The Data Mining Technique Using RapidMiner Software for New Zeotropic Refrigerant

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ABSTRACT

This research presents the development of environmentally-friendly and energy efficient refrigerant for medium temperature refrigeration systems that new azeotropic refrigerant mixture of hydrofluorocarbons and hydrocarbon that can retrofit in the refrigeration system using R404A. The medium back pressure refrigeration testing standard that follow CAN/ANSI/AHRI540 standard air-conditioning, heating, and refrigeration institute (AHRI) and The properties of refrigerants and refrigeration simulation system that used national institute of standards and technology (NIST) reference fluid thermodynamic and transport properties database (REFPROP) software and NIST vapor compression cycle model accounting for refrigerant thermodynamic and transport properties (CYCLE_D-HX) software. The methodology uses decision tree function in datamining by rapid minor software that first of KDnuggets annual software poll that showed new azeotropic refrigerant mixture had cooling capacity, refrigerant effect, GWP and boiling point were lower than R404A but work and pressure for medium temperature refrigeration system of azeotropic refrigerant mixture were higher than R404A. The artificial intelligence (AI) by data mining technic can predictivly environmentally-friendly and energy efficient refrigerant for medium temperature refrigeration. The result of refrigerant mixed by R134A, R32, R125 and R1270 and is consistent with the evolution of fourth-generation refrigerants that contain a mixture of HFCs and HC which are required to produce a low-GWP, zero-ozone-depletion-potential (ODP), high-capacity, low-operating-pressure, and nontoxic refrigerant.

Keywords:
Refrigerant; refrigeration system; energy efficiency; environmentally friendly; data mining

1. Introduction

Energy use in Thailand’s business sector has been ranked second among overall energy users in the country and has thus been targeted for energy-saving options [1]. The number of convenience stores in Thailand was more than 20,000 in 2019, and this number continuously increases on an annual basis [2]. The majority are open 24 hours per day and, consequently, the retail sector is the fourth largest consumer of energy in the business sector, consuming more energy than residences [3]. The components that contribute to the energy consumption of convenience stores in Thailand,
ranked from highest to lowest, are refrigeration systems, air-conditioning systems, electrical equipment, and lighting [4,5]. The proportions of energy use in convenience stores in Taiwan have been previously ranked, as shown in Figure 1 below [6].

![Fig. 1. Proportions of energy use in Taiwanese convenience stores [6]](image_url)

The best options for reducing energy consumption in convenience stores in Thailand are high energy efficiency and an efficient energy-management system. A good example of energy savings in refrigeration systems is shown in Figure 2 below [7]. Energy savings in refrigeration systems can be achieved through decreased power consumption of the compressor, as this it is the component that utilizes the most energy.

Refrigerant trends in Thailand have shown improvements through increased energy efficiency and decreased global warming potential (GWP), as shown in Figure 3 [8,9], which is related to the hydrofluorocarbon (HFCs) phase-down schedule, as shown in Figure 4 [10]. First- and second-generation refrigerants are composed of natural refrigerants and hydrocarbons (HCs), both of which do not impact the environment, have low GWP, and have zero ozone-depletion potential (ODP) [11–13]. R744 operates under high pressure and is highly toxic and flammable [14–16]. Following the second generation, third-generation refrigerants are composed of chlorofluorocarbons (CFCs) [17–19] and hydrochlorofluorocarbons (HCFCs) [20–22], which are easy to use, can operate under low pressure, and are non-toxic. However, they have high GWP and ODP, contributing to ozone depletion and global warming. Therefore, in the development of refrigerants, significantly decreased ODP and GWP are highly desirable. Moreover, third-generation refrigerants (i.e., CFCs and HCFCs) were further developed into hydrofluorocarbon (HFCs) refrigerants that possessed low GWP and zero ODP [23–25]. Fourth-generation refrigerants are mainly hydrofluoroolefins (HFOs) with low GWP and low capacity [26–28]. These refrigerants are generally a mixture of HFCs [29–31], HFOs [32–34], and HCs [35–37]. Natural refrigerants are low-GWP, zero ODP, high-capacity, low-pressure, and non-toxic [38–40].
Fig. 2. Examples of energy savings in refrigeration systems [7]

