14th IEA Heat Pump Conference
15-18 May 2023, Chicago, Illinois

Preliminary test result of an oil compatibility of a low-GWP refrigerant as an alternative to R410A in a compressor test loop

Junhyun Cho[a,*], Gilbong Lee[a], Bongsu Choi[a], Bong Seong Oh[a], Ho-Sang Ra[a], Sun Ik Na[a], Eunseok Wang[a], Gyunchul Hur[a], Jongjae Cho[a], Beomjoon Lee[a], Young-Jin Baik[a*]

[a]Korea Institute of Energy Research, 152 Gajeong-ro, Yusung-gu, Daejeon 34129, South Korea

Abstract

A new alternative refrigerant has to be tested under real operating conditions to investigate its compatibility with lubricant oil, additives, seals, copper or any metal components and varnish in a compressor driving motor. In this study, oil compatibility characteristics of a low-GWP refrigerant as an alternative to R410A in a compressor test loop is preliminarily studied. To determine short and long-term lubricant oil compatibility of a low-GWP refrigerant in a compressor, a simple heat pump cycle test loop is designed and preliminarily tested under accelerated test protocol. R466A is selected as an alternative to R410A. A 6 hp of compressor for R410A, a 20 kW of condenser are selected. To reduce heat source capacity and to control inlet condition of a compressor, a shell type evaporator with a 15 kW electric heater is designed. An oil characteristic such as a viscosity and a decomposed ion using an ion chromatography are measured after each operation time schedule.

Keywords: Type your keywords here, separated by semicolons ;

1. Introduction

In accordance with global carbon-neutral policies and refrigerant regulations to limit global temperature rise, alternative refrigerants with low global warming potential (GWP) and heat pump technology using them are being developed. System air conditioners used for heating and cooling homes and commercial buildings, that is, variable refrigerant flow (VRF) heat pumps, currently use HFC (hydrofluorocarbons) R410A refrigerant with a global warming potential of 2088. The US CARB (California Air Resource Board), which leads environmental regulations, plans to use refrigerants with a GWP of less than 750 for new residential and commercial products from 2025 and for VRF systems from 2026 [1]. In addition, the European F-gas regulation stipulates that HFC refrigerant usage in 2030 be reduced by 79% compared to 2015, and from 2025, sales of single-split air conditioners with a refrigerant volume of 3 kg or less that uses a GWP of 750 or more refrigerant would be forbidden [2].

R410A is a mixed refrigerant composed of 50% R32 (CH_2F_2) and 50% R125 (C_2HF_5). A mixed refrigerant R466A which is composed of 49% R32, 11.5% R125, and 39.5% R13I1 (CF_3I) was developed as a replacement of R410A by Honeywell who is one of the representative refrigerant manufacturers [3]. The GWP of R466A is 733, and some manufacturers are developing systems for R466A as the safest A1 class refrigerant.

When a new refrigerant is developed, it is essential to evaluate its compatibility with lubricants, especially in compressors. Oil for lubrication is used in the compressor, and this oil serves not only to lubricate but also to cool frictional heat and motor heat. In addition, it serves as a sealing and anti-rust function in mechanical seals and piston rings. To this end, oil flows into the compressor together with the refrigerant, so the heat pump system can be stably operated only when an appropriate combination of new refrigerant and oil is configured.

* Corresponding author. Tel.: +82-42-860-3581; fax: +82-42-367-5067.
E-mail address: jhcho@kier.re.kr.

As a representative method for evaluating refrigerant oil adequacy, the sample accelerated test technique of ASHRAE (American Society of Heating, Refrigerating and Air conditioning Engineers) standard 97-2007 is used [4]. It is a method of evaluating physical properties after sealing in a test tube mixed with oil in a 1:1 weight ratio and aging at a temperature of 175 ° C for 14 days.

