Hydro Chlorofluorocarbon
HCFC	Hydro Chlorofluorocarbon
HFC	Hydrofluorocarbon
HFO	Hydrofluorolefin
ODP	Ozone depletion potential (−)
TWEI	Total Equivalent Warming Impact (kg of CO_2)
VCC	Volumetric cooling capacity (kJ/m^3)

1. Introduction

The Chlorofluorocarbons(CFCs) and Hydrochlorofluorocarbons (HCFCs) lead to ozone layer depletion because of the presence of chlorine atoms in the molecule structure. Therefore, Montreal protocol established the phase out of them. The HFC refrigerants are candidates as substitutes to CFCs and HCFCs, since they contain no chlorine atoms in the molecule structure (zero ozone depletion potential). R134a is one of pure hydrofluorocarbons (HFCs). Through research in the last years, it was observed that R134a raises the global warming because it contains fluorine in the molecule structure(Global Environmental Change Report, 1997).Global warming potential (GWP) in recent years becomes significant in evaluating the potential of refrigerant as ozone depletion potential(ODP).Thus,Kyoto protocol established the phased out of R134a, which has a high GWP(GWP≫150). Subsequently,there is a need to determine alternatives of R134a with low GWP (GWP< 150).

Many researchers have performed investigations on HFC refrigerants and their mixture or HFC/HC mixture in refrigeration systems in spite of these refrigerants are a source of global warming. Jabaraji et al., 2006 have used R407C/ R600a/R290 mixture as a substitute for R22 in a residential window type air conditioner. It was observed that the mixtures demand lengthening of the condenser to keep the discharge pressure within acceptable limits. Dalkilic and Wongwises, 2010 studied the performance analysis of refrigerant mixtures with various ratios based on R134a, R152a, R1270, R290, R32, R600 and R600a as alternative refrigerants to R12, R134a and R22. Among the refrigerants tested, two blends of R290/R600a (40/60% by weight) and R290/ R1270 (20/80% by weight) were the best possible alternatives to R12 and R22 respectively at evaporating temperatures ranging between −30 °C and 10 °C and condensation temperature of 50 °C. Baskaran, and Koshy, 2012 analyzed and compared the performance of various environment-friendly refrigerants such as HFC152a, HC290, HFC32, HC600a, HC1270 and RE170 with R134a in a vapor compression refrigeration system. Their results revealed that the RE170, R600a and R152a have a little higher performance coefficient (COP) than R134a under the same aforementioned operating conditions in the paper [3]. Wu et al., 2009 have used HFC mixture consisted of R152a/R125/R32 (48/18/34, by weight) in domestic air conditioner charged with R22. Likewise, the performance of binary mixture composed of the R32 and R134a was tested in air conditioner by Chen and Yu, 2008. Han et al. 2011 have used the small scale refrigeration system to experiment the R161 as a substitute for R410A. Their Results showed that refrigerant R161 was the most suitable refrigerant to R410A. Bitzer, 2007 concluded the refrigerants R152a, R32, R143a and R134a as good alternatives in domestic refrigeration system. Padilla et al., 2010 studied the exergy analysis of R413A(mixture of 3%R600a, 9%R218, 88% R134a) as a substitute to R134a and R12 in domestic refrigerator. Fatouh and Kafafy, 2006 have used hydrocarbon mixtures with different propane mass fractions as working fluids to replace R134a in household refrigerators. The results indicated that R290 was not appropriate for use as a drop in replacement for R134a in domestic refrigerators because of the increase of the operating pressures and low COP. Gang et al.,2005 have analyzed that the mixture of R152a and R125 in the composition of 85% mass fraction of R152a has a similar performance with R12. The experimental results indicated that R152a/R125 can be used to replace R12 as a new generation refrigerant of domestic refrigerators, due to its well environmentally acceptable. Experimental analysis of three Hydrofluorocarbon refrigerants R12, R152a and R134a were done by Bolaji *et.al.,* 2011. They found that the R152a could be used as an alternative refrigerant to R134a in the vapor compression system.

In few years, a number of hydrofluoroolefins (HFOs) and their mixtures have been introduced as a low GWP alternatives refrigerants to the HFCs and CFCs in heat pump and air conditioning systems (Pearson, 2013). HFOs are a new class of unsaturated HFC refrigerants which have very low GWPs of less than 6, higher cost than R134a, environmental friendliness and shorter atmospheric lifetimes. R1234yf, R1234ye, R1234zf, R1234ze(z) and R1234ze(e) are examples of HFOs. A Few studies have been done on these refrigerants. At international level, a number of studies have been carried out in China on pure HFO. While other studies have done on refrigeration systems with mixtures of pure HFO and refrigerants such as R32, R600a, R125 and R152a. Brown, 2009 concluded the thermo-physical properties of R1234ze(z). He also tested the performance of R1234ze(z) as a substitute to R114 in high temperature heat pump applications. Pham and Rajendran, 2012 used the R32 and HFO blends for replacing R410A in heat pump and air conditioning applications. Fujitaka et al., 2010 compared the system performances of pure R1234yf and R1234yf/R32 mixtures to that of R410A in a room air conditioner. The system performance of R1234yf was significantly lower than that of R410A. However, the system performance of the R1234yf/R32 mixture improved as the R32 concentration was increased. Zhang et al., 2010 have a theoretical study to examine the performance of HFOs with their mixtures as alternatives to R134a in air conditioning and R114 in high-temperature heat pump systems. In their study, the mixture M1A composed of R1234zf/R290 (60%/40% of the mass) offered lower pressure ratio and discharge temperature and higher COP with a similar VCC to that R134a. Giulia *et.al.,* 2015 have presented a experimental study to investigate the performance of three small GWP refrigerants HC600a, HFO1234yf, and HFO1234ze(e) in household refrigerators. Their test conditions were completed at different refrigerant mass flow rates and two evaporation temperatures,-15 and -20 °C.Their results showed that the HFO1234yf can be considered a direct drop-in substitute for HFC134a. Atilla and Vedat, 2015 investigated some characteristics of low global warming potential refrigerants R1234yf, L40, DR-5 and R444B. The theoretical results showed that R1234yf, L40, DR-5 and R444B refrigerants was a suitable substitute for R134a, R404A, R410A and R22, respectively.

