SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

Performance Analysis of Using Hydrocarbon Mixed Refrigerant R32-R290 as an Alternative to R410A in Reducing the GWP Value of Household Split Air Conditioners

Widodo[1,2,*], Berkah Fajar Tamtomo Kiono[1], Sonny Handoyo Winoto[1], Tony Suryo Utomo[1]

[1] Mechanical Engineering, Diponegoro University, Jl. Prof. Sudarto, SH Semarang 50275, Indonesia
[2] Department of Mechanical Engineering, Politeknik Enjinering Indorama, Purwakarta Indonesia

ARTICLE INFO

Article history:
Received 10 April 2023
Received in revised form 15 June 2023
Accepted 21 June 2023
Available online 7 July 2023

Keywords:
Refrigerant; mixed; R290; R32; energy; exergy; GWP

ABSTRACT

An experiment conducted on the mixed refrigerant R32-R290, which is used in household air conditioners, is aimed at reducing the global warming potential and improving the environmental CO_2 quality. This mixed refrigerant has a lower GWP and density than the refrigerant R410A. This research was conducted to determine the effect of the increased mass charge of R290 as a mixed refrigerant on the performance of split air conditioner. Three percentage compositions of 20%/80%, 25%/75%, and 30%/70% were applied as a change to R410A in household air conditioners. For the testing equipment condition, the air inlet evaporator and condenser temperatures were 17°C (300 K) and 35°C (308 K), respectively. In the first performance test, refrigerant mass charge of 100% (340 g) was employed. In the second test, mass charge of 40% (136 g), 50% (170 g), and 60% (204 g) were utilized for mixed refrigerant R32-R290. Compared to the performance of R410A, the experimental results for the mixed refrigerant indicated a 0.5% increase in the air outlet evaporator temperature, a 1% decrease in the air condenser outlet, a 29.7% increase in the average COP, a 12.9% decrease in the electrical power consumption from 545.12 W to 474.7 W, a 9.1% increase in the average exergy destruction average from 401.5 W to 441.6 W, and a 19.7% increase in the average exergy efficiency from 24.2 W to 30.1 W.

1. Introduction

The Kyoto Protocol was aimed at reducing CO_2 equivalent emissions in 40 countries (Annex-1 parties) by 2008-2012. The agreed reduction in emissions for six key greenhouse gases (CO_2, CH_4, N2O, HFCs, PFCs, and SF_6) and fluorocarbon content for the refrigerant HFC referred to a 1990 baseline [1]. The parties agreed to reduce the risk of climate change and take other business actions to reduce CO_2 emissions. Regulations established via the Montreal Protocol over the past 20 years can ensure significant climate mitigation by helping reduce sudden climate changes. Hydrofluorocarbon (HFC) emission projections increased after 2013 and are predicted to increase after 2025. By 2050, global HFC R410A emissions are projected to be 5.5-8.8 Gt CO_2-equivalent per

* *Corresponding author.*
E-mail address: widodo@pei.ac.id

https://doi.org/10.37934/arfmts.107.2.103116

year, which is equivalent to 9–19% of the global CO_2 emissions [2]. The mixed R32-R290 percentage composition of 68%/32%, which is utilized as an alternative to the R410A used in split air conditioner. R410A, a mixed that consists of R32 (50%) and R125 (50%), has a boiling point of -51.4°C, a value of ozone-depleting potential (ODP) of 0 and a global warming potential (GWP) of 2088. R32 has an ODP of 0 and a GWP of 675. R290 has an ODP of 0 and GWP of 20. The experimental results indicated a decrease in the mass refrigerant charge of 30%-35% and an increase in the cooling and heating capacities in the range of 14%-23.7%. The cooling capacities and COP were increased by 6.4% and 6.8%, respectively [3].

Experiments have been carried out on a solar-assisted auto-cascade heat pump cycle (SAHPC) and conventional air-sourced heat pump cycle (CAHPC) equipment in a small-scale water heater machine that uses mixed refrigerant R32-R290 with a mass mixed composition of 20%/80%. The test results revealed that the condenser outlet temperature was in the range of 40–60°C and that the evaporator temperature was in the range of -15°C to -10°C. By using the SAHPC, the COP increased by 0.1%-0.3%, the heating volume capacity increased by 7.4%, and the compressor pressure ratio decreased by 7.6% [4]. Experiments test R1270 (propylene) and R290 (propane) on a split air conditioner with a capacity of 2.4 kW, an efficiency energy ratio (EER) of 3.2, and a charge of 1150 g using refrigerant R22. In this experiment, the compressor was replaced by one with a volume capacity of displacement greater than 20%. The charge mass for refrigerants R290 and R1270 is decreased by 590 g and 570 g (38.3% and 36.7%, respectively), the cooling capacity is increased by 2.4%, and the efficiency energy ratio exceeds 0.8%. R1270 and R290 are suitable alternatives for R22 [5]. Replacement for the R410A refrigerant by creating a mixed of R32 and R600a and a mixed of R32 and R1234ze for split-type air conditioning: the test results show a reduction in the GWP of 70% and 73%, respectively, the COP for the mixed refrigerants decreased by 0.6% and 1.2% compare to R410A, respectively. The total equivalent warming impact (TEWI) was reduced by 23% and 20% for mixed R32/R600a [6].

Performance of R410A with R290 by varying the mass charge of R290 by 45%–55% to that of R410A in split air conditioning. The test results showed that the COP for R410A was 4.9% higher than that of R290 and that the refrigeration capacity and compressor power consumption of R290 was 31.3% and 35.7% lower than that of R410A. The total exergy destruction and exergy efficiency of R410A was 524.7W and R290 was 336.1 W efficiency was 24% and 20% higher than that of R290 [7]. Modified the heat pump using a mixed of refrigerants R32 and R290 for heating in cold region. The results indicate an evaporator outlet temperature range of -25°C to 5°C, an increase in condenser outlet temperature of 60°C, an increase in the COP by 19-9%, 37-12% higher volumetric heating capacity [8]. An analytical study has been conducted on a rotary compressor with R290 working at a high ambient temperature in the range of 35°C, 46° and 55°C. The results obtained by testing a split air conditioner demonstrated increased efficiency and lower discharge pressure, and R290 was shown to be an excellent and environmentally friendly alternative. Synthetic and mineral oil or the compressor had solubility levels of 15%–16% and 22%–25% [9]. The influence mixed of R1311 (trifluoroiodomethane) on the flammability of R32 and R290. Experimental system was verified by test of pure R290 and R32. The flammability limit of R32-R290, R1311-R32 and R1311-R290 binary mixed were measured at 60°C and atmospheric pressure, R32-R290 were obtained can be well predicted by Le Chatelier's maximum absolute deviation of 1% [10].

