Performance Studies on Low GWP Refrigerants as Eco-friendly Alternatives for R134a in Household Refrigerator

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Performance studies on low GWP refrigerants as eco-friendly alternatives for R134a in household refrigerator

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Abstract

Climate changes are a significant environmental issue and rises global temperature. The key environmental objectives are to reduce carbon emissions and to mitigate the climate change impacts. The household refrigerator is the most important emitter of greenhouse gases because they use high global warming potential refrigerants. The Kyoto Protocol states that the power consumption and environmental effects of household refrigerators must be reduced. In the development of future household refrigerator, the replacement of existing refrigerants and enhance its energy efficiency will play an important role. Therefore, the performance of a household refrigerator operating with various environmentally friendly refrigerant mixtures was investigated using analytical methods. This simulation was carried out using MATLAB software, and the REFPROP database was used to obtain thermophysical properties of the refrigerants. The findings have shown that the COP of HFO mixtures is drops from 4% to 20% compared to R134a. The R1234ze/R134a (90/10) is a better mixture, with its estimated COP and energy efficiency 3.7% to 16.4% and 4% to 16% respectively above the other mixtures considered in this analysis and its performance is very similar to the R134a. It could be a good substitute for R134a in the refrigerator to satisfy the Montreal and Kyoto Protocol expectations.

Keywords: *R1234ze mixtures, climate change, simulation, refrigerator, exergy, MATLab*

Introduction

The climate change is a significant environmental issue and it increases the global temperature. In December 2015, the Paris Climate Conference set out an international action plan to bring down global warming below 2°C. Therefore, the main environmental targets are to minimize carbon emissions and mitigate the impact of climate change (Guo et al., 2018). The household refrigerator is one of the most important emitter of greenhouse gases because they use high GWP refrigerants as working fluids (Aprea et al., 2017). The greenhouse gases emits by the refrigeration system in two ways such as leakage of high GWP refrigerants are done by directly during the maintenance and charging process and indirectly through the generation of energy used to supply the system (Tassou et al. 2010). Moreover, the direct release of refrigerants is calculated to be responsible for 2% of the

overall emissions of the equivalent CO_2, while indirect releases represent about ten times the total direct releases, the total contribution to global warming by the refrigeration sector is approximately 20% (Mota-Babiloni et al., 2020).

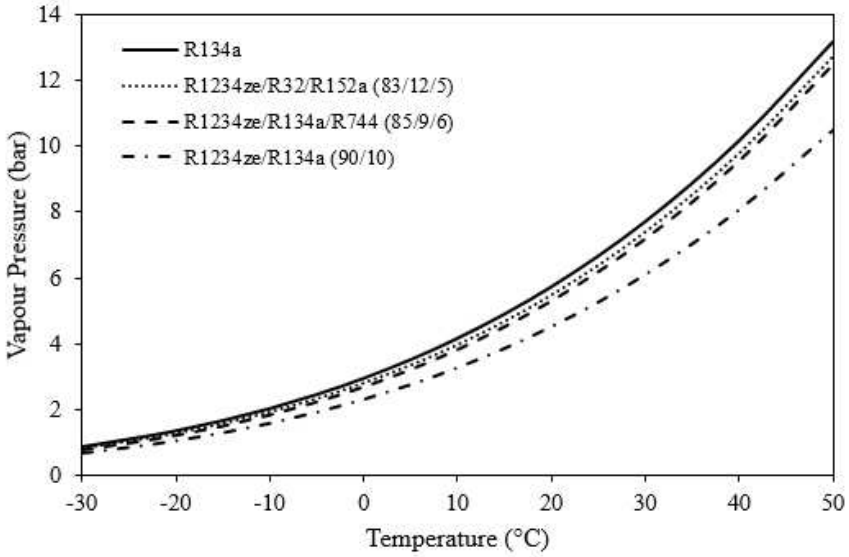
Due to its excellent thermophysical properties, R134a is the most commonly used refrigerant in household refrigerators but its high GWP will have to be phased out earlier. The European Union recently announced that alternative refrigerants would have a GWP of less than 150 in order to reduce greenhouse gas emissions (Saji et al., 2019). In order to meet global environmental targets, conventional refrigerants must be replaced by eco-friendly and energy-efficient refrigerants. The experimental tests carried out on household refrigerator to replace R134a with R1234yf, the refrigeration capacity improved slightly, making R134a an appropriate substitute for household refrigerator (Aprea et al., 2016). The R1234yf, R1234ze (E), and R600a are low-GWP refrigerants that can be used to replace R134a. Among the refrigerants, R1234yf may be an alternate solution for R134a due to similar efficiency and the same mass flow rate in household refrigerators (Righetti et al., 2015). The experimental investigation carried out on R1234yf and R1234ze in an R134a system with various evaporation and condensation temperatures. It indicates that R1234ze has a lower average refrigeration capacity and COP than R134a by around 30% and between 2% and 8%, respectively. Similarly, R1234yf has a less cooling capacity about of 9% and between 5% and 30% less COP than R134a (Navarro et al., 2013). Furthermore, the flammability of these refrigerants is a big concern. Owing to its flammability, one of Europe's major car manufacturers declined to use R1234yf.

There are various applications such as household refrigerator, beverage coolers and mobile air conditioners, an azeotropic mixture R1234yf /R134a is offered to replace R134a. Adding 10-11% of R134a to R1234yf, the mixture is non-flammable and it's COP, discharge temperature and refrigeration capacity are like that of R134a (Yohan et al., 2013). The HFO/HFC mixtures are suitable alternatives of HFC refrigerants and it has low GWP (GWP<150). It has been observed that adding 10% R134a to R1234yf will make the refrigerant mixture to be non-flammable and it is suitable alternative for R134a due its energy efficiency (Aprea et al., 2016). The HFO/HFC mixtures have improved performance, and their expected COP and exergy efficiency are 4% to 8.3% and 5.1% to 10.5% respectively higher than the HFO (Saji et al., 2019).

Therefore, the energy analysis on a household refrigerator operating with low GWP refrigerant mixtures as environmental friendly alternatives for R134a has been studied using mathematical simulation. The household refrigeration system has been modeled and the performance has been studied to find the best composition of the mixture to operate the system. This simulation was carried out using MATLab software, and the REFPROP database was used to obtain thermophysical properties of the refrigerants. Due to the environmentally friendly properties and flammability aspects, R1234ze/R134a (90/10) could be a good substitute for R134a in the refrigerator to satisfy the Montreal and Kyoto Protocol expectations.

82 **Refrigerant Selection**

83 One of the essential methods of identifying the suitable refrigerant is the selection of refrigerants based on
84 its thermo-physical properties. For operating temperatures -30ºC to 50ºC, the properties of refrigerants obtained
85 from REFPROP 9.0 have been plotted. The vapor pressures of HFO refrigerant mixtures are lower than that of
86 R134a as shown in Fig. 1. The vapor pressure of R1234ze/R134a is 21.5% lower than that of R134a among the
87 different mixtures. This can cause a reduced energy consumption. Fig. 2. shows that the latent heat of
88 R1234ze/R134a/R744 and R1234ze/R134a are 6.4% and 6.8% lower than R134a respectively. In the case of
89 R1234ze/R32/R152a mixture, the latent heat is 1.3% greater than the R134a. The thermo-physical properties used
90 in this analysis are shown in Table 1.
91



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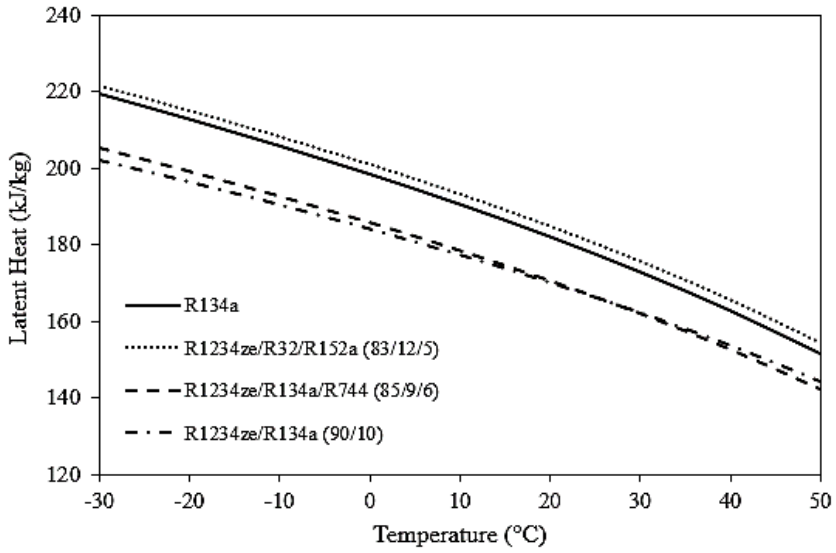
93 **Fig. 1** Variation of vapour pressure as a function of temperature



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95 **Fig. 2** Variation of latent heat as a function of temperature

96

Table 1. Thermophysical properties of the refrigerants

Refrigerants	Composition (Mass fraction %)	GWP	Safety group	Critical Pressure (bar)	Critical Temperature (°C)	Boiling Point at 1 atm (°C)
R134a	0	1430	A1	40.6	101.06	-26.07
R1234ze/R32/R152a	83/12/5	92.88	A2L	41.38	101	-25.09
R1234ze/R134a/R744	85/9/6	133.86	A2L	47.13	103	-23.98
R1234ze/R134a	90/10	148.4	A2L	36	381.6	-20.6

Analytical study

Figure 3 shows a schematic diagram of the refrigeration system used throughout this analysis. It consists of a reciprocating compressor, air-cooled condenser, capillary tube, and evaporator. The simulation of the above components was performed using MATLAB software. To obtain the thermo-physical properties of refrigerants, REFPROP is directly interlinked with MATLAB. A 190 *l* household refrigerator has been considered in this modeling. The property variations are one dimensional, steady state condition, constant mass flow rate, polytropic process in compression, efficiency of electrical motor is 85% and pressure drop in the heat exchanger is negligible. The above assumptions are taken into account in this analysis to minimize the complexities of the simulation.

