Kütahya Dumlupınar University
Institute of Graduate Studies

Journal of Scientific
Reports-A
E-ISSN: 2687-6167
Number 53, June 2023

RESEARCH ARTICLE

THEORETICAL INVESTIGATION OF PERFORMANCE OF VAPOR COMPRESSION COOLING CYCLE FOR DME, R125, R134A, R143A, R152A, AND R32 REFRIGERANTS AND THEIR MIXTURES

Oğuz Ozan YOLCAN[1,*]

[1] Kütahya Dumlupinar University, Faculty of Engineering, Department of Mechanical Engineering, Kütahya,
oguzozan.yolcan@dpu.edu.tr, ORCID: 0000-0002-6664-5675

Receive Date:28.12.2022   *Accepted Date: 04.05.2023*

ABSTRACT

In this study, the performances of refrigerant mixtures in ideal vapor compression refrigeration cycles were investigated theoretically. By choosing six different refrigerants as dimethyl ether (DME), R125, R134a, R143a, R152a, and R32, eleven different refrigerant mixtures were handled. Each mixture's vapor compression refrigeration cycle performances were evaluated according to three different condenser outlet temperatures and nine different mass fractions (90%/10% to 10%/90%). To examine the thermodynamic performance of refrigerant mixtures, constant evaporator outlet temperature (-10 ^{o}C) and different constant condenser outlet temperatures (20 ^{o}C, 25 ^{o}C, and 30 ^{o}C) were determined. According to the evaluated refrigerant mixtures, the COP_R values of the refrigerant mixtures containing DME were calculated as the highest among all the mixtures. In the mixtures containing DME, it was observed that the COP_R values decreased as the mass percentage of DME decreased. The COP_R values are calculated in the range of 3.66-5.70 for the R134a/R32 mixture, 3.82-5.81 for the R134a/R143a mixture, 3.97-5.99 for the R143a/R32 mixture, 3.83-5.83 for the R125/R143a mixture, 3.86-5.98 for the R125/R32 mixture, 4.34-6.24 for R134a/R152a mixture, 3.78-5.81 for R143a/R152a mixture, 3.57-5.55 for R152a/R32 mixture, 3.40-6.28 for DME/R125 mixture, 4.34-6.27 for DME/R134a mixture and 3.59-5.82 for the DME/R32 mixture.

When the pure forms and mixtures of the refrigerants discussed in the study are compared, it is seen that the pure DME and R32 gases are slightly more performant than the gas mixtures examined. The R125 gas mixture shows a higher performance than the pure R125 gas, and the R134a and R143a mixtures show slightly higher performance than the pure gas forms. Finally, the specific energies of pure refrigerants and refrigerant mixtures were calculated within the scope of the study. DME has the highest specific energy among pure refrigerants, while DME/R32 mixture has the highest specific energy among refrigerant mixtures.

Keywords: *Refrigerant mixture, Dimethyl Ether, R125, R134a, R143a, R152a, R32,* COP_R.

1. INTRODUCTION

Heat pumps and refrigeration machines work according to the vapor compression refrigeration cycle, and refrigerants are used in these cycles. Different refrigerants perform differently in vapor compression refrigeration cycles with the same pressure ranges. In this study, eleven different refrigerant mixtures were created by choosing six different refrigerants. The performance (COP_R) of the refrigerant mixtures in the ideal vapor compression refrigeration cycle has been investigated theoretically. This study aims to compare the refrigerant mixture performances with the pure refrigerant performances.

Dalkılıç theoretically investigated the performance of various refrigerants/refrigerant mixtures in a cascade refrigeration cycle in his study. Mixtures of mixed refrigerants consisting of HFC-134a, HFC-152a, HC-600a, and HC-290 were investigated. Theoretical calculations were made according to different evaporator and condenser temperatures. It has been stated that azeotrope mixtures have higher performance than zeotrope mixtures [1]. Hasan and Chitheer investigated the performance of various pure refrigerants and binary or triple refrigerant mixtures in the refrigeration cycle [2]. Kılıç and İpek investigated the thermodynamic performance of R410A gas, which is a mixture of R125 and R32 gases. COP values of the cycle were calculated according to different evaporator and condenser temperatures [3]. Taylor et al. compared the thermodynamic performances of binary alkane mixtures and pure alkanes. COP values and exergy efficiencies of the mixtures were calculated [4]. Wu et al. investigated the thermodynamic performance of zeotropic mixtures of refrigerants. In addition, expressions giving residual enthalpy and entropy values are created [5]. Zühlsdorf et al. investigated the thermodynamic performance of 14 different refrigerants by simulating their mixtures with each other [6]. Khordad and Mirhosseini theoretically investigated the thermal conductivity of refrigerant mixtures and studied the relationship of thermal conductivity with temperature [7]. Baskaran and Mathews investigated the thermodynamic performance of DME and R152a mixtures. According to the results, it was determined that the mixture was more performant than the pure R152a fluid [8]. Saleh et al. investigated the thermodynamic performances of pure refrigerants and refrigerant mixtures in ideal and cascade refrigeration cycles [9]. Sawjanya and Rao examined the mixtures of 27 different refrigerants according to 3 different mixing methods and compared the Vapor-Liquid Equilibrium of the theoretical data with the experimental data [10]. Bolaji and Huan investigated the thermodynamic performance of R290 and R600a refrigerant mixtures in different mass fractions. According to the results obtained, it was stated that the mixtures showed more cooling effect than the R134a refrigerant, and the COP values were close to each other [11]. Arcaklıoğlu and Erişen investigated the thermodynamic performances of binary/triple/quadruple mixtures of R12, R125, R134a, R143a, R152a, R22, R290, R32, R502, and R600a refrigerants. It was stated that the COPR values of all mixtures ranged from 3.7 to 6.7. Fixed evaporator and condenser temperatures are considered in theoretical calculations [12]. Ranjan Panda and Behera experimentally investigated the performances of R290/R600a, R290/R600, LPG (R290/R600/R600a) and LPG/R134a refrigerant blends. Theoretical calculations depended on the different condenser and evaporator temperatures [13]. This study investigated and evaluated the ideal vapor-compression refrigerant cycle performances of DME, R125, R134a, R143a, R152a, and R32 refrigerants at different condenser outlet temperatures. Energy efficiency can be achieved by putting the studies on the ideal cycle into practice.

2. MATERIAL and METHOD

2.1. Selected Refrigerants

This study evaluated the thermodynamic performance of DME refrigerant and R125, R134a, R143a, R152a, and R32 refrigerants. Although DME is a highly flammable substance, it has recently found reuse as a working fluid in cooling and heating systems due to its minimal GWP and zero ODP [14,15]. Ozone Depletion Potential (ODP) and Global Warming Potential (GWP) values and ASHRAE Safety Groups of the selected refrigerants are shared in Table 1. All selected refrigerants have ODP values of 0, while R125 and R143a refrigerants have high GWP values. DME fluid has a low GWP. In the selection of refrigerants, attention was paid to the low ODP value, fire safety, cost-effectiveness, and accessibility of the thermophysical properties of the refrigerants for theoretical calculations. Thermophysical properties of all refrigerants whose thermodynamic performances were examined were obtained from NIST databases [16]. Theoretical calculations of the refrigerant mixture performances were made under ideal vapor compression refrigeration cycle conditions. Evaporator and condenser outlet temperatures were determined to suit all mixing ratios' ideal vapor compression refrigeration cycle conditions. The mass fractions of the mixtures were evaluated for primary and secondary gas; 90%/10%, 80%/20%, 70%/30%, 60%/40%, 50%/50%, 40%/60%, 30%/70%, 20%/80%, and 10%/90% respectively.