Fig. 3. Evolution of refrigerants [8,9]
Refrigerants need to be low-GWP, zero -ODP, high-capacity, low-pressure, and non-toxic, and should, thus, be mixed with HCs and HFOs; however, current refrigerants need to developed. An alternative is to incorporate other HFCs. R32 is low-GWP, zero ODP, high-capacity, and non-toxic, but operates under high pressure and is flammable; in contrast to R134a, which possesses highly similar properties but can operate under low pressure and has low capacity. Current refrigeration systems use R22 [41], as well as R417A [42], R417B [43], R422A [44], R422B [45], R422C [46], R422D [47], R424A [48], R433A [49], R437A [50], R438A [51], and R453A [52], all of which were developed as alternatives to R22 and which are mixed with HCs and HFCs, as shown in Table 1–4. The lowest normal boiling points (of R422A and R422C) are -46.80 °C and -46.20 °C, respectively, lower than that of R22 by 12.82% and 11.69%. This is due to the presence of hydrofluorocarbon (HFCs) R125 in their composition (85.1% and 82.0%, respectively), consistent with those of R410A and R507, which have boiling points of -51.6 °C and -46.74 °C, respectively, and are considered attractive as alternative refrigerants to R134a and R404A, due to their HFCs R125 content of 50%. The boiling point of R125 is -48.1 °C, with a high GWP value (3,450); leading to R422A and R422C having the high GWP values of 3,143 and 3,185, respectively. R422A and R422C also have hydrocarbon (HCs) R601a in their composition (3%). The boiling point and GWP of R601a are 0 and -11.73 °C, respectively, the effect of which is reducing the GWP and increasing the boiling point of refrigerant mixtures it is contained in. The lower GWP, compared with R22 R453A and R437A (1,765 and 1,805, respectively) is due to hydrofluorocarbon (HFCs) R134a (53.8% and 78.5%) in their composition and hydrofluorocarbon (HFCs) R32 (20%) in the composition of R453A; this is consistent with R407A, R407H, and R407F, which combine R134a and R32 with R744 in contents of 6% and 3%, respectively, in their compositions. The boiling point and GWP naturally change when adjusting the composition of the refrigerant. The refrigerant effect and heat rejection of R453A were found to be higher than those of R22, due to the presence of hydrofluorocarbon (HFCs) R32 (20%). R453A also has the hydrocarbon (HCs) R600 (0.6%) in its composition. The lowest refrigerant work was found for R422A, which possesses HCs R600a (3%) in its composition.

The mixed-refrigerant design should be comparable to natural refrigerants, in terms of having a strong refrigerant effect and high heat rejection, but certain hydrocarbon refrigerant types (e.g., R290 and R1270) are commonly selected for their refrigerant effect and high heat rejection.
Table 1
Properties of R22, R417A, and R417B

| Condition          | Refrigerant | Composition | Mass percentage | Boiling point (°C) | Critical Pressure (kPa) | Critical Temperature (°C) | ODP    | GWP   | Class | Lubricant type |
|--------------------|-------------|-------------|-----------------|-------------------|-------------------------|---------------------------|--------|-------|-------|----------------|
|                    | R22 [41]    | R125/R134a/R600a | 85.1/11.5/3.4   | -46.80            | 3,665                   | 72                        | 0.055  | 1,600 | A1    | MO/AB/POE      |
|                    | R417A [42]  | R125/R134a/R600a | 50.5/47/1.9/0.9/0.6 | -41.59            | 3,857                   | 82                        | 0.0    | 1,950 | A1    | MO/AB/POE      |
|                    | R417B [43]  | R125/R134a/R600a | 19.5/78.5/1.4/0.6 | -38.70            | 3,969                   | 72                        | 0.0    | 1,950 | A1    | MO/AB/POE      |

Table 2
Properties of R422A, R422B, and R422C

| Condition          | Refrigerant | Composition | Mass percentage | Boiling point (°C) | Critical Pressure (kPa) | Critical Temperature (°C) | ODP    | GWP   | Class | Lubricant type |
|--------------------|-------------|-------------|-----------------|-------------------|-------------------------|---------------------------|--------|-------|-------|----------------|
|                    | R422A [44]  | R125/R134a/R600a | 85.1/11.5/3.4   | -46.80            | 3,665                   | 72                        | 0.055  | 1,600 | A1    | MO/AB/POE      |
|                    | R422B [45]  | R125/R134a/R600a | 50.5/47/1.9/0.6 | -41.59            | 3,857                   | 82                        | 0.0    | 1,950 | A1    | MO/AB/POE      |
|                    | R422C [46]  | R125/R134a/R600a | 19.5/78.5/1.4/0.6 | -38.70            | 3,969                   | 72                        | 0.0    | 1,950 | A1    | MO/AB/POE      |

Table 3
Properties of R422D, R424A, and R437A

| Condition          | Refrigerant | Composition | Mass percentage | Boiling point (°C) | Critical Pressure (kPa) | Critical Temperature (°C) | ODP    | GWP   | Class | Lubricant type |
|--------------------|-------------|-------------|-----------------|-------------------|-------------------------|---------------------------|--------|-------|-------|----------------|
|                    | R422D [47]  | R125/R134a/R600a | 85.1/11.5/3.4   | -46.80            | 3,665                   | 72                        | 0.055  | 1,600 | A1    | MO/AB/POE      |
|                    | R424A [48]  | R125/R134a/R600a/R601a | 50.5/47/1.9/0.9/0.6 | -41.59            | 3,857                   | 82                        | 0.0    | 1,950 | A1    | MO/AB/POE      |
|                    | R437A [50]  | R125/R134a/R600a/R601a | 19.5/78.5/1.4/0.6 | -38.70            | 3,969                   | 72                        | 0.0    | 1,950 | A1    | MO/AB/POE      |

