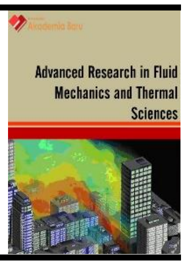
Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879



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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ARTICLE INFO

Article history:
Received 5 April 2020
Received in revised form 13 August 2020
Accepted 20 August 2020
Available online 8 October 2020

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

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/CO_2). The R463A refrigerant (GWP=1494) is a non azeotropic 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 (CO_2) R744, and also has a lower global warming potential (GWP) than the R404A due to the hydrofluoroolefins (HFOs) by R1234yf. The properties of the R463A and R404A that uses the REFPROP and CYCLE_D-HX software, is in accordance to the CAN/ANSI/AHRI540 standard air-conditioning, heating, and refrigeration institute (AHRI). The normal boiling point of the R463A was found to be higher than the R404A by 23%, with a higher cooling capacity and a lower GWP value by 63% than the R404A. The critical pressure and temperature of the R463A was found to be higher than the R404A, i.e. it can be used in a high ambient temperature environment, and emits a higher refrigerant effect and heat reject with a lower global warming potential (GWP) than the R404A by 52%, 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.

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https://doi.org/10.37934/arfmts.76.1.113123

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.

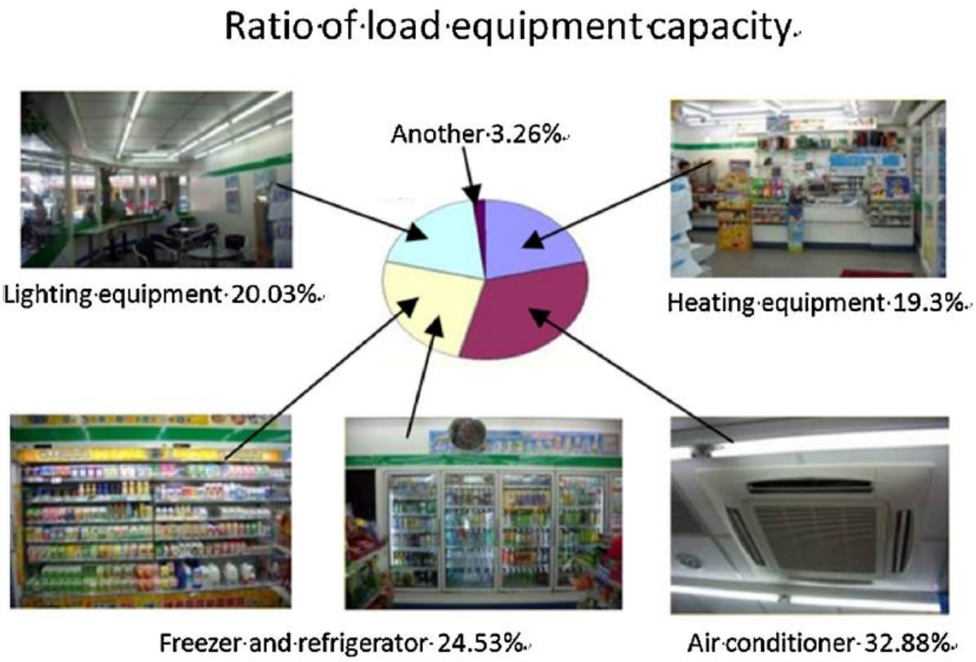

Fig. 1. The energy used ratio of convenience store in Taiwan [2]

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.