Table 1. ODP and GWP values of selected refrigerants.

Refrigerant	ODP	GWP (100 years)	Safety Group [17]	Reference
Dimethyl ether (DME)	0	0.3	A3	[14,18]
R125	0	2800	A1	[19]
R134a	0	1300	A1	
R143a	0	3800	A2	
R152a	0	140	A2	
R32	0	650	A2	

2.2. Ideal Vapor Compression Cooling Cycle

The performances of the refrigerant mixtures were evaluated in the ideal vapor compression refrigeration cycle. To examine the thermodynamic performance of refrigerant mixtures, constant evaporator outlet temperature (-10 ^{o}C) and three different constant condenser outlet temperatures (20 ^{o}C, 25 ^{o}C, and 30 ^{o}C) were determined. The specific pressure-enthalpy and temperature-entropy diagrams of the ideal vapor compression refrigeration cycle are shown in Figure 1 [20].

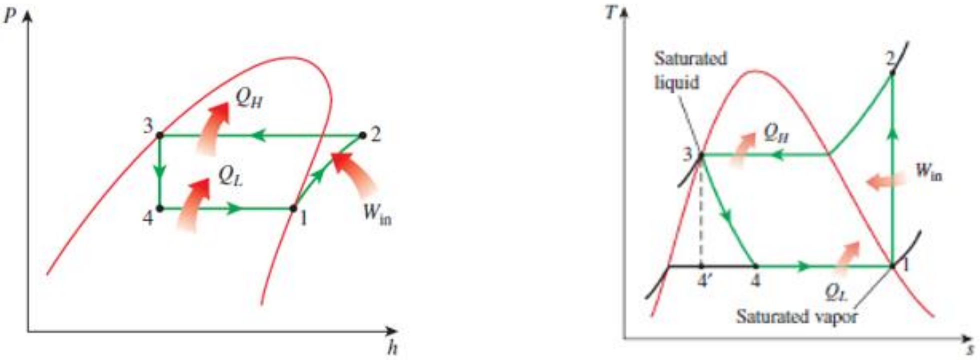

Figure 1. P-h and T-s diagrams of the ideal vapor compression refrigeration cycle [20].

The COP_R value of the ideal vapor compression refrigeration cycle is calculated by Eq. 1.

$$COP_R = \frac{h_1 - h_4}{h_2 - h_1} \quad (1)$$

Depending on the isentropic efficiency of the compressor, the enthalpy of point 2 is calculated by Eq. 2.

$$h_2 = \frac{(h_{2s} - h_1)}{\eta_c} + h_1 (kJ/kg) \quad (2)$$

The assumptions made in the calculations are given below.

Assumptions

- Steady-state flow.
- The cycle is accepted as the ideal vapor compression refrigeration cycle.
- In the calculations, the pressure drops in the cycle components, heat losses from the cycle to the environment, and heat gains from the environment to the cycle are neglected.
- The evaporator outlet temperature (T_1) was accepted as -10 ^oC, condenser outlet temperature (T_3) was accepted as 20 ^oC, 25 ^oC, and 30 ^oC.
- Compressor isentropic efficiency is accepted as 80%.
- Mixing ratios are given as mass fractions.

3. RESULTS

3.1. Thermodynamic Performance of Refrigerant Mixtures

The COP_R charts of the refrigerant mixtures, according to their mass fractions and condenser outlet temperatures, are given below.

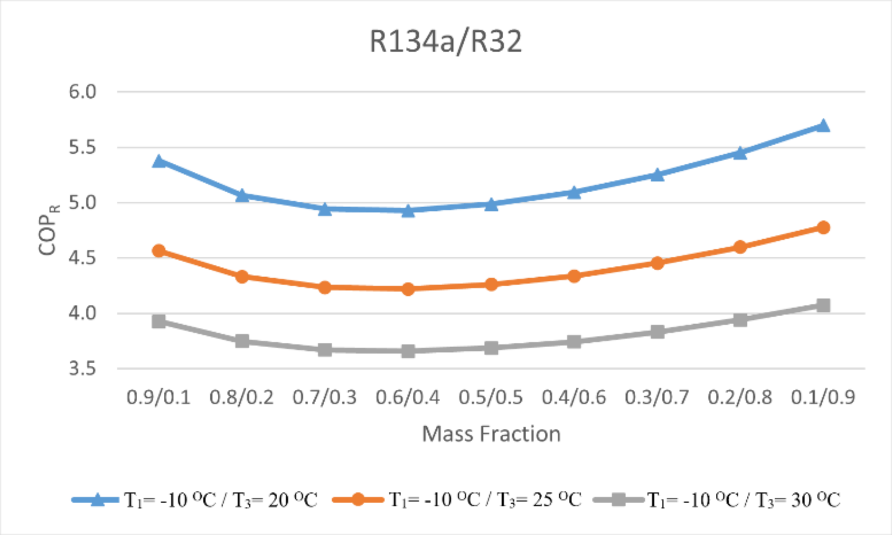

Figure 2. Thermodynamic performance of R134a/R32 mixture.

Figure 2 shows the COP_R values of the R134a/R32 mixture according to different condenser outlet temperatures and mass fractions. While it was observed that the COP_R value increased as the R32 mass ratio in the mixture increased, the highest COP_R values were calculated for the condenser outlet temperature of 20 ^{o}C. COP_R values are in the range of 3.66-5.70, in line with the acceptances.

Figure 3 shows the COP_R values of the R134a/R143a mixture according to different condenser outlet temperatures and mass fractions. While the mass ratio of R134a is high in the mixture, it is seen that the COP_R values are higher. The highest COP_R values were calculated for the condenser outlet temperature of 20 ^{o}C. COP_R values are in the range of 3.82-5.81, in line with the acceptances.

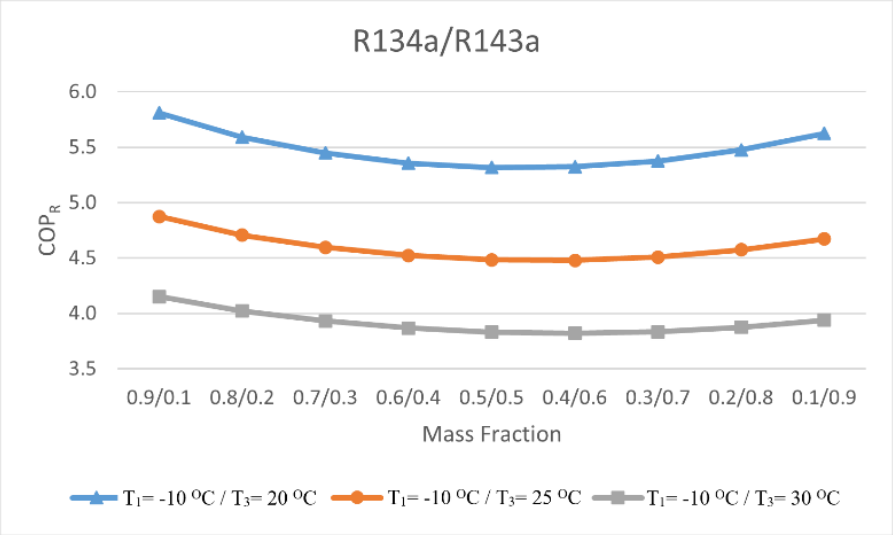

Figure 3. Thermodynamic performance of R134a/R143a mixture.

Figure 4 shows the COP_R values of the R143a/R32 mixture according to different condenser outlet temperatures and mass fractions. It is seen that the COP_R value of the mixture increases as the R32 mass ratio increases in the mixture. The highest COP_R values were calculated for the condenser outlet temperature of 20 ^oC. COP_R values are in the range of 3.97-5.99, in line with the acceptances.

