The Performance Simulation of The New R463A
HFC/HFO/Carbon Dioxide Refrigerant with Lower GWP, As an Alternate Option for The R404A Refrigeration System

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ABSTRACT

This study presents the performance simulation of the R463A that has been developed to be retrofitted to replace the R404A. The R463A is primarily composed of hydrofluorocarbons/hydrocarbon/carbon dioxide (HFCs/HCs/CO₂). The R463A refrigerant (GWP=1494) is a non azotrop mixture of R32 (36%), R125 (30%), R134a (14%), R1234yf (14%), and R744 (6%). It is composed of polyol ester oil (POE), and classified as a Class A1 incombustible and non-toxic refrigerant. The R463A has a higher cooling capacity (Qe) than the R404A, as it is composed of hydrofluorocarbons (HFCs) R32 and carbon dioxide (CO₂) R744, and also has a lower global warming potential (GWP) than the R404A due to its hydrofluoroolefins (HFOs) by R1234yf component. The COP of the R463A was found to be higher than the R404A by 10% under low temperature application.

Keywords:
Refrigeration system; Energy technology; R463A Refrigerant; Environmentally friendly

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1. Introduction

1.1 Convenience Stores in Thailand

Energy usage in Thailand’s business sector is ranked second for the overall energy users, and are thus targeted for energy savings options [35]. The number of convenience stores in Thailand currently amounts to more than 20,000 locations in 2020, and tends to increase continuously on an annual basis. The majority of them are opened 24 hours day, and thus the retail sector is the 4th largest consumer of energy in the business sector, which is more than the energy consumed by residences [1].

1.2 Convenience Store Power Consumptions

The order of the energy ratio used by convenience stores in Thailand, ranked from high to low are; refrigeration system, air conditioning system, electrical equipment, and lighting, respectively. However, for convenience stores in Taiwan, they are ranked as shown in Figure 1 below [2]. The best options for decreased energy consumption by convenience stores in Thailand, is recommended to be high energy efficiency and an efficient energy management system.

![Ratio of load to equipment capacity](image)

**Fig. 1.** The energy used ratio of convenience store in Taiwan [2]

A good example for energy savings in the refrigeration system is as shown in Figure 2 below [3]. Energy savings in the refrigeration system can be achieved through decreased power consumption of the compressor, as it is the primary component that utilizes the most energy. This research will show an average energy saving of 7.9%, 5,667 kWh/ year per 5 stores, and a decreased global warming potential (GWP) of 70%, through the use of a digital scroll compressor.
1.3 Evolution of the Refrigerant

The refrigerant trends in Thailand has shown progressive improvement in increasing energy efficiency, and at the same time decrease global warming potential (GWP), as shown in Figure 3 below, which is related to the HFCs phase-down schedule, as shown in Figure 4 below [4-6]. First and second-generation refrigerants were composed of natural refrigerants and hydrocarbons (HCs), both of which does not impact the environment, has a low global warming potential (GWP), and a zero-ozone depletion potential (ODP). R744 operates under high pressure, is highly toxic, and flammable [37]. Following the second generation, third generation refrigerants was composed of chlorofluorocarbons (CFCs) and hydrochlorofluorocarbon (HCFCs), that was easy to use, they could operate under low pressure, is non-toxic, and possess a high GWP and ODP. The R22 had an ODP = 0.055 and GWP = 1810, that effected ozone and global warming [7,36]. Therefore, the development of refrigerates has significantly decreased ODP and GWP. The R407C, R453A, R417A, R424A and R422D was developed as an alternative to the R22, which had zero ODP, but a COP not greater than R22 [7-10]. Moreover, the third-generation refrigerants, CFCs and HCHCs will be developed to hydrofluorocarbons (HFC) refrigerants that will still possess GWP and zero ODP. The R134A, is a generation of HFC that possess zero ODP and a GWP = 1800, that was developed for the R22, but it has a low refrigerant effect [38]. The R513A, R515A, R450A, R456A were developed to be alternatives to R134, but the performances of all refrigerants were nearly, subsequently, the refrigerant developed to the R404A [11-14]. The fourth generation R404A was the baseline for this research, and is currently the most used refrigerant, as shown Figure 5 below [6]. The R404A is a near azeotropic blend of 143a/125/134a, with zero ODP but a GWP = 3922 [12]. Fourth generations are hydrofluoroolefins (HFO) with low GWP and low capacity. The R1234ze and R1234yf are categorized as Class A2L with a low GWP, which is an alternative for R134A. and not for because the performance of R134A, R1234yf and R1234ze were similar [15-17]. Therefore, fourth generation refrigerants; R407A, R407F, R407H, R410A, R448A, R449A, R442A, R453A, and R463A, are refrigerants mixed with HFC, HFO, HC. Natural refrigerants require low GWP, zero ODP, high capacity, low pressure, and is non-toxic [6].
The R410A and R407F refrigerants were developed to be retrofitted to the R404A. The hydrofluorocarbons (HFCs) R410A (GWP=2088) is a near azeotropic mixture of R32 (50%), R125 (50%), and the hydrofluorocarbons (HFCs) R407F (GWP=1825) is a non-azeotropic mixture of R32 (30%), R125 (30%) and R134a (40%), and can be used to retrofit in the refrigeration system which is using R404A. Both refrigerants use polyol ester oil (POE), are Class A1 incombustible (Figure 6), and has a lower toxicity. The R410A and 407F have a higher cooling capacity (Qe) and lower global warming potentials (GWP) than the R404A as it is composed of hydrofluorocarbons (HFCs) R32 [5]. The results show a decreased global warming potential of 46.8% and 53.5% for the R410A and R407F respectively. The R407F also shows a COP higher than the R404A. Both refrigerants contain R32 (A2L) and R125 (A1) mixed in the same mass percentage as the A1 class of refrigerants mix [18]. The R448A refrigerant was developed to be retrofitted to the R404A. The hydrofluorocarbons/hydrofluoro-olefins (HFCs/HFOs) R448A (GWP=1390) is a non-azeotropic mixture of R32 (26%), R125 (26%), R1234yf (20%), R134a (21%), and R1234ze (E) (7%), which can easily be retrofitted to the R404A refrigeration system. The R404A hydrofluorocarbons (HFCs) (GWP=3735) is a near azeotropic mixture
of R125 (26%), R143A (52%), and R134A (4%) [19]. Both refrigerants use polyol ester oil (POE), are Class A1 incombustible (Figure 6), and has a lower toxicity. The R448A has a higher cooling capacity (Qe) than the R404A as it is composed of the hydrofluorocarbons (HFCs) R32 [5,18,20]. And it has a lower global warming potential (GWP) than the R404A, which is composed of hydrofluoroolefins (HFOs) by R1234yf and R1234ze (E) [21,22]. The result shows a decrease in the global warming potential by 70%, and a COP higher than R404A as shown in Figure 7 [11,23].