Hydrocarbon refrigerants have been widely employed as an alternative to synthetic refrigerants. The values for each refrigerant were R32: 0.306 kg/m^3; R290: 0.038 kg/m^3; R1270: 0.043 kg/m^3; R600a: 0.043 kg/m^3; and R170: 0.037 kg/m^3; have the potential to reduce the GWP [11]. R32 mixed as a basic mixed with other refrigerants to replace R134a, R404A, and R410A refrigerant mixed has been carried out with the mixed product names R446A, R447B, R452B, ARM71A, ARM20A, ARM20B, R463A, and R466A. The profit obtained by the GWP is reduced to 50–75%; however, the problems with this mixed refrigerant are the critical temperature and higher boiling point, flammability, high discharge temperature, and a decrease in the COP [12].

Refrigerants R290 and R600a to fulfill EU517/2014 (F-GAS) regulations, where the GWP value regarding the use of refrigerants for small-capacity air conditioning in Europe was limited to 150 until 2015. As an alternative to lowering the GWP value, a mixed refrigerant that consisted of R290-R744 increased the COP to a value between 3.4% and 7.9%, increased the volumetric cooling capacity (VCC) to a value between 28.8% and 38.9%, and for the mixed of R32-R290, the COP increased to a value between 0.8% and 2.3% with a VCC of 8.8% and 13%, respectively [13]. Other research for the thermodynamic analysis of mixed refrigerant R32-R1123 with variations in mass amount charge of 42%/58% and 28%/72% applied to air conditioners can reduce the GWP value by 200–300 compared to R410A-R32. R32-R1123 has the best thermodynamic properties at operating pressure, moderately good temperature glide, and 40% energy savings due to an increased COP [14]. Research has indicated that the charging limit for the amount of R290 hydrocarbon refrigerant mass filling in split air conditioners was 0.380 kg according to EN 378-1: 2016 standards and 0.419 kg according to IEC 60335-2-40: 2015 standards. When charging refrigerant, adherence to work safety standards and the lower flammability limit (LFL)-upper flammability limit (UFL) threshold conditions in the range of 8–38 g/m^3 is necessary to avoid a fire hazard [15].

Thermodynamic characteristics of refrigerant compression process in the cylinder rotary compressor using refrigerant low GWP R290, R1270, R32 replace to R22 in the air conditioning system. The results for R290 showed a higher COP and lower power consumption. The COP of R290 at the outdoor temperature of 45°C was 9.5%, the COP at 50°C was 5.1% greater than that at 32°C, and the COP at 40°C was 4% greater than that for R1270 [16]. The application of R32 as a substitute for R410A in split-type air conditioning used in Europe and America. R32 has a lower GWP value than R410A, but R32 has flammable properties included in class A2L according to the ASHRAE 34 standard for approved compressor discharge temperatures [17]. Related research and development have been conducted to reduce the refrigerant aspect of the flammable mixed R32 with hydrofluoroolefin (HFOs) and HFC-125 for cylindrical heat exchanger applications. By using R32-R1234yf with a percentage charge of 73.6%/26.4%, respectively, as a substitute for R1234yf and R1234ze to be compared with R410A and R32 as a medium flammable refrigerant, it was able to reduce the flammability level by 48.6%, and the GWP was 268 [18].

Research on leakage detection of R290 has been carried out for 1 HP split air conditioners as an alternative refrigerant to replace the HCFC R22. R290 is highly flammable, with a concentration limit of 2.1%–9.5% by volume. If a leak occurs in a 0.5 mm hole at a distance of 0 to 0.8 m from the floor, no fire will occur even though it is mass charge of 350 g, while the maximum content without fire is at least 200 g with a leakage hole measuring 1 mm in diameter [19]. Solubility and low compatibility studies have been conducted between non-flammable refrigerants and lubricating oils in refrigerants and lubricants for air conditioning applications. Most refrigerants, including R410A, R404A, and R134a, used in air conditioning have high GWP value [20].

The exergetic performance analysis of low-GWP refrigerants for alternative R410A in air conditioner. Several substitute refrigerants for R410A, namely R32, R447A, R447B, R452B, and R454B, have been analyzed for their energy performance. R447A has a higher COP of 9.2% and a higher exergy efficiency of 9.3% than R410A but a lower exergy destruction of 15.4% [21]. Research has been carried out on the thermodynamics assessment of two-stage cascade refrigeration with low-GWP hydrocarbon refrigerants such as T2butane, toluene, cyclopentane, and T2butene, and is-2-Butene are used for high-temperature circuits. The research results can increase the minimum COP to 7.21%, the total compressor work is lower at 6.26 kW, the maximum exergy efficiency is 55.70%, and the minimum exergy is 2.84 kW [22]. Mixed refrigerant with fluorinated gas consisting of R32, R125, R134a, and R152a mixed with propane R32-R290 at a higher pressure than other mixtures were linearly more efficient with increasing temperature. For the R290 mole fraction, the mixed refrigerant R32-R90 has a lower pressure than a single refrigerant [23]. In heat exchangers, propane gas (R290) is used for split-type air conditioners with an inner diameter of 5 mm. To avoid the danger of a leak, the measured concentration of R290 has been obtained due to the time response. The critical conditions for refrigerants that can be released are 4.3 g and 8 g for a 1-mm leak hole at 1.8 m and 2.2 m, respectively, and the installation height of the indoor unit is 2.2 m and 1.5 m, respectively, from the floor. The formula for a small releasable payload less than 17.8 g is proposed [24]. The characteristic of two-phase flow boiling using R290 with an inner diameter of 3 mm, a hydraulic diameter of 2 mm, and a length of 2 mm is that the temperature is varied from 9.97 to 9.58°C, with a constant mass flux of 101.43 kg/m^2.s for saturation temperature as a result of increases in relative vapour quality [25]. The control of temperature in a multi-circuit air conditioning system contributes a high percentage of the energy consumption; the compressor is the majority component for air conditioning and utilizes up to 90% of the energy [26]. Energy efficiency for supermarkets retrofitted with low glass doors for open refrigerated. The average saving power consumption per 7 days was 576 kWh/day (39.67%) and daytime was 418 kWh/day (41.9%) [27]. The variation effect of inlet velocity is the cooling capacity for refrigerated containers. The range of air inlet velocity was 4 m/s, 6 m/s, 8 m/s, and 10m/s. The results of simulation show that the greater the inlet speed, the faster the cooling speed [28].

This experiment is aimed at complementing the research that has been conducted regarding mixed refrigerant R32-R290 by increasing the percentage mass amount of R290 as a mixed with R32. In addition, tests of electric power consumption to calculate total energy and exergy efficiency were also carried out. These experiments evaluate a split air conditioner that was installed with refrigerant R410A with a mass charge amount of 340 g and compare it with a split air conditioner that uses mixed refrigerant R32-R290 with percentage compositions of 20%/80%, 25%/75%, and 30%/70% and mass charge amounts of 40%, 50% and 60%. This experiment is aimed at producing a better performance for a split air conditioning cooling system by reducing global warming, electric power consumption, and high exergy efficiency.