Oil and additives are screened through these sample tests, and reliability tests are conducted through actual system operation. R466A has similar physical properties and thermodynamic performance to R410A, and it has been announced in previous studies that the POE (Polyolester) oil used in R410A can be used [5], but the refrigerant-oil compatibility in actual heat pump system operation situation Experimental data are scarce. Therefore, in this study, for the alternative refrigerant R466A, not a sample test, but a core device such as a compressor constituting a heat pump system in an actual operating state, various parts such as valves, and refrigerant-oil compatibility and system reliability were evaluated. Therefore, key factors of the compatibility evaluation method were determined, cycle operating conditions were determined for the accelerated real operation test, and a compressor test loop was designed for the long-term reliability test.

2. Key factors for evaluating refrigerant-oil compatibility

In order to evaluate the suitability of refrigerant and oil, three evaluation factors were determined by referring to the existing literature [4] for the physical property index to be analyzed after deterioration due to long-term real operation of the system.

First, it is possible to evaluate the adequacy with the refrigerant by measuring the acidic product produced by the oxidation of oil as an index of TAN (Total Acid Number). Potentiometric titration using KOH (ASTM D 664) is used.

Second, the degree of decomposition of the refrigerant or oil can be grasped by analyzing the decomposition ions generated by the reaction between the refrigerant and oil as a decomposed ion indicator. When fluoride is detected, the refrigerant is decomposed, and when organic acids such as propanoate and hexanoate are detected, it can be evaluated that oil is decomposed. For this, ion chromatography is used.

Third, the compatibility can be evaluated by measuring the viscosity that decreases with the deterioration of the oil as a viscosity index. Viscosity is measured using a Brookfield viscometer (ASTM D 4402).

3. Previous researches on R466A-oil compatibility

Honeywell's sample accelerated test for R466A refrigerant under the condition of POE oil (ISO 32 3MAF) for R410A and additive combination According to the results of previous research, fluoride was detected at 50 ppm, 25 times higher than 2 ppm for R410A, in the R466A test, and iodide It has been reported that 22 ppm, which is hundreds of times greater than <0.1 ppm of R410A, is detected [6].

Accordingly, after a sample accelerated test in the same POE oil using additives whose components were not disclosed at Honeywell, it was shown that fluoride was 2 ppm and iodide was <1.5 ppm, and compatibility could be satisfied [6].

In addition, it was reported that R23(CF_3H) was decomposed and detected in the combination of zinc-aluminum alloy and R466A-POE base oil [7], and it was also shown that compatibility can be satisfied through the addition of additives. It is evaluated that the iodine component of CF_3I of R466A reacts with oil and zinc-based metal materials.

Some information on the additive material can be obtained from Honeywell's patent, which is a combination of alkylated naphthalene (NA-LUBE), farnesene ($C_{15}H_{24}$), a diene compound, and BHT (Butylated Hydroxi Toluen), a phenolic compound [8].

4. Test scenario for R466A oil compatibility evaluation in actual operation

In order to evaluate the oil suitability of R466A according to the actual long-term operation of the compressor, a heat pump test cycle was constructed and an operating scenario was determined.

In order to accelerate the deterioration by the refrigerant-oil reaction, test scenario of start-continuous operation (8 hours)-stop was determined under the AHRI (Air Conditioning, Heating and Refrigeration Institute) Standard 210/240 MOC (Maximum Operating Condition) condition or more harsh condition. In this operating condition, refrigerant-oil samples would be taken every 100 hours repeatedly and test loop would be operated for a cumulative 300 hours.