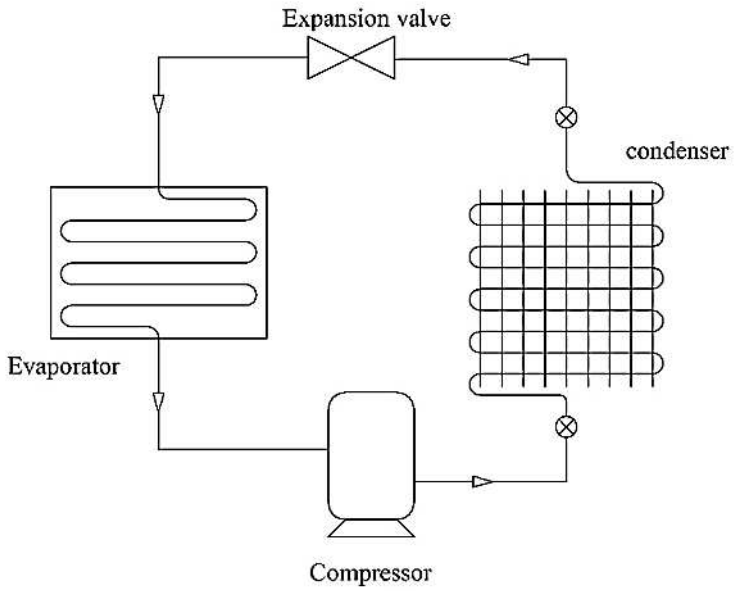

Fig. 3 Schematic diagram of refrigeration system

Compressor model

A 100W reciprocating type compressor has been taken for the study and it is divided in to three control volumes such as compressor shell, swept volume and discharge tube (William and Doyle, 1988). The following equation is used to determine the swept volume:

$$\dot{m}_o h_o = Q_{comp} + \frac{dW}{dt} + \dot{m}_\iota h_i - (\Delta P)_V \quad (1)$$

The displacement volume is calculated at each time step using the following equation:

$$v(t) = V_{cylinder.} + \frac{\pi D_{cyl}^2}{8} + L_{swept}\ (1 - cos(\omega t)) \quad (2)$$

The following equation is used to calculated compressor work:

$$W_{comp} = \frac{n}{n-1} P_s V \left\{ \left(\frac{P_{discharge}}{P_{Suction}} \right)^{\frac{n-1}{n}} - 1 \right\} \tag{3}$$

Condenser model

The condenser is divided into de-superheated region, two-phase region, and sub-cooled region. The following correlations are used to measure the refrigerant side heat transfer coefficient in the single-phase region (Minor et al., 2010):

In laminar region ($Re < 2100$)

$$Nu = 1.86 Re^{0.33} Pr^{0.33} \left(\frac{D_i}{L} \right) \left(\frac{\mu_b}{\mu_w} \right)^{0.5} \tag{4}$$

In turbulent region ($Re > 10{,}000$)

$$Nu = 0.023 Re^{0.8} Pr^{0.33} \left(\frac{D_i}{L} \right) \left(\frac{\mu_b}{\mu_w} \right)^{0.14} \tag{5}$$

The air-side heat transfer coefficient of the condenser is calculated using the correlations below (Marques et al. 2014):

$$Nu = 0.3 + \left(\frac{0.62 Ra^{0.167}}{\left[1 + \left(\frac{0.559}{Pr} \right)^{\frac{9}{16}} \right]^{\frac{8}{27}}} \right) \tag{6}$$

Evaporator model

The evaporator is divided into two-phase region and superheated region. The convective heat transfer coefficient of single-phase region and two-phase region are compute by the equation no. (7), (8) & (9) (Wattelet et al., 1994; Chang et al., 2000; Cooper, 1984; Navarro et al., 2013 & Nielsen et al., 2007):

In laminar region ($Re < 2100$)

$$Nu = 1.86 Re^{\frac{1}{3}} Pr^{\frac{1}{3}} \left(\frac{D_i}{L} \right) \left(\frac{\mu_b}{\mu_w} \right)^{0.13} \tag{7}$$

In turbulent region ($Re > 10{,}000$)

$$Nu = 0.023 Re^{0.8} Pr^{\frac{1}{3}} \left(\frac{D_i}{L} \right) \left(\frac{\mu_b}{\mu_w} \right)^{0.14} \tag{8}$$

$$h_{evap} = 55 Mo^{-0.5} q^{0.67} Pr^{0.12} (log Pr)^{0.55} + F h_l R \tag{9}$$

Capillary tube model

The flow of a capillary tube can be separated into single-phase and two-phase. Pressure drops in the capillary tube causes due to friction, momentum loss, and gravitational effect. Sudden contraction happened by the pressure drop, is calculated by following equation (Perry and Chilton, 1984).

$$P_i - P_{init} = \frac{G^2 V_f}{2} \left\{ \left(\frac{1}{C_{con}} - 1 \right) + \left(1 + \frac{A^2}{A_1^2} \right) \left(1 + \frac{V_{fg}}{V_f} \right) X \right\} \tag{10}$$

Coefficient of contraction is calculated by following equation:

$$C_c = 0.55 \left(\frac{A_{ma}}{A_1} \right)^3 - 0.242 \left(\frac{A_{ma}}{A_1} \right)^2 + 0.111 \left(\frac{A_{ma}}{A_1} \right) + 0.585 \tag{11}$$

$$COP = \frac{Qevap}{W_{Comp}} \tag{12}$$

Exergy Analysis

The aim of the exergy analysis is to assess the irreversibility of each component of a household refrigerator. Fig. 4 depicts the T-S diagram and the exergy balance equations are taken from the previous studies (Bayrakci HC and Ozgur, 2009) and shown in Table 2.

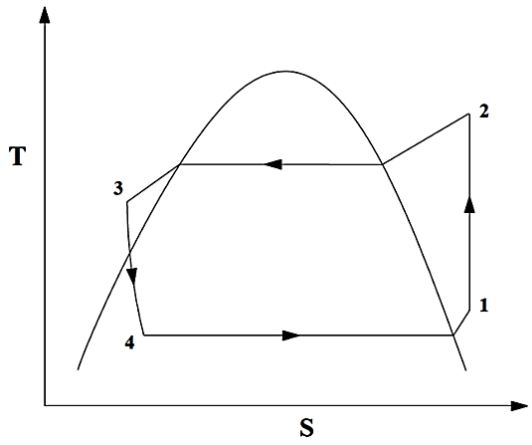

Fig. 4 T–S diagram

Table 2 Irreversibility equation of each Component

Components	Irreversibility
Compressor	$I_{comp} = \dot{m}\psi_1 + W - \dot{m}\psi_2$
Condenser	$I_{cond} = \dot{m}\psi_2 - \dot{m}\psi_3 - Q_{cond}\left(1 - \frac{T_o}{T_{cond}}\right)$
Capillary tube	$I_{capi} = \dot{m}\psi_3 - \dot{m}\psi_4$
Evaporator	$I_{evap} = \dot{m}\psi_4 + Q_{evap}\left(1 - \frac{T_o}{T_{evap}}\right) - \dot{m}\psi_1$

The total exergy destruction of the system is determined by:

$$I_{total} = I_{comp} + I_{cond} + I_{capi} + I_{evap} \tag{13}$$

Table 3. Operating conditions

Parameters	Household Refrigerator
Evaporator temperature (ºC)	-18
Condenser Temperature (ºC)	45
Ambient temperature range (ºC)	22, 26, 30, 36 & 43