2. Methodology

2.1 Basic Characteristics of Refrigerants

In analyzing the mixed of R32 and R290, attention must be paid to the properties of R410A, especially at the boiling point temperature, suction and discharge pressures, critical pressure, critical temperature, and density. The mixed of R32 and R290 is a characteristic substance with a lower molecular weight than R410A, which can reduce the amount of refrigerant introduced into the air conditioner system. This mixed refrigerant is not allowed to leak, which can cause temperature differences in the evaporator and condenser, affecting performance. Using REFPROP V.9 2010, it is possible to calculate the dew point temperature and bubble point of R32-290 with a series of mixing ratios, determining the mixing ratio as rounded values of 20%/80%, 25%/75%, and 30%/70% by weight refrigerant charging in units of 40%, 50%, and 60%, which corresponds to a relatively low temperature similar to R410A. The basic properties correspond to the mixed refrigerants R32, R290, and R410A. Table 1 provides an essential reference for the properties of refrigerants.

Table 1
Basic Properties of R410A, R32 and R32/R290 [3]

Properties of Refrigerants	R410A	R32	R290	R32/R290		
				20%/80%	25%/75%	30%/70%
Molecular weight (g mol^{-1})	72.58	52.02	44.10	45.48	45.84	46.21
Normal boiling point (K)	222.03	221.50	231.04	228.80	228.60	228.20
Critical temperature (K)	344.51	351.26	369.89	359.47	356.14	350.04
Critical pressure (kPa)	4901.90	5782.02	4251.20	4859.70	4911.70	4927.20
Density kg/m^3	459.53	424.01	220.48	244.96	253.59	262.24
GWP	2088	675	3	137	171	205

2.2 Saturated Pressure

The saturated liquid pressure at three mixed compositions of 20%/80%, 25%/75%, and 30%/70% is determined for the mixed refrigerant R32-R290. Its properties are similar to those of R410A as a whole, but the mass of the mixed gas was affected by the saturated pressure gas. Figure 1 shows the characteristics of saturated liquid pressure versus temperature. The mixed refrigerant has properties similar to refrigerant R410A (baseline), for the three mixed variations, that come closed R410A is a percentage composition (30%/70%).

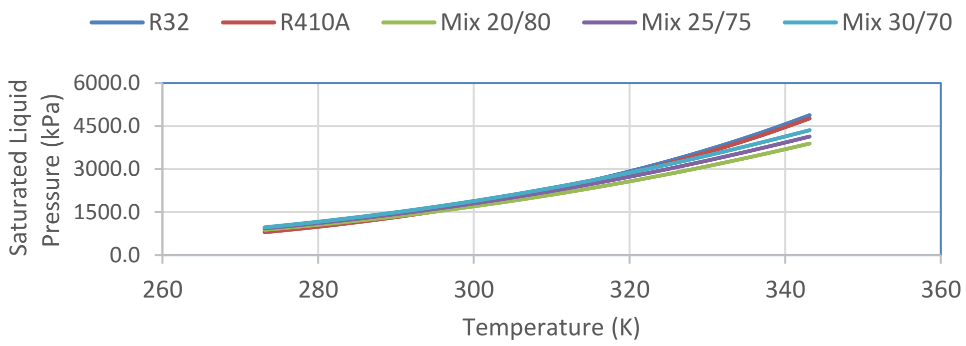


Fig. 1. Saturated liquid pressure versus temperature

Figure 2 shows that the characteristics of saturated vapor pressure versus temperature for the mixed refrigerant having properties similar to R410A with a percentage composition of 30%/70%. The pressure and temperature differences for saturated liquid pressure show a large gap in R410A.

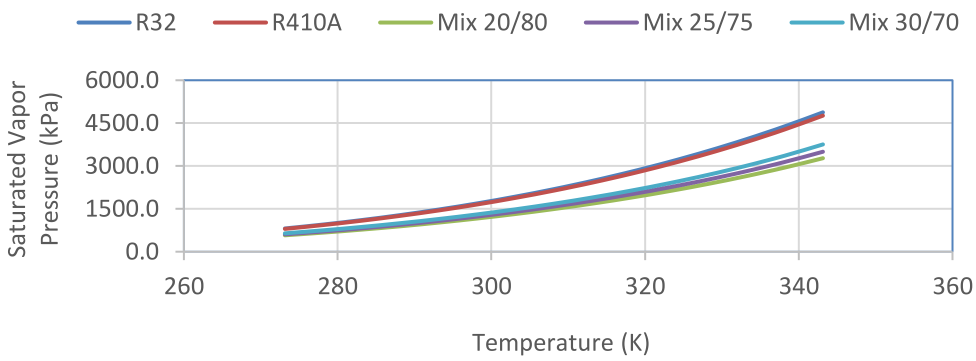


Fig. 2. Saturated vapor pressure versus temperature

2.3 Experimental Setup

The experiment is divided into two stages, indoor and outdoor, with a split air conditioner unit with a refrigeration capacity of 5000 BTUH (1.465 kW). The condenser and evaporator were placed in a polyurethane duct with dimensions of 520 mm by 750 mm. The air temperature in the condenser and evaporator is set by installing a heater and cooler to maintain temperature stability is controlled by an electronic thermostat. Pressure and temperature of the refrigerant in the system were measured using Bourdon gauge class 1.6 (accuracy: 1.6%) and thermocouple autonics TM4-N2RB (accuracy: 0.05°C). The electrical power compressor was measured using an Arduino wattmeter with a PZEM-004T sensor, and maximum operation of 22–26 kW. Air conditioner testing was carried out in two stages, the first using R410A and the second using R32-R290. The initial stage of testing the split air conditioner with R410A charge amount of 100% (340 g) refrigerant refers to the specifications of the dedicated air conditioning. During testing, the evaporator temperature was kept at 17°C (300°K) and the condenser was kept at 35°C (308°K). In the second stage, the unit air conditioner test with variations in the refrigerant mass charge of 40% (136 g), 50% (170 g), and 60% (204 g) was performed for mixed compositions 20%/80%, 25%/75%, and 30%/70%, and the condenser was set to the same conditions used in the test with R410A, as shown in Figure 3.