Figure 5 shows the COP_R values of the R125/R143a mixture according to different condenser outlet temperatures and mass fractions. It is seen that the COP_R value of the mixture increases as the R143a mass ratio increases in the mixture. The highest COP_R values were calculated for the condenser outlet temperature of 20 ^oC. COP_R values are in the range of 3.83-5.83, in line with the acceptances.

Figure 6 shows the COP_R values of the R125/R32 mixture according to different condenser outlet temperatures and mass fractions. It is seen that the COP_R value of the mixture increases as the R32 mass ratio increases in the mixture. The highest COP_R values were calculated for the condenser outlet temperature of 20 ^oC. COP_R values are in the range of 3.86-5.98, in line with the acceptances.

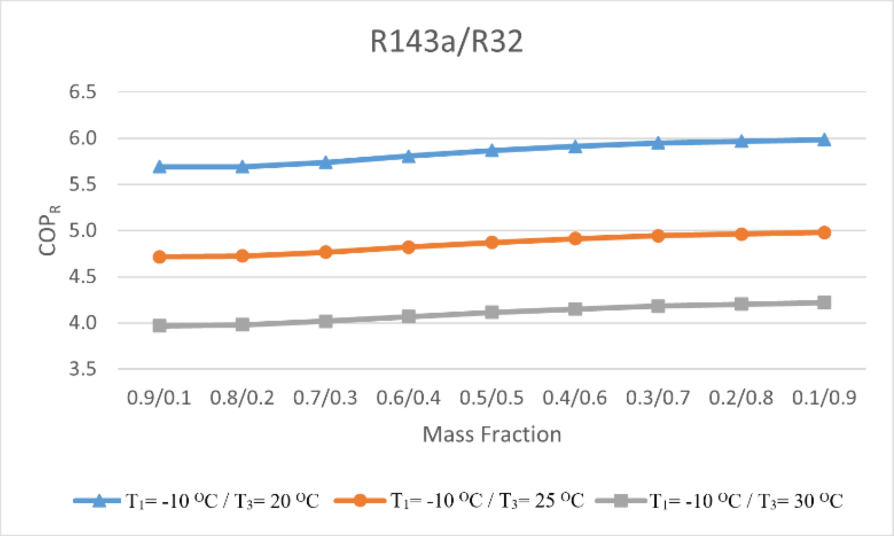

Figure 4. Thermodynamic performance of R143a/R32 mixture.

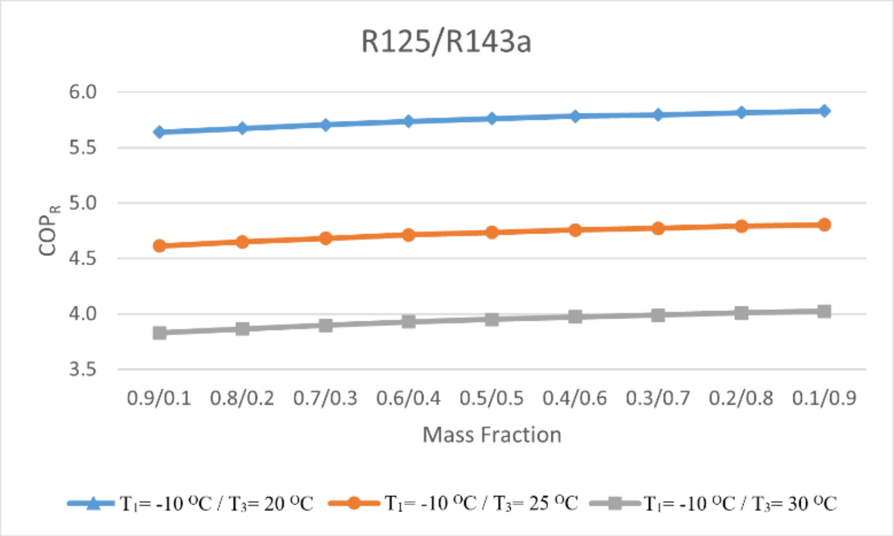

Figure 5. Thermodynamic performance of R1125/R143a mixture.

Figure 7 shows the COP_R values of the R134a/R152a mixture according to different condenser outlet temperatures and mass fractions. Although the COP_R values are constant according to the mass fractions, the COP_R values increase slightly as the ratio of R152a increases in the mixture. The highest

COP_R values were calculated for the condenser outlet temperature of 20 ^oC. COP_R values are in the range of 4.34-6.24, in line with the acceptances.

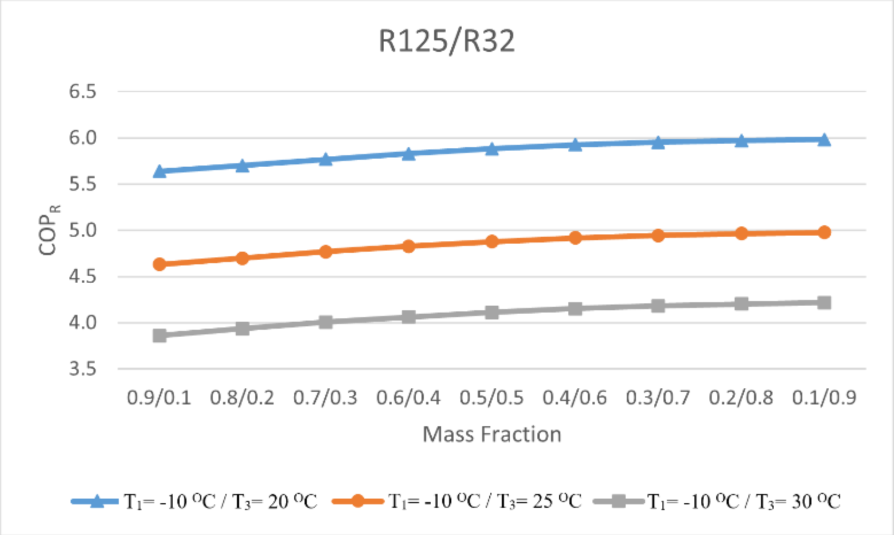

Figure 6. Thermodynamic performance of R125/R32 mixture.

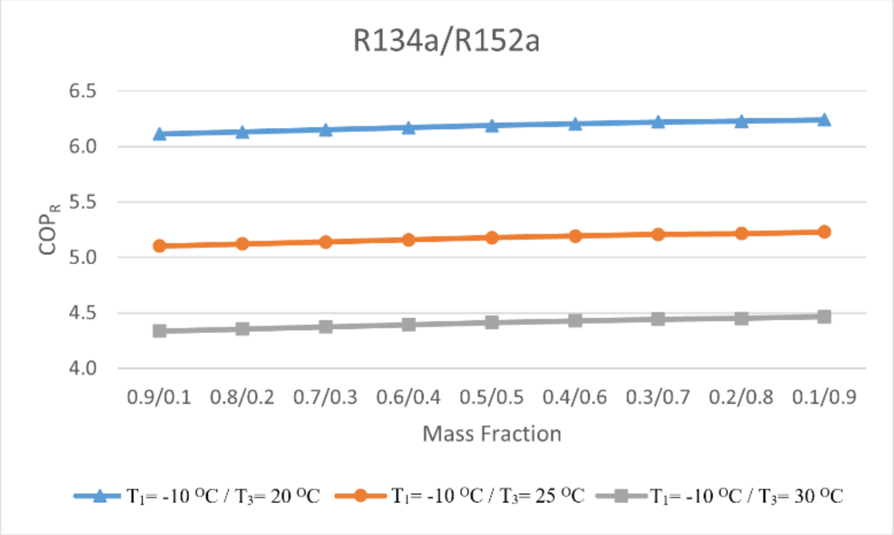

Figure 7. Thermodynamic performance of R134a/R152a mixture.