The above literature review exposed that many researchers reported the performance of HFC refrigerants and/or their mixture or HFC/HC mixtures in vapor compression refrigeration systems. However, the possibility of using low GWP refrigerants: two pure HFC refrigerants (R161 and R152a) and two pure HFO refrigerants (R1234yf and R1234ze(e)) as a substitute for R134a in the vapor compression cycle needs further investigation. These refrigerants are not new refrigerants.They are studied previously in the search for a zero ozone depletion potential solution, but were not adopted due to some limitations such as flammability and toxicity problems. But nowadays, the requirement for low Global warming potential(GWP<150) probability requires accepting some flammability constraints for the refrigerants.Therefore, the major aim of this study is to examine theoretically the performance of R161, R152a R1234yf, and R1234ze(e) and their potential as alternative refrigerants to R134a in the vapor compression refrigeration cycle under varying operating conditions.

2. Selection of Refrigerants

An alternative refrigerant must satisfy several requirements: eco-friendly (low GWP and zero-ODP), low energy consumption, high latent heat of vaporization, high critical temperature, low cost, non-flammable and non-toxic (ASHRAE Handbook-Refrigeration, 2010). The alternative refrigerants do not have all these properties but it have at least both eco-friendly and energy efficient. The analysis has narrowed the refrigerant selection down to four refrigerant options: two pure hydrofluorocarbons (R161 and R152a) and two hydrofluoroolefins (R1234yf and R1234ze(e)). These low GWP refrigerants are often mildly flammable. The European standard EN378 gives the safety requirements for a wide variety of applications. As per the EN378 and ASHRAE 15, the refrigerant charge limit is approximately 15g/m^3 for R161, 20.8 g/m^3 for R1234yf and for R134a it is 250g/m^3. However, the refrigerant R134a was taken into account in the analysis as a reference refrigerant. The physical and environmental characteristics of selected refrigerants are given in Table 1. Fig. 1 displays the variation of saturation vapor pressure for selected refrigerants versus the temperature ranging from -60°C to 60°C, which covers the operating temperatures in most refrigeration systems. As shown in figure, the refrigerants are very similar in their relationship between saturation vapor pressure and temperature. At 60°C, the highest saturation vapor pressure refrigerant among the five is R161 and the lowest saturation pressure vapor refrigerant is R1234ze(e). At 60°C, the saturation vapor pressure of R161 is 28.7 % greater than the saturation vapor pressure of R134a, while R1234yf, R152a and R1234ze(e) are lower by 2.5 %, 10.6 % and 24.2 % respectively than the vapor pressure of R134a.

Specifications/Properties	Refrigerant				
Trade name	**R134a**	**R161**	**R152a**	**R1234yf**	**R1234ze(e)**
Chemical formula	CH2FCF3	CH3CH2F	CH3CHF2	CH2CFCF3	CF3CH=CHF
GWP_{100}	1300	12	140	4	6
ODP	0	0	0	0	0
Lubricant	Polyolester	Polyolester	Polyolester	Polyolester	Polyolester
Normal boiling point (°C)	-26.1	–37.6	-24.0	-29.4	-19
Critical pressure(bar)	40.59	47	45.23	33.82	35.76
Critical temperature(°C)	101.1	102.2	113.27	94.7	111.25
Critical density [kg/m^3]	511.9	644	365	476	489
Molecular weight (kg/kmol)	102.02	48.06	66.05	114.04	114.04
Safety group	A1	A3	A2	A2L	A2L
Lifetime (Yrs)	14.6	0.21	2	0.031	0.038

Table 1: Refrigerants data.