Table 1. AHRI Standard 210/240 MOC conditions for R466A

Condensing Temperature (℃)	Outdoor Temperature (℃)	Evaporative Temperature (℃)	Indoor Temperature (℃)
55.1	46.1	7	26.7
Superheat (℃)	Subcooling (℃)	Compressor Rotational Speed	
5.5	5.5	Full	

Table 2. Temperature and Pressure conditions of R410A and R466A cycles

State	Temperature (℃)	Pressure (bar)	Temperature (℃)	Pressure (bar)
1	7.0	9.9	7.0	10.6
2	92.3	34.8	100.1	36.4
3	55.1	34.5	55.1	36.0
4	9.7	10.8	9.8	11.5

As shown in Table 1, the outdoor temperature standard under the MOC condition is 46.1℃, and the corresponding condensing temperature on the refrigerant side is 55.1℃, which is 9℃ higher by referring to Honeywell's AHRI 210/240-A condition performance test reference [8], and the evaporative temperature was selected as 7℃. Superheating and subcooling were selected as 5.5℃.

Cycle design was carried out to derive compressor operating conditions under MOC operating conditions. The cycle was designed using an in-house code that can predict the heat pump design performance using the thermodynamic governing equation, and the calculation was performed using the mixture properties of REFPROP using the composition ratio of R466A.

In addition, calculations were performed for R410A under the same conditions. As shown in Fig. 1, the cycle operating conditions and performance of R466A and R410A under MOC conditions were predicted. The pressure loss was assumed to be 1% in the condenser and 8% in the evaporator.

As shown in Table 2, under the R466A MOC condition, the condensing temperature/pressure was 55.1℃/36.0 bar, the evaporative temperature/pressure was 7℃/10.6 bar, and the compressor discharge temperature was calculated as 100.1℃. Under R410A MOC conditions, the condensing temperature/pressure was 55.1℃/34.5 bar, the evaporative temperature/pressure was 7℃/9.9 bar, and the compressor discharge temperature was 92.3℃. Since the conditions are almost similar, commercial parts based on R410A were used when designing and manufacturing the actual test loop.

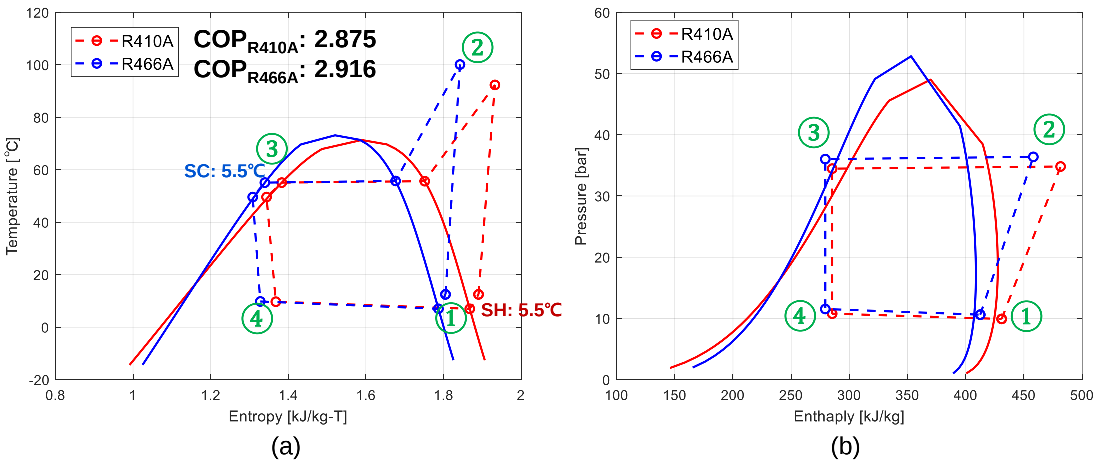

Fig. 1. T-s (a) and P-h (b) charts of R410A and R466A cycles

In this study, the main purpose is to evaluate the refrigerant-oil compatibility and reliability according to long-term cycle operation rather than cycle performance characteristics analysis, a simplified test loop for long-term operation was designed and manufactured