Figure 8 shows the COP_R values of the R143a/R152a mixture according to different condenser outlet temperatures and mass fractions. While it was observed that the COP_R value increased as the R152a mass ratio in the mixture increased, the highest COP_R values were calculated for the condenser outlet temperature of 20 ^oC. COP_R values are in the range of 3.78-5.81, in line with the acceptances.

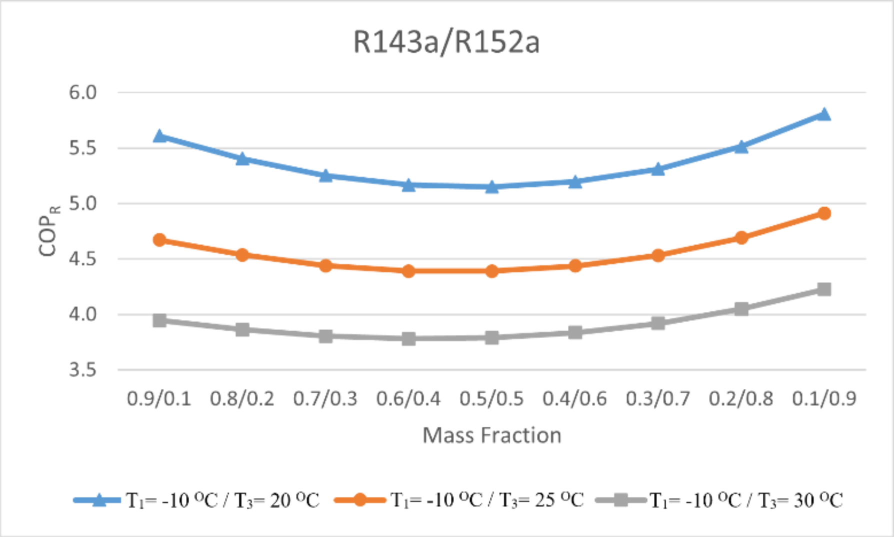

Figure 8. Thermodynamic performance of R143a/R152a mixture.

Figure 9 shows the COP_R values of the R152a/R32 mixture according to different condenser outlet temperatures and mass fractions. While it was observed that the COP_R value increased as the R152a mass ratio in the mixture increased, the highest COP_R values were calculated for the condenser outlet temperature of 20 ^oC. COP_R values are in the range of 3.57-5.55, in line with the acceptances.

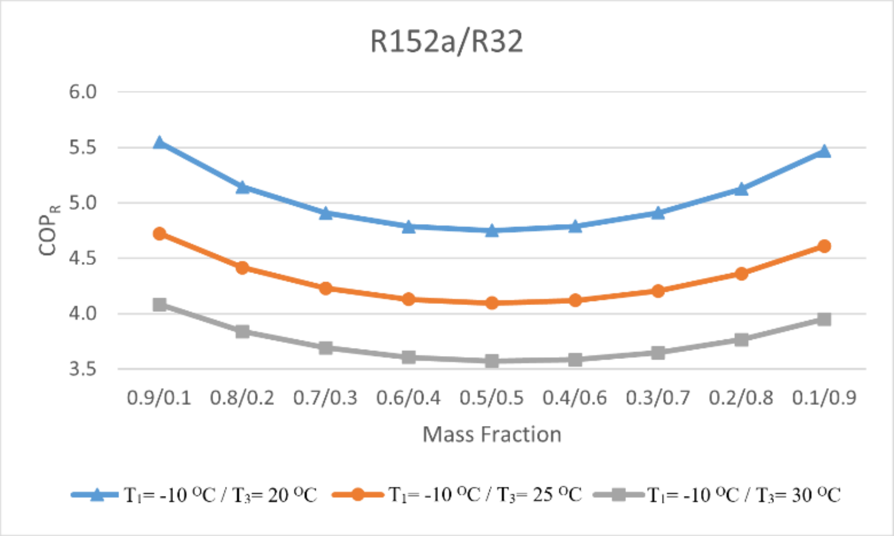

Figure 9. Thermodynamic performance of R152a/R32 mixture.

Figure 10 shows the COP_R values of the DME/R125 mixture according to different condenser outlet temperatures and mass fractions. As the mass ratio of R125 increases in the mixture, there is a sharp decrease in the COP_R values. The highest COP_R values were calculated for the condenser outlet temperature of 20 ^{o}C. COP_R values are in the range of 3.40-6.28, in line with the acceptances.

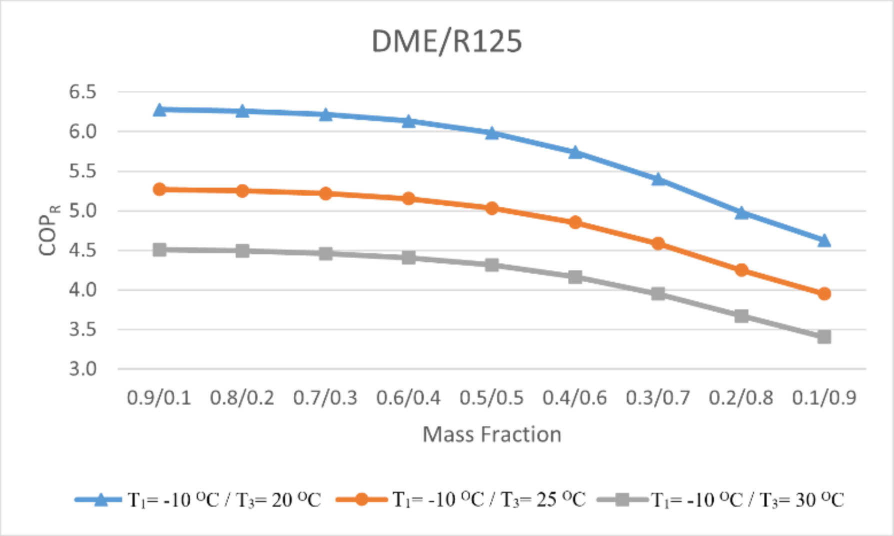

Figure 10. Thermodynamic performance of DME/R125 mixture.

Figure 11 shows the COP_R values of the DME/R134a mixture according to different condenser outlet temperatures and mass fractions. Although the COP_R values are constant according to the mass fractions, the COP_R values increase slightly as the ratio of DME increases in the mixture. The highest COP_R values were calculated for the condenser outlet temperature of 20 ^oC. COP_R values are in the range of 4.34-6.27, in line with the acceptances.

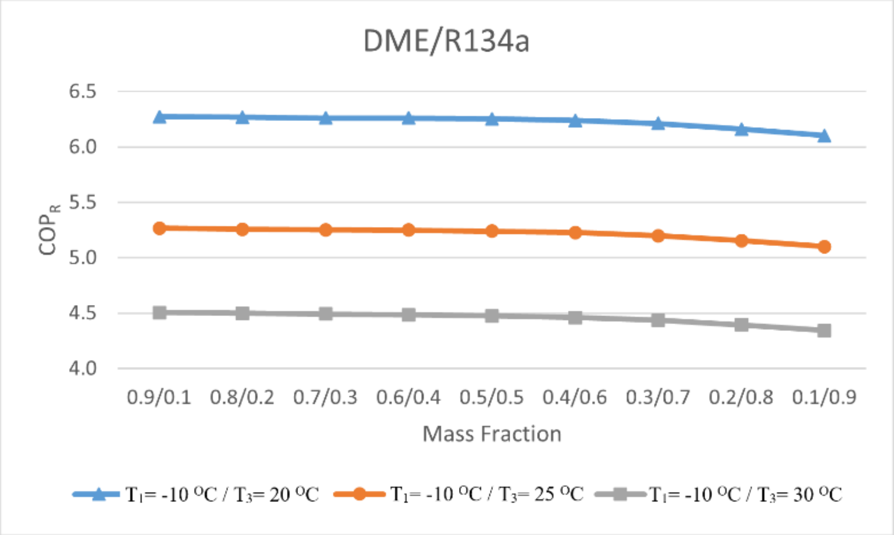

Figure 11. Thermodynamic performance of DME-R134a mixture.