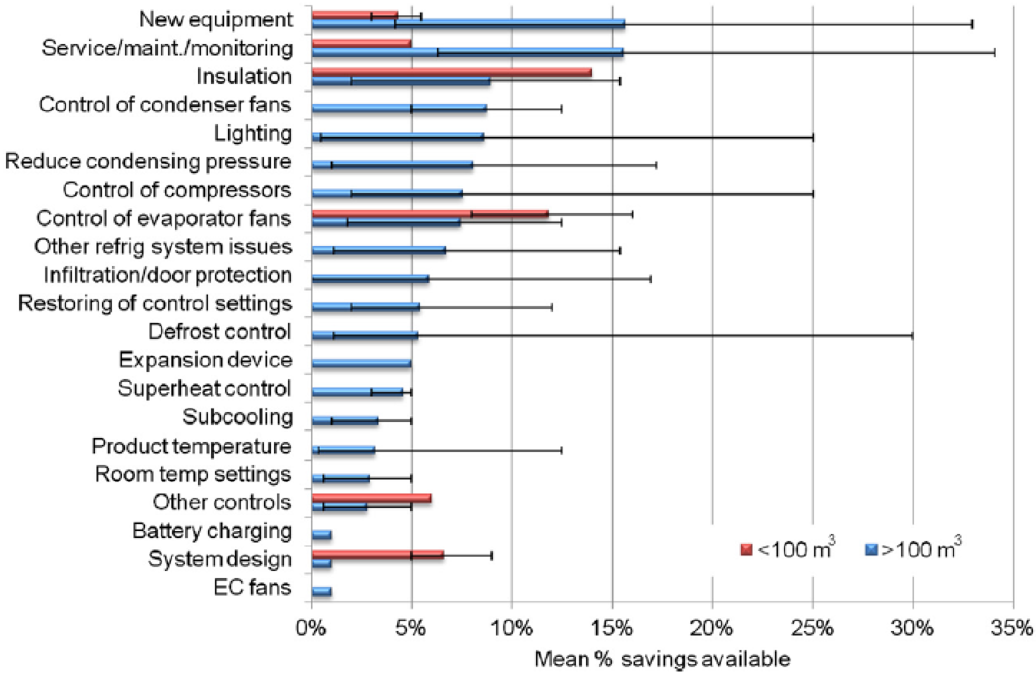

Fig. 2. Example of energy savings in the refrigeration system [3]

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].

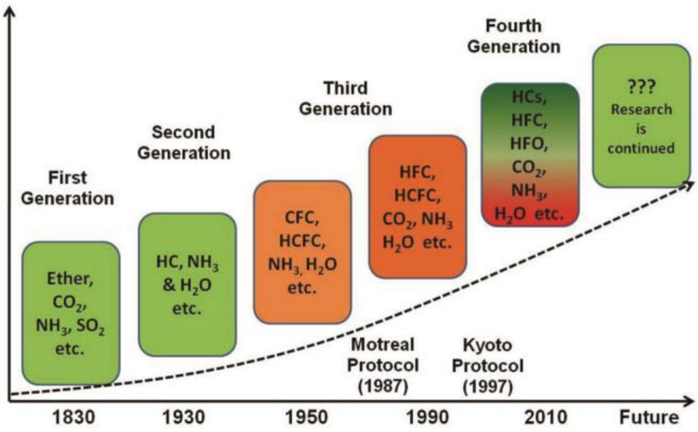

Fig. 3. Evolution of Refrigerants [4,5]