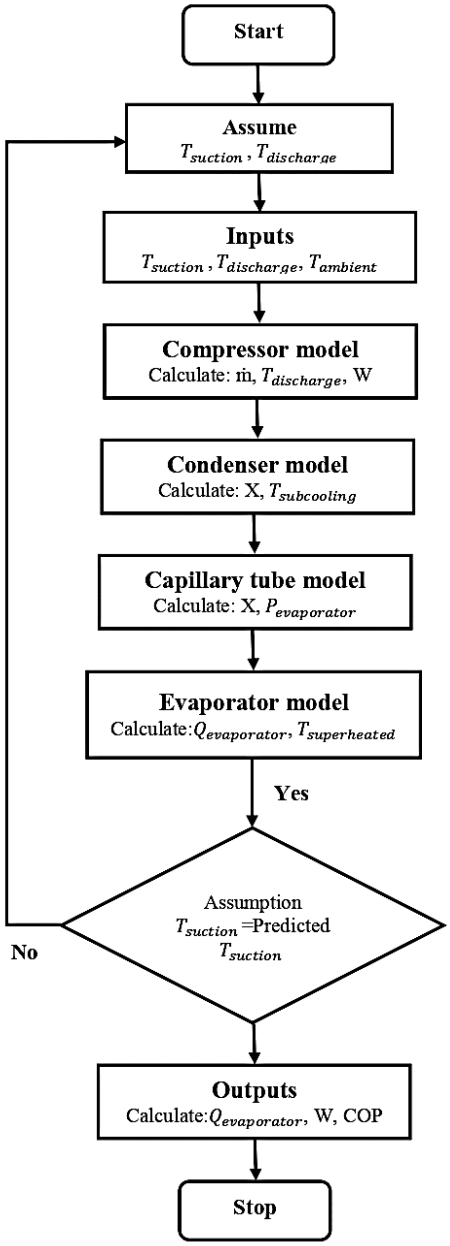

Fig. 5 Flow chart for simulation model

Validation

The experimental values are compared to the simulation results in order to validate the simulation model, as shown in Fig. 6. The experimental COP of R134a has been taken from the previous studies (Saji et al., 2017). The figure indicates that the simulation COP deviates from the experimental COP by 9% to 12% for various ambient conditions at the evaporator temperature of -12°C. Since this difference is nominal, the validity of the mathematical approach has been verified.

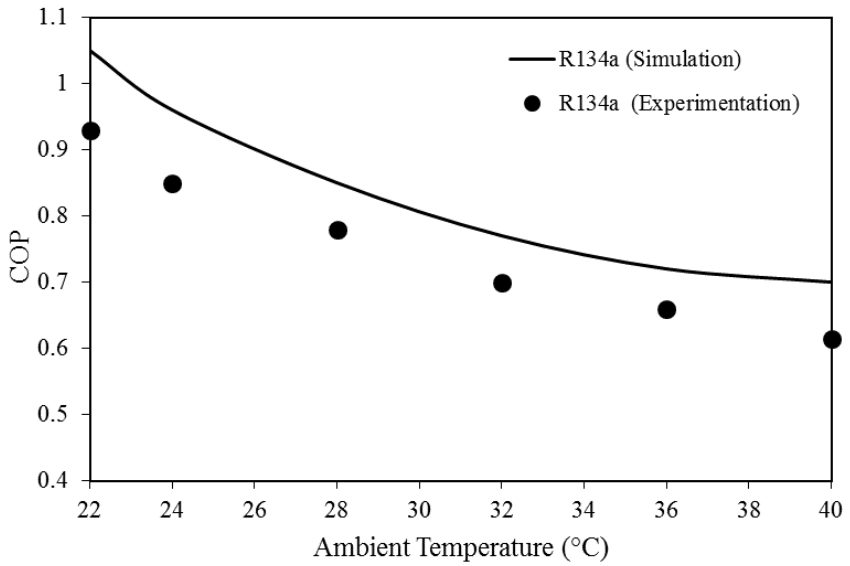

Fig. 6 Variation of theoretical COP with ambient temperature

Results and Discussion

The energy analysis on a household refrigerator through environmentally friendly refrigerant mixtures was theoretically studied for different ambient temperatures at an evaporator temperature of -18 ºC. The findings would examine the output parameters including the compressor work, COP, total exergy destruction, exergy efficiency and TEWI.

As seen in Fig. 7, the function of the compressor work increases as the atmospheric temperature increases. This is because the input pressure of compressor and mass flow rate increases. The R1234ze/R134a mixture has been observed to reduce compressor work from 4.3% to 8.5 % than other two mixtures. Because of low evaporator pressure and high molecular weight of the mixture. The difference of COP with ambient temperature was calculated and plotted using with HFO mixtures in Fig. 8. It has been noted that the COP of R1234ze/R134a mixture is higher than the other two mixtures by about of 16.4%. This may be because, the refrigerant mixture has a high latent heat.

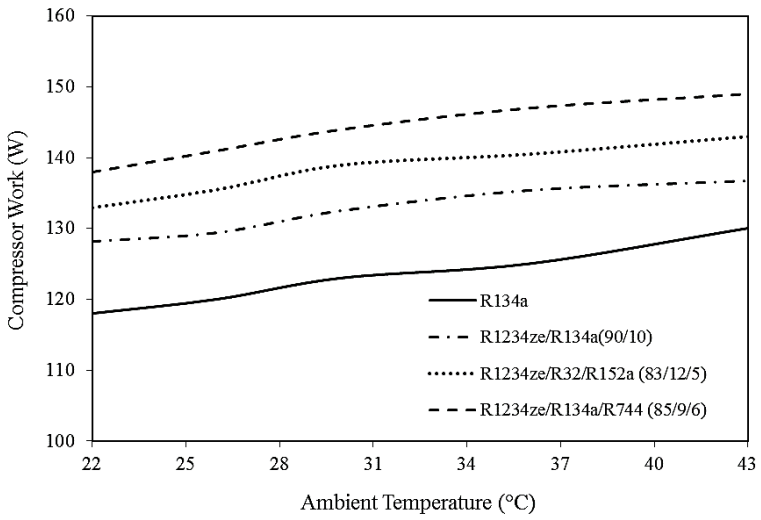

Fig. 7 Variation of compressor work with ambient temperature

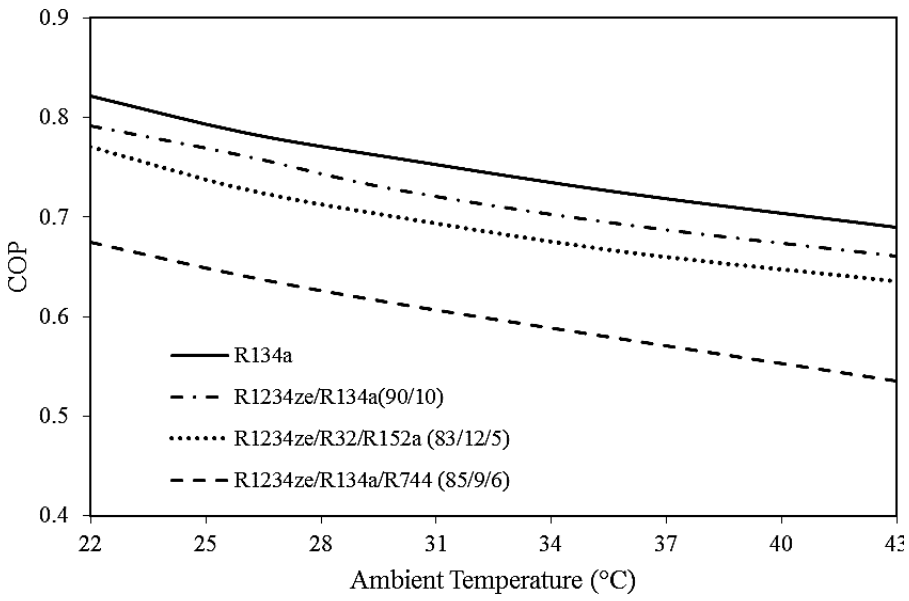

Fig. 8 Variation of COP with ambient temperature

Fig. 9 indicates that as the function of the total exergy destruction increases as the atmospheric temperature increases. The previous studies have found a similar pattern (Siva et al., 2012). The overall irreversibility of the R1234ze/R134a mixture is decreases from 5.2% to 12.4% than the other two mixtures that can be attributed to the high compression ratio. Since the exergy efficiency is used to determine the quality of energy used by a system, it has been calculated for HFO refrigerant mixtures and shown in Fig. 10. The exergy efficiency of the R1234ze/R134a mixture improves from 4% to 16% as compared to the other two mixtures, and it also has a lower exergy efficiency at high ambient temperatures. Among all the HFO mixtures, R1234ze/R134a mixture shows better performance and it is very similar to the R134a.

