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An Experimental Study on Oil Separation Characteristics of CO_2/PAG Oil Mixture in an Oil Separator

Byung Ha Kang†, Kyung Jae Kim*, Sung Kwang Lee*

School of Mechanical and Automotive Engineering, Kookmin University, Seoul 136-702, Korea

Graduate School of Mechanical Engineering, Kookmin University, Seoul 136-702, Korea

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Abstract

Lubricant oil is needed in air conditioning and refrigeration system because the compressor requires oil to prevent surface to surface contact between its moving parts, to remove heat, to provide sealing, to keep out contaminants, to prevent corrosion, and to dispose of debris created by wear. Thus, the oil separation in an oil separator is one of the most important characteristics for proper compressor operation. In this study, a gravity type of oil separator is used. Oil separation characteristics have been investigated for CO_2/PAG mixture in the range of oil concentration 0 to 5 weight-percent and the mixture temperature range of 0℃ to 15℃ at 50 bar and 70℃ to 90℃ at 80 bar. The results obtained indicate that the oil separation is increased with an increase in the oil concentration. It is also found that the oil separation in liquid state is increased with an increase in the mixture temperature while the oil separation in gas state is decreased.

Key words: Oil concentration, PAG(Poly Alkylene Glycol) oil, Carbon dioxide, Oil separator

Nomenclature

OC : oil concentration [%]

R : oil separation ratio [%]

m_o : the weight of oil [kg]

m_r : the weight of refrigerant [kg]

Greek letters

ρ_o : density of pure CO_2 [g/ml]

$\rho_{separator}$: density of mixture with separator [g/ml]

$\rho_{no\text{-}separator}$: density of mixture w/o separator [g/ml]

1. Introduction

Lubricant is needed in air conditioning and refrigeration systems because it is required to prevent surface-to-surface contact between its moving parts, to remove heat, to provide sealing, to keep out contaminants, to prevent corrosion, and to dispose of debris created by wear in the compressor. The lubricant mostly stays in the compressor but some lubricant is circulated in the refrigeration system with refrigerant. Unfortunately, a quantity of return oil is less than that of discharge oil. The successful operation of the refrigeration system requires sufficient oil return into the compressor because a lack of proper lubrication has always been one of the main causes of the compressor failure. While the lubricant is needed inside the compressor crankcase, it represents an undesired effect in any other components such as an evaporator and a gas cooler. It may cause an increase of the pressure drops and a decrease of the heat transfer coefficient in the heat exchangers.[1-3]

Much work has been done on oil return charcteristics. Fung et al. studied oil return characteristics of R-404A with MO and POE oil.[4] As a result, oil return characteristics were better in the case of low condensing temperature and high evaporative temperature. And R-404A/POE showed better oil return characteristics than R-404A/MO. Moreover, the evaporative heat transfer of R-404A/POE for the system was better than that of R-404A/MO. Sumida et al. tested R-410A/AB to observe flow patterns in the liquid line and evaluate oil return characteristics.[5] They found that non-accumulation of oil in the liquid line was

†Corresponding author. Tel.: +82 2 910 4681, Fax.: +82 2 910 4839
E-mail address: bhkang@kookmin.ac.kr

achieved by keeping the oil circulation ratio under 1 wt.%. They observed oil levels to evaluate oil return characteristics in a split air conditioner by a sight glass in the compressor. They reported that the R-410A/AB pair had reliable oil return characteristics. Lee proposed a model on oil retention in CO_2 air conditioning systems. PAG oil was used as the lubricant.[6] The oil retention was experimentally measured in micro-channel gas cooler, evaporator, and in the suction line of the system. The effect of oil retention on pressure drops was shown in the suction line, evaporator, and gas cooler. Pressure drops can easily double when the oil mass fraction increases up to 5 wt%. Recently, Cremaschi et al. studied oil retention in the evaporator, condenser, liquid and suction lines of R22 and R410A air conditioning systems.[7] They plotted the cumulative oil retention in each component and measured an increase in the pressure drop due to oil retention.