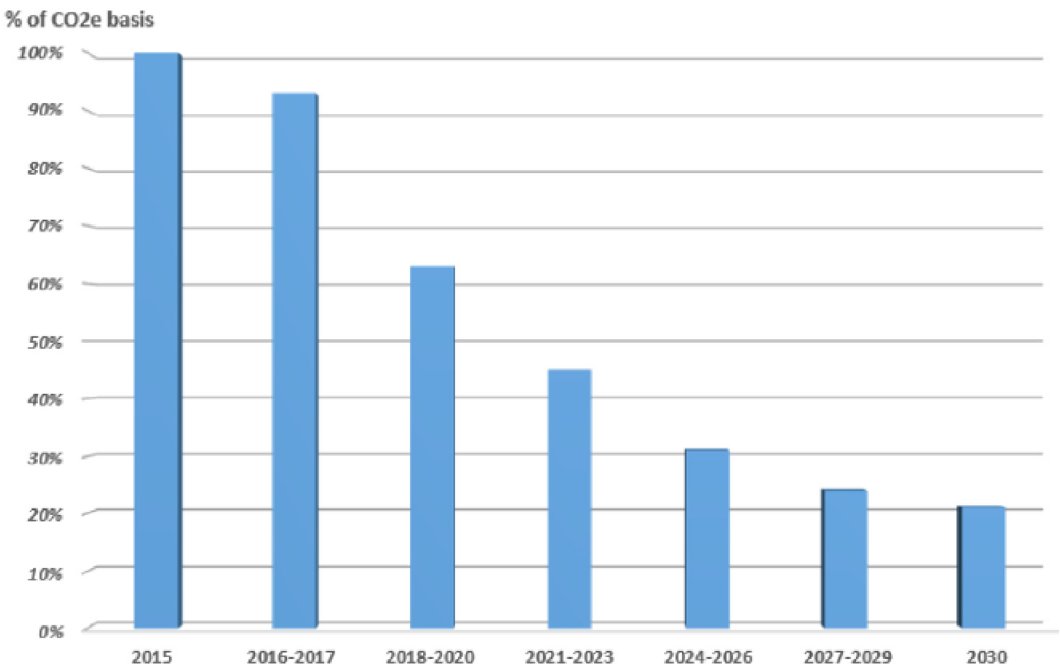

Fig. 4. HFC phase-down schedule (%Co2e) [6]

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].

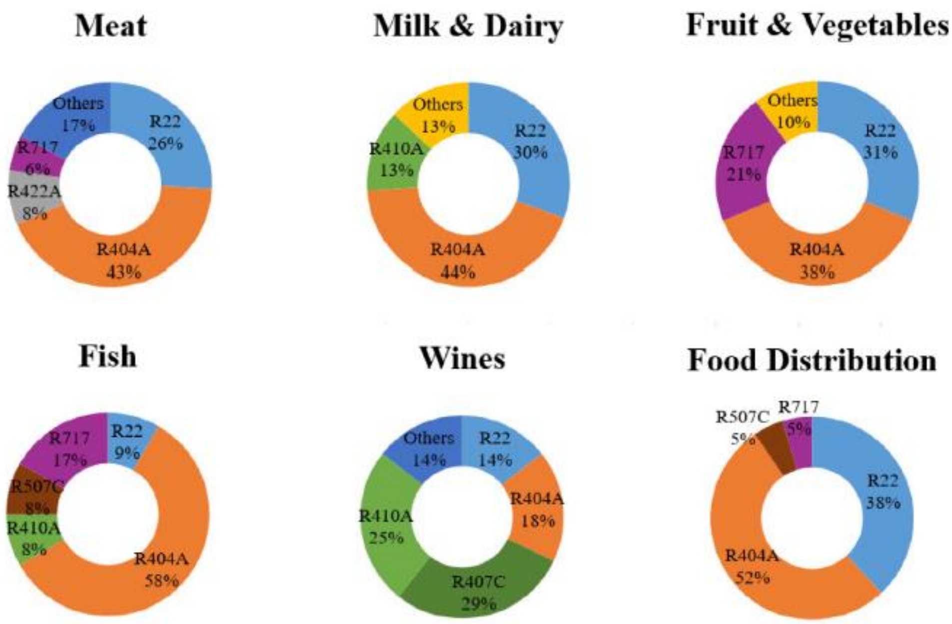

Fig. 5. Top Refrigerants used in the Food Industry [6]