Table 4
Properties of R438A and R453A

| Condition          | Refrigerant | Composition | Mass percentage | Boiling point (°C) | Critical Pressure (kPa) | Critical Temperature (°C) | ODP    | GWP   | Class | Lubricant type |
|--------------------|-------------|-------------|-----------------|-------------------|-------------------------|---------------------------|--------|-------|-------|----------------|
|                    | R438A [51]  | R125/R134a/R32/R600/R601a | 85.1/11.5/3.4   | -46.80            | 3,665                   | 72                        | 0.055  | 1,600 | A1    | MO/AB/POE      |
|                    | R453A [52]  | R125/R134a/R32/R600/R601a | 50.5/47/1.9/0.9/0.6 | -41.59            | 3,857                   | 82                        | 0.0    | 1,950 | A1    | MO/AB/POE      |
|                    | R437A [50]  | R125/R134a/R600a/R601a | 19.5/78.5/1.4/0.6 | -38.70            | 3,969                   | 72                        | 0.0    | 1,950 | A1    | MO/AB/POE      |
However, the high refrigerant work and high operating pressure of such refrigerants affect the power consumption of the compressor. Considering systems that operate with R134a [53], R450A [54], R456A [40], R513A [55], and R515A [40] are all refrigerants that have been developed as an alternative to R134a, which are mixed with HCs, HFCs, and HFOs and operated under low pressure, achieving similar results to R453A operating under high pressure with 20% hydrofluorocarbon (HFCs) R32 content in its composition, as shown in Table 5.

Table 5

| Refrigerant  | R134a [53] | R450A [54] | R456A [40] | R513A [55] | R515A [40] |
|--------------|------------|------------|------------|------------|------------|
| Composition  | R134a      | R134a/R32/ | R134a/R12354ze(E) | R134a/R1234ye(E) | R134a/R1234ye(E) |
| Mass percentage | 100       | 42/58      | 45/6/49    | 44/56      | 12/88      |
| Boiling point (°C) | –26.07    | –23.5      | –30.75     | –28.3      | –18.75     |
| Critical pressure (kPa) | 4060      | 3814       | 4175       | 3700       | 3555       |
| Critical temperature (°C) | 101.06    | 105.87     | 102.65     | 97.7       | 108.65     |
| ODP           | 1430       | 547        | 687        | 570        | 387        |
| Class         | A1         | A1         | A1         | A1         | A1         |
| Lubricant type | POE        | POE        | POE        | POE        | POE        |

The fourth-generation refrigerant R404A was the basis for this research, which is currently the most-used refrigerant, as shown in Figure 5. R404A is an azeotropic blend of 143a/125/134a with zero ODP, which is non-flammable, non-toxic, and operates under low pressure, with a GWP of 3922 [56]. R407A [57], R407F [58], R407H [59], R410A [60], R442A [52], R448A [61], R449A [62], R452A [63], R453A [64], and R463A [65] are all refrigerants developed to be retrofitted to replace R404A, as shown in Table 6–9.
The lowest normal boiling point of R463A is $-60.13\,^\circ\text{C}$, which is lower than that of R404A by 23%. This is due to hydrofluorocarbon (HFCs) R32 (36%) and carbon dioxide (CO$_2$) R744 (7%) being in its composition, consistent with R445A \[64\] and R455A \[65\]. R445A and R455A both have low boiling points ($-49.15\,^\circ\text{C}$ and $-52.0\,^\circ\text{C}$, respectively) and are attractive as alternative refrigerants with lower GWP than R134a and R404A, due to the CO$_2$ R744 content of 6% and 3%, respectively, in their compositions. R448A and R449A displayed the lowest GWP values of 1273 and 1282, respectively, due to the HFOs R1234yf and R1234ze(E) in their compositions. R463A has a lower boiling point than that of R404A by 23%; even though the ratio of R1234yf in R463A is less than that in both R448A and R449A. However, the GWP of R463A has been found to be slightly higher than those of R448A and R449A. The cost of R463A is also lower than R448A and R449A.