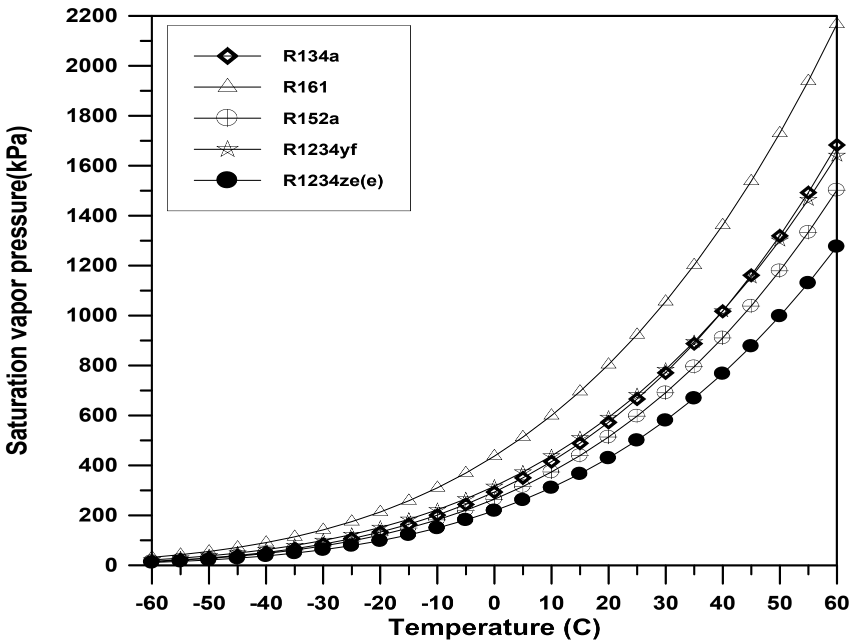


Fig. 1: Saturation pressure versus temperature

3- Performance parameter analysis

A vapour compression refrigeration system can be theoretically used under steady state conditions for various applications like air conditioning system, domestic refrigerator, chillers, cold storage warehouses, food storage locker and many more. The basic vapor compression system consists of four primary components; a compressor, a condenser, an expansion device and an evaporator. These components form a complete refrigeration cycle as shown in fig. 2a. In order to simulate the cycle, all models are interconnected with each other to form the complete model. In this study, a computer program is used to calculate COPs, volumetric cooling capacities, compressor input powers, mass flow rates, pressure ratios, and compressor discharge temperatures of the selected refrigerants (R134a, R161, R152a, R1234yf, and R1234ze(e)). The thermodynamic properties of these refrigerants are calculated using the Engineering Equation Solver (EES) software (Klein, 2015). These properties are calculated from the equation of state. The refrigeration cycle can be described by p-h diagram as shown in fig 2. In order to simplify the simulations, the following assumptions are made,

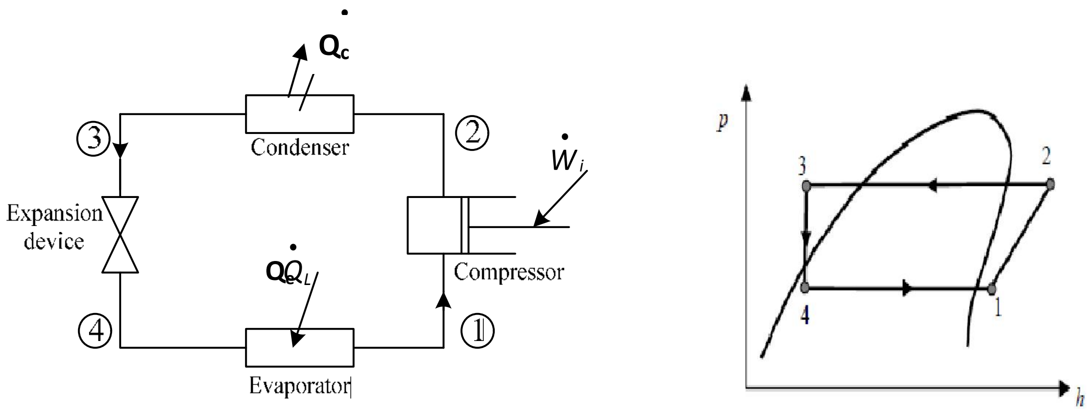
1-Steady state conditions are considered in all components

2-Compression process in the compressor and expansion process in the expansion device are assumed to be isentropic and isenthalpic, respectively.

3-Isentropic efficiency of the compressor is 75%,

4- No pressure drops are assumed throughout the condenser and evaporator.

5- Heat capacities for vapor and liquid refrigerant are assumed to be constant.



(a) **(b)**

Fig. 2: a) System schematic diagram b) Pressure-enthalpy diagram of a simple refrigeration cycle

At steady state, the refrigerant mass flow rate is assumed to be the same at all the components of cycle. The main parameters of the compressor are volumetric efficiency (η_v), refrigerant mass flow rates ($\dot{m}_r$) and isentropic power ($\dot{W}_{is}$):

$$\eta_v = \left[1 + C - C(\Pr)^{\frac{1}{n}}\right] \qquad (1)$$

$$\dot{m}_r = \frac{V_d . N . \eta_v}{v} \qquad (2)$$

$$\dot{W}_{is} = \dot{m}_r .(H_{2is} - H_1) \qquad (3)$$

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

$$\dot{W}_I = \frac{\dot{W}_{is}}{\eta_{is}} \qquad (4)$$

The heat extracted by the refrigerant in the evaporator or cooling capacity is expressed as:

$$\dot{Q}_e = \dot{m}_r .(H_1 - H_4) \qquad (5)$$

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

$$\dot{Q}_c = \dot{m}_r .(H_2 - H_3) \qquad (6)$$

The cooling coefficient of performance (COP) of the system is expressed as:

$$COP = \frac{\dot{Q}_e}{\dot{W}_I} \qquad (7)$$

The volumetric cooling capacity (VCC) is the refrigerating effect divided by the vapor specific volume entering the compressor and is a measure for the compressor size.. It is expressed as [10]:

$$VCC = \frac{\dot{Q}_e}{\dot{m}_r \cdot v_1} \cdot \eta_v \quad (8)$$

The pressure ratio ($\Pr$) is defined as the ratio of the condenser pressure to the evaporator pressure. The $\Pr$ can be expressed as;

$$\Pr = \frac{P_c}{P_e} \quad (9)$$

The Total Equivalent Warming Impact (TEWI) parameter is calculated for both direct and indirect equivalent CO_2 contribution (Davies and Caretta, 2004)

$$TEWI = \text{Direct contribution} + \text{Indirect contribution} \qquad \text{(kg of CO2)}$$
$$TEWI = (m \times l \times S_l \times GWP_{100}) + (E \times S_l \times B) \quad (10)$$

The following assumptions are used:

1-The refrigerant charge leakage per year (l) is assumed to be 7 % (Rocca and Panno, 2011).