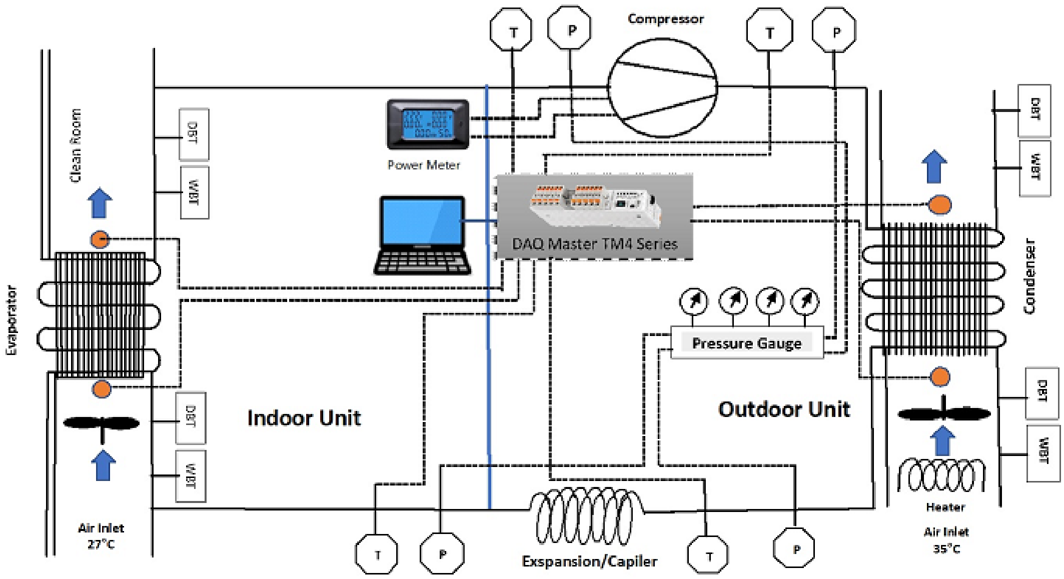
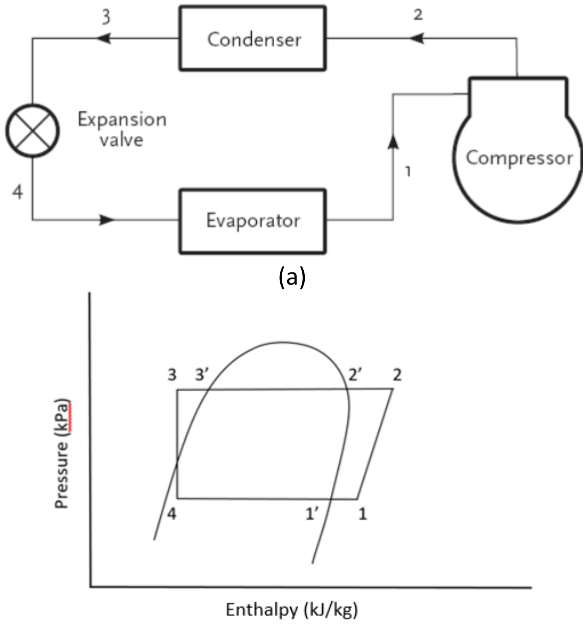


Fig. 3. Schematic of experimental equipment

2.4 Energy and Exergy Performance Calculation

Energy and exergy in the vapor compression cycle can be calculated with a mathematical formulation. A vapor compression system has four main components: compressor, condenser, expansion valve and evaporator. Figure 4(a) and Figure 4(b) shows schematics of the vapor compression cycle. Energy from the outside is used to drive the compressor and provide additional heat to the system in the evaporator, and the condenser removes heat. The heat that enters and leaves each refrigerant varies, which is caused by changes in the system's energy efficiency. The energy loss of each component varies. In thermodynamic analysis, there is a specific energy loss conductor in the system. The following assumptions are made in this study: Steady-state for each component, heat gain, both incoming and outgoing, from the system, is disregarded, kinetic energy, potential energy, and energy losses are disregarded.



(b)

Fig. 4. (a) Schematic and (b) P-H diagram of vapor compression system

To calculate the energy and exergy in the vapor compression refrigeration system for each component, the following expressions are written [7].

Isentropic compression in the compressor (Process 1-2)

$$W_c = (h_2 - h_1) \tag{1}$$

Isobaric heat rejection in the condenser (Process 2-3)

$$Q_c = (h_2 - h_3) \tag{2}$$

Isentropic throttling in the capillary tube (Process 3-4)

$$h_3 = h_4 \tag{3}$$

Isobaric heat addition in the evaporator (Process 1-4)

$$Q_e = (h_1 - h_4) \tag{4}$$

Coefficient of Performance

$$COP = \frac{heat\ absorbed\ by\ evaporator}{work\ compressor} \tag{5}$$

Power of the compressor

$$P = V \times I \times PF \tag{6}$$

Specific exergy in any state

$$e_f = h - h_0 - T_0(s - s_0) \tag{7}$$

Refrigerating capacity for the evaporator

$$\dot{Q}_{41'} = \dot{m}(h_1 - h_4) \tag{8}$$

Exergy destruction

$$\dot{E}_{d41'} = \left(1 - \frac{T_0}{T_{41'}}\right)\dot{Q}_{41'} + \dot{m}\left(e_{f4} - e_{f1'}\right) \tag{9}$$

Work in the compressor

$$\dot{W}_{12} = \dot{m}(h_1 - h_2) \tag{10}$$

$$\dot{W}_{d12} = -\dot{W}_{12} + \dot{m}\left(e_{f1} - e_{f2}\right) \tag{11}$$

Heat loss in the condenser

$$\dot{Q}_{d2'3'} = \dot{m}(h_{3'} - h_{2'}) \tag{12}$$

Exergy destruction in the subcooling

$$\dot{E}_{d2'3'} = \left(1 - \frac{T_0}{T_{2'3'}}\right)\dot{Q}_{2'3'} + \dot{m}\left(e_{f2'} - e_{f3'}\right) \tag{13}$$

Height of the capillary tube

$$h_3 = h_4 \tag{14}$$

Exergy destruction in the capillary tube

$$\dot{E}_{d34} = \dot{m}\left(e_{f3} - e_{f4}\right) \tag{15}$$

Total exergy destruction

$$\dot{E}_{dt} = \dot{E}_{d41'} + \dot{E}_{d12} + \dot{E}_{2'3'} + \dot{E}_{d34} \tag{16}$$

Exergy efficiency

$$\eta_{ex} = COP\left(1 - \frac{T_0}{T_e}\right) \tag{17}$$

3. Results

3.1 Experimental Data

The test results have been plotted with a pressure–enthalpy (P-H) diagram for an R410A charge amount of 340 g as a reference for comparison with a mixed refrigerant. The air temperatures entering the evaporator and condenser were 17°C and 35°C respectively, and the air temperatures at the outlet of the evaporator and condenser were 18,1°C (291.2 K) and 41,8°C (314.9 K), respectively. The suction and discharge pressures were 1227 kPa and 3095 kPa, respectively. Table 2 shows the performance data the all refrigerant test.