### Table 6

Properties of R404A, R407A, and R407F

| Condition | R404A [56] | R404A [56] | R404A [56] |
|-----------|------------|------------|------------|
| Composition | R125/R143/R134a | R125/R143/R134a | R125/R143/R134a |
| Mass percentage | 44/52/4 | 44/52/4 | 44/52/4 |
| Boiling point (°C) at 1 kPa | $-46.6$ | $-46.6$ | $-46.6$ |
| Critical pressure (kPa) | 3728 | 3728 | 3728 |
| Critical temperature (°C) | 72.1 | 72.1 | 72.1 |
| ODP | 0 | 0 | 0 |
| GWP | 3943 | 3943 | 3943 |
| Class | A1 | A1 | A1 |
| Lubricant type | POE | POE | POE |
| $Q_{\text{evap}}$ (kJ/kg) | 139.02 | 139.02 | 139.02 |
| $Q_{\text{cond}}$ (kJ/kg) | 198.57 | 198.57 | 198.57 |
| Work (kJ/kg) | 59.55 | 59.55 | 59.55 |
| COPc | 2.335 | 2.335 | 2.335 |
| Evaporator pressure (kPa) | 477.3 | 477.3 | 477.3 |
| Condenser pressure (kPa) | 2284.10 | 2284.10 | 2284.10 |

### Table 7

Properties of R407H, R410A, and R422A

| Condition | R407H [59] | R410A [60] | R422A [52] |
|-----------|------------|------------|------------|
| Composition | R125/R32/R134a | R125/R32 | R125/R32/R134a/R227ea/R152A |
| Mass percentage | 15/32.5/52.5 | 50/50 | 31/31/30/5/3 |
| Boiling point (°C) | $-44.6$ | $-51.6$ | $-46.5$ |
| Critical pressure (kPa) | 4856 | 4811 | 4760 |
| Critical temperature (°C) | 86.53 | 70.81 | 82.4 |
| ODP | 0 | 0 | 0 |
| GWP | 1400 | 1900 | 1888 |
| Class | A1 | A1 | A1 |
| Lubricant type | POE | POE | POE |
| $Q_{\text{evap}}$ (kJ/kg) | 155.8 | 188.53 | 184.39 |
| $Q_{\text{cond}}$ (kJ/kg) | 229.56 | 271.65 | 266.68 |
| Work (kJ/kg) | 73.76 | 83.12 | 82.29 |
| COPc | 2.112 | 2.268 | 2.241 |
| Evaporator pressure (kPa) | 379.10 | 636.30 | 417.50 |
| Condenser pressure (kPa) | 2265.80 | 3013.70 | 2342.40 |
Hydrofluorocarbons can also be combined with carbon dioxide (CO$_2$), which has a lower GWP and boiling point. The lower boiling point and GWP are consistent with the evolution of the fourth-generation refrigerants that contain a mixture of HFCs, HFOs, HCs, and natural refrigerants, which are required to produce a low-GWP, zero ODP, high-capacity, low-operating pressure, and non-toxic refrigerant. The refrigerant effect and heat rejection of R463A have been found to be higher than those of R404A, due to the presence of hydrofluorocarbon (HFCs) R32 (36%) and carbon dioxide (CO$_2$) R744 (7%) in its composition, consistent with R424A and R453A, which are composed of hydrocarbons (HCs) at contents of 1.8% and 1.2%, respectively. The mixed-refrigerant design should be comparable to natural refrigerants, in terms of having a strong refrigerant effect and high heat rejection. Refrigerants operated under low pressure display low refrigerant work value; in this case, the lowest refrigerant work is observed in R452A. This refrigerant possesses HFOs R1234yf and R1234ze(E) in its composition. The highest refrigerant work value is observed for R463A, which contains hydrofluorocarbon (HFCs) R32 (36%) and carbon dioxide (CO$_2$) R744 (7%), and operates at the highest evaporator pressure. This means that a refrigerant system which is operated at low pressure should use a mix of refrigerants that can operate under low pressure, such as R1234yf, R1234ze(E), and R134a. R450A [49], R456A [50], R513A [51], and R515A [50], which are mixed with hydrofluoroolefins (HFOs) and can operate under low pressure, have achieved similar results. R453A had the highest COPc, as R453A does not have the highest refrigerant effect and heat rejection, nor the lowest boiling point, but can be operated under low pressure, which has an impact on low refrigerant work. The COPc level of R463A was recorded at 1.34, which is 10% higher than that of R404A under low-temperature conditions only.

| Table 8 Properties of R448A, R449A, and R452A |
| Condition | Medium Temperature |
|---|---|
| Refrigerant Composition | R448A [61] | R449A [62] | R452A [63] |
| **Composition** | R125/R32/R134a/R1234yf/R1234yf/R1234ze(E) | R125/R32/R134a/R1234yf | R125/R32/R1234yf |
| **Mass percentage** | 26/26/20/21/7 | 24.7/24.3/25.7/25.3 | 59/11/30 |
| **Boiling point (°C)** | –40.1 | –45.95 | –47.2 |
| **Critical pressure (kPa)** | 4675 | 4662 | 4014 |
| **Critical temperature (°C)** | 83.66 | 83.85 | 75.05 |
| **ODP** | 0 | 0 | 0 |
| **GWP** | 1273 | 1282 | 1945 |
| **Class** | A1 | A1 | A1 |
| **Lubricant type** | POE | POE | POE |
| **Q$_{evap}$ (kJ/kg)** | 172.76 | 170.94 | 92.46 |
| **Q$_{cond}$ (kJ/kg)** | 249.11 | 245.91 | 141.82 |
| **Work (kJ/kg)** | 76.35 | 74.98 | 49.36 |
| **COPc** | 2.263 | 2.28 | 1.873 |
| **Evaporator pressure (kPa)** | 410.60 | 409.60 | 443.70 |
| **Condenser pressure (kPa)** | 2265.90 | 2240.20 | 2423.00 |
Table 9
Properties of R453A and R463A