2-The service life (S_l)is 10 year

3-The hours of operation air conditioning unit are 12 hr/day,

4-The term (B) is assumed to be 0.45 $(kg\ CO_2/kW.h)$.

4. Discussion of Results

4.1 Standard operating conditions

In this study, the standard operating conditions are taken from unitary air-conditioning system (as example of vapor compression refrigeration system) according to the ANSI/ARI standard 540-1999. The calculations are done in a condensing temperature of 54.4°C and an evaporating temperature of 7.2°C. The vapor is superheated by 5.6 °C in the evaporator and the liquid is subcooled by 8.3 °C in the condenser. Based on these operating conditions, theoretical performance parameters for unitary air-conditioning system of selected refrigerants are calculated as shown in Table 2.

Table 2: Comparison of main performance parameters for selected refrigerants

Performance parameters	Refrigerants				
Trade name	R134a	R161	R152a	R1234yf	R1234ze(e)
Compressor input power(kW)	0.5283	0.7541	0.4916	0.5152	0.3948
Condenser heat rejection(kW)	2.46	3.521	2.349	2.333	1.851
Pressure ratio(-)	3.906	3.488	3.876	3.616	3.959
Refrigerant mass flow rate (kg/s)	0.01358	0.009679	0.007922	0.01649	0.01119
Volumetric cooling capacity(kJ/m^3)	2246	3220	2160	2114	1693
Coefficient of performance (-)	3.656	3.686	3.779	3.528	3.687
Condenser pressure(kpa)	1474	1917	1317	1448	1117
Evaporator pressure(kpa)	377.5	549.8	339.8	400.4	282

4.2 Effects variation of operation conditions

The performance characteristics of the vapor compression refrigeration system working with R134a, R161, R152a, R1234yf, and R1234ze(e) under the effects variation of the operating temperatures are studied in this investigation. The operating temperatures are the subcooling and superheating temperatures ranging from 6 to 13°C, the evaporating temperatures ranging from -30 to 5 °C and condensing temperatures ranging from 30 to 65 °C. All the results are compared to R134A which is chosen as a reference refrigerant.

Fig. 3 shows that the COPs increases with increasing condenser subcooling temperatures. This figure also showed that R152a is found to be higher COP than the other refrigerants. The COPs of R161 are closer to that of R134a at high range of subcooling temperatures. The average coefficient of performances of R1234ze(e) and R161 are 0.7% and 0.5% higher than that of R134a, respectively, whereas the average coefficient of performances of R152a and R1234yf are 3% higher and 3.2% lower as compared to the R134a respectively.

As shown in **Fig. 4**, the COPs of the selected refrigerants with exception of R161 and R152a increase with increasing superheating temperatures. The theoretical results of coefficient of performances indicated that R152a is the highest COP. The average COPs for R152a, R1234ze(e) and R161 are higher by 2.9%, 1% and 0.3% than that of R134a, respectively. Whereas the average COP for R1234yf is lower by about 2.9% compared to R134a.

In **figs. 5** to **17**, the evaporation temperature is varied from 30 to 5 °C while condensing temperature, superheating and sub-cooling temperatures are fixed at 55 °C, 5.6 °C and 8.3 °C respectively. **Fig. 5** shows that the volumetric cooling capacity (VCC) of the investigated refrigerants with evaporating temperatures is compared. The volumetric cooling capacity of the selected refrigerants decreases with increasing in evaporating temperatures. It is clear from figure 4, R1234ze(e) and R161 have the lowest and the highest volumetric cooling capacity, respectively. Therefore, the bigger size of compressor is required for R1234ze(e). The volumetric cooling capacity of R152a and R1234yf are closer to that of R134a for evaporating temperature between -30°C and -10°C.

The comparison of the amount of heat rejected from the condenser has been shown in **Fig. 6** for various investigated refrigerants**.** The condenser heat rejection increases with increasing evaporator temperature. R1234ze(e) and R16 yield the lowest and highest condenser heat rejection, respectively.

Fig. 7 shows the pressure ratio of selected refrigerants with evaporating temperatures. The pressure ratio decreases rapidly with increasing the evaporating temperatures because of increasing evaporator pressure. It is noted from fig. 6 that the average pressure ratio of R1234ze(e), R134a and R152a are very close to each other in the lower range in **fig. 7**. While the average pressure ratio for R1234yf and R161 are lower by 13% and 18.3% than that of R134a, respectively.

Fig. 8 presents the mass flow rate as a function of evaporating temperatures. With increasing evaporator temperature for all refrigerants, the mass flow rate across the compressor increases, causing compressor work to increase slowly and the cooling capacity also increases because of a rise in the volumetric refrigeration effect. It can be seen that R1234ze(e), R161, and R152a exhibit a lower mass flow rate than R134a, while R1234yf has the highest mass flow rate than R134a.