5. Design and construction of test loop

For the evaluation of compressor refrigerant-oil compatibility and reliability in accelerated operation, the test loop was designed as shown in Fig. 2. The core cycle devices such as the compressor, heat exchanger, and electronic expansion valve were selected with commercially available parts for R410A, and a rotary compressor with a capacity of 6 HP and an inverter control system was used. In order to simulate the MOC condition in the long term, we tried to simplify the heat source facilities corresponding to the secondary side of the condenser and evaporator. Therefore, after the compressor, working fluid is discharged (state 2), a bypass loop is placed before entering the condenser, so that the refrigerant that has passed through the condenser is expanded in the EEV (Electric Expansion Valve) 1, and the bypassed refrigerant passes through EEV2 and 3. After expansion, it was configured to be mixed in an evaporator. EEVs were selected with Danfoss' R410A standard commercial product, and the bypass loop is composed of two loops to control the flow rate and expansion ratio fluctuations that may occur when R466A refrigerant is used in the valve. EEV2 and EEV3 are controlled by manual and/or remote signal by PLC controller.

The refrigerant that has passed through EEV1, EEV2, and EEV3 is introduced into a shell containing a 15 kW electric heater and mixed. This shell-type heater operates as an evaporator in order to control the evaporative temperature and superheat of the compressor easily because of uncertain characteristics of R466A. R466A is a mixed refrigerant of three types. In response to the temperature change that can occur during heat exchange, an electric heater that can directly control the temperature is used to allow only gaseous R466A to flow in from the compressor inlet, enabling stable testing.

A visualization window and an oil extraction valve were configured in the loop returning from the oil separator to the compressor after compressor discharge, so that oil sampling was possible, and a mass flowmeter (OVAL, ±0.1%) was installed on the compressor discharge side and the condenser rear side. A pressure gauge (Autrol) of ±0.075% was used at the inlet and outlet of the compressor, and a pressure gauge (Keller) of ±0.5% was used for other parts, and a Class A RTD was used for the temperature, and the temperature for controlling EEV1 was measured using a thermocouple. Temperature and pressure data were obtained through a data logger (Yokogawa GM10), and EEV control was configured with a PLC.

As shown in Figure 3, the test loop was completed, and the stability of the system was verified through the pressure resistance test and air tightness test. Afterwards, R410A refrigerant is sealed, and core device performance, data acquisition, cycle control, and safety issues are checked through a test run, and then the test is conducted with R466A refrigerant.

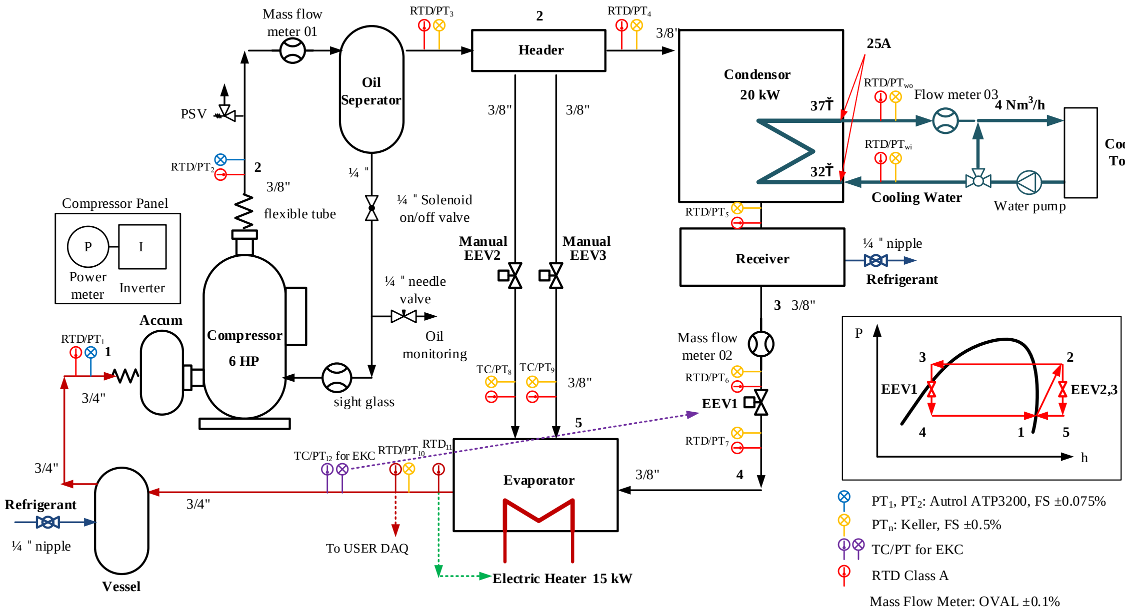

Fig. 2. Schematic of the test loop for refrigerant-oil compatibility test under long-term operation