| Condition | Medium Temperature |
|-----------|--------------------|
| Refrigerant | R453A [64], R125/R32/R134a/R227ea/R600/R601a | R463A [65] |
| Composition | | |
| Mass percentage | 20/20/53.8/5/0.6/0.6 | 30/36/14/14/6 |
| Boiling point (°C) | -42.2 | -60.13 |
| Critical pressure (kPa) | 4530 | 5283 |
| Critical temperature (°C) | 87.9 | 73.15 |
| ODP | 0 | 0 |
| GWP | 1765 | 1377 |
| Class | A1 | A1 |
| Lubricant type | POE | POE |
| \( Q_{\text{evap}} \) (kJ/kg) | 184.91 | 178.36 |
| \( Q_{\text{cond}} \) (kJ/kg) | 312 | 255.92 |
| Work (kJ/kg) | 127.56 | 77.56 |
| COPc | 1.45 | 2.3 |
| Evaporator pressure (kPa) | 121.00 | 342.10 |
| Condenser pressure (kPa) | 1808.70 | 2002.50 |

The promising results for COPc obtained by R407F, R448A, and R449A are due to the refrigerants being operated under low pressure, which has an impact on low refrigerant work. The same effect has been observed for R453A; however, these four refrigerants do not have a low normal boiling point or high \( \text{Cp} \) liquid/vapor or liquid/vapor conductivity. This shows that a mixed-refrigerant design should consider all parameters, such as the GWP, boiling point, \( \text{Cp} \) liquid/vapor and liquid/vapor conductivity, refrigerant effect, heat rejection, refrigerant work, evaporator pressure, high pressure, and COPc.

Due to the costs shown in Figure 6 [43], refrigerants should be mixed with HFOs. The figure shows that the HFOs had the highest refrigerant cost, but does not include HCs refrigerant costs compared with HFO refrigerant costs, and is presented for comparative purposes in this research (as it is generally composed of HCs). The class properties of hydrocarbon refrigerants are shown in Figure 7 below. Some zero ODP and near-zero GWP Class A3 refrigerants, as shown in Table 10 and 11, are R170 [66], R290 [67], R600 [68], R600a [69] and Table 2 for R601 [70], R601a [71], R1150 [72], and R1270 [73]. The lowest boiling points were found to be -88.70 °C and -103.8 °C, respectively, for R170 and R1270; however, their critical temperatures were found to be 32.17 °C and 9.5 °C. This means that these cannot be operated as refrigerants in accordance with the CAN/ANSI/AHRI540 Air-Conditioning, Heating, and Refrigeration Institute (AHRI) standards considered in this research [74-76]. R290 and R1270 were found to have boiling points near that of with R22 (-42.1 °C and -47.7 °C, respectively), but operate at high condenser pressures, which affect the evaporator pressure, condenser pressure, and cooling coefficient of performance. Therefore, in this research, we used R1270 for the base line for new refrigerant mixes, as R1270 has a low boiling point and high refrigerant effect.
Fig. 6. Cost of refrigerant [43]

Table 10
Properties of R170, R290, R600, and R600a

| Condition          | Medium Temperature |
|--------------------|--------------------|
| Refrigerant        | R170 [66]          |
| Formula            | C₂H₆                |
| Chemical name      | Ethane             |
| Boiling point (°C) | -88.7              |
| Critical Pressure  | 4872               |
| Critical Temperature (°C) | 32.17       |
| ODP                | 0                  |
| GWP                | 3                  |
| Class              | A3                 |
| Lubricant type     | MO/POE             |
| Q_{evap} (kJ/kg)   | N/A                |
| Q_{cond} (kJ/kg)   | N/A                |
| Work (kJ/kg)       | N/A                |
| COPc               | N/A                |
| Evaporator Pressure (kPa) | N/A             |
| Condenser Pressure (kPa) | N/A               |

| R290 [67]          |
| C₃H₈                |
| Propane             |
| -42.1              |
| 4251               |
| 96.74              |
| 0                  |
| 3                  |
| A3                 |
| MO/POE             |
| 240.37             |
| 349.48             |
| 109.11             |
| 2.2                |
| N/A                |
| 385.9              |
| 1803.1             |