Figure 12 shows the COP_R values of the DME/R32 mixture according to different condenser outlet temperatures and mass fractions. As the mass ratio of DME increases in the mixture, there is a sharp decrease in the COP_R values. The highest COP_R values were calculated for the condenser outlet temperature of 20 ^oC. COP_R values are in the range of 3.59-5.82, in line with the acceptances.

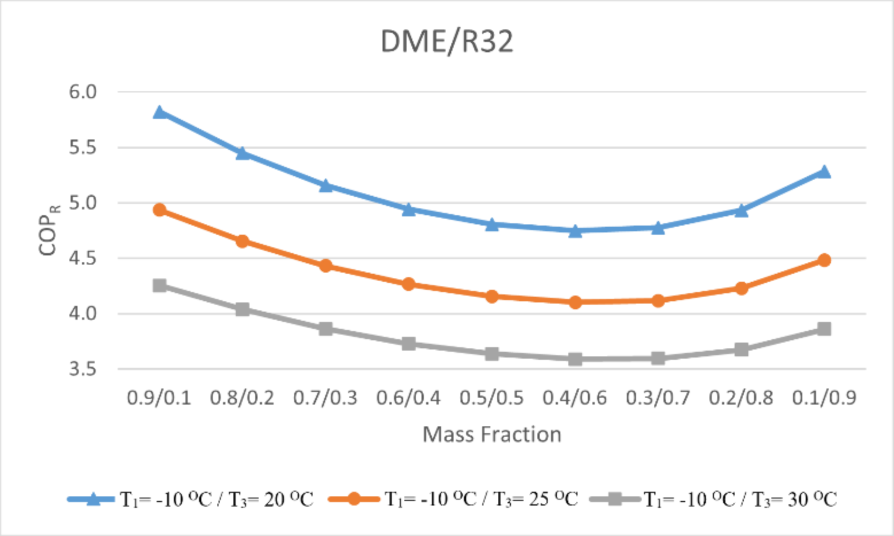

Figure 12. Thermodynamic performance of DME/R132 mixture.

The COP$_R$ values of the refrigerant mixtures according to the condenser outlet temperatures and mass fractions are given in Table 2.

Table 2. COP$_R$ values of the refrigerant mixtures according to the condenser outlet temperatures and mass fractions.

Mixture	Mass Fraction	T_1 (^{o}C)	T_3 (^{o}C)	COP$_R$	Mixture	Mass Fraction	T_1 (^{o}C)	T_3 (^{o}C)	COP$_R$
R134a/R32	0.9/0.1	-10	20	5.38	R134a/R143a	0.9/0.1	-10	20	5.81
	0.8/0.2			5.07		0.8/0.2			5.59
	0.7/0.3			4.94		0.7/0.3			5.45
	0.6/0.4			4.93		0.6/0.4			5.36
	0.5/0.5			4.99		0.5/0.5			5.32
	0.4/0.6			5.09		0.4/0.6			5.32
	0.3/0.7			5.25		0.3/0.7			5.37
	0.2/0.8			5.45		0.2/0.8			5.48
	0.1/0.9			5.70		0.1/0.9			5.63
	0.9/0.1		25	4.56		0.9/0.1		25	4.87
	0.8/0.2			4.33		0.8/0.2			4.71
	0.7/0.3			4.23		0.7/0.3			4.60
	0.6/0.4			4.22		0.6/0.4			4.52
	0.5/0.5			4.26		0.5/0.5			4.48
	0.4/0.6			4.34		0.4/0.6			4.48

	0.3/0.7			4.45		0.3/0.7			4.51
	0.2/0.8			4.60		0.2/0.8			4.57
	0.1/0.9			4.78		0.1/0.9			4.67
	0.9/0.1		30	3.93		0.9/0.1		30	4.15
	0.8/0.2			3.75		0.8/0.2			4.02
	0.7/0.3			3.67		0.7/0.3			3.93
	0.6/0.4			3.66		0.6/0.4			3.87
	0.5/0.5			3.69		0.5/0.5			3.83
	0.4/0.6			3.74		0.4/0.6			3.82
	0.3/0.7			3.83		0.3/0.7			3.83
	0.2/0.8			3.94		0.2/0.8			3.88
	0.1/0.9			4.07		0.1/0.9			3.94

Table 2. COP$_R$ values of the refrigerant mixtures according to the condenser outlet temperatures and mass fractions (continued).

Mixture	Mass Fraction	T_1 (^{o}C)	T_3 (^{o}C)	COP$_R$	Mixture	Mass Fraction	T_1 (^{o}C)	T_3 (^{o}C)	COP$_R$
R143a/R32	0.9/0.1	-10	20	5.69	R125/R143a	0.9/0.1	-10	20	5.64
	0.8/0.2			5.69		0.8/0.2			5.67
	0.7/0.3			5.74		0.7/0.3			5.71
	0.6/0.4			5.81		0.6/0.4			5.74
	0.5/0.5			5.87		0.5/0.5			5.76
	0.4/0.6			5.91		0.4/0.6			5.78
	0.3/0.7			5.95		0.3/0.7			5.80
	0.2/0.8			5.97		0.2/0.8			5.82
	0.1/0.9			5.99		0.1/0.9			5.83
	0.9/0.1		25	4.72		0.9/0.1		25	4.61
	0.8/0.2			4.72		0.8/0.2			4.65
	0.7/0.3			4.77		0.7/0.3			4.68
	0.6/0.4			4.82		0.6/0.4			4.71
	0.5/0.5			4.87		0.5/0.5			4.74
	0.4/0.6			4.91		0.4/0.6			4.76
	0.3/0.7			4.94		0.3/0.7			4.77
	0.2/0.8			4.96		0.2/0.8			4.79
	0.1/0.9			4.98		0.1/0.9			4.80
	0.9/0.1		30	3.97		0.9/0.1		30	3.83
	0.8/0.2			3.98		0.8/0.2			3.87
	0.7/0.3			4.02		0.7/0.3			3.90
	0.6/0.4			4.07		0.6/0.4			3.93
	0.5/0.5			4.12		0.5/0.5			3.95
	0.4/0.6			4.15		0.4/0.6			3.97
	0.3/0.7			4.18		0.3/0.7			3.99

	0.2/0.8			4.20		0.2/0.8			4.01
	0.1/0.9			4.22		0.1/0.9			4.02

Table 2. COP_R values of the refrigerant mixtures according to the condenser outlet temperatures and mass fractions (continued).