In **Fig. 9**, with the increase of evaporating temperatures, COPs increase for all refrigerants. As shown in **fig. 9**, R152a has the highest average COPs by about 5.1% than that of R134a and R1234yf have the lowest COPs by about 5.9% than that of R134a for all evaporating temperatures. The results of other refrigerant were R161 and R1234ze(e) are closer to refrigerant R134a in the range of high evaporating temperatures.

The discharge temperature decreases with increasing evaporating temperatures for all refrigerants as illustrated in **fig. 10**. The discharge temperature of compressor for refrigerant R152a is a significantly higher compared to R134a by 25.7% to 14.7% with increase in evaporator temperature. Whereas, R1234yf has the lower discharge temperature than that of R134a by 23.2% to 14.2% at similar conditions. The lower discharge temperature is beneficial for compressor.

Fig. 11 shows that the pressure ratio increases when condensing temperature increases for all refrigerants under the study. The pressure ratio for R1234ze(e) is the highest and R161 is lower than the other refrigerants.

As shown in **Fig. 12**, volumetric cooling capacity decreases with increasing condensing temperatures for all refrigerants. As it is seen from **Fig. 12**, the average volumetric cooling capacity for R1234ze(e) is lower by about 24.5% than that of R134a while R161 is higher by about 40.5% than that of R134a for all condensing temperatures. The volumetric cooling capacity of R152a is close to R134a at condensing temperature 65°C. The The average volumetric cooling capacity of R152a is about 5.57 % lower compared to that of R134a over all condensing temperatures.

Fig. 13 shows compressor input power versus condensing temperatures of the selected refrigerants. When condensing temperature increases, the compressor input power also increases. The compressor input power for R161 and R1234ze(e) is higher and lower than the other refrigerants. This is because R161 and R1234z(e) have highest and lowest saturation pressures than the other. The compressor input power of R161 is about 41.2% higher compared to R134a while R1234yf, R152a, and R1234ze(e) are about 2.3%, 7.34%, and 25.2% lower compared to that of R134a.

Fig. 14 displays the heat rejection of condenser decrease with increasing condensing temperature. As shown in Figure, the average heat rejection for R161 and R1234yf are higher by about 56.9 % and 7% compared to that of R134a whereas the other refrigerants R152a and R1234ze(e) are lower by about 7.8% and 15.8% compared to that of R134a, respectively.

Fig. 15 reveals the refrigerant mass flow rate versus condensing temperatures for all the refrigerants. The mass flow rate of R1234yf is 21.2% higher compared to that of R134a, whereas the mass flow rate for R1234ze(e), R161 and R152a are 17.5%, 29.1% and 41.7% lower than that of R134a, respectively.

Fig. 16 shows the COP versus the condensing temperature at constant evaporating temperature. As shown in Figure, the COPs decrease for all refrigerants with the increase of condensing temperatures because of increasing in temperature lift which is the difference between the condenser and evaporator temperatures. R152a has the highest COPs than for the other considered refrigerants due to its high critical temperature (113.27°C), whereas R1234yf has the lowest COPs than the other refrigerants. R152a and R1234ze(e) are slightly greater in average coefficient of performance by 1.9% and 0.8%, respectively when compared to R134a, while R161 and R1234yf are lower in coefficient of performance by 0.4% and 2.2%, respectively than that of R134a.

Fig. 17 shows the variation of compressor discharge temperatures of different refrigerants versus increasing condensing temperatures. The compressor discharge temperature for all four refrigerants increases with increasing condensing temperatures. R161 shows the highest discharge temperature, which is about 8.1°C to 16.9°C higher than R134a while R1234yf has the lowest discharge temperature than the other refrigerants.

4.3. Environmental impact

The total equivalent warming impact (TEWI) expressed in terms of kg of CO_2 is accepted measure for assessing the global warming impact of a refrigeration system is It is desirable to maintain this parameter as low as possible. The TEWI value of a refrigeration system is calculated according to ANSI/ARI standard setting conditions, 1999 for unitary air conditioning system, as shown in **fig. 18**. The power consumption of refrigerant R161 is the highest than the other refrigerants under the standard conditions. Hence, it is not a very suitable substitute for R134a based on TEWI analysis. Other results showed that the TEWI values for R1234yf, R152a and R1234ze(e) are lower about 5.8 % , 9.7 % , and 27.7 % than R134a.

5. Conclusions

In the present work performance analysis of vapor compression refrigeration cycle for R134a and its alternate refrigerants (R161, R152a, R1234yf and R1234ze(e)) has been carried out by varying evaporator temperature between -30°C to 5°C, condenser temperature between 30°C to 65°C, degree of subcooling and superheating between 6°C to 13°C. The parametric investigation, such as COP, VCC, pressure ratio for the selected refrigerants have been carried out theoretically and have been compared with R134a as reference refrigerant. The main conclusions are as follows:

1- Increasing evaporating temperatures at a constant condensing temperature lead to increase the coefficient of performance, volumetric cooling capacity, heat rejection and mass flow rate while these parameters decrease with increasing condensing temperatures at constant evaporating temperature.

2- The average input power of compressor for R161 is the highest and R1234ze(e) is lower than for the other considered refrigerants.

3-R152a gives the highest coefficient of performance while R1234yf has the lowest coefficient of performance than the other refrigerants under various operating conditions.

4-R152a and R1234yf are an appropriate near replacement for R-134a because the value of volumetric cooling capacity are both nearly identical to that of R134a values.

5-With increasing evaporating and condensing temperatures, the average pressure ratio for R1234ze(e) is higher and R161 is the lowest than the other refrigerants.