| R600 [68]          |
| C₄H₁₀              |
| Butane             |
| -0.5               |
| 3796               |
| 151.98             |
| 0                  |
| 3                  |
| A3                 |
| MO/POE             |
| 261.99             |
| 371.49             |
| 109.51             |
| 2.39               |
| 80.2               |
| 535.4              |

| R600a [69]         |
| C₄H₁₀              |
| Isobutane          |
| -11.73             |
| 3629               |
| 134.66             |
| 0                  |
| 3                  |
| A3                 |
| MO/POE             |
| 231.52             |
| 332.01             |
| 100.49             |
| 2.3                |
| 123.5              |
| 736.8              |
### Table 11
Properties of R601, R601a, R1150, and R1270

| Condition | Medium Temperature |
|-----------|--------------------|
| Refrigerant | R601 [70] | R601a [71] | R1150 [72] | R1270 [73] |
| Formula | C₅H₁₂ | C₅H₁₂ | C₂H₄ | C₃H₆ |
| Chemical name | Pentane | Isopentane | Ethylene | Propylene |
| Boiling point (°C) | 36.1 | 27.7 | -103.8 | -47.7 |
| Critical Pressure (kPa) | 3370 | 3378 | 5042 | 4660 |
| Critical Temperature (°C) | 196.55 | 187.2 | 9.5 | 92.4 |
| ODP | 0 | 0 | 0 | 0 |
| GWP | 4 | 4 | 3 | 2 |
| Class | A3 | A3 | A3 | A3 |
| Lubricant type | MO/POE | MO/POE | MO/POE | MO/POE |
| \( Q_{\text{evap}} \) (kJ/kg) | 267.22 | 248.05 | N/A | 247.13 |
| \( Q_{\text{cond}} \) (kJ/kg) | 376.31 | 350.99 | N/A | 358.77 |
| Work (kJ/kg) | 109.09 | 102.94 | N/A | 111.64 |
| COPc | 2.45 | 2.41 | N/A | 2.21 |
| Evaporator Pressure (kPa) | 18.1 | 25.9 | N/A | 478.1 |
| Condenser Pressure (kPa) | 175.1 | 225.4 | N/A | 2143.8 |

![Fig. 7. Refrigerant classification [2]](image)

### 2. Methodology

For the properties of refrigerants and the refrigeration simulation system, we used the REFPROP database and CYCLE_D-HX software from the National Institute of Standards and Technology [77-79], respectively, as shown in Figure 8 below. The properties of all refrigerants, summarized in Table 14, conformed to the use of REFPROP and the CYCLE_D-HX software, as stipulated by the National Institute of Standards and Technology (NIST) [77-79], in accordance with the CAN/ANSI/AHRI540 Air-Conditioning, Heating, and Refrigeration Institute (AHRI) standards, as shown in Table 12 [74-76]. Both software programs can pre-define mixtures and create new refrigerant mixtures. REFPROP can display results related to refrigerant properties under various conditions, and the CYCLE_D-HX software can also display results related to refrigerant cycles under various conditions. The results illustrated the relationships of all parameters, such as GWP, boiling point, refrigerant effect, heat rejection, refrigerant work, evaporator pressure, high pressure, and cooling coefficient of performance (COPc), as well as the result of the decision tree function through datamining using the RapidMiner software (which came first in the 2013 KDnuggets annual software poll [80-82]), as
shown in Figure 9 below. The baseline refrigerant, using R134a, R32, R125, and R1270, was determined from the literature review [83-89].

![Figure 8. The REFPROP software used for refrigerant properties [77-79]](image)

**Table 12**

| Temperature Point | Air Conditioning and Heat Pump | Refrigeration |
|-------------------|--------------------------------|---------------|
|                   | Heating | Cooling | Low | Medium | High |
| Suction dew point (°C) | −15.0  | 10.0    | −31.5 | −6.5 | 7.0  |
| Discharge dew point (°C) | 35.0   | 46.0    | 40.5 | 43.5 | 54.5 |
| Suction return gas temperature (°C) | −4.0   | 21.0    | 4.5  | 18.5 | 18.5 |
| Superheat (K)      | 11.0    | 11.0    | 4.0  | 11.0 | 11.0 |
| Subcooling (K)     | 0.0     | 0.0     | 0.0  | 0.0  | 0.0  |

![Figure 9. Report of the KDnuggets annual software poll on the most-used data mining tools [80]](image)

**Data Mining Tools used in 2013**

(1880 voters)

- RapidMiner/RapidAnalytics (737) *
- R (704) *
- Excel (527) $
- Weka / Pentaho (269) *
- Python; iPython (250) *
- RapidAnalytics/RapidMiner Comm. (225) $
- SAS (202) $
- MATLAB (186) $
- StatSoft Statistica (170) $
- IBM SPSS Statistics (164) $
- Microsoft SQL Server (131) $
- Tableau (118) $
- IBM SPSS Modeler (114) $
- KNIME Free (110) *
- SAS Enterprise Miner (110) $
- Rattle (84) *
- JMP (77) $
3. Results and Discussion