One of the important issues in refrigeration systems for the reliability and the system life is oil separation characteristics. Kim et al. studied the performance improvement of a centrifugal separator for gas liquid two phase flow.[8] Based upon the obtained solutions, tangential velocities, centrifugal forces, vortices and total pressure losses were analyzed to find out the best design parameters. Andresen et al. studied stability of model emulsions and determination of droplet size distributions in a gravity separator with different inlet characteristics.[9]

From the literature survey, not much work has been done on CO_2/oil mixtures. This paper presents experimental results of oil separation characteristics of CO_2/PAG oil mixture in the oil separator.

2. Experimental setup

The experimental apparatus for the present study has been built up to operate at high pressure. Fig. 1 shows a schematic diagram of the present experimental system, which consists of a refrigerant flow loop and a coolant flow loop. The refrigerant flow loop contains a liquid line, oil injection, magnetic refrigerant pump, a mass flow meter and densimeter. For the measurement of mass flow rate and density in line, mass flow meter/densimeter (Oval model CT9401) were used in this experiment.. The range of measurement for mass flow meter is 0~2 kg/min, the error tolerance is ±0.1%FS, and the accuracy of densimeter is ±0.002 g/ml. Likewise, a T type thermocouple and an absolute manometer for measuring temperature and pressure were used. The error tolerance of temperature measurement is ±0.2℃, The range of pressure measurement is 0~13.8 MPa, and the error tolerance is ±0.1%FS.

The magnetic gear pump circulates the refrigerant and the mass flow rate was measured by the mass flow meter. The lubricant can be injected into the

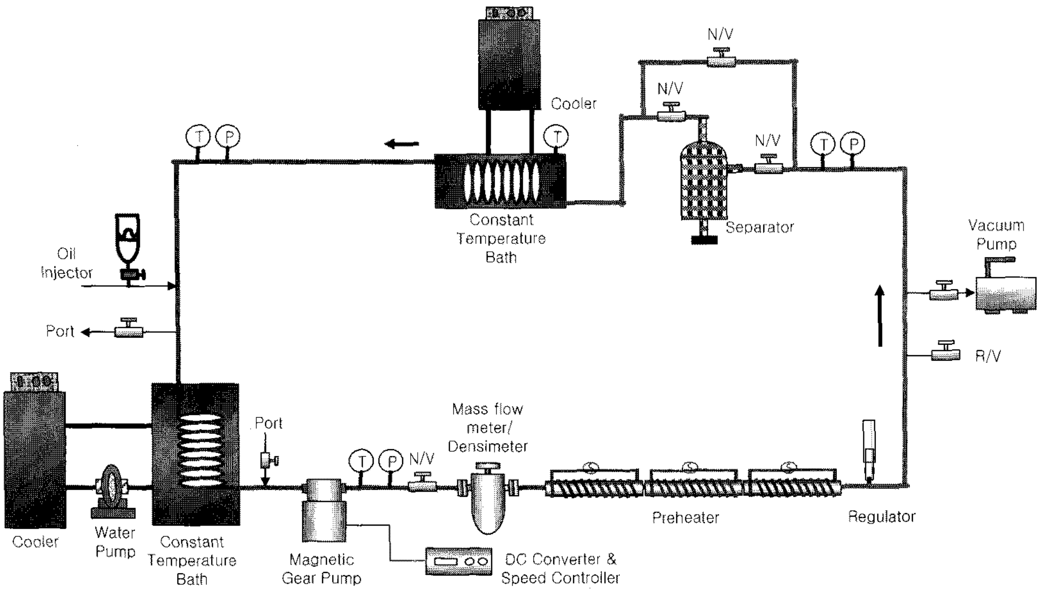

Fig. 1. Schematic diagram of experimental apparatus.

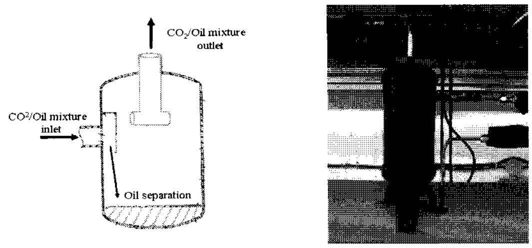

Fig. 2. Schematic diagram and photo of oil separator.

system through an oil injection port by pressure difference to make oil/refrigerant mixture. All the pipes were made of stainless steel and connected by high-pressure fitting to endure the high pressure and insulated to minimize heat loss. T-type thermocouples and absolute pressure transducers were connected into the tube.