6- R1234ze(e) has the lowest TEWI value over the four compared low GWP refrigerants, whereas R161 has the highest.

7- R152a has a significantly higher compressor discharge temperature than the other refrigerants with increasing the evaporating temperatures, whereas R161 has a significantly higher discharge temperature with increasing the condensing temperatures. On the other hand, R1234yf has the lowest discharge temperature as compared to other refrigerants for various operating conditions.

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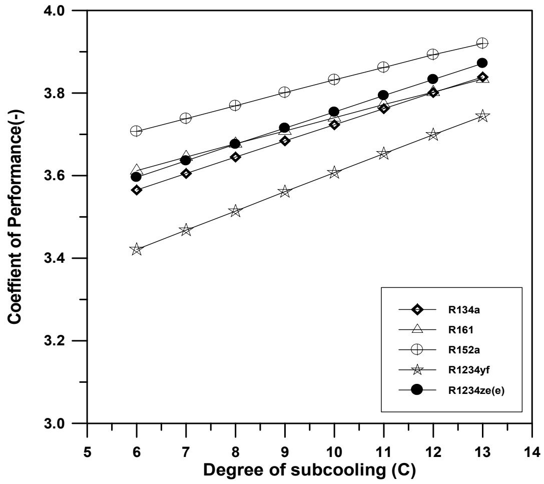

Fig. 3 shows COP versus sub-cooling temperature

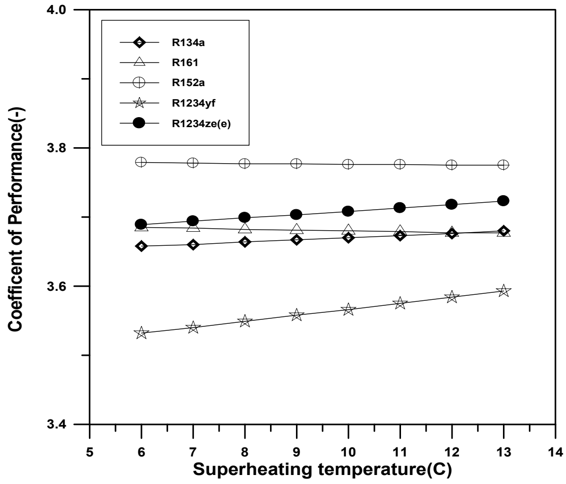

Fig. 4 shows COP versus superheating temperature

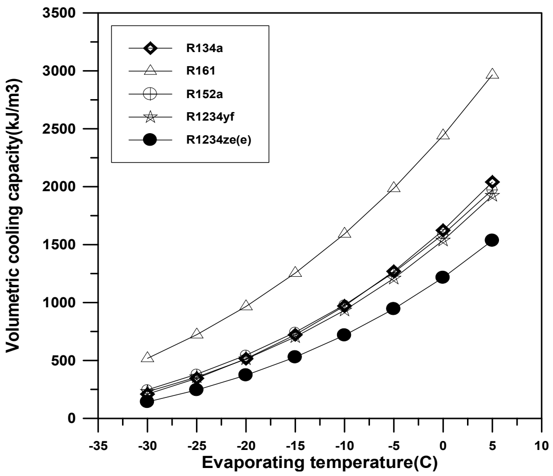

Fig. 5 shows volumetric cooling capacity versus evaporating evaporating temperature