Mixture	Mass Fraction	T_1 (°C)	T_3 (°C)	COP_R	Mixture	Mass Fraction	T_1 (°C)	T_3 (°C)	COP_R
R125/R32	0.9/0.1	-10	20	5.64	R134a/R152a	0.9/0.1	-10	20	6.12
	0.8/0.2			5.70		0.8/0.2			6.13
	0.7/0.3			5.77		0.7/0.3			6.15
	0.6/0.4			5.83		0.6/0.4			6.17
	0.5/0.5			5.88		0.5/0.5			6.19
	0.4/0.6			5.93		0.4/0.6			6.21
	0.3/0.7			5.95		0.3/0.7			6.22
	0.2/0.8			5.97		0.2/0.8			6.23
	0.1/0.9			5.98		0.1/0.9			6.24
	0.9/0.1		25	4.63		0.9/0.1		25	5.10
	0.8/0.2			4.70		0.8/0.2			5.12
	0.7/0.3			4.77		0.7/0.3			5.14
	0.6/0.4			4.83		0.6/0.4			5.16
	0.5/0.5			4.88		0.5/0.5			5.18
	0.4/0.6			4.92		0.4/0.6			5.19
	0.3/0.7			4.95		0.3/0.7			5.21
	0.2/0.8			4.96		0.2/0.8			5.22
	0.1/0.9			4.98		0.1/0.9			5.23
	0.9/0.1		30	3.86		0.9/0.1		30	4.34
	0.8/0.2			3.94		0.8/0.2			4.36
	0.7/0.3			4.00		0.7/0.3			4.38
	0.6/0.4			4.06		0.6/0.4			4.39
	0.5/0.5			4.11		0.5/0.5			4.41
	0.4/0.6			4.15		0.4/0.6			4.43
	0.3/0.7			4.18		0.3/0.7			4.44
	0.2/0.8			4.20		0.2/0.8			4.45
	0.1/0.9			4.22		0.1/0.9			4.46

Table 2. COP_R values of the refrigerant mixtures according to the condenser outlet temperatures and mass fractions (continued).

Mixture	Mass Fraction	T_1 (^oC)	T_3 (^oC)	COP_R	Mixture	Mass Fraction	T_1 (^oC)	T_3 (^oC)	COP_R
R143a/R152a	0.9/0.1	-10	20	5.61	R152a/R32	0.9/0.1	-10	20	5.55
	0.8/0.2			5.40		0.8/0.2			5.14
	0.7/0.3			5.25		0.7/0.3			4.91
	0.6/0.4			5.17		0.6/0.4			4.79
	0.5/0.5			5.15		0.5/0.5			4.75
	0.4/0.6			5.20		0.4/0.6			4.79
	0.3/0.7			5.31		0.3/0.7			4.91
	0.2/0.8			5.51		0.2/0.8			5.13
	0.1/0.9			5.81		0.1/0.9			5.47
	0.9/0.1		25	4.67		0.9/0.1		25	4.72
	0.8/0.2			4.54		0.8/0.2			4.41
	0.7/0.3			4.44		0.7/0.3			4.23
	0.6/0.4			4.39		0.6/0.4			4.13
	0.5/0.5			4.39		0.5/0.5			4.10
	0.4/0.6			4.44		0.4/0.6			4.12
	0.3/0.7			4.53		0.3/0.7			4.20
	0.2/0.8			4.69		0.2/0.8			4.36
	0.1/0.9			4.91		0.1/0.9			4.61
	0.9/0.1		30	3.95		0.9/0.1		30	4.08
	0.8/0.2			3.86		0.8/0.2			3.84
	0.7/0.3			3.80		0.7/0.3			3.69
	0.6/0.4			3.78		0.6/0.4			3.61
	0.5/0.5			3.79		0.5/0.5			3.57
	0.4/0.6			3.84		0.4/0.6			3.59
	0.3/0.7			3.92		0.3/0.7			3.65
	0.2/0.8			4.05		0.2/0.8			3.76
	0.1/0.9			4.23		0.1/0.9			3.95

Table 2. COP_R values of the refrigerant mixtures according to the condenser outlet temperatures and mass fractions (continued).

Mixture	Mass Fraction	T_1 (^oC)	T_3 (^oC)	COP_R	Mixture	Mass Fraction	T_1 (^oC)	T_3 (^oC)	COP_R
DME/R125	0.9/0.1	-10	20	6.28	DME/R134a	0.9/0.1	-10	20	6.27
	0.8/0.2			6.26		0.8/0.2			6.27
	0.7/0.3			6.22		0.7/0.3			6.26
	0.6/0.4			6.13		0.6/0.4			6.26
	0.5/0.5			5.98		0.5/0.5			6.25

	0.4/0.6			5.74		0.4/0.6			6.24
	0.3/0.7			5.40		0.3/0.7			6.21
	0.2/0.8			4.98		0.2/0.8			6.16
	0.1/0.9			4.63		0.1/0.9			6.10
	0.9/0.1		25	5.27		0.9/0.1		25	5.27
	0.8/0.2			5.25		0.8/0.2			5.26
	0.7/0.3			5.22		0.7/0.3			5.25
	0.6/0.4			5.15		0.6/0.4			5.25
	0.5/0.5			5.04		0.5/0.5			5.24
	0.4/0.6			4.85		0.4/0.6			5.23
	0.3/0.7			4.59		0.3/0.7			5.20
	0.2/0.8			4.25		0.2/0.8			5.16
	0.1/0.9			3.95		0.1/0.9			5.10
	0.9/0.1		30	4.51		0.9/0.1		30	4.51
	0.8/0.2			4.49		0.8/0.2			4.50
	0.7/0.3			4.46		0.7/0.3			4.49
	0.6/0.4			4.41		0.6/0.4			4.49
	0.5/0.5			4.31		0.5/0.5			4.48
	0.4/0.6			4.17		0.4/0.6			4.46
	0.3/0.7			3.95		0.3/0.7			4.44
	0.2/0.8			3.67		0.2/0.8			4.39
	0.1/0.9			3.40		0.1/0.9			4.34

Table 2. COP$_R$ values of the refrigerant mixtures according to the condenser outlet temperatures and mass fractions (continued).

Mixture	Mass Fraction	T_1 (°C)	T_3 (°C)	COP$_R$
DME/R32	0.9/0.1	-10	20	5.82
	0.8/0.2			5.45
	0.7/0.3			5.16
	0.6/0.4			4.94
	0.5/0.5			4.81
	0.4/0.6			4.75
	0.3/0.7			4.78
	0.2/0.8			4.93
	0.1/0.9			5.28
	0.9/0.1		25	4.93
	0.8/0.2			4.66
	0.7/0.3			4.43
	0.6/0.4			4.27
	0.5/0.5			4.16
	0.4/0.6			4.10
	0.3/0.7			4.12

	0.2/0.8			4.23
	0.1/0.9			4.48
	0.9/0.1		30	4.25
	0.8/0.2			4.04
	0.7/0.3			3.86
	0.6/0.4			3.73
	0.5/0.5			3.64
	0.4/0.6			3.59
	0.3/0.7			3.60
	0.2/0.8			3.67
	0.1/0.9			3.86

3.2. Comparison of Thermodynamic Performances of Pure and Mixed Refrigerants

In this part of the study, the pure thermodynamic performances of six different refrigerants whose thermodynamic performances were examined in the mixed state were evaluated. The conditions and assumptions applied in the thermodynamic performances discussed in the mixed form are also valid for pure refrigerants.

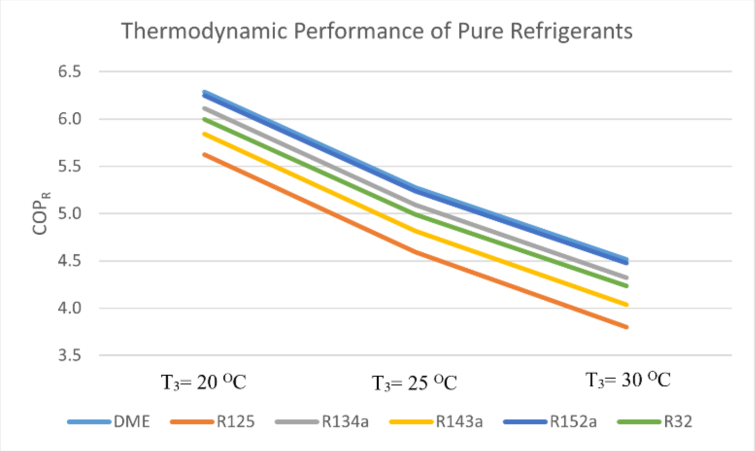

Figure 13. Thermodynamic performance of pure refrigerants.