Fig. 3. Components of the test loop with a chiller unit (a), an inverter and controllers (b), the final test loop (c), a data acquisition unit (d) and a control PLC monitor (e)

6. Conclusions and Future works

For the R466A refrigerant of GWP 733, which replaces the R410A refrigerant of GWP 2088 currently used in commercial VRF systems, a test loop that can evaluate the compatibility and reliability of compressor refrigerant-oil that may occur during long-term actual operation was designed and manufactured.

First, TAN, decomposed ion, and viscosity were determined as indicators to be evaluated through the investigation of the refrigerant-oil compatibility evaluation method. Through previous research analysis, it was confirmed that the use of POE-type oil, the same as R410A, but the use of appropriate additives to suppress corrosion due to the influence of CF_3I included in R466A was necessary, and information on target additive candidates was investigated in the refrigerant manufacturer's patents.

AHRI 210/240 MOC conditions that can simulate accelerated deterioration conditions were selected and the corresponding R466A cycle design was performed, and the cycle operating conditions of 10.6 bar in the low-pressure part, 36.4 bar in the high-pressure part, and 100.1 ℃ discharge temperature of the compressor were selected. Based on this, in order to simplify the long-term acceleration test, a test loop including a bypass loop after compressor discharge and a shell-type evaporator using an electric heater was designed and manufactured.

Currently, the test loop verification is in progress based on the R410A refrigerant, and after that, the R466A refrigerant drop-in test would be performed to analyze the change in the characteristics of the refrigerant and oil after long-term room operation, and the deterioration of the compressor and accessories.

Acknowledgements

This work was supported by Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government (MOTIE) (20212020800070, Development of next-generation alternative refrigerant and efficient heat pump system)

References

[1] CARB, Prohibitions on Use of Certain Hydrofluorocarbons in Stationary Refrigeration, Chillers, Aerosols-Propellants, and Foam End-Uses Regulation, 2022, 01. https://ww2.arb.ca.gov/ rulemaking/2020/hfc2020
[2] Global trend on refrigerant regulation and alternatives, Trane Korea, 2017
[3] https://sustainability.honeywell.com/us/en/products/ refrigerants/hfo-blends/solstice-n41-r-466a
[4] Ngoc Dung (Rosine) Rohatgi, Robert W. Clark and David R. Hurst, 2012, "Material Compatibility & Lubricants Research for Low GWP Refrigerants - Phase I: Thermal and Chemical Stability of Low GWP Refrigerants with Lubricants", AHRTI Report No. 09004-01
[5] Atilla G. Devecioglu and Vedat Oruc, 2020, "Energetic performance analysis of R466A as an alternative to R410A in VRF systems", Engineering Science and Technology, an International Journal, Vol. 23, pp. 1425~1433
[6] Kaimi Gao, Henna Tangri, Greg Smith, Ankit Sethi and Samuel Yana Motta, 2021, "Reduced GWP Refrigerant for Residential and Commercial Air Conditioning Systems", International Refrigeration and Air Conditioning Conference. Paper 2191
[7] Stephen Anthony Kujak and Elyse Sorenson, 2021, "Chemical Stability and Equipment Reliability Impacts of R-13I1 (CF3I) in R-466A", International Refrigeration and Air Conditioning Conference. Paper 2091
[8] Honeywell Intenational Incorp. Patent 10-2020-7009907, South Korea