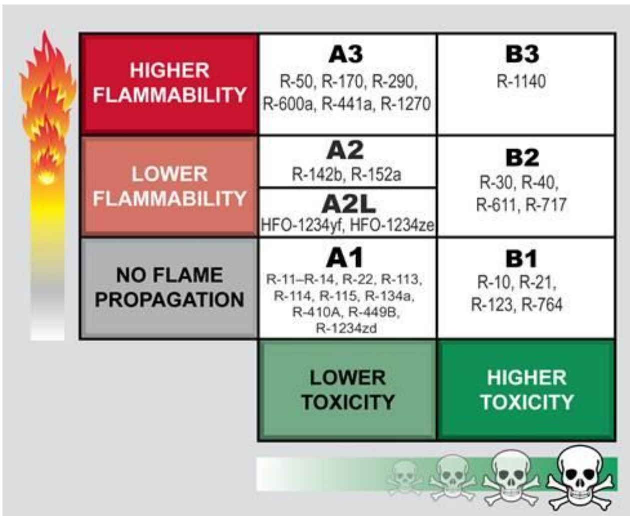

Fig. 6. Classification of Refrigerants

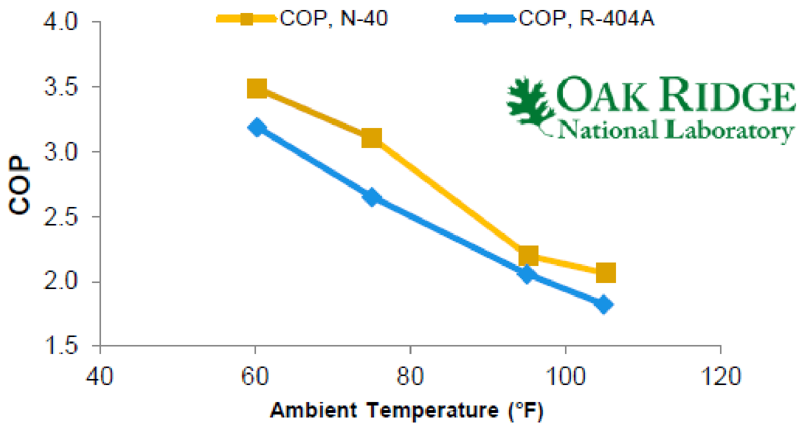

Fig. 7. COP Result Comparison between R448A and R404A [23]

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].

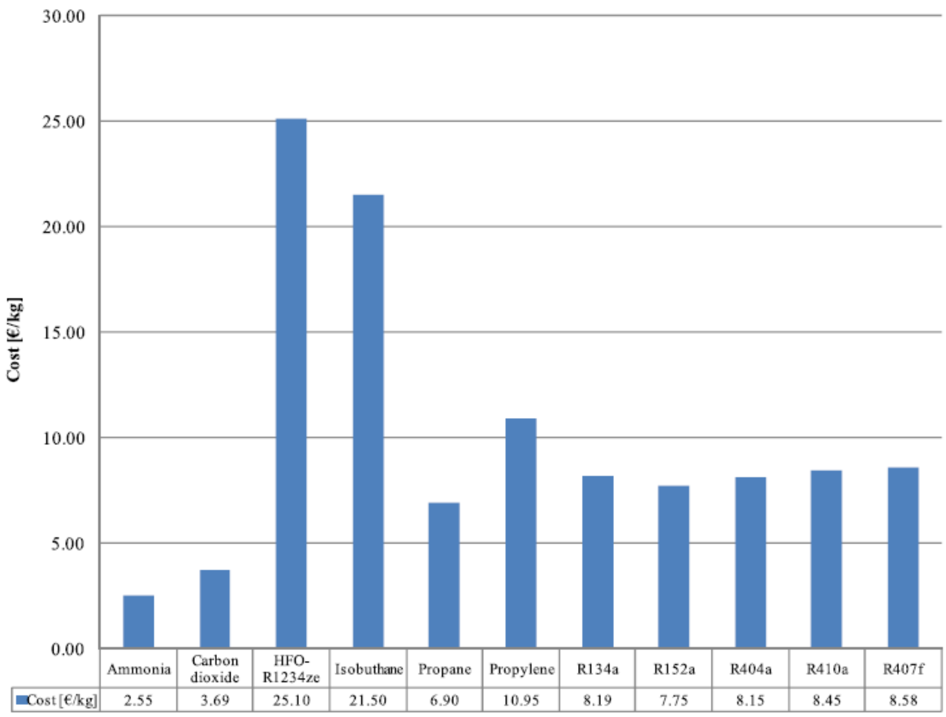

Fig. 8. Cost of Refrigerant [18]

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/CO_2), 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 (Co_2) 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/AHRI540 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/AHRI540 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