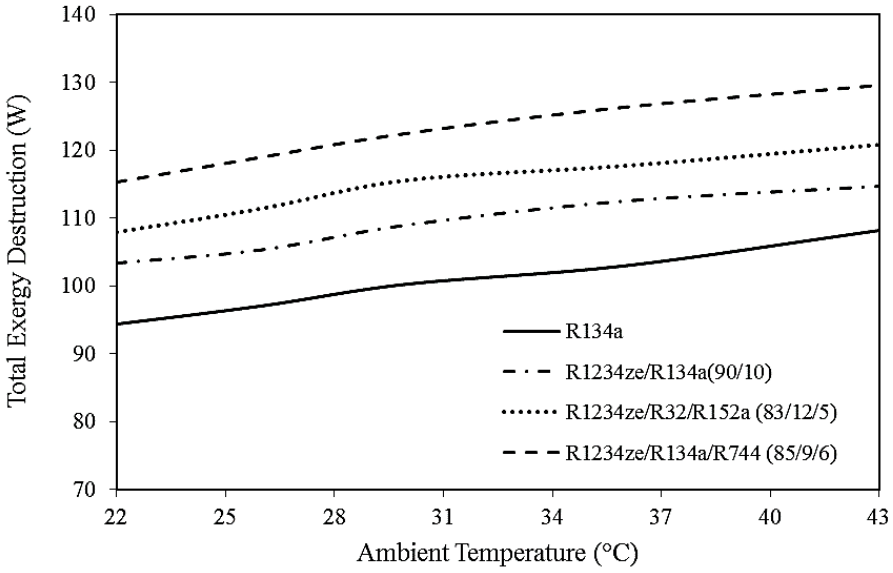

Fig. 9 Variation of total exergy destruction with ambient temperature

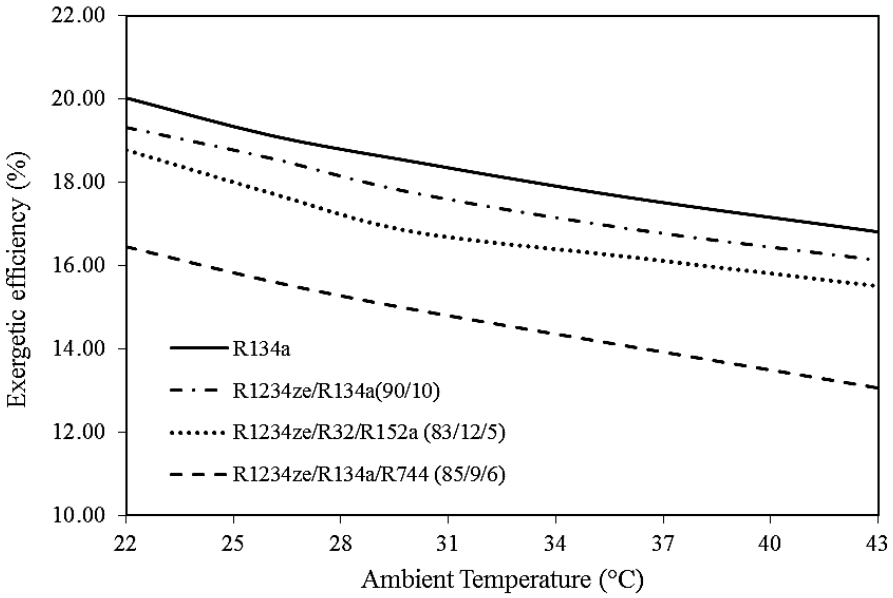

Fig. 10 Variation of exergetic efficiency with ambient temperature

Total Equivalent Warming Impact

The TEWI is an environmental index. It represents the quantity of direct and indirect effects that are calculated using the following equation (Saji et al. 2020):

$$TEWI = Direct\ effect + Indirect\ effect$$
$$= (m \times l \times S_l \times GWP_{100}) + (E \times S_l \times r) \quad (14)$$

Table 4. shows that the R1234ze/R134a has a lower TEWI than R134a by about of 5.9%. This is because of less energy efficiency, but direct emissions are significantly lower than R134a.

Table 4. TEWI for the both refrigerants

Refrigerant	**R134a**	**R1234ze/R134a**
Charge quantity (kg), *m*	0. 135	0. 129
Leakage rate per year (%), *l*	6.6	6.6
Service life (year), S_l	15	15
GWP	1430	148
Direct effect	191	19
Power consumption per year (kWh), E	701	756
CO_2 emission (kgCO_2 / kWh), *r*	0. 89	0. 89
Indirect effect	9358	10,093
TEWI	**9549**	**10,112**

Conclusion

The low-GWP refrigerants such as R1234ze/R134a, R1234ze/R32/R152a, and R1234ze/R134a/R744 have been studied theoretically in household refrigerator. Among the mixtures, R1234ze/R134a (90/10) performs best, with estimated COP and exergetic efficiency 3.7% to 16.4% and 4% to 16% higher than the other mixtures. The R1234ze/R134a has a lower TEWI than R134a by about of 5.9%.This is because of less energy efficiency, but direct emissions are significantly lower than R134a. Even though the performance of the mixture R1234ze/R134a is slightly lower than R134a, but it is superior to other HFO mixtures. It may also be an appropriate alternative for R134a in the household refrigerator to address environmental problems according to the Kyoto Protocol.

Nomenclature

A	:	Area (m^2)
C	:	Coefficient
COP	:	Coefficient of Performance
D	:	Coil mean diameter (m)
F	:	Empirical constant
G	:	Mass flux (kg m^{-2} s^{-1})
GWP	:	Global Warming Potential
h	:	Specific enthalpy (J kg^{-1})
L	:	Length (m)
$\dot{m}$	:	Mass flow rate (kg s^{-1})
Mo	:	Molecular weight (g $kmol^{-1}$)
n	:	Polytropic index
Nu	:	Nusselt number
P	:	Pressure (kPa)
Pr	:	Prandtl number
Q	:	Heat (J)
Ra	:	Rayliegh number
Re	:	Reynolds number
t	:	time (s)
T	:	Temperature
TEWI	:	Total Equivalent Warming Impact
V	:	Volume (m^3)
W	:	Work (W)
X	:	Refrigerant quality
ω	:	Angular velocity (rad s^{-1})
μ	:	Dynamic viscosity (Pa s)
ψ	:	Exergy (J/kg)

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Authors' contributions

Saji Raveendran Padmavathy handled conceptualization, methodology, data collection Murugan Paradesi Chockalingam was responsible for writing, reviewing and final editing of the manuscript. Godwin Glivin was in responsibility of data analysis and preliminary paper writing, while Nithyanandhan Kamaraj was in control of result interpretation. Venkatesh Thangaraj aided in the analysis and editing of the manuscript. The methodology and data gathering were the responsibility of Bharathiraja Moorthy. The final manuscript was read and approved by all of the authors.

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Data availability

The dataset generated during this work are not publicly available, however they are available upon reasonable request to the corresponding author.

Compliance with ethical standards

Ethics approval and consent to participate: Not Applicable.

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References

Aprea C, Greco A, Maiorino A (2016) An experimental investigation on the substitution of HFC134a with HFO1234YF in a domestic refrigerator. Appl. Therm. Eng. 106: 959–967. https://doi.org /10.1016/j.applthermaleng.2016.06.098

Aprea C, Greco A, Maiorino A (2017) An experimental evaluation of the greenhouse effect in the substitution of R134a with pure and mixed HFO in a domestic refrigerator. Int. J. Heat Technol. 35:S413–S418. https://doi.org /10.18280/ijht.35Sp0156

Bayrakci HC, Ozgur AE (2009) Energy and exergy analysis of vapour compression refrigeration system using pure hydrocarbon refrigerants. International Journal of Energy Research. 33; 1070-1075. https://doi.org/10.1002/er.1538

Chang YS, Kim MS, Ro ST (2000) Performance and heat transfer characteristics of hydrocarbon refrigerants in a heat pump system. International Journal of Refrigeration. 23; 232-242. https://doi.org/10.1016/S0140-7007(99)00042-0

Cooper MG (1984) Heat flow rated in saturated nucleate pool boiling-wide ranging examination using reduced properties. Advanced in heat transfer, 16; 157-239. https://doi.org/10.1016/S0065-2717(08)70205-3

Guo Q, Li M, Gu H (2018) Condensation heat transfer characteristics of low-GWP refrigerants in a smooth horizontal mini tube, Int. J. Heat Mass Transf. 126; 2-38 . https://doi.org/10.1016/j.ijheatmasstransfer.2018.05.034

Lemmon EW, Huber ML, McLinden MO (2007) Reference Fluid Thermodynamic and Transport Properties (REFPROP), Version 9.1, in NIST Standard Reference Database 23. National Institute of Standards and Technology, Gaithersburg. MD.

Marques A, Davies G, Maidment G, Evans, J, Wood I (2014) Novel design and performance enhancement of domestic refrigerators with thermal storage. Applied Thermal Engineering. 63; 511-519. https://doi.org/10.1016/j.applthermaleng.2013.11.043

Minor B, Montoya C (2010) HFO-1234yf performance in a beverage cooler. In: International Refrigeration and Air Conditioning Conference at Purdue. West Lafayette, IN. USA, paper No. 2422.