The ideal vapor compression refrigeration cycle performances of pure refrigerants at evaporator outlet temperatures -10 ^oC and three different condenser outlet temperatures (20 ^oC, 25 ^oC, and 30 ^oC) are shown in Figure 13. According to the calculations, for the specified evaporator and condenser outlet temperatures, the COP_R values calculated; for DME gas are 6.3, 5.3, and 4.5; the COP_R values of R125 gas are 5.6, 4.6, and 3.8, and the COP_R values of R134a gas are 6.1, 5.1 and 4.3, COP_R values of R143a gas 5.8, 4.8 and 4.0, COP_R values of R152a gas 6.2, 5.2 and 4.5, COP_R values of R32 gas 6.0, 5.0 and 4.2, respectively.

Table 3 compares the refrigerants' pure state performances with the mixing performances. In Table 3, the COPR values of the pure refrigerants according to the condenser outlet temperatures and the highest and lowest COPR values of the evaluated refrigerants in the mixture (IM) are given. Mixture details are given in the table description (MF=mass fraction).

Table 3. Comparison of pure and mixed refrigerants (a=DME/R125, T_3= 20 ^{O}C, MF=0.9/0.1, b=DME/R125, T_3= 30 ^{O}C, MF=0.1/0.9, c=DME/R134a, T_3= 20 ^{O}C, MF=0.9/0.1, d=R134a/R32, T_3= 30 ^{O}C, MF=0.6/0.4, e=R143a/R32, T_3= 20 ^{O}C, MF=0.1/0.9, f=R134a/R32, T_3= 30 ^{O}C, MF=0.6/0.4, g=R134a/R152a, T_3= 20 ^{O}C, MF=0.1/0.9, h=R152a/R32, T_3= 30 ^{O}C, MF=0.5/0.5).

	T_3= 20 ^{o}C	T_3= 25 ^{o}C	T_3= 30 ^{o}C	Highest COP_R IM	Lowest COP_R IM
DME	6.3	5.3	4.5	6.28 (a)	3.40 (b)
R125	5.6	4.6	3.8	6.28 (a)	3.40 (b)
R134a	6.1	5.1	4.3	6.27 (c)	3.66 (d)
R143a	5.8	4.8	4.0	5.99 (e)	3.78 (f)
R152a	6.2	5.2	4.5	6.24 (g)	3.57 (h)
R32	6.0	5.0	4.2	5.99 (e)	3.57 (h)

When Table 3 is examined, it is seen that pure DME and R32 gases are slightly more performant than the gas mixtures examined. The R125 gas mixture performs better than the pure R125 gas, and the R134a and R143a mixtures show slightly higher performance than the pure gas forms.

The specific energies (SE) of pure refrigerants and refrigerant mixtures are also calculated. While calculating the specific energies, the evaporator cooling load is considered in the ideal cycle. The specific cooling energy is calculated by Eq. 3.

$$SE = h_1 - h_4 (kJ/kg)$$
(3)

Table 4. Specific energies of pure refrigerants according to different condenser outlet temperatures (kJ/kg).

Refrigerant	T_3=-20 ^{o}C	T_3=-25 ^{o}C	T_3=-30 ^{o}C
DME	377.16	365.02	352.74
R125	102.22	95.37	88.33
R134a	165.19	158.11	150.94
R143a	151.52	143.35	134.98
R152a	265.38	256.42	247.35
R32	276.9	267.42	257.7

The specific energies of pure refrigerants are shown in Table 4. Accordingly, the highest specific energy was calculated for DME fluid in the ideal vapor compression cycle, and the lowest specific energy was calculated for R125 fluid. As the constant condenser outlet temperature increases, the specific energy decreases.

The specific energies of the refrigerant mixtures according to different mass fractions and condenser outlet temperatures are shown in Table 5. The DME/R32 mixture had the highest specific energy, while the lowest was in the R125/R143a mixture. As the constant condenser outlet temperature increases, the specific energy decreases. In mixtures containing DME, it is seen that the mass fraction of DME and the specific energy are directly proportional.

Table 5. Specific energies of refrigerant mixtures according to different mass fractions and condenser outlet temperatures (kJ/kg).

T_3 (^{o}C)	MF	R134a / R32	R134a / R143a	R143a / R32	R125 / R143a	R125 / R32	R134a/ R152a
20	0.9/0.1	176.41	164.17	160.93	107.81	119.04	176.06
	0.8/0.2	187.68	163.08	171.25	113.19	135.64	186.67
	0.7/0.3	198.97	161.94	182.38	118.39	152.31	197.05
	0.6/0.4	210.28	160.72	194.26	123.44	169.21	207.24
	0.5/0.5	221.56	159.43	206.8	128.36	186.43	217.26
	0.4/0.6	232.79	158.07	219.92	133.17	203.96	227.12
	0.3/0.7	243.96	156.61	233.57	137.87	221.79	236.85
	0.2/0.8	255.05	155.04	247.64	142.5	239.91	246.46
	0.1/0.9	266.05	153.36	262.11	147.04	258.28	255.97
25	0.9/0.1	169.1	157	152.58	100.82	111.84	168.75
	0.8/0.2	180.14	155.8	162.74	106.07	128.13	179.15
	0.7/0.3	191.19	154.56	173.73	111.13	144.51	189.32
	0.6/0.4	202.26	153.24	185.46	116.05	161.15	199.32
	0.5/0.5	213.3	151.85	197.88	120.84	178.11	209.14
	0.4/0.6	224.29	150.37	210.88	125.52	195.39	218.83
	0.3/0.7	235.22	148.8	224.41	130.09	212.99	228.38
	0.2/0.8	246.07	147.12	238.38	134.59	230.88	237.82
	0.1/0.9	256.81	145.32	252.74	139	249.02	247.17
30	0.9/0.1	161.68	149.71	144.02	93.65	104.46	161.35
	0.8/0.2	172.47	148.41	154.01	98.77	120.42	171.53
	0.7/0.3	183.28	147.06	164.83	103.69	136.51	181.5
	0.6/0.4	194.1	145.63	176.43	108.48	152.87	191.29
	0.5/0.5	204.88	144.12	188.71	113.13	169.56	200.93
	0.4/0.6	215.62	142.53	201.59	117.68	186.6	210.43
	0.3/0.7	226.29	140.84	215.01	122.12	203.96	219.81
	0.2/0.8	236.88	139.03	228.87	126.48	221.61	229.08
	0.1/0.9	247.36	137.09	243.13	130.77	239.53	238.26

Table 5. Specific energies of refrigerant mixtures according to different mass fractions and condenser outlet temperatures (kJ/kg) (continued).