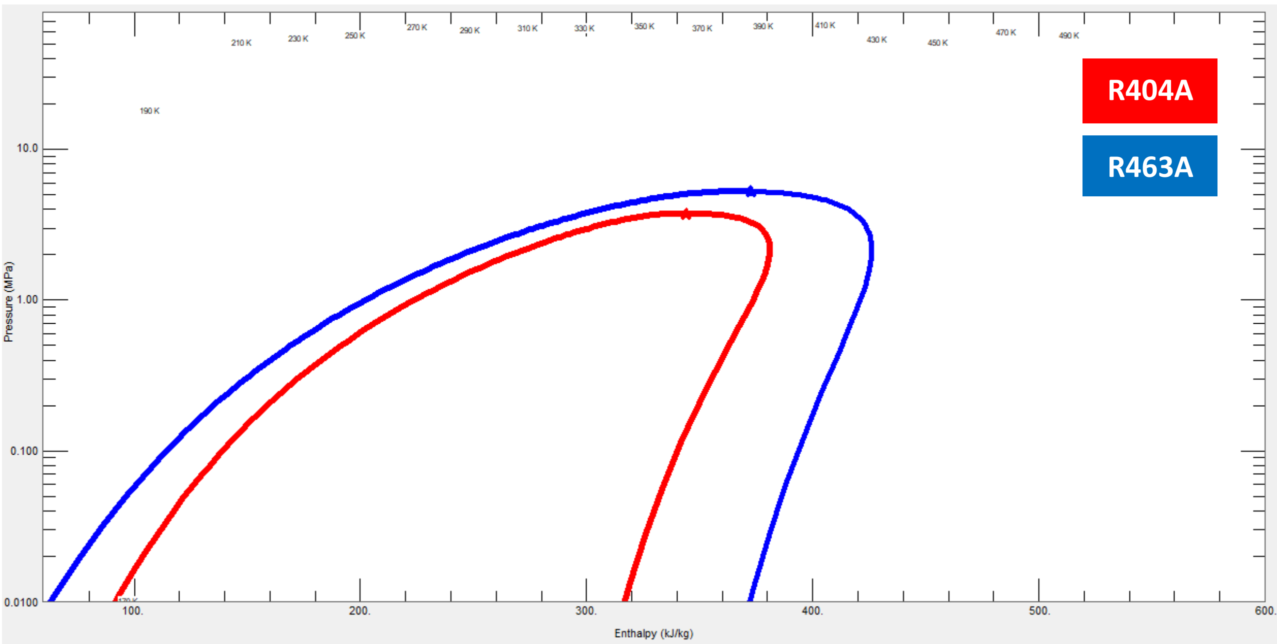

Fig. 9. Properties of R463A obtained from REFPROP [29,31,32]

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
Subcool °C	0	0	0	0	0	0
Suction temp °C	4.5	18.5	18.5	4.5	18.5	18.5
Liquide Temp °C	40.5	43.5	54.5	40.5	43.5	54.5
Qevap kJ/kg	146.91	139.02	N/A	195.08	186.07	168.25
Qcond kJ/kg	283.28	198.57	N/A	340.04	273.5	239.3
Work kJ/kg	136.37	59.55	N/A	144.96	87.43	71.05
COPc	1.077	2.335	N/A	1.346	2.128	2.368
Evaporator Pressure PSIa	27.15	69.23	N/A	30.33	80.37	135.57
Condenser Pressure PSIa	295.65	331.28	N/A	394.87	433.39	548.93
Evaporator Temp glide °C	-0.4	-0.5	N/A	-6.3	-6.1	-5.6
Condenser Temp glide °C	0.3	0.3	N/A	6.5	6.2	4.9

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

Table 1 (SI). Reference Rating Conditions[2]

Temperature Points	Air Conditioning and Heat Pump		Refrigeration		
	Heating	Cooling	Low[1]	Medium[1]	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
or Superheat[4], K	11.0	11.0	11.0	11.0	11.0
Subcooling[3], 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 (CO_2), 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.

Acknowledgement
This study Supported by SANYO S.M.I. (Thailand) Co., Ltd., Buranin Industry Co. Ltd.