Mota-Babiloni JR, Barbosa Jr, Makhnatch P, Lozano JA (2020) Assessment of the utilization of equivalent warming impact metrics in refrigeration, air conditioning and heat pump systems. Renew. Sustain. Energy Rev. 129; 109929. https://doi.org/10.1016/j.rser.2020.109929

Navarro- Esbri J, Mendoza-Miranda JM, Mota-Babiloni A, Barragan-Cervera A, Belman-Flores JM (2013) Experimental analysis of R1234yf as a drop-in replacement for R134a in a vapor compression system. International Journal of Refrigeration. 36; 870-880. https://doi.org/10.1016/j.ijrefrig.2012.12.014

Nielsen OJ, Javadi MS, Sulbak A, Hurley MD, Wallington TJ, Singh R (2007) Atmospheric chemistry of $CF_3CF{=}CH_2$; kinetics and mechanisms of gas-phase reactions with Cl atoms, OH radicals, and O3. Chem. Phys. Lett. 439; 18-22. https://doi.org/10.1016/j.cplett.2007.03.053

Perry RH, Chilton CH (1984) Perry's Chemical Engineering Hand book 6th edition, McGraw Hill Professional. New York.

Righetti G, Zilio C, Longo GA (2015) Comparative performance analysis of the low GWP refrigerants HFO1234yf, HFO1234ze(E) and HC600a inside a roll-bond evaporator Int. J. Refrig. vol. 54: 1–9. https://doi.org/10.1016/j.ijrefrig.2015.02.010

S.A. Tassou, Y. Ge, A. Hadaway, D. Marriott, Energy consumption and conservation in food retailing, Appl. Therm. Eng. 31 (2011) 147–156. https://doi.org/10.1016/j.applthermaleng.2010.08.023

Saji Raveendran P, Joseph Sekhar S (2017) Exergy analysis on domestic refrigeration system with brazed plate heat exchanger as condenser. Journal of Thermal Analysis Calorimetry.127:2439-46. https://doi.org/10.1007/s10973-016-5847-2

Saji Raveendran P, Joseph Sekhar S (2019) Energy and exergy analysis on HFO/HFC refrigerant mixtures in low and medium temperature small-scale refrigeration systems. Proceedings of the institution of mechanical engineers Part E- Journal of process Mechanical Engineering. 1-13. https://doi.org/10.1177/0954408919881306

Saji Raveendran P, Joseph Sekhar S (2020) Experimental studies on the performance improvement of household-refrigerator connected to domestic water system with a water-cooled condenser in tropical regions. Applied Thermal Engineering.179: 115684. https://doi.org/10.1016/j.applthermaleng.2020.115684

Siva Reddy V, Panwar NL, Kaushik SC (2012) Exergetic analysis of a vapour compression refrigeration system with R134a, R143a, R152a, R404A, R407C, R410A, R502 and R507A. Clean Technology Environmental Policy.14:47–53. https://doi.org/10.1007/s10098-011-0374-0

Wattelet JP, Chato JC, Souza, AL, Christoffersen, BR (1994) Evaporative Characteristics of R12, R134a and Mixture at a Low Mass Fluxes. ASHRAE Transactions. pp. 603-615.

William AM, Doyle Thompson H (1988) An Analytical Model of Heat Transfer to the Suction Gas in a Low-Side

Hermetic Refrigeration Compressor. International Compressor Engineering Conference School of Mechanical Engineering. Purdue University. Paper 662.

Yohan Lee, Dong-gyu Kang, Dongsoo Jung (2013) Performance of virtually non-flammable azeotropic HFO1234yf/HFC134a mixture for HFC134a applications, International Journal of Refrigeration. 36:1203-1207. https://doi.org/10.1016/j.ijrefrig.2013.02.015