Fig. 5. Top Refrigerants used in the Food Industry [6]

Fig. 6. Classification of Refrigerants
Fig. 7. COP Result Comparison between R448A and R404A [23]

The R442A and R453A refrigerants were developed to be retrofitted to the R404A. The hydrofluorocarbons/ hydrocarbon (HFCs) R442A (GWP=1888) is a non-azeotropic mixture of R125 (31%), R32 (31%), R134a (30%), R227ea (5%), and R152 (3%), and the R453A refrigerant was developed to be retrofit to the R404A. The hydrofluorocarbons/hydrocarbon (HFCs/HCs) R453A (GWP=1765) is an azeotropic mixture of R125 (20%), R32 (20%), R134a (53.8%), R227ea (5%), R600 butane (0.6%), and R601a isopentane (0.6%), could be retrofitted into the refrigeration system using R404A. Both refrigerants use polyol ester oil (POE), and are classified as a Class A1 incombustible and non-toxic refrigerant. The R448A has a higher cooling capacity (Qe) than the R404A, and a lower global warming potential (GWP) due to the presence of hydrofluorocarbons (HFCs) R32, R600, and R601a hydrocarbon (HCs) in its component [5, 24]. The result shows a decrease in the global warming potential by 52% for the R442A, and 55% for the R443A. The R453A is made up of R600 butane (0.6%) and R601a (0.6%) isopentane, which is a Class A3 natural and cheap refrigerant, see Figure 8, in its component which accounts for not more than 1.2%, and is also a Class A1 incombustible refrigerant [25].

Fig. 8. Cost of Refrigerant [18]
1.4 R463A Refrigerant

The R463A refrigerant is a non-azeotropic refrigerant and was developed to be retrofitted to the R404A. The hydrofluorocarbons/ hydrocarbon/carbon dioxide (HFCs/HCs/Co2) R463A (GWP=1494) is an azeotropic mixture of R32 (36%), R125 (30%), R134a (14%), R1234yf (14%), and R744 (6%) [12]. The R463A is composed of polyol ester oil (POE), and classified as a Class A1 incombustible and non-toxic refrigerant. The components of the R463A is consistent to the R445A, which is a mixture of R1234z3 (85%), R134 (9%), R744 (6%) (HFOs/HFCs/Co2), and also consistent with the components of R455A; which is a mixture of R1234yf (75.5%), R32 (21.5%), R744 (3%) (HFOs/HFCs/Co2.) [26,27]. The R463A, R445A, R455A have a higher cooling capacity (Qe) than the R404A due to the hydrofluorocarbons (HFCs) R32 and carbon dioxide (Co2) R744 in its component, and a lower global warming potential (GWP) than the R404A due to the presence of hydrofluoroolefins (HFOs) by R1234yf [5,21,28]. The properties of the R463A and R404A are summarized in Figure 9 and Table 1. Both of the refrigerants conform to the use of the REFPROP and CYCLE_D-HX software, and are in accordance to the CAN/ANSI/AHR540 air-conditioning, heating, and refrigeration institute (AHRI) standards, as shown in Figure 10 below [29,30].