References
[1] Shen, Hanyan, Ke Xu, and James Freihaut. "A statistical study on energy performance of US convenience stores: Investigation of factors and bench marking on store energy use." *Energy and Buildings* 183 (2019): 792-802. https://doi.org/10.1016/j.enbuild.2018.10.018
[2] Chou, Ding-chin, Ching-Shan Chang, and Yong-Zhi Hsu. "Investigation and analysis of power consumption in convenience stores in Taiwan." *Energy and Buildings* 133 (2016): 670-687. https://doi.org/10.1016/j.enbuild.2016.10.010
[3] Evans, J. A., E. C. Hammond, A. J. Gigiel, A. M. Fostera, L. Reinholdt, K. Fikiin, and C. Zilio. "Assessment of methods to reduce the energy consumption of food cold stores." *Applied Thermal Engineering* 62, no. 2 (2014): 697-705. https://doi.org/10.1016/j.applthermaleng.2013.10.023
[4] Arora, Pinklesh, Geetha Seshadri, and Ajay Kumar Tyagi. "Fourth-generation refrigerant: HFO 1234yf." *Biology* 115 (2018): 1497. https://doi.org/10.18520/cs/v115/i8/1497-1503
[5] 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
[6] Cardoso, Bruno J., Francisco B. Lamas, Adélio R. Gaspar, and José B. Ribeiro. "Refrigerants used in the Portuguese food industry: Current status." *International Journal of Refrigeration* 83 (2017): 60-74. https://doi.org/10.1016/j.ijrefrig.2017.07.013
[7] Devecioğlu, Atilla G., and Vedat Oruç. "The influence of plate-type heat exchanger on energy efficiency and environmental effects of the air-conditioners using R453A as a substitute for R22." *Applied Thermal Engineering* 112 (2017): 1364-1372. https://doi.org/10.1016/j.applthermaleng.2016.10.180
[8] Oruc, Vedat, and Atilla G. Devecioğlu. "Thermodynamic performance of air conditioners working with R417A and R424A as alternatives to R22." *International Journal of Refrigeration* 55 (2015): 120-128. https://doi.org/10.1016/j.ijrefrig.2015.03.021
[9] Aprea, Ciro, and Angelo Maiorino. "An experimental investigation of the global environmental impact of the R22 retrofit with R422D." *Energy* 36, no. 2 (2011): 1161-1170. https://doi.org/10.1016/j.energy.2010.11.032
[10] Kasera, Shailendra, and Shishir Chandra Bhaduri. "Performance of R407C as an Alternate to R22: A Review." *Energy Procedia* 109 (2017): 4-10. https://doi.org/10.1016/j.egypro.2017.03.032
[11] Mendoza-Miranda, Juan Manuel, Adrián Mota-Babiloni, and Joaquín Navarro-Esbrí. "Evaluation of R448A and R450A as low-GWP alternatives for R404A and R134a using a micro-fin tube evaporator model." *Applied Thermal Engineering* 98 (2016): 330-339. https://doi.org/10.1016/j.applthermaleng.2015.12.064
[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] Makhnatch, Pavel, Adrián Mota-Babiloni, Alejandro López-Belchí, and Rahmatollah Khodabandeh. "R450A and R513A as lower GWP mixtures for high ambient temperature countries: Experimental comparison with R134a." *Energy* 166 (2019): 223-235.
https://doi.org/10.1016/j.energy.2018.09.001

[14] Mota-Babiloni, Adrián, Juan Manuel Belman-Flores, Pavel Makhnatch, Joaquín Navarro-Esbrí, and Juan Manuel Barroso-Maldonado. "Experimental exergy analysis of R513A to replace R134a in a small capacity refrigeration system." *Energy* 162 (2018): 99-110.
https://doi.org/10.1016/j.energy.2018.08.028

[15] Sieres, Jaime, and José Manuel Santos. "Experimental analysis of R1234yf as a drop-in replacement for R134a in a small power refrigerating system." *International Journal of Refrigeration* 91 (2018): 230-238.
https://doi.org/10.1016/j.ijrefrig.2018.05.019

[16] Li, Zhaohua, Kun Liang, and Hanying Jiang. "Experimental study of R1234yf as a drop-in replacement for R134a in an oil-free refrigeration system." *Applied Thermal Engineering* 153 (2019): 646-654.
https://doi.org/10.1016/j.applthermaleng.2019.03.050