Figures

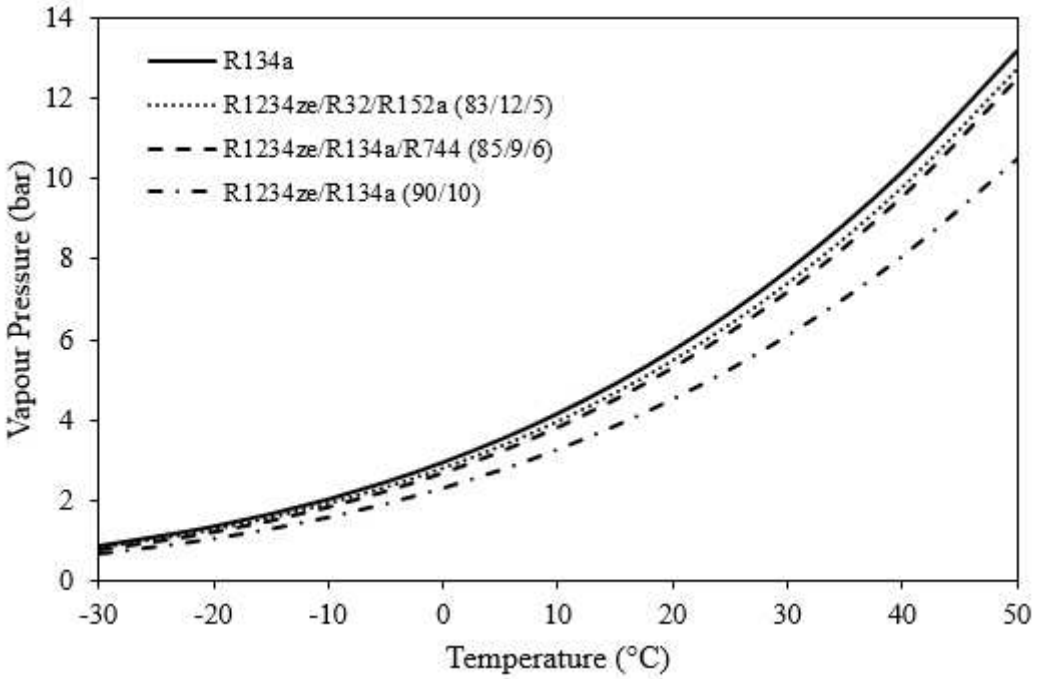

Figure 1

Variation of vapour pressure as a function of temperature

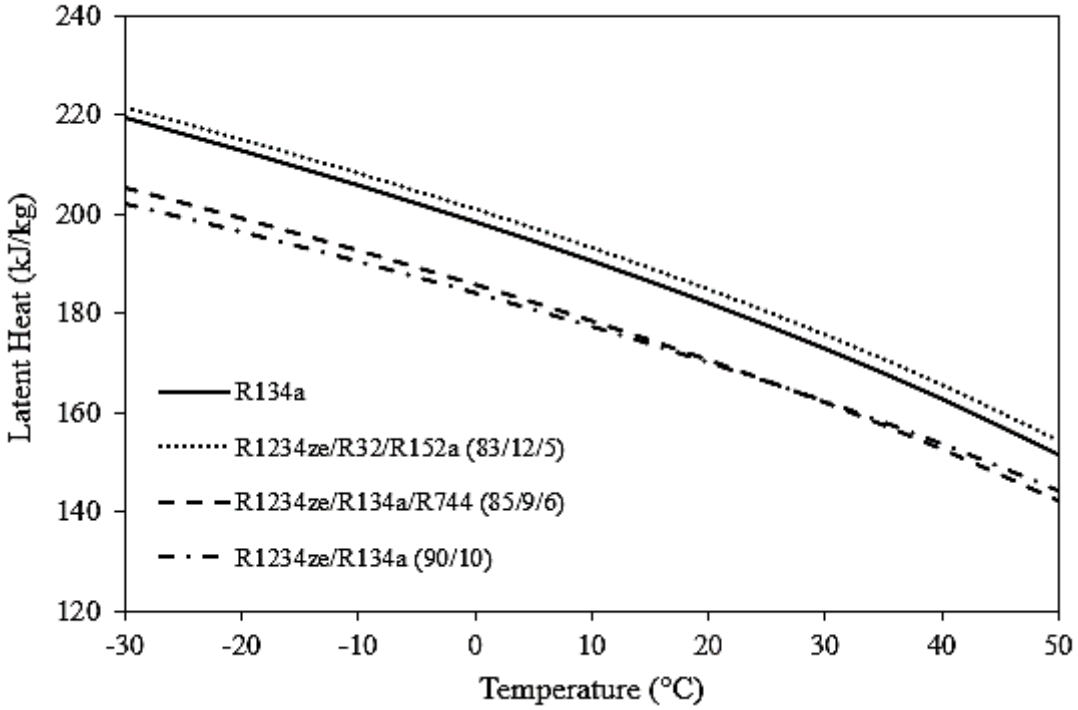

Figure 2

Variation of latent heat as a function of temperature

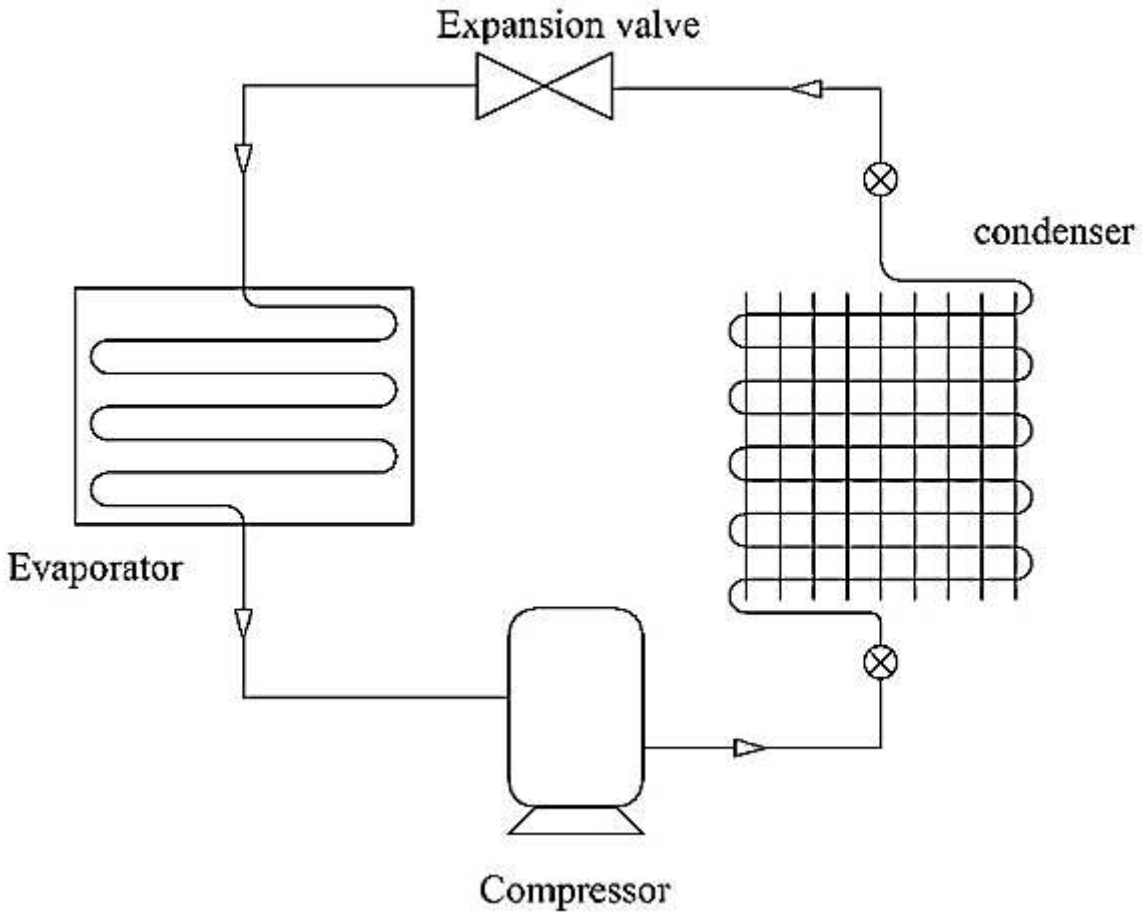

Figure 3

Schematic diagram of refrigeration system