T_3 (°C)	MF	R143a / R152a	R152a / R32	DME / R125	DME / R134a	DME / R32
20	0.9/0.1	162.32	266.77	353.34	357.12	370.7
	0.8/0.2	173.33	268.23	329.24	336.96	363.73
	0.7/0.3	184.46	269.74	304.79	316.67	356.18
	0.6/0.4	195.7	271.25	279.89	296.21	348.01
	0.5/0.5	207.04	272.73	254.41	275.53	339.1
	0.4/0.6	218.48	274.09	228.14	254.57	329.37
	0.3/0.7	230.02	275.32	200.79	233.25	318.65
	0.2/0.8	241.68	276.28	171.82	211.43	306.68
	0.1/0.9	253.46	276.88	140.23	188.87	293.01
25	0.9/0.1	154.11	257.79	341.78	345.49	358.89
	0.8/0.2	165.06	259.22	318.26	325.85	352.24
	0.7/0.3	176.12	260.69	294.38	306.07	345.02
	0.6/0.4	187.29	262.16	270.05	286.12	337.15
	0.5/0.5	198.55	263.59	245.13	265.96	328.54
	0.4/0.6	209.9	264.9	219.43	245.51	319.09
	0.3/0.7	221.35	266.06	192.63	224.7	308.63
	0.2/0.8	232.92	266.96	164.19	203.37	296.88
	0.1/0.9	244.61	267.48	133.08	181.31	283.41
30	0.9/0.1	145.7	248.68	330.09	333.74	346.94
	0.8/0.2	156.61	250.08	307.15	314.62	340.63
	0.7/0.3	167.62	251.5	283.85	295.36	333.71
	0.6/0.4	178.72	252.92	260.09	275.93	326.16
	0.5/0.5	189.91	254.29	235.75	256.28	317.84
	0.4/0.6	201.18	255.54	210.62	236.34	308.66
	0.3/0.7	212.55	256.63	184.36	216.04	298.44
	0.2/0.8	224.03	257.44	156.45	195.22	286.91
	0.1/0.9	235.63	257.87	125.8	173.66	273.6

4. EVALUATIONS

In this study, by choosing six different refrigerants as dimethyl ether (DME), R125, R134a, R143a, R152a, and R32, 11 different refrigerant mixtures were handled, and vapor compression refrigeration cycle performances of each mixture were evaluated according to three different condenser outlet temperatures and nine different mass fractions.

According to the evaluated refrigerant mixtures, the COP_R values of the refrigerant mixtures containing DME were calculated as the highest among all the mixtures. The COP_R value of the DME&R125 mixture with 90% DME - 10% R125 mass fraction was calculated as 7.85 for -10 ^{o}C evaporator outlet temperature and 20 ^oC condenser outlet temperature. The COP_R value of the DME&R134a mixture with 90% DME - 10% R134a mass fraction was calculated as 7.84 for -10 ^oC evaporator outlet temperature and 20 ^oC condenser outlet temperature.

When the pure forms and mixtures of the refrigerants discussed in the study are compared, it is seen that the pure DME and R32 gases are slightly more performant than the gas mixtures examined. The R125 gas mixture shows a higher performance than the pure R125 gas, and the R134a and R143a mixtures show a slightly higher performance than the pure gas forms.
In this study, the vapor compression refrigeration cycle performances of six different pure refrigerants were determined, and the vapor compression refrigeration cycle performances of eleven different refrigerant mixtures formed by these pure refrigerants were theoretically investigated under the accepted conditions. In future studies, the performance of refrigerant mixtures under real conditions can be evaluated by considering an example system. At the same time, exergy analyses of refrigerant mixtures will be evaluated in future studies.

ACKNOWLEDGMENT

There is no conflict of interest with any person/institution in the paper.

REFERENCES

[1] Dalkılıç, A.S. (2012). Theoretical analysis on the prediction of performance coefficient of two-stage cascade refrigeration system using various alternative refrigerants. Journal of Thermal Science and Technology, 32 (1), 67–79.

[2] Ismael Hasan, M. and Mohsin Chitheer, J. (2021). Theoretical analysis of vapour refrigeration cycle with hybrid refrigerant of different types and mixing ratios. University of Thi-Qar Journal for Engineering Sciences, 111 (2), 24–32.

[3] Kılıç, B. and İpek, O. (2021). Performance analysis of vapor compression refrigeration system using mixed refrigerant R410a. International Journal of Energy Applications and Technologies, 8 (2), 60–64.

[4] Taylor, J.J., Carson, J.K., Hoang, D.K., Walmsley, T.G., Chen, Q. and Cleland, D.J. (2022). Use of refrigerant blends to improve thermal efficiency of heat pump cycles. Chemical Engineering Transactions, 94 (1), 1189–1194.

[5] Wu, Y., Zhang, H., Zhang, Q., Qiu, J. and Rui, S. (2017). The study of thermodynamic properties of zeotropic mixtures of R600a/R23/R14. Advances in Mechanical Engineering, 9 (3), 168781401769121.

[6] Zühlsdorf, B., Jensen, J.K., Cignitti, S., Madsen, C. and Elmegaard, B. (2017). Improving efficiency of heat pumps by use of zeotropic mixtures for different temperature glides.

Proceedings of ECOS 2017: 30th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems, San Diego, California, USA, 2-6 July 2017.

[7] Khordad, R. and Mirhosseini, B. (2015). Transport Properties of refrigerant mixtures: thermal conductivity. Iranian Journal of Chemistry and Chemical Engineering, 34 (1), 75–85.

[8] Baskaran, A. and Mathews, K. (2015). Thermodynamic analysis of R152a and Dimethylether refrigerant mixtures in refrigeration system. Jordan Journal of Mechanical and Industrial Engineering, 9 (4), 289–296.

[9] Saleh, B., Aly, A.A., Alsehli, M., Elfasakhany, A. and Bassuoni, M.M. (2020). Performance analysis and working fluid selection for single and two stages vapor compression refrigeration cycles. Processes, 8 (9), 1017.

[10] Sawjanya, Y. and Rao, Y.C. (2007). Prediction of VLE data for alternative refrigerant mixtures. Korean Journal of Chemical Engineering, 24 (1), 106–112.

[11] Bolaji, B.O. and Huan, Z. (2013). Thermodynamic analysis of the performance of a vapour compression refrigeration system, working with R290 and R600a mixtures. Scientia Iranica B, 20 (6), 1720–1728.

[12] Arcaklioğlu, E. and Erişen, A. (2003). Soğutucu akışkan karışımlarının buhar sıkıştırmalı soğutma sisteminde termodinamik analizi. Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi, 9 (2), 153–162.

[13] Ranjan Panda, S. and Behera, P. (2019). Experimental research on the performance of environmental friendly refrigerant mixtures in a vapour compression refrigeration system. Proceedings of International Conference on Artificial Intelligence in Manufacturing & Renewable Energy (ICAIMRE), Bhubaneswar, India, 25-26 October 2019.

[14] Gil, B., Fievez, A. and Zajaczkowski, B. (2021). Pool boiling heat transfer coefficient of dimethyl ether and its azeotropic ternary mixtures. International Journal of Heat and Mass Transfer, 171 (1), 121063.

[15] Gil, B. and Fijałkowska, B. (2019). Experimental study of nucleate boiling of flammable, environmentally friendly refrigerants. Energies, 13 (1), 160.

[16] NIST. (2020). NIST chemistry webbook, SRD 69, thermophysical properties of fluid systems. National Institute of Standards and Technology, USA.

[17] ASHRAE. (2008). ASHRAE standard designation and safety classification of refrigerants.

[18] Good, D.A., Francisco, J.S., Jain, A.K. and Wuebbles, D.J. (1998). Lifetimes and global warming potentials for dimethyl ether and for fluorinated ethers: CH_3 OCF_3 (E143a), CHF_2 $OCHF_2$ (E134), CHF_2 OCF_3 (E125). Journal of Geophysical Research: Atmospheres, 103 (D21), 28181–28186.

[19] Roy, Z. and Halder, G. (2020). Replacement of halogenated refrigerants towards sustainable cooling system: a review. Chemical Engineering Journal Advances, 3 (1), 100027.

[20] Cengel, Y.A. and Boles, M.A. (2015). Thermodynamics: an engineering approach. 8th Edition McGraw-Hill.