[17] Rangel-Hernández, V. H., J. M. Belman-Flores, D. A. Rodríguez-Valderrama, D. Pardo-Cely, A. P. Rodríguez-Muñoz, and J. J. Ramírez-Minguela. "Exergoeconomic performance comparison of R1234yf as a drop-in replacement for R134a in a domestic refrigerator." *International Journal of Refrigeration* 100 (2019): 113-123.
https://doi.org/10.1016/j.ijrefrig.2019.01.016

[18] Bortolini, Marco, Mauro Gamberi, Rita Gamberini, Alessandro Graziani, Francesco Lolli, and Alberto Regattieri. "Retrofitting of R404a commercial refrigeration systems using R410a and R407f refrigerants." *International Journal of Refrigeration* 55 (2015): 142-152.
https://doi.org/10.1016/j.ijrefrig.2015.02.015

[19] Mota-Babiloni, Adrián, Joaquín Navarro-Esbrí, Bernardo Peris, Francisco Molés, and Gumersindo Verdú. "Experimental evaluation of R448A as R404A lower-GWP alternative in refrigeration systems." *Energy Conversion and Management* 105 (2015): 756-762.
https://doi.org/10.1016/j.enconman.2015.08.034

[20] Makhnatch, Pavel, Adrián Mota-Babiloni, Jörgen Rogstam, and Rahmatollah Khodabandeh. "Retrofit of lower GWP alternative R449A into an existing R404A indirect supermarket refrigeration system." *International Journal of Refrigeration* 76 (2017): 184-192.
https://doi.org/10.1016/j.ijrefrig.2017.02.009

[21] Pereira, Leandro, Gleberson Humia, Ali Khosravi, Rémi Revellin, Jocelyn Bonjour, Luiz Machado, and Juan J. Garcia Pabon. "A study on the fluid refrigerant charge in a two-phase mechanically pumped loop system using R134a and R1234yf." *Applied Thermal Engineering* 158 (2019): 113727.
https://doi.org/10.1016/j.applthermaleng.2019.113727

[22] Mendoza-Miranda, Juan Manuel, Adrián Mota-Babiloni, J. J. Ramírez-Minguela, V. D. Muñoz-Carpio, M. Carrera-Rodríguez, Joaquín Navarro-Esbrí, and C. Salazar-Hernández. "Comparative evaluation of R1234yf, R1234ze (E) and R450A as alternatives to R134a in a variable speed reciprocating compressor." *Energy* 114 (2016): 753-766.
https://doi.org/10.1016/j.energy.2016.08.050

[23] Ally, Moonis R., Vishaldeep Sharma, and Kashif Nawaz. "Options for low-global-warming-potential and natural refrigerants part I: Constrains of the shape of the P-T and T-S saturation phase boundaries." *International Journal of Refrigeration* 106 (2019): 144-152.
https://doi.org/10.1016/j.ijrefrig.2019.05.010

[24] Sánchez, D., R. Cabello, R. Llopis, I. Arauzo, J. Catalán-Gil, and E. Torrella. "Energy performance evaluation of R1234yf, R1234ze (E), R600a, R290 and R152a as low-GWP R134a alternatives." *International Journal of Refrigeration* 74 (2017): 269-282.
https://doi.org/10.1016/j.ijrefrig.2016.09.020

[25] Oruç, Vedat, Atilla G. Devecioğlu, and Sertaç Ender. "Improvement of energy parameters using R442A and R453A in a refrigeration system operating with R404A." *Applied Thermal Engineering* 129 (2018): 243-249.
https://doi.org/10.1016/j.applthermaleng.2017.10.035

[26] Devecioğlu, Atilla G., and Vedat Oruç. "An analysis on the comparison of low-GWP refrigerants to alternatively use in mobile air-conditioning systems." *Thermal Science and Engineering Progress* 1 (2017): 1-5.
https://doi.org/10.1016/j.tsep.2017.02.002

[27] Mota-Babiloni, Adrián, Jorge Haro-Ortuno, Joaquín Navarro-Esbrí, and Ángel Barragán-Cervera. "Experimental drop-in replacement of R404A for warm countries using the low GWP mixtures R454C and R455A." *International Journal of Refrigeration* 91 (2018): 136-145.
https://doi.org/10.1016/j.ijrefrig.2018.05.018