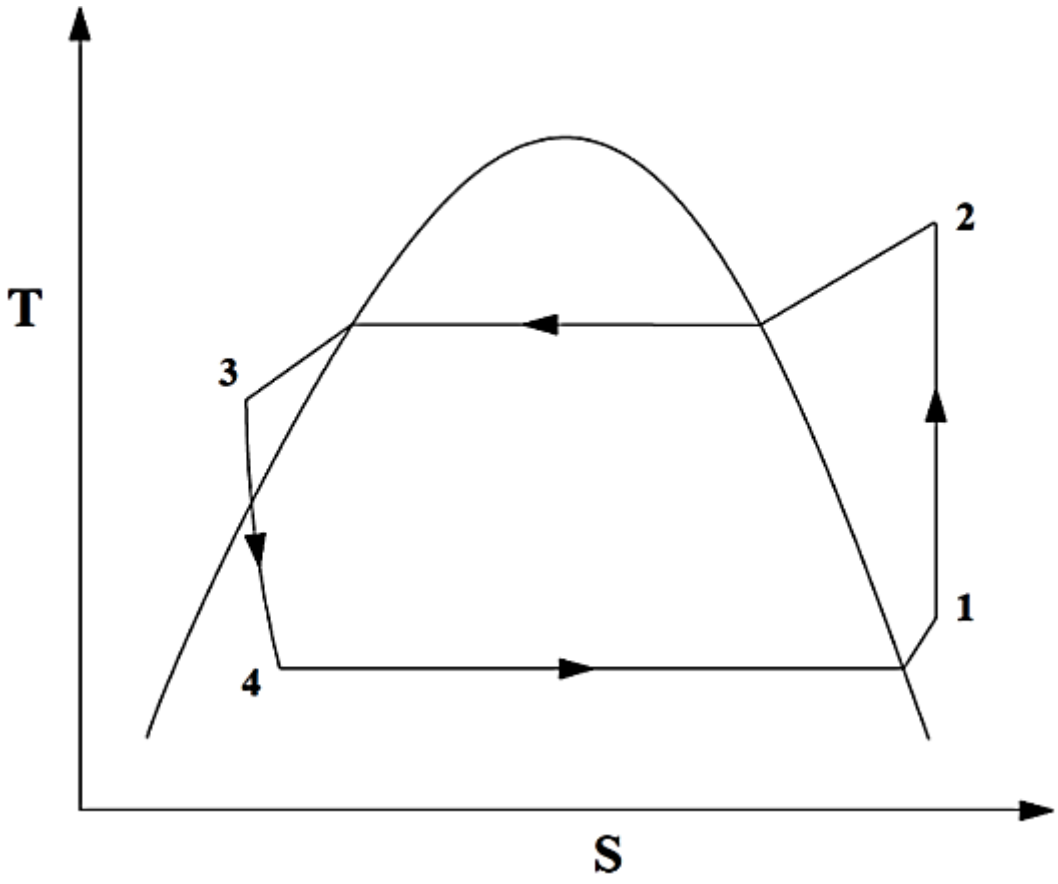

Figure 4

T–S diagram

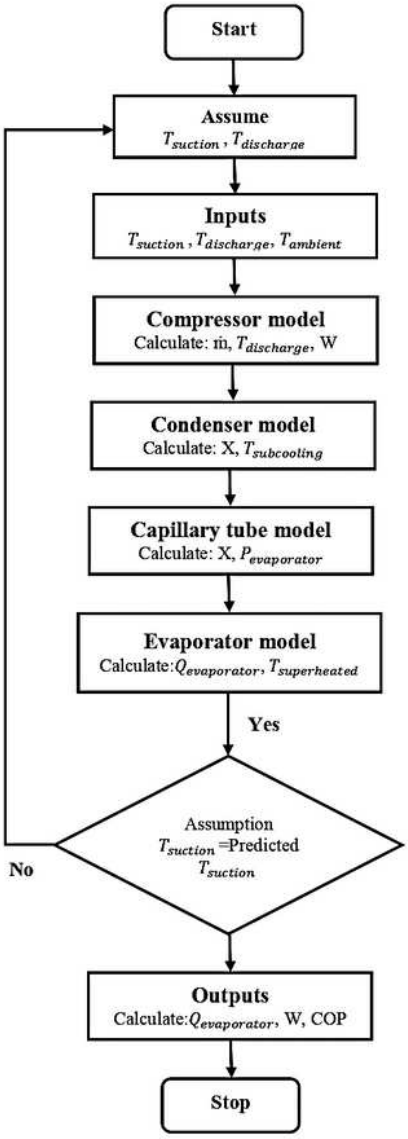

Figure 5

Flow chart for simulation model

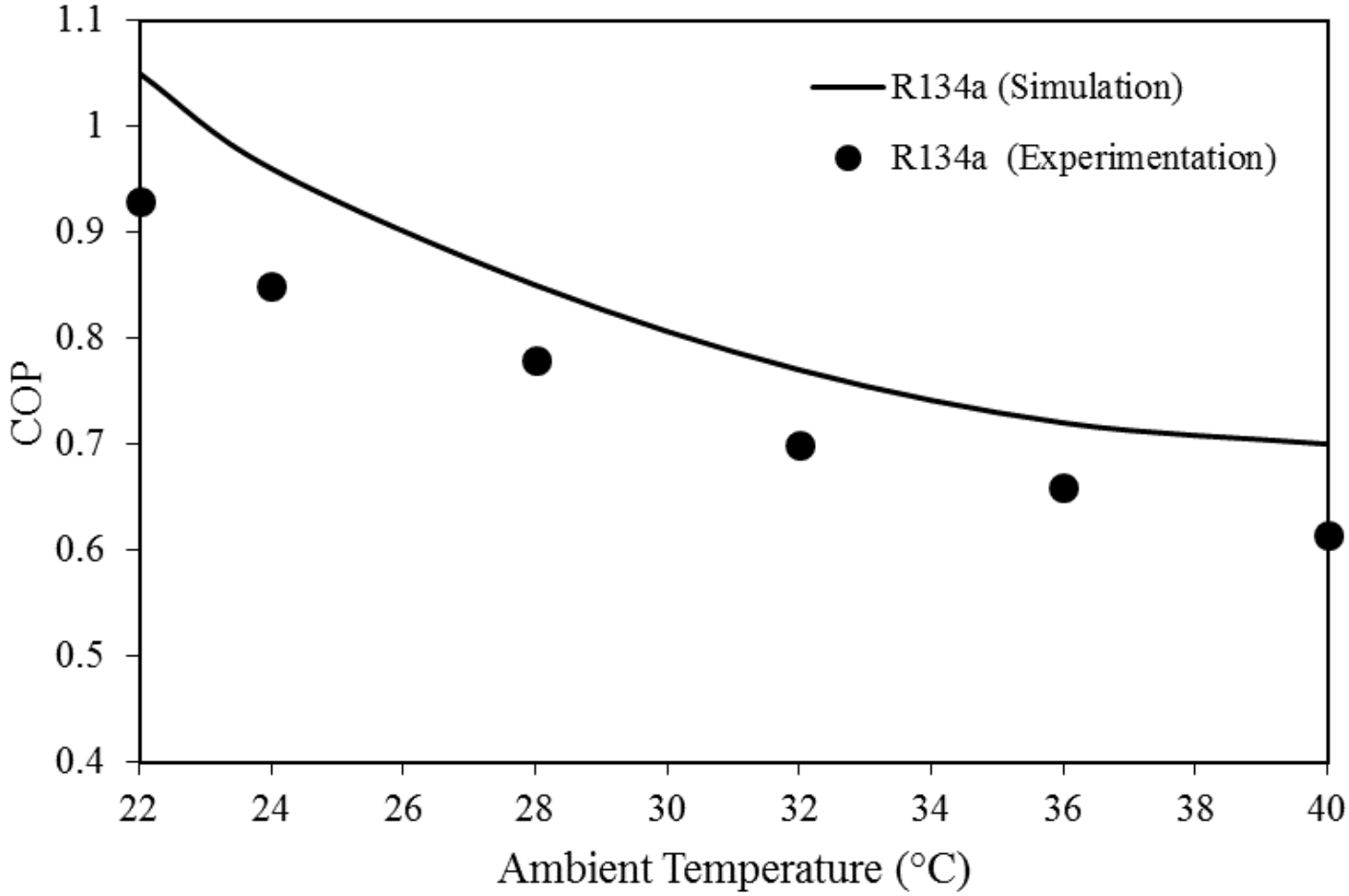

Figure 6

Variation of theoretical COP with ambient temperature

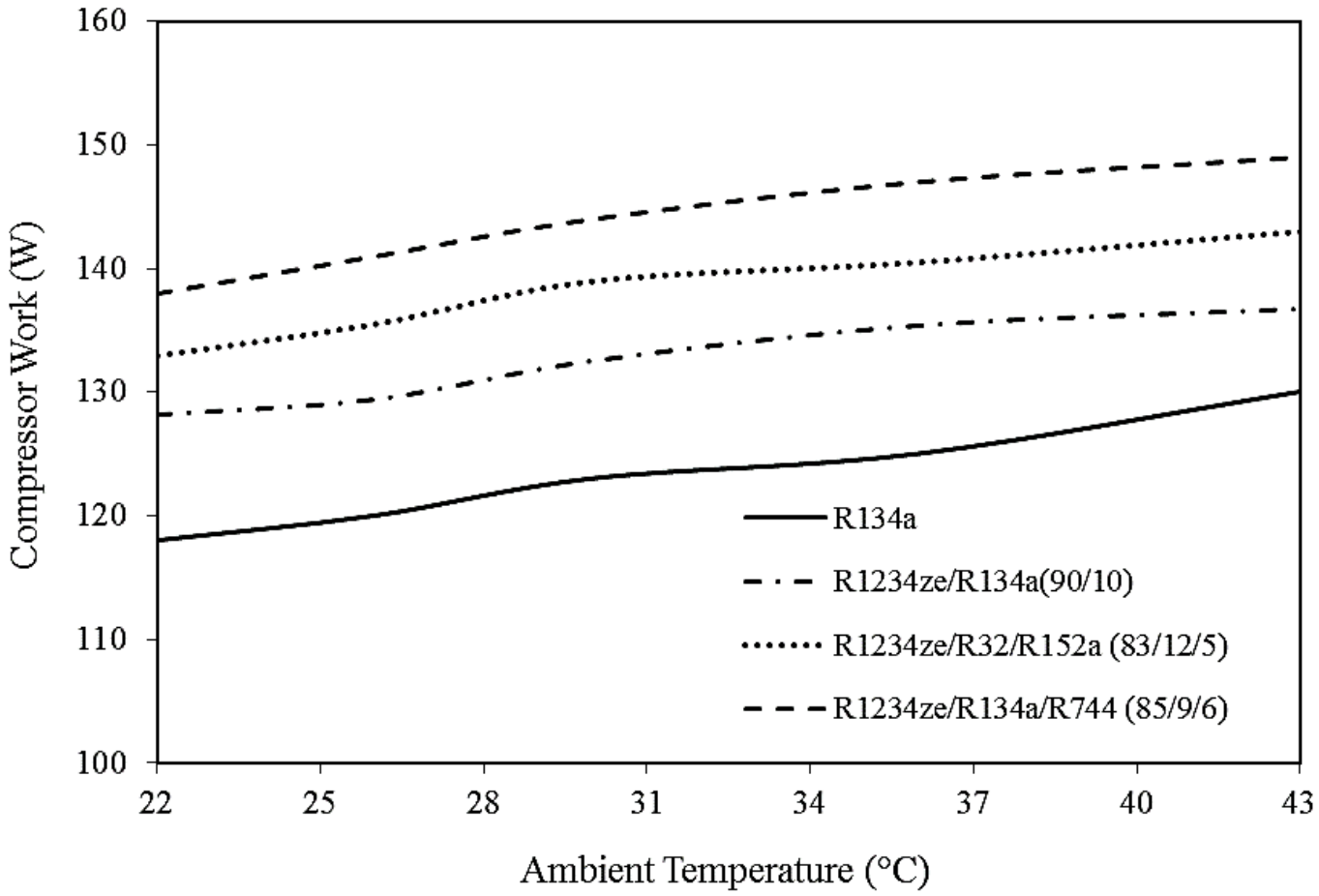

Figure 7

Variation of compressor work with ambient temperature