The coolant flow loop contains a constant temperature bath, a cooler and a water pump. The temperature of CO_2/oil mixture can be controlled by the temperature of Ethylene Glycol/Water in the cooler and the flow rate. Fig. 2 shows the details of the gravity type oil separator which was made of copper to endure the high pressure and insulated to minimize heat loss.

3. Experimental conditions and procedure

Several key properties should be evaluated, including solubility, miscibility and stability to select the proper oil for CO_2 refrigeration systems. PAG oil has excellent lubricity, good low-temperature fluidity and good compatibility with most elastomers PAG oil was studied in this paper as a lubricant candidate for CO_2 refrigerant. Table 1 shows the typical properties of the lubricant oil.

An oil separator is employed to simulate oil separation characteristics in a CO_2 refrigeration system with oil separator. Table 2 shows the test conditions. There are liquid and gas states for CO_2/PAG mixture. Oil separation characteristics has been investigated for CO_2/PAG mixture in the range of oil concentration 0 to 5 weight-percent and the mixture temperature range of 0℃ to 15℃ when the operating pressure is given at 50 bar and mass flow rate is at 1.0 kg/min. Also, Oil separation characteristics has been investigated for CO_2/PAG mixture in the range of oil concentration 0 to 5 weight-percent and the mixture temperature range of 70℃ to 90℃ when the operating pressure is given at 80 bar and mass flow rate is at 0.8 kg/min.

Table 1. Typical properties of oils.

Items	Property
Type	PAG oil
Manufacturer	CPI engineering
Model	RPAG-100
Specific gravity at 15℃	1.007
Pour point (℃)	-40
Flash point (℃)	168
Viscosity at 40℃(cSt)	100

Table 2. Test conditions.

Parameter	Case 1. (liquid)	Case 2. (gas)
Injection rate of oil	0wt%~5wt%	0wt%~5wt%
Test temperature	0℃~15℃	70℃~90℃
Test pressure	50 ±1bar	80 ±0.5bar
Mass flow rate	1kg/min	0.8kg/min
Measurement	Density Temperature Oil concentration	

Before CO_2 refrigerant is injected to the system, inside of the system is vacuumed by vacuum pump. After the weight of oil injector is measured by precise scale, the oil m_o is injected into the system through an oil injection port by pressure difference. And CO_2 m_r is injected into the system through a charging port. The oil concentration (OC) is defined by Eq. (1).

There are two kinds of refrigerants that are pure CO_2 and CO_2/PAG oil mixture. The density is measured for various temperatures and oil concentrations by the densimeter when the oil separator is attached or not. The oil separation ratio (R) is defined by Eq. (2).

$$OC = \frac{m_o}{m_r + m_o} \quad (1)$$

$$R = 1 - \frac{\rho_{separator} - \rho_r}{\rho_{no-separator} - \rho_r} \quad (2)$$

To remove effects of oil retention in the experimental apparatus on oil concentration, oil concentrations are compared with oil separator and oil concentration without oil separator at the same operating condition. The oil concentration at the inlet of separator is assumed to be the same as oil concentration without oil separator. In the system, the oil is accumulated into the oil separator initially in case of flow of CO_2/oil mixture. After the some amount of oil is accumulated in the oil separator, the oil is not accumulated any more and reach a steady state. In the steady state, the density of mixture with separator becomes $\rho_{separator}$, which is compared with the density without oil separator. It was measured that the value of density according to the changes of pressure and temperature with circulating the pure CO_2, which oil is not injected, in the system. The measured data was compared with thermal properties in nistwebbook, and satisfied the error tolerance of ±0.83%.