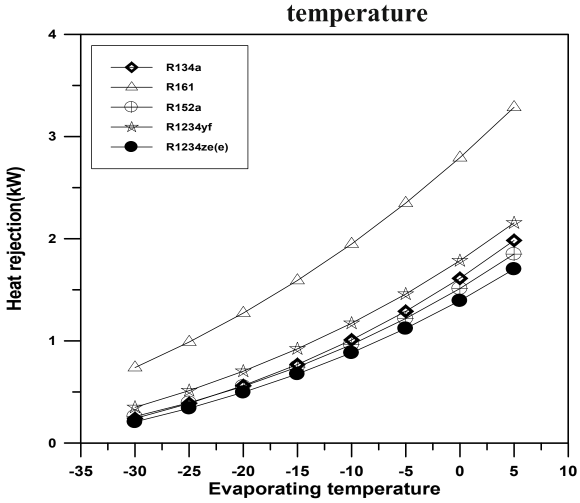

Fig. 6 shows heat rejection versus temperature

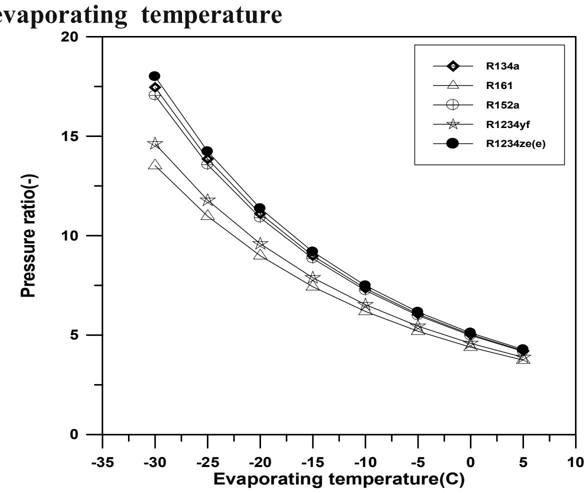

Fig. 7 6 shows pressure ratio versus evaporating temperature

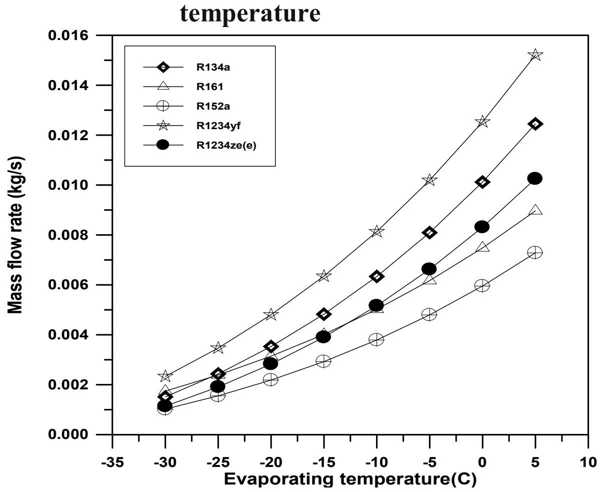

Fig. 8 refrigerant mass flow rate versus evaporating temperature

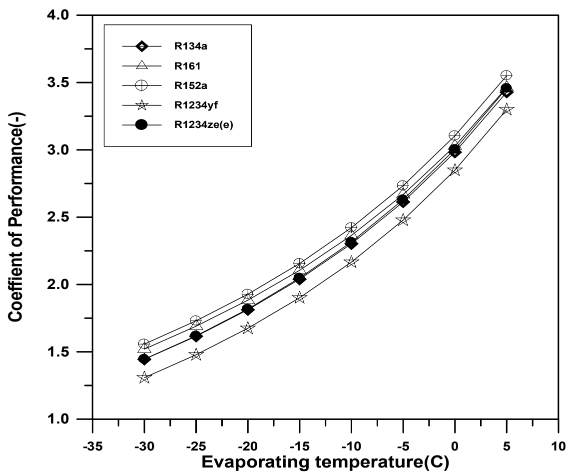

Fig. 9 6 shows COP versus evaporating temperature

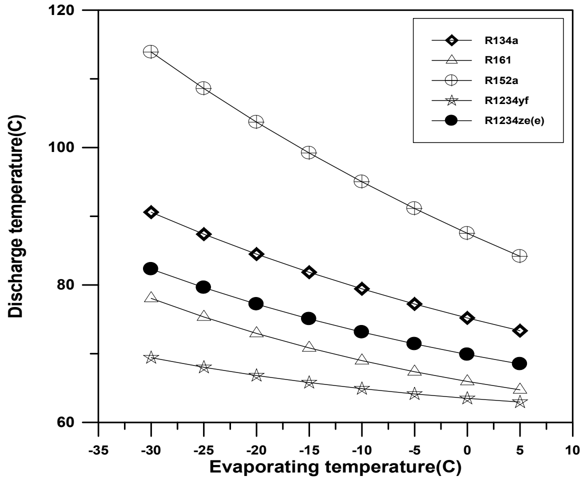

Fig. 10 6 shows compressor discharge temperature versus evaporating temperature

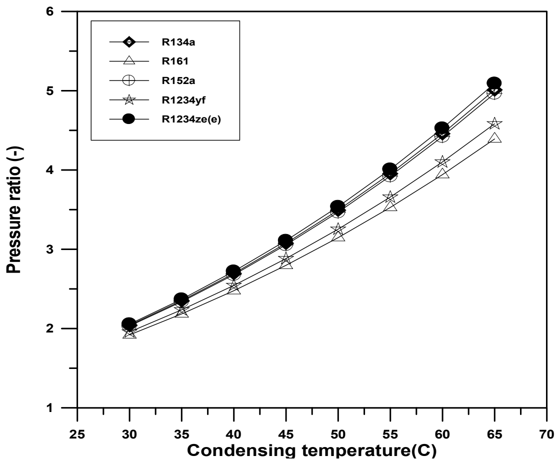

Fig. 11 6 shows pressure ratio versus condensing temperature

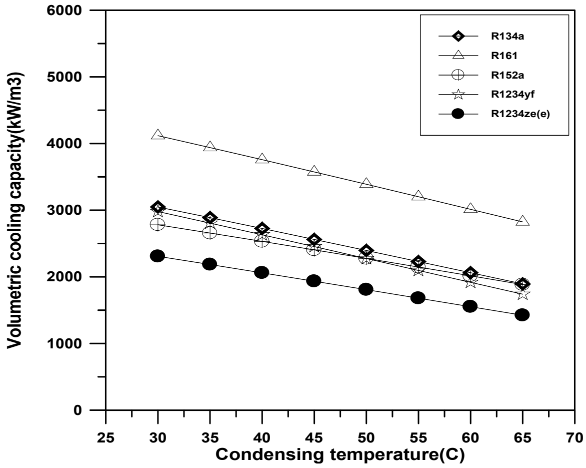