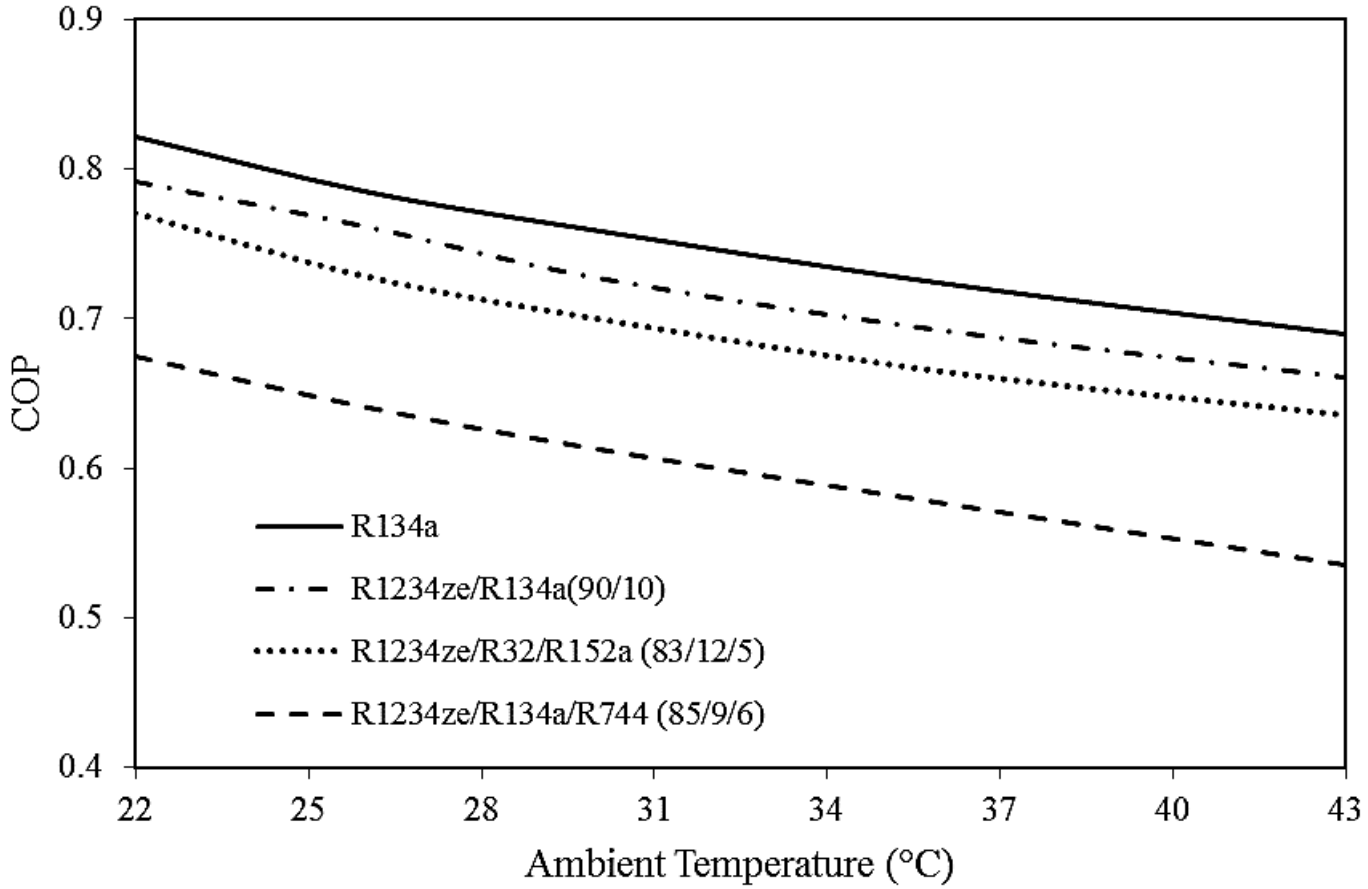

Figure 8

Variation of COP with ambient temperature

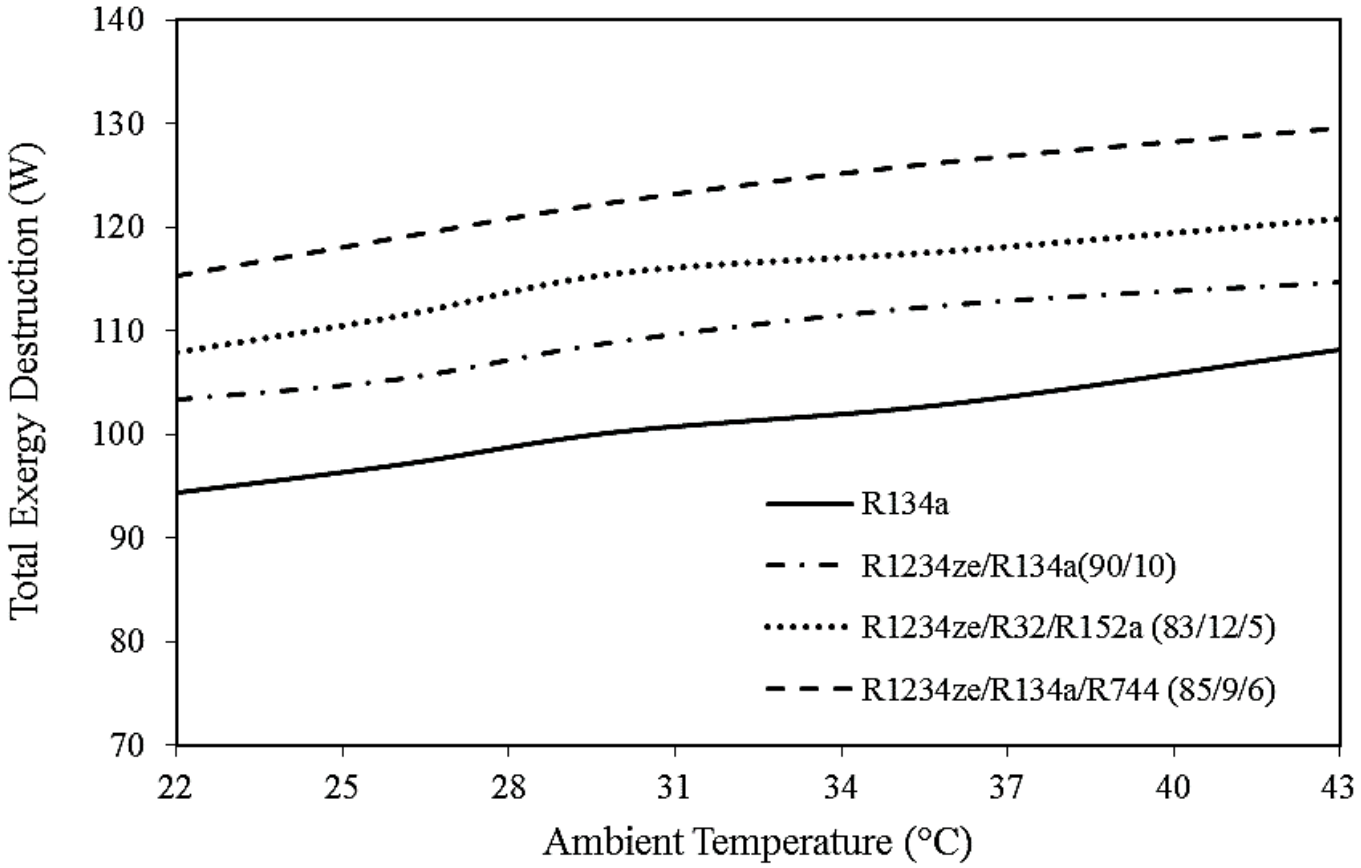

Figure 9

Variation of total exergy destruction with ambient temperature

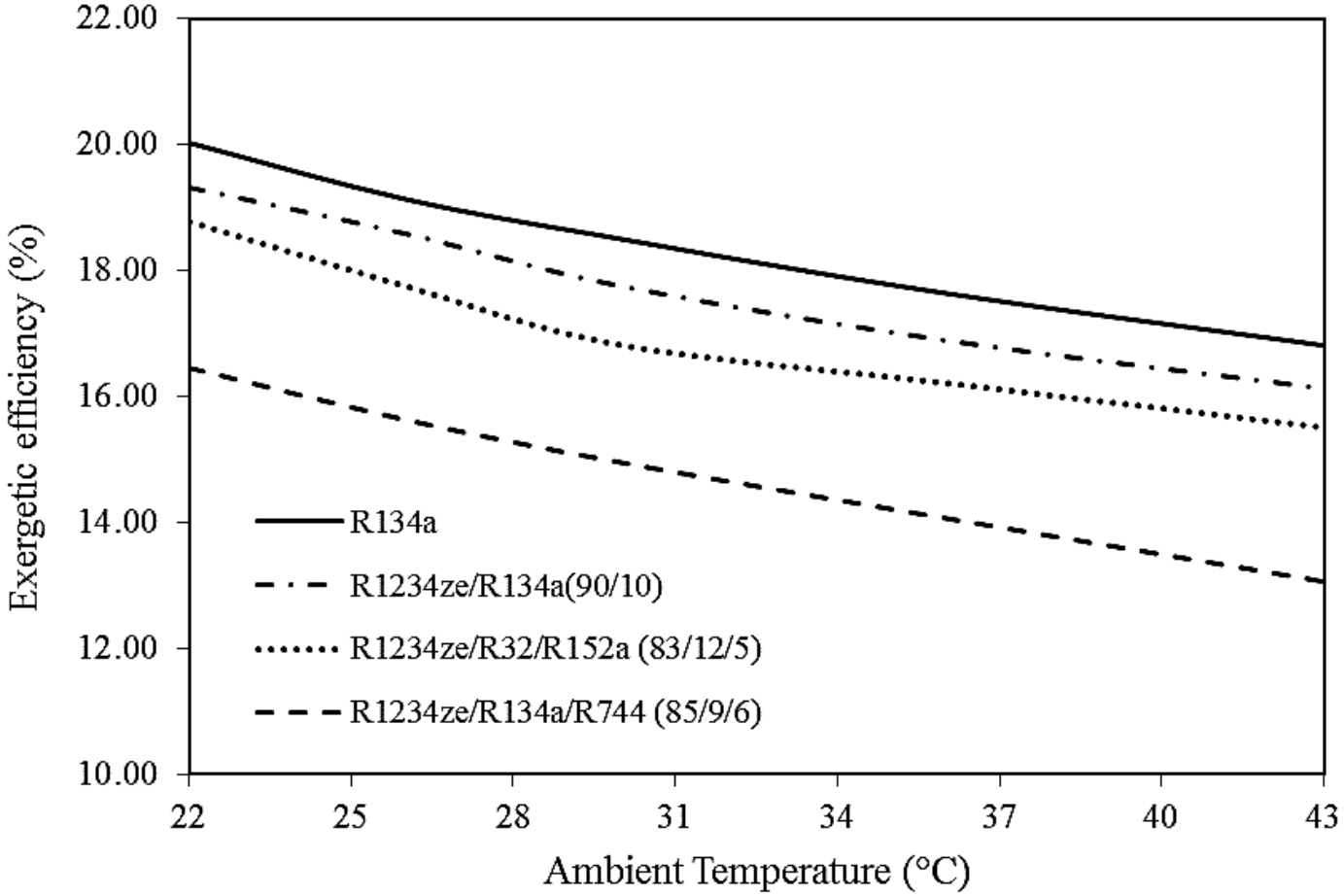

Figure 10

Variation of exergetic efficiency with ambient temperature