Table 2
Data Performance test results

Description	R410A	20%/80%			25%/75%			30%/70%		
		40%	50%	60%	40%	50%	60%	40%	50%	60%
Air inlet evap. temp. (K)	300.1	300.1	301.7	299.2	299.1	300.1	299.2	299.4	299.4	300.1
Air outlet evap. temp. (K)	291.2	292.2	292.2	293.3	294.1	293.3	293.3	292.6	292.1	292.2
Air inlet cond. temp. (K)	308.5	308.2	308.2	307.3	306.9	308.2	307.3	306.7	307.4	307.9
Air outlet cond. temp. (K)	314.9	311.2	311.2	311.8	310.7	311.2	311.8	311.4	312.3	312.9
Pressure suction (kPa)	1227.0	1008.9	1022.7	1146.8	988.2	1160.6	1202.0	1077.9	1202.2	1270.9
Pressure discharge (kPa)	3095.0	2348.6	2593.3	2626.1	2598.2	2674.0	2663.7	2636.2	2803.6	2939.4

Figure 5 shows the result for composition of 20%/80% for various mass charge amounts of 40%, 50%, and 60%. The temperature for composition of 20%/80% at the air outlet evaporator of R410A was 0.48% lower than that from 18.06°C (291.2 K) to 19.46°C (292.6 K), and the suction and discharge pressures of the mixed 20%/80% lower than R410A, at 64.4% and 19.4%, respectively.

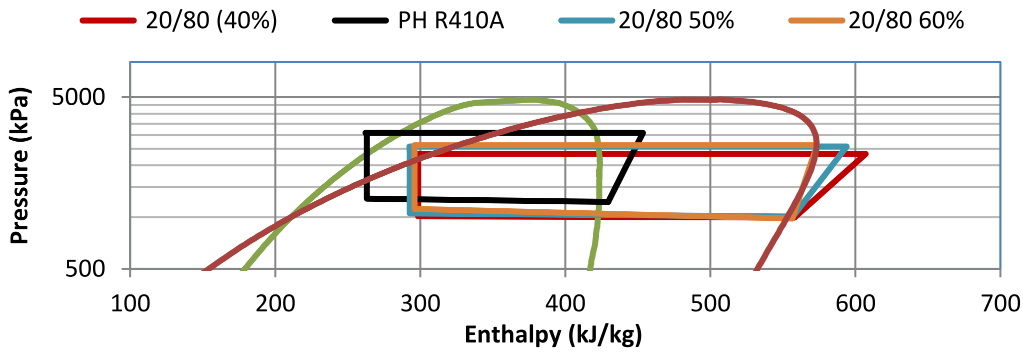


Fig. 5. P-H R410A versus mixed composition of 20%/80% at charge mass of 40%, 50%, and 60%

Figure 6 shows the result for composition of 25%/75% mass at various mass charge amounts of 40%, 50%, and 60%. The air temperature outlet of the evaporator is 18.6°C (291.2 K), and the refrigerant mixed was 20.36°C (293.5 K) higher than that of R410A. The suction and discharge pressure composition of 25%/75% lower than that of R410A, 62.5% and 15.6% higher than 5.13% of R410A, and 4.5% compared to composition of 20%/80%.

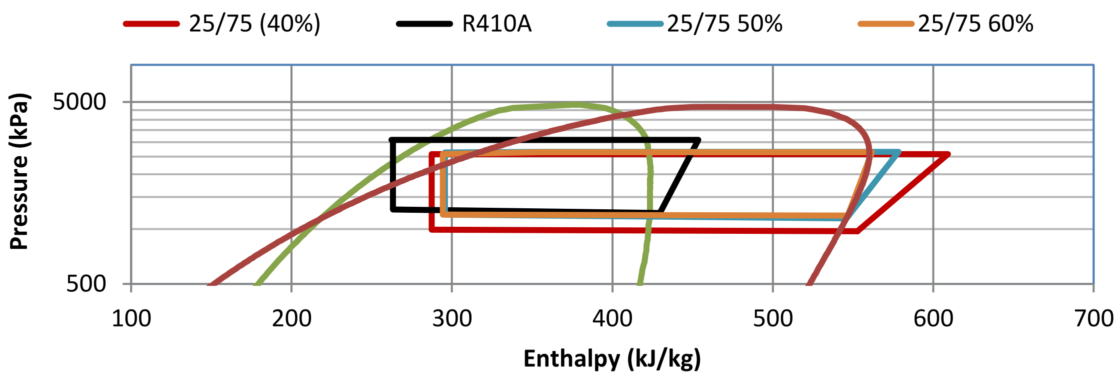


Fig. 6. P-H R410A versus mixed composition of 25%/75% at charge mass of 40%, 50%, and 60%

Figure 7 shows the result for composition of 30%/70%. The air temperature outlet of the evaporator at R410A was 18.06°C (291.2 K) to mixed average was 19.16°C (292.3 K), and the suction pressures of the lower at 60.0% and discharge at 10.8% higher at 10.5% and 9.5% compared to a mixed composition of 20%/80% and higher at 5.6% and 5.3% when compared to the mixed of 25%/75%. The mixed refrigerant had lower suction and discharge pressures than R410A for the entire experiment.

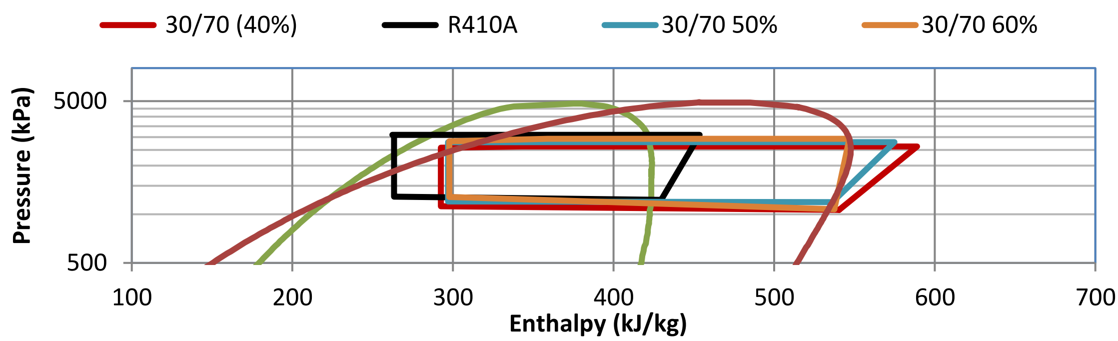


Fig. 7. P-H R410A versus mixed composition of 30%/70% at charge mass of 40%, 50%, and 60%

3.2 Energy Analysis

Figure 8 shows the comparison results of refrigeration capacity with COP for each variation of R410A, which is 8.89 higher compared to mixed of 20%/80% on average 9.48, but lower compared to mixed of 25%/75% (10) and 30%/70% (15.38). The refrigeration capacity shows a linear increase with each COP.