Fig. 12 6 shows volumetric cooling capacity versus condensing temperature

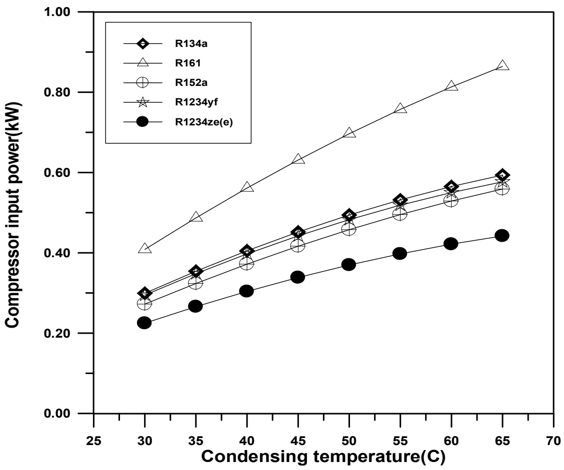

Fig. 13 shows compressor input power versus condensing temperature

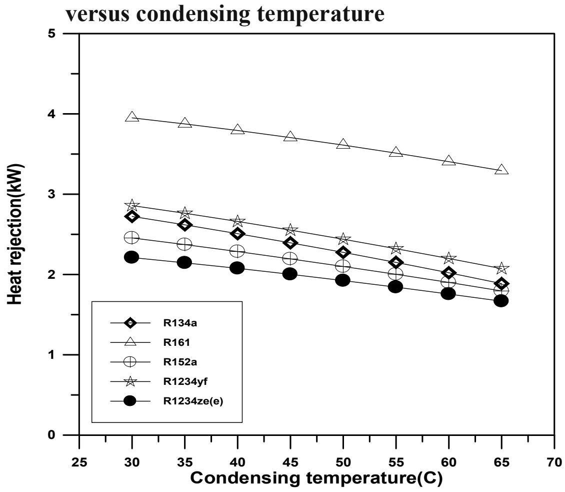

Fig. 14 shows heat rejection versus condensing temperature

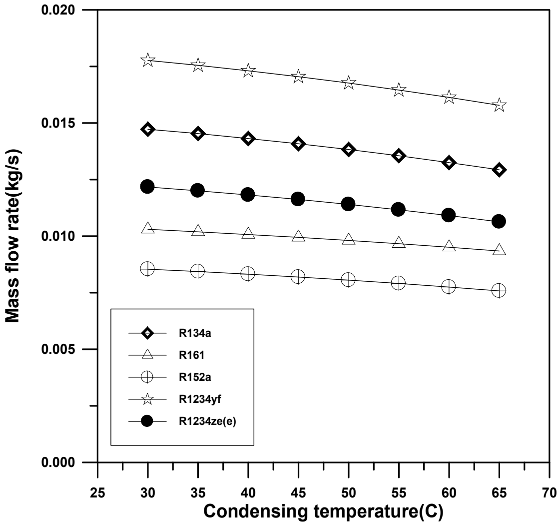

Fig. 15 shows refrigerant mass flow rate versus condensing temperature

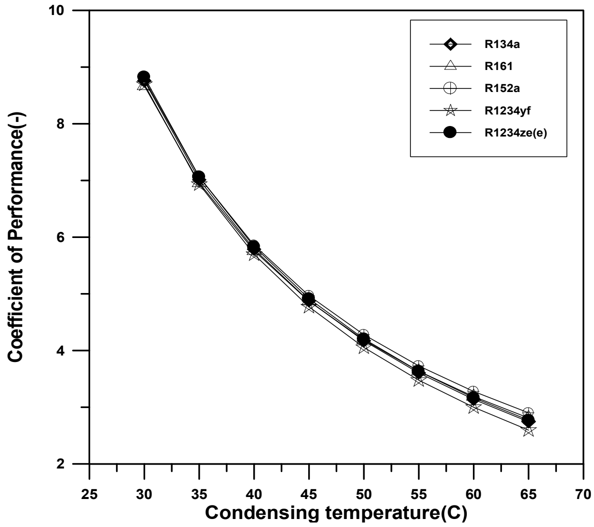

Fig. 16 shows COP versus condensing temperature

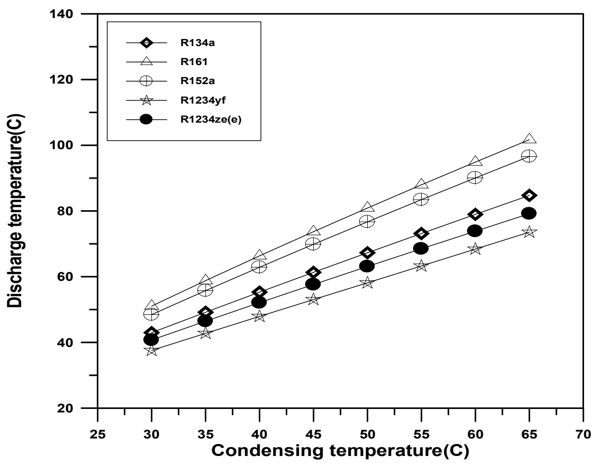

Fig. 17 shows compressor discharge temperature versus condensing temperature

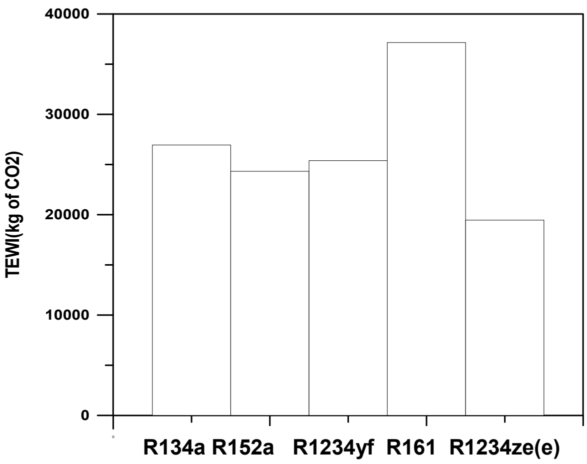

Fig.18 shows TEWI for investigated refrigerants