The refrigerants mixed by R134a, R32, R125 and R1270 that can happen 4,539 type in Table 13 as below has showed the refrigerants mixed by R134a, R32, R125 and R1270 by fixed R1270 in 1% for refrigerant no frame propagation class A1 and varies mass percentage of R134a, R32 and R125 and the refrigerants mixed class A2 that mass percentage of R32 higher than R125. The GWP calculated by mass percentage of refrigerants and boiling point simulate by REFPROP software at 0.1 Mpa and pressure at evaporator temperature -6.5 °C and pressure at condenser temperature 43.5 °C simulate by and CYCLE_D-HX software from national institute of standards and technology [19]. The refrigerant mixed were developed to low GWP, zero ODP, high capacity, low pressure, no toxify [6] that can select the refrigerant requirement from refrigerant data 4,539 type by rapid minor software that first of report of the software poll that used for data mining too. The refrigerant requirement was class A1, boiling point lower than boiling point R404 at -46.5 °C and GWP lower than 2000. The datamining functional by decision tree in rapid minor software showed the 4 refrigerant result that follow refrigerant requirement as Figure 10, 11 and Table 14 below.

Table 13
Refrigerant mixtures of R134a, R32, R125, and R1270

| Refrigerant No | R134a | R32  | R125 | R1270 | Summary | GWP  | Boiling Point | Class A |
|---------------|-------|------|------|-------|---------|------|--------------|---------|
| R-No.1        | 1     | 1    | 97   | 1     | 100     | 3,366| -47.91       | 1       |
| R-No.2        | 1     | 2    | 96   | 1     | 100     | 3,339| -47.95       | 1       |
| R-No.3        | 1     | 3    | 95   | 1     | 100     | 3,311| -47.98       | 1       |
| R-No.4        | 1     | 4    | 94   | 1     | 100     | 3,283| -48.02       | 1       |
| R-No.94       | 1     | 94   | 4    | 1     | 100     | 786 | -51.26       | 2       |
| R-No.95       | 1     | 95   | 3    | 1     | 100     | 758 | -51.30       | 2       |
| R-No.96       | 1     | 96   | 2    | 1     | 100     | 730 | -51.33       | 2       |
| R-No.97       | 2     | 3    | 94   | 1     | 100     | 3,289| -47.76       | 1       |
| R-No.98       | 2     | 4    | 93   | 1     | 100     | 3,262| -47.80       | 1       |
| R-No.99       | 2     | 5    | 92   | 1     | 100     | 3,234| -47.84       | 1       |
| R-No.100      | 2     | 6    | 91   | 1     | 100     | 3,206| -47.87       | 1       |
| R-No.187      | 2     | 93   | 4    | 1     | 100     | 792 | -51.00       | 2       |
| R-No.188      | 2     | 94   | 3    | 1     | 100     | 764 | -51.04       | 2       |
| R-No.189      | 2     | 95   | 2    | 1     | 100     | 736 | -51.08       | 2       |
| R-No.190      | 3     | 3    | 93   | 1     | 100     | 3,268| -47.54       | 1       |
| R-No.191      | 3     | 4    | 92   | 1     | 100     | 3,240| -47.58       | 1       |
| R-No.192      | 3     | 5    | 91   | 1     | 100     | 3,212| -47.62       | 1       |
| R-No.4534     | 92    | 3    | 4    | 1     | 100     | 1,354| -27.96       | 1       |
| R-No.4535     | 92    | 4    | 3    | 1     | 100     | 1,327| -28.00       | 2       |
| R-No.4536     | 92    | 5    | 2    | 1     | 100     | 1,299| -28.04       | 2       |
| R-No.4537     | 93    | 3    | 3    | 1     | 100     | 1,333| -27.74       | 1       |
| R-No.4538     | 94    | 3    | 2    | 1     | 100     | 1,311| -27.52       | 2       |
| R-No.4539     | 95    | 3    | 1    | 1     | 100     | 1,290| -27.30       | 2       |
**Fig. 10.** The datamining function by decision tree in RapidMiner