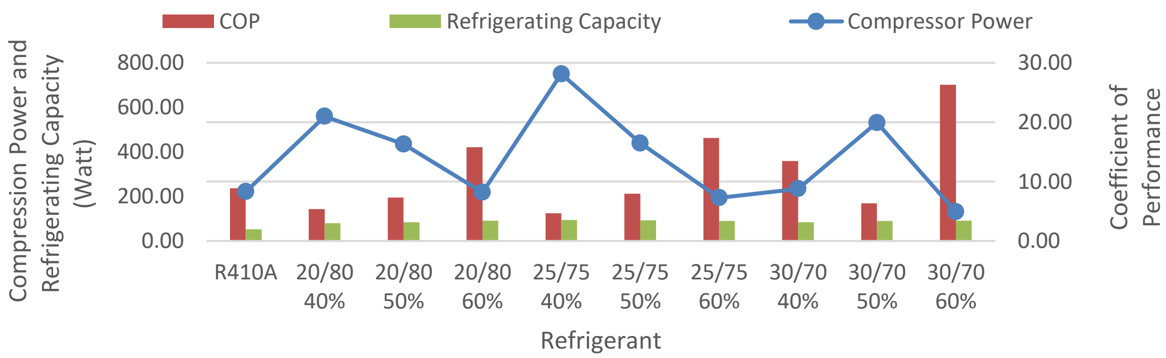


Fig. 8. Compressor power, refrigerating capacity, and COP versus various refrigerants

Figure 9 shows the results of the compression work by a mixed composition at 20%/80%, 25%/75%, 30%/70%, and 60% mass of charging, which has lower work than R410A. COP: the higher the compression work is, the lower the COP.

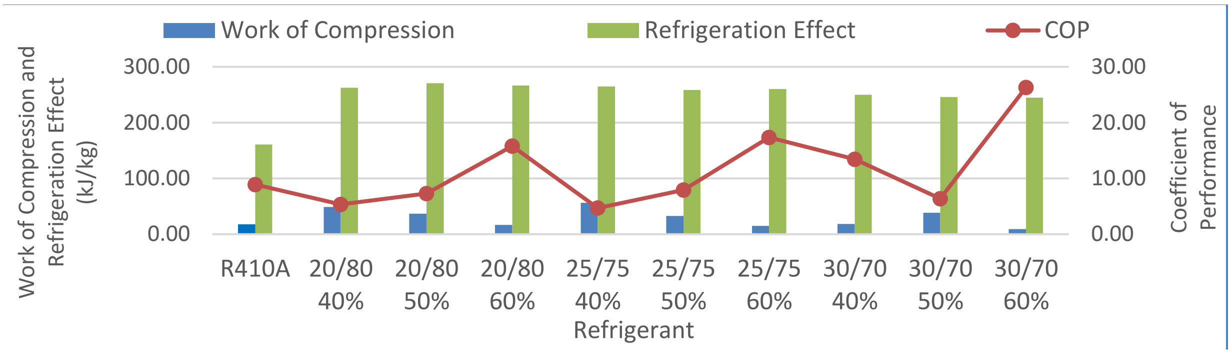


Fig. 9. Work of compression, refrigeration effect and COP versus various refrigerants

Figure 10 shows the results of the electric power of R410A, which is higher than that of the mixed composition at 20%/80%, 25%/75%, and 30%/70% of 545.12 W, while the average for the all mixed composition was 474.69 W, resulting in a savings of 12.9%.

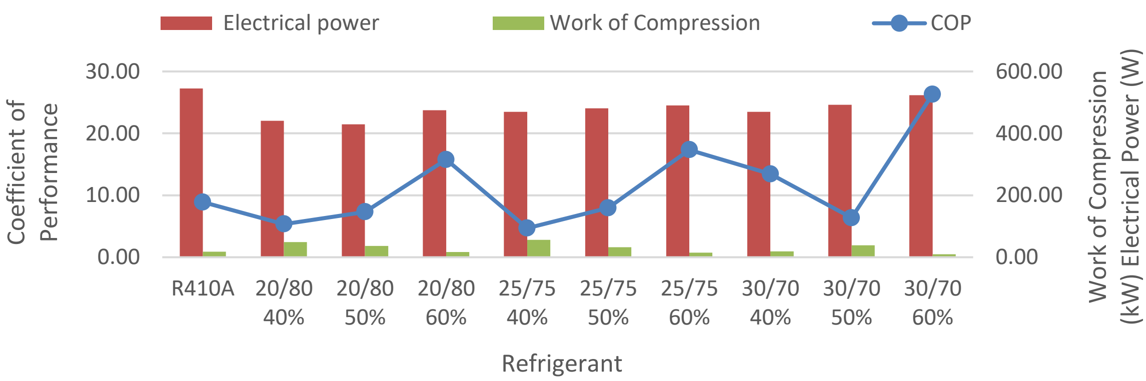


Fig. 10. Electrical power, work of compression and COP versus various mixed with compositions of 20%/80%, 25%/75%, and 30%/70% with various charging of 40%, 50%, 60%

3.3 Exergy Analysis

Figure 11 shows the results of the exergy destruction for each main component of R410A mass charged of 100% at the compressor of 80.4 W, the condenser of 100 W, the expansion of 32.8 W, the evaporator of 188.3 W, and a total exergy of 401.5 W.

Exergy destruction at the compositions of 20%–80% for a mass charge of 40% at the compressor of 107.2 W, condenser of 155.2 W, expansion of 82.0 W, and at the evaporator of 50 W, with a total exergy of 394.3 W and an exergy efficiency of 24.2%. For a refrigerant mass charge of 50% at the compressor of 54.8 W, the condenser of 112.6 W, the expansion of 71.0 W, and the evaporator of 44.6 W, with a total of 283.0 W and efficiency of 18.9%. For a refrigerant mass charge of 60% at the compressor of 66.7 W, at the condenser of 135.3 W, at the expansion of 76.6 W, and at the evaporator of 19.1 W, with a total of 297.7 and an efficiency of 40.7%.

Exergy destruction for compositions of 25%/75% for a mass charge of 40% at the compressor of 137.3 W, the condenser of 134.2 W, the expansion of 99.2 W, and the evaporator of 115.8 W, with a total of 486.5 W and an efficiency of 12.4%. For a refrigerant mass charge of 50% at the compressor of 66.3 W, the condenser of 235.2 W, the expansion of 117.7 W, and the evaporator of 76.7 W, with a total exergy of 495.9 W and an efficiency of 20.4%. For a mass charge of 60% at the compressor of 66.4 W, the condenser of 243.0 W, the expansion of 52.5 W, and the evaporator of 129.3 W, with a total exergy of 491.2 W and an efficiency of 44.4%.

The exergy destruction for mixture 30%/70% with a mass charge of 40% on the compressor is 96.1 W, the condenser is 219.9 W, the expansion is 116.9 W, the evaporator is 62.0 W, with a total of 494.9 W, and an efficiency of 35.3%. The 50% mass charge on the compressor is 46.7 W, the condenser is 228.4 W, the expansion is 105.6 W, and the evaporator is 70.1 W, for a total exergy of 450.8 W and an efficiency of 16.4%. The mass charge is 60%, the compressor is 51.8 W, the condenser is 276.8 W, the expansion is 136.5 W, and the evaporator is 115.0 W, for a total exergy of 580.1 W and an efficiency of 68.3%.