2. Methodology

The properties of the R463A and R404A summarized in Figure 9 and Table 1, conform to the use of the REFPROP [39] and CYCLE_D-HX [40] software as stipulated by the National Institute of Standards & Technology (NIST), and is accordance to the CAN/ANSI/AHR540 air-conditioning, heating, and refrigeration institute (AHRI) standards, as shown in Figure 10 below [26,29-34]. The results show the relationship of all the parameters, such as GWP, boiling point, refrigerant effect, heat reject, refrigerant work, evaporator pressure, high pressure, and COPc.

3. Results

3.1 The Simulation Results of R463A and R404A

![Fig. 9. Properties of R463A obtained from REFPROP [29,31,32]](image-url)
Table 1

| Property Summary of R463A and R404A |
|-------------------------------------|
| Condition                           | LT       | MT       | HT       | LT       | MT       | HT       |
| Refrigerant                         | R404A    |          |          | R463A    |          |          |
| Normal Boring Point °C              | -46.5    |          |          | -60.13   |          |          |
| Critical temperature °C             | 72.12    |          |          | 75.63    |          |          |
| Critical Pressure Psia              | 541.70   |          |          | 760.58   |          |          |
| Density Kg/m                        | 486.7    |          |          | 465.56   |          |          |
| Molar mass kg/kmol                  | 97.604   |          |          | 74.724   |          |          |
| GWP                                 | 3129     |          |          | 1494     |          |          |
| Class                               | A1       |          |          | A1       |          |          |
| Evaporating Sat °C                  | -31.5    | -6.5     | 7        | -31.5    | -6.5     | 7        |
| Condensing Sat °C                   | 40.5     | 43.5     | 54.5     | 40.5     | 43.5     | 54.5     |
| Superheat °C                        | 11       | 11       | 11       | 11       | 11       | 11       |
| Suction °C                          | 4.5      | 18.5     | 18.5     | 4.5      | 18.5     | 18.5     |
| Condenser °C                        | 40.5     | 43.5     | 54.5     | 40.5     | 43.5     | 54.5     |
| Qevap kJ/kg                         | 146.91   |          |          | 195.08   |          |          |
| Qcond kJ/kg                         | 283.28   | 198.57   |          | 340.04   | 273.5    |          |
| Work kJ/kg                          | 136.37   | 59.55    |          | 144.96   | 87.43    |          |
| COPc                                | 1.077    |          |          | 1.346    |          |          |
| Evaporator Pressure Psia            | 27.15    |          |          | 30.33    |          |          |
| Condenser Pressure Psia             | 295.65   |          |          | 394.87   |          |          |
| Evaporator Temp glide °C            | -0.4     |          |          | -6.3     |          | -5.6     |
| Condenser Temp glide °C             | 0.3      |          |          | 6.5      |          | 6.2      |

5.3 Reference Rating Conditions (SI). Reference Rating Conditions are specified in Table 1 (SI).

| Temperature Points                  | Air Conditioning and Heat Pump | Refrigeration |
|-------------------------------------|--------------------------------|---------------|
| Suction Dew Point, °C               | Heating | Cooling | Low | Medium | High |
| Discharge Dew Point, °C             | -15.0   | 10.0    | -31.5 | -6.5 | 7.0 |
| Suction Return Gas Temperature, °C or Superheat, K | -4.0 | 21.0 | 4.5 | 18.5 | 54.5 |
| Subcooling, K                       | 0.0     | 0.0     | 0.0  | 0.0   | 0.0  |

Notes:
1) The manufacturer shall clearly state which superheat is published.
2) Refer to Figure 1 (SI) graphical representation of the Reference Rating Conditions.
3) Refer to Appendix C for subcooling calculation for capacity.
4) Refer to Appendix D for superheat correction for capacity.

Fig. 10. Medium back pressure standard testing for refrigeration system [30]

4. Conclusions

The results of the R463A and R404A simulation that used the REFPROP and CYCLE_D-HX software, and followed the CAN/ANSI/AHRI540 air-conditioning, heating, and refrigeration institute (AHRI) standards, shows the normal boiling of the R463A to be higher than the R404A by 23%, with a high cooling capacity and a lower GWP than the R404A by 63%. The critical pressure and temperature of the R463A was found to be higher than the R404A, i.e. it can operate in a higher ambient temperature, with a higher refrigerant effect and heat reject, and a lower global warming potential.
(GWP) than the R404A by 52%, due to the presence of hydrofluoroolefins (HFOs) by R1234yf in its component. The COP of the R463A was found to be higher than the R404A in a low temperature application. This means that, the refrigerant mixed design should be designed by taking into account of all the parameters, such as GWP, boiling point, refrigerant effect, heat reject, refrigerant work, evaporator pressure, high pressure, and COPc. The R463A is another alternate refrigerant option, that is composed of 7% carbon dioxide (CO2), and is consistent with the evolution of the fourth-generation refrigerants that contains a mixture of HFC, HFO, HC, and natural refrigerants required to produce low GWP, zero ODP, high capacity, low operating pressure, and contains no toxicity.

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