**Fig. 11.** The four refrigerants following our refrigerant requirements

| Refrigerant | R134a | R32 | R125 | R1270 | Summary | GWP  | Boiling Point | Class A |
|-------------|-------|-----|------|-------|---------|------|--------------|---------|
| R-No.682    | 8     | 45  | 46   | 1     | 100     | 1,995| -47.96       | 1       |
| R-No.595    | 7     | 46  | 46   | 1     | 100     | 1,898| -48.21       | 1       |
| R-No.769    | 9     | 45  | 45   | 1     | 100     | 1,793| -47.74       | 1       |
| R-No.939    | 11    | 44  | 44   | 1     | 100     | 1,958| -47.26       | 1       |
The simulation system then used the REFPROP and CYCLE_D-HX software of the National Institute of Standards and Technology [19] to define new mixtures from the results of the RapidMiner software, in order to verify that the properties and simulation system follow the CAN/ANSI/AHRI540 standard of the Air-conditioning, Heating, and Refrigeration Institute (AHRI), as shown in Table 14 and 15. All refrigerant results were composed of polyol ester oil (POE), which is classified as a Class A1 incombustible and non-toxic refrigerant. R-No.595 had the lowest boiling point at -48.21 \degree C, lower than that of R404A by 4.58%. This was due to the presence of hydrofluorocarbon (HFCs) R32 (36%) and hydrocarbon (HCs) R1270 (1%). The lowest GWP was 1,958, 50.34% lower than that of R404A, which was due to the presence of hydrofluorocarbon (HFCs) R134a (11%) and hydrocarbon (HCs) R1270 (1%). The critical pressures and temperatures of all refrigerants were found to be higher than those of R404A and, so, they can all be used in high ambient temperature environments. The highest refrigerant effect was attained by R-No.595, with 142.93 kJ/kg f. The highest heat rejection was 212.52 kJ/kg, consistent with the normal boiling point. This was due to the presence of hydrofluorocarbon (HFCs) R32 and hydrocarbon (HCs) R1270; however, R32 operates at high pressures, thus affecting the evaporator pressure, condenser pressure, and COPc under medium temperature conditions (as the work of compressor will be high). This shows that a mixed-refrigerant design should consider all parameters, such as the GWP, boiling point, \( C_p \) liquid/vapor and liquid/vapor conductivity, refrigerant effect, heat rejection, refrigerant work, evaporator pressure, high pressure, and COPc.

### Table 15

| Condition          | Medium Temperature |
|--------------------|--------------------|
| Refrigerant        | R404A              |
| Composition        | R125/R143/R134a    |
| Mass percentage    | 14/52/4            |
| Boiling point (\degree C) | 44.6               |
| Critical Pressure (kPa) | 3728              |
| Critical Temperature (\degree C) | 72.1              |
| ODP                | 0                  |
| GWP                | 3943               |
| Class              | A1                 |
| Lubricant type     | POE                |
| \( Q_{\text{evap}} \) (kJ/kg) | 139.02             |
| \( Q_{\text{cond}} \) (kJ/kg) | 198.57             |
| Work (kJ/kg)       | 59.55              |
| COPc               | 2.335              |
| Evaporator Pressure (kPa) | 477.3             |
| Condenser Pressure (kPa) | 2284.10           |
| Evaporator Temp glide (\degree C) | -0.5              |
| Condenser Temp glide (\degree C) | 0.3               |

### 4. Conclusions

In this paper, we determined new refrigerant mixtures comprised of R134a, R32, R125, and R1270 by using refrigerant composition results of the decision tree function in the RapidMiner software, which came first in KDnuggets annual software poll. All resulting refrigerants were composed of polyol ester oil (POE), which has been classified as a Class A1, incombustible, and non-toxic refrigerant. The properties of the refrigerants were verified using the National Institute of Standards and Technology (NIST) reference fluid thermodynamic and transport properties database (REFPROP).
software and the NIST vapor compression cycle model accounting for refrigerant thermodynamic and transport properties (CYCLE_D-HX) software, and were in accordance with the CAN/ANSI/AHRI540 standards of the Air-Conditioning, Heating, and Refrigeration Institute (AHRI). It was indicated that the normal boiling point of R-No.595 was higher than that of R404A by 4.58%, with a higher cooling capacity and a lower GWP than those of R404A by a margin of 50.34% due to the presence of hydrofluorocarbon (HFCs) R32 and hydrocarbon (HCs) R1270. It should be emphasized that a mixed-refrigerant design must consider all relevant parameters, such as the GWP, boiling point, Cp liquid/vapor and liquid/vapor conductivity, refrigerant effect, heat rejection, refrigerant work, evaporator pressure, high pressure, and COPc. The proposed refrigerant mixes provide alternate refrigerant options which are composed of 1% hydrocarbon (HCs) R1270, consistent with the evolution of the fourth-generation refrigerants; which contain a mixture of HFCs, HFOs, HCs, and natural refrigerants, in order to produce a low-GWP, zero ODP, high-capacity, low-operating pressure, and non-toxic refrigerants. In the future, researchers should incorporate the use of natural refrigerants that have low cost. The problems of high evaporator pressure and high condenser pressure, which lead to high refrigerant work, can be solved by adjusting the composition of the refrigerant or mix (i.e., by using a refrigerant that operates at low pressure), thereby improving the COP of the refrigerant.

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