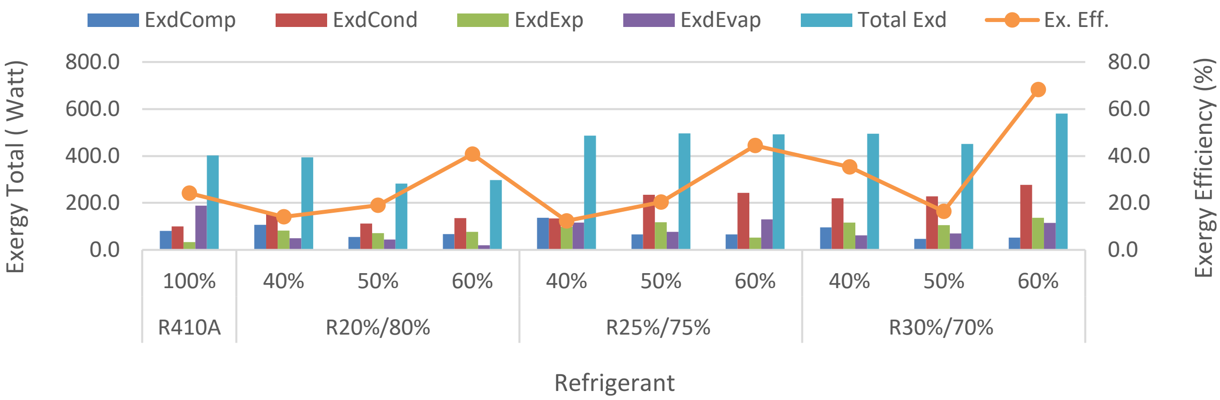


Fig. 11. Total exergy destruction, exergy destruction compressor, condenser, capillary, evaporator and exergy efficiency versus various mixed compositions of 20%/80%, 25%/75%, 30%/70% for various mass charging mass refrigerants

4. Conclusions

Based on Figure 8, the performance of mixed refrigerant R32-R290 with variations in composition percentages (20%/80%, 25%/75%, and 30%/70%) and mass charge amounts of 40%, 50%, and 60% is obtained from experiments and calculations carried out to obtain the performance results regarding the compression work for R410A, which is 41.1% smaller than the mixed refrigerant for the 40% and 50% charging periods. In comparison, during the 60% charging period, it is 23.3% lower, and the cooling effect on the mixed refrigerants is 37.7% higher than that of R410A. The COP for R410A is higher than the mixed refrigerant by 20%–80%. The average COP for the mixed refrigerant is 25%–75% and 30%–70%, or 29.9% higher than that of R410A. The average air temperature in the evaporator for R410A is 0.5% lower than that of the mixed refrigerant. According to Figure 9, the electric power used by the mixed refrigerant is 12.9% lower than that of R410A, which impacts the reduction in electricity consumption Figure 10. The average total exergy destruction of the mixed refrigerant was 9.1%, and the exergy efficiency was 19.7% higher compared to using R410A Figure 11. The experimental results and calculations indicate that this mixed refrigerant has the potential to be an alternative to R410A for household air conditioners, especially for a mixed of 20%/80% mass charge of 40%, a mixed of 25%/75% mass charge of 40%, and a mixed of 30%/70% mass charge of 40%. In the future, it will be necessary to develop mixed refrigerant experiments using both types of hydrocarbons to reduce the GWP.

Acknowledgment
The author thanks the Diponegoro University laboratory assistants in Indonesia who have assisted with the testing and data collection. This research is also supported by PT PERTAMINA (Oil and Gas Company), which has provided Refrigerant R290 (001/F20200/2018-S3), and the management of Indorama Engineering Polytechnic.

References
[1] Velders, Guus JM, Stephen O. Andersen, John S. Daniel, David W. Fahey, and Mack McFarland. "The importance of the Montreal Protocol in protecting climate." *Proceedings of the National Academy of Sciences* 104, no. 12 (2007): 4814-4819. https://doi.org/10.1073/pnas.0610328104
[2] Molina, Mario, Durwood Zaelke, K. Madhava Sarma, Stephen O. Andersen, Veerabhadran Ramanathan, and Donald Kaniaru. "Reducing abrupt climate change risk using the Montreal Protocol and other regulatory actions to complement cuts in CO_2 emissions." *Proceedings of the National Academy of Sciences* 106, no. 49 (2009): 20616-20621. https://doi.org/10.1073/pnas.0902568106
[3] Tian, Qiqi, Dehua Cai, Liang Ren, Weier Tang, Yuanfei Xie, Guogeng He, and Feng Liu. "An experimental investigation of refrigerant mixture R32/R290 as drop-in replacement for HFC410A in household air conditioners." *International Journal of Refrigeration* 57 (2015): 216-228. https://doi.org/10.1016/j.ijrefrig.2015.05.005
[4] Lv, Xiaolong, Gang Yan, and Jianlin Yu. "Solar-assisted auto-cascade heat pump cycle with zeotropic mixture R32/R290 for small water heaters." *Renewable Energy* 76 (2015): 167-172. https://doi.org/10.1016/j.renene.2014.11.012
[5] Wu, J. H., L. D. Yang, and J. Hou. "Experimental performance study of a small wall room air conditioner retrofitted with R290 and R1270." *International Journal of Refrigeration* 35, no. 7 (2012): 1860-1868. https://doi.org/10.1016/j.ijrefrig.2012.06.004
[6] Ng, WenBin, Haslinda Mohamed Kamar, Nazri Kamsah, and Fu-Jen Wang. "Performance analysis of low GWP refrigerants mixture as a substitute for R410A in residential air conditioner in tropical region." In *IOP Conference Series: Earth and Environmental Science*, vol. 268, no. 1, p. 012104. IOP Publishing, 2019. https://doi.org/10.1088/1755-1315/268/1/012104
[7] Fajar, TK Berkah, P. Restu Bagas, S. Ukhi, M. I. Alhamid, and Arnas Lubis. "Energy and exergy analysis of an R410A small vapor compression system retrofitted with R290." *Case Studies in Thermal Engineering* 21 (2020): 100671. https://doi.org/10.1016/j.csite.2020.100671
[8] Fan, Chaochao, Gang Yan, and Jianlin Yu. "Theoretical study on a modified heat pump cycle with zeotropic mixture R32/R290 for district heating in cold region." *Applied Thermal Engineering* 156 (2019): 702-707. https://doi.org/10.1016/j.applthermaleng.2019.04.112
[9] Wang, Che, Jianhua Wu, Yanjun Du, Jinbo Li, and Wenqing Du. "Experimental study on startup characteristics of a R290 room air conditioner under various ambient temperatures." *International Journal of Refrigeration* 109 (2020): 37-44. https://doi.org/10.1016/j.ijrefrig.2019.09.022
[10] Zhong, Quan, Yujie Huang, Huan Zhao, Xiao Wang, Youlin Zhang, and Jun Shen. "Experimental study on the influence of trifluoroiodomethane on the flammability of difluoromethane and propane." *International Journal of Refrigeration* 135 (2022): 14-19. https://doi.org/10.1016/j.ijrefrig.2021.12.002
[11] Gupta, Saurabh, and Srinivas Pendyala. "Flammability issue of hydrocarbons in air conditioning industry." *Materials Today: Proceedings* 28 (2020): 2247-2250. https://doi.org/10.1016/j.matpr.2020.04.555
[12] Heredia-Aricapa, Y., J. M. Belman-Flores, Adrián Mota-Babiloni, Juan Serrano-Arellano, and Juan J. García-Pabón. "Overview of low GWP mixtures for the replacement of HFC refrigerants: R134a, R404A and R410A." *International Journal of Refrigeration* 111 (2020): 113-123. https://doi.org/10.1016/j.ijrefrig.2019.11.012
[13] Calleja-Anta, Daniel, Laura Nebot-Andrés, Jesús Catalán-Gil, Daniel Sánchez, Ramón Cabello, and Rodrigo Llopis. "Thermodynamic screening of alternative refrigerants for R290 and R600a." *Results in Engineering* 5 (2020): 100081. https://doi.org/10.1016/j.rineng.2019.100081
[14] Uddin, Kutub, So Arakaki, and Bidyut Baran Saha. "Thermodynamic analysis of low-GWP blends to replace R410A for residential building air conditioning applications." *Environmental Science and Pollution Research* 28 (2021): 2934-2947. https://doi.org/10.1007/s11356-020-10656-9
[15] Colbourne, D., and K. O. Suen. "Hydrocarbon refrigerant charge limits for quiescent rooms." *International Journal of Refrigeration* 125 (2021): 75-83. https://doi.org/10.1016/j.ijrefrig.2021.01.006
[16] Fang, Xing, Jie Lin, and Xiaoming Ma. "Simulation study on compression characteristics of low GWP refrigerants in the cylinder of rotary compressors." *Applied Thermal Engineering* 193 (2021): 117056. https://doi.org/10.1016/j.applthermaleng.2021.117056