Employing the estimated uncertainty in each physical measurement, an uncertainty analysis for the experimental results is performed by Eq. (3). Since the error of the density of pure CO_2 was estimated to be ±0.83% The relative uncertainty in the oil separation ratio R was calculated to be ±1.8%

$$\frac{\Delta R}{R}=\left[\left(\frac{\partial R}{\partial \rho_{no-separator}}\frac{\rho_{no-separator}}{R}u_{\rho_{no-separator}}\right)^2+\left(\frac{\partial R}{\partial \rho_{separator}}\frac{\rho_{separator}}{R}u_{\rho_{separator}}\right)^2+\left(\frac{\partial R}{\partial \rho_r}\frac{\rho_r}{R}u_{\rho_r}\right)^2\right]^{1/2} \quad (3)$$

4. Results and discussion

4.1 Oil separation characteristics at liquid phase

Fig. 3 shows the density of liquid CO_2/PAG oil mixture at various oil concentrations and temperatures before and after the oil separator was attached. The solid dotted data in Fig. 3 represents the density of CO_2/PAG oil mixture when the oil separator was not installed, and the blank dotted data shows the density of CO_2/PAG oil mixture when the oil separator was installed. Therefore, the oil separation ratio for the liquid phase in the oil separator can be estimated by the difference between the two fitted curves.

Fig. 4 represents the PAG oil separation ratio in the oil separator at various oil concentration 0 to 5 weight-percent. In the case of the temperature of 15℃ and the mass flow rate of 1 kg/min, the oil separation ratio was 79% at the oil concentration of 1 wt.%, the oil separation ratio was 83% at that of 3 wt.% and the oil separation ratio was 85% at that of 5 wt.%. The oil separation ratio is increased with an increase in PAG oil concentration at given temperatures.

Fig. 5 shows the PAG oil separation ratio in the oil separator at various temperature 0 to 15℃. In the case of the oil concentration of 5 wt.% and the mass flow rate of 1 kg/min, the oil separation ratio was 70% at

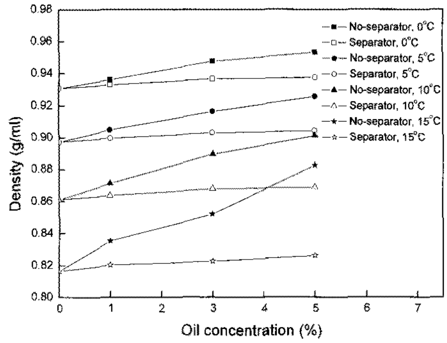

Fig.3. Effect of oil concentration on mixture density for various mixture temperatures at liquid state.

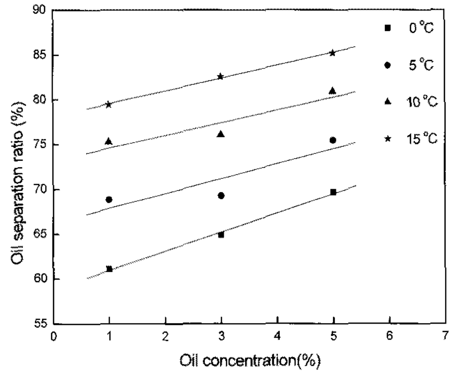

Fig. 4. Effect of oil concentration on oil separation ratio for various mixture temperatures at liquid state.

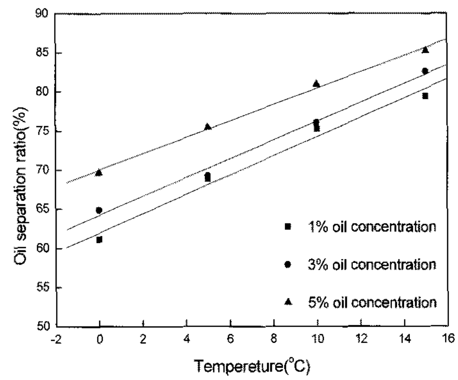

Fig. 5. Effect of mixture temperature on oil separation ratio for various oil concentration ratio at liquid state.

the temperature of 0℃, the oil separation ratio was 75% at that of 5℃, the oil separation ratio was 81% at that of 10℃ and the oil separation ratio was 66% at that of 15℃.The oil separation ratio for the liquid phase is increased with an increase in the temperature at given PAG oil concentrations. oil separation ratio for the liquid phase is increased with an increase in the temperature at given PAG oil concentrations. Lee[6] found that the solubility of CO_2 is decreased with an increase in the temperature of CO_2/oil mixture at liquid phase. thus, the oil separation ratio in the oil separator is decreased with an increased in the mixture temperature. because the miscibility of PAG oil and CO_2 is decreased at liquid phase.