[28] Sobieraj, Michał, and Marian Rosiński. "Experimental study of the heat transfer in R744/R600a mixtures below the R744 triple point temperature." *International Journal of Refrigeration* 103 (2019): 243-252. https://doi.org/10.1016/j.ijrefrig.2019.03.038

[29] Tomassetti, Sebastiano, Gianluca Coccia, Mariano Pierantozzi, Giovanni Di Nicola, and J. Steven Brown. "Vapor phase and two-phase PvTz measurements of difluoromethane+ 2, 3, 3, 3-tetrafluoroprop-1-ene." *The Journal of Chemical Thermodynamics* 141 (2020): 105966. https://doi.org/10.1016/j.jct.2019.105966

[30] Standard, A. H. R. I. "Performance Rating Of Positive Displacement Refrigerant Compressors and Compressor Units." *AHRI Standard 540* (2015).

[31] Miyara, Akio, Md Jahangir Alam, and Keishi Kariya. "Measurement of viscosity of trans-1-chloro-3, 3, 3-trifluoropropene (R-1233zd (E)) by tandem capillary tubes method." *International Journal of Refrigeration* 92 (2018): 86-93. https://doi.org/10.1016/j.ijrefrig.2018.05.021

[32] Fouad, Wael A., and Lourdes F. Vega. "Transport properties of HFC and HFO based refrigerants using an excess entropy scaling approach." *The Journal of Supercritical Fluids* 131 (2018): 106-116. https://doi.org/10.1016/j.supflu.2017.09.006

[33] Bell, Ian H., Piotr A. Domanski, Mark O. McLinden, and Gregory T. Linteris. "The hunt for nonflammable refrigerant blends to replace R-134a." *International Journal of Refrigeration* 104 (2019): 484-495. https://doi.org/10.1016/j.ijrefrig.2019.05.035

[34] Domanski, Piotr A., Riccardo Brignoli, J. Steven Brown, Andrei F. Kazakov, and Mark O. McLinden. "Low-GWP refrigerants for medium and high-pressure applications." *International Journal of Refrigeration* 84 (2017): 198-209. https://doi.org/10.1016/j.ijrefrig.2017.08.019

[35] Saengsikhiao, Piyanut, Juntakan Taweekun, Kittinan Maliwan, Somchai Sae-ung, and Thanansak Theppaya. "Investigation and Analysis of R463A as an Alternative Refrigerant to R404A with Lower Global Warming Potential." *Energies* 13, no. 6 (2020): 1514. https://doi.org/10.3390/en13061514

[36] Aziz, Azridjal, Thalal, and Afdhal Kurniawan Mainil. "Effect of Cooling Load on the Performance of R22 Residential Split Air Conditioner when Retrofitted with Hydrocarbon Refrigerant (HCR22)." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 48, no. 1 (2018): 100-108.

[37] Balthazar, Pravinth, and Muzathik Abdul Majeed. "Simulation analysis of two-phase heat transfer characteristics in a smooth horizontal ammonia (R717) evaporator tube." *CFD Letters* 10, no. 2 (2018): 49-58.

[38] Jamaluddin, Mohd Syahmiyadiy, Md Mizanur Rahman, Mohd Faizal Hasan, Aminuddin Saat, and Mazlan Abd Wahid. "Performance evaluation of a small-scale solar driven refrigeration system." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 36, no. 1 (2017): 10-20.

[39] Saengsikhiao, Piyanut, Juntakan Taweekun, Kittinan Maliwan, Somchai Sae-ung, and Thanansak Theppaya. "The Improvement of Energy Efficiency for Refrigeration System in Thailand Convenience Store by Digital Scroll Compressor." Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 74, no. 1 (2020): 144-150.

[40] Saengsikhiao, Piyanut, Juntakan Taweekun, Kittinan Maliwan, Somchai Sae-ung, and Thanansak Theppaya. " The Replacement of the R404A Refrigeration System with The Environmentally Friendly R448A, to Improve Convenience Store Energy Efficiency in Thailand." Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 75, no. 1 (2020): 137-146.