[17] Mota-Babiloni, Adrián, Joaquín Navarro-Esbrí, Pavel Makhnatch, and Francisco Molés. "Refrigerant R32 as lower GWP working fluid in residential air conditioning systems in Europe and the USA." *Renewable and Sustainable Energy Reviews* 80 (2017): 1031-1042. https://doi.org/10.1016/j.rser.2017.05.216
[18] Li, Zhenning, Bo Shen, and Kyle R. Gluesenkamp. "Multi-objective optimization of low-GWP mixture composition and heat exchanger circuitry configuration for improved system performance and reduced refrigerant flammability." *International Journal of Refrigeration* 126 (2021): 133-142. https://doi.org/10.1016/j.ijrefrig.2021.01.003
[19] Ning, Qian, Guogeng He, Wei Sun, Mingjing Fan, Xiao Li, and Zhiwei Hong. "R290 leakage hazards assessment of a 1 HP split-type household air conditioner by concentration detection and ignition experiment." *International Journal of Refrigeration* 139 (2022): 70-83. https://doi.org/10.1016/j.ijrefrig.2022.04.005
[20] Tangri, Henna, Nilesh Purohit, Ankit Sethi, and Ryan Hulse. "Solubility, miscibility and compatibility studies of low GWP non-flammable refrigerants and lubricants for refrigeration and air conditioning applications." *International Journal of Refrigeration* 148 (2023): 45-63. https://doi.org/10.1016/j.ijrefrig.2022.12.022
[21] Mishra, Punit, Shubham Soni, and Govind Maheshwari. "Exergetic performance analysis of low GWP refrigerants as an alternative to R410A in split air conditioner." *Materials Today: Proceedings* 63 (2022): 406-412. https://doi.org/10.1016/j.matpr.2022.03.343
[22] Faruque, Md Walid, Mohammed Raihan Uddin, Sayedus Salehin, and M. Monjurul Ehsan. "A comprehensive thermodynamic assessment of cascade refrigeration system utilizing low GWP hydrocarbon refrigerants." *International Journal of Thermofluids* 15 (2022): 100177. https://doi.org/10.1016/j.ijft.2022.100177
[23] González-Barramuño, Bastián, Esteban Cea-Klapp, Ilya Polishuk, Roberto I. Canales, Héctor Quinteros-Lama, and José Matías Garrido. "Interfacial properties of fluorinated (F)-gases in azeotropic condition." *Journal of Molecular Liquids* 350 (2022): 118604. https://doi.org/10.1016/j.molliq.2022.118604
[24] Ning, Qian, Guogeng He, Mingjing Fan, Jun Xiong, and Xiao Li. "Flammable refrigerant leakage hazards control for split-type household air conditioners." *International Journal of Refrigeration* 144 (2022): 188-201. https://doi.org/10.1016/j.ijrefrig.2022.08.009
[25] Akbar, Ronald, J. T. Oh, and A. S. Pamitran. "Two-Phase Flow Boiling Heat Transfer Coefficient with R290 in Horizontal 3 mm Diameter Mini Channel." *Journal of Advanced Research in Experimental Fluid Mechanics and Heat Transfer* 3, no. 1 (2021): 1-8.
[26] Oleolo, Ibrahim, Hayati Abdullah, Ismail Mustapha, Maziah Mohamad, Mohammad Nazri Mohd Jaafar, Hasan Alqaraghuli, Emmanuel Abiodun Abioye, Akeem Olowolayemo, Balogun Wasiu Adebayo, and Sapiah Sulaiman. "Long Short-Term Memory Neural Network Model for the Control of Temperature in A Multi-Circuit Air Conditioning System." *CFD Letters* 14, no. 12 (2022): 84-98. https://doi.org/10.37934/cfdl.14.12.8498
[27] Saengsikhiao, Piyanut, Juntakan Taweekun, Kittinan Maliwan, Somchai Sae-ung, and Thanansak Theppaya. "Improving Energy Efficiency in the Supermarket by Retrofitting Low E Glass Doors for Open Refrigerated." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 20, no. 1 (2020): 11-17. https://doi.org/10.37934/araset.20.1.1117
[28] Budiyanto, Muhammad Arif, and Nadhilah Suheriyanto. "Analysis of the Effect of Inlet Velocity on Cooling Speed in a Refrigerated Container using CFD simulations." *CFD Letters* 12, no. 12 (2020): 55-62. https://doi.org/10.37934/cfdl.12.12.5562