4.2 Oil separation characteristics at gas phase

Fig. 6 shows the density of gas CO_2/PAG oil mixture at various oil concentrations and temperatures before and after the oil separator was attached. The solid dotted data in Fig. 6 represents the density of CO_2/PAG oil mixture when the oil separator was not installed, and the blank dotted data shows the density of CO_2/PAG oil mixture when the oil separator was installed. Also, the oil separation ratio for the gas phase in the oil separator can be estimated by the difference between the two fitted curves.

Fig. 7 represents the PAG oil separation ratio in the oil separator at various oil concentration 0 to 5

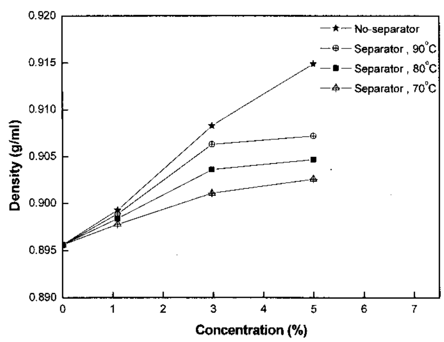

Fig. 6. Effect of oil concentration on oil mixture density for various mixture temperatures at gas state.

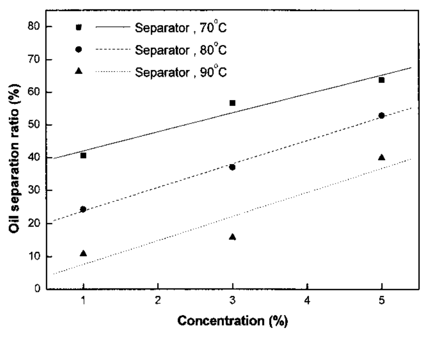

Fig. 7. Effect of oil concentration on oil separation ratio for various mixture temperatures at gas state.

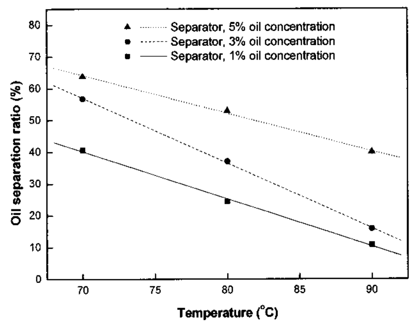

Fig. 8. Effect of mixture temperature on oil separation ratio for various oil concentration ratio at gas state

weight-percent. In the case of the temperature of 70℃ and the mass flow rate of 1 kg/min, the oil separation ratio was 41% at the oil concentration of 1 wt.%, the oil separation ratio was 57% at that of 3 wt.% and the oil separation ratio was 64% at that of 5 wt.%. The oil separation ratio is increased with an increase in PAG oil concentration at given temperatures.

Fig. 8 shows the PAG oil separation ratio in the liquid line at various temperature 70 to 90℃. In the case of the oil concentration of 5 wt.% and the mass flow rate of 1 kg/min, the oil separation ratio was 64% at the temperature of 70℃, the oil return ratio was 53% at that of 80℃, the oil return ratio was 40% at that of 90℃. The oil separation ratio for the gas phase is decreased with an increase in the temperature at given PAG oil concentrations. As temperature of CO_2/oil mixture is increased, the oil separation ratio is decreased because the oil may evaporate and merge into the CO_2 gas flow.

5. Conclusions

An experimental study has been carried out to investigate the oil separation characteristics in CO_2 oil separator for various operating conditions of CO_2/PAG oil mixture. The Characteristics of oil separation depend on the oil concentration and the temperature. The maximum performance of oil separator in liquid phase is 85% and that in gas phase is 64%.

The oil separation ratio is increased with an increase in PAG oil concentration at given temperatures. The oil separation ratio in the liquid phase is increased with an increase in the temperature at given PAG oil concentrations due to the miscibility of CO_2/oil mixture. The oil separation ratio in the gas phase is decreased with an increase in the temperature at given PAG oil concentrations due to the quantity of evaporative CO_2/oil mixture.

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