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ABSTRACT

Lubricant oil is needed in air conditioning and refrigeration system because the compressor requires it 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. The present study has been carried out to select the suitable refrigeration oil for a CO_2 refrigeration system. The oil return is one of the most important characteristics for refrigeration oils. PAG and POE oils are considered as a test fluids in this study. An evaporator model is employed to simulate the evaporator of a CO_2 refrigeration system. Oil return characteristics has been investigated for CO_2/PAG and CO_2/POE mixtures in the range of oil concentration 0 to 5 weight-percent and the mixture temperature range of 0℃ to 15℃ and the mass flow rate range of 1.4 kg/min to 2.0 kg/min. The results obtained indicate that oil return is decreased with an increase in the oil concentration and mixture temperature for both POE and PAG oils. It is also found that oil return is increased as the mass flow rate is increased for both oils. As a result, POE oil is seen to be superior to PAG oil in terms of oil return in an evaporator of a CO_2 refrigeration system.

1. INTRODUCTION

A modern industrial society is presently considering not only technical development, but also environmental protection to enhance the quality of the life. Among the environment problems, ozone depletion and global warming effect are arisen seriously. Due to ozone depletion and global warming effects of synthetic refrigerants, in this overall perspective, the use of CFCs and HCFCs has been restricted by Montreal and Kyoto protocol. [1]

In order to solve this problem, environmentalists are requesting the introduction of natural refrigerant that uses natural materials as a refrigerant. For reasons mentioned above, natural material, such as NH_3, N_2, CO_2 and propane etc., becomes an important issue in refrigeration system. Among the natural refrigerants, carbon dioxide has been focused on as a refrigerant with many remarkable advantages, environmental attractiveness, non-toxicity, non-inflammability, light weight and large refrigeration capacity. With these attractions, it has good thermal characteristics such as low surface tension and low liquid viscosity.

With regard to alternative refrigerant applying to a refrigeration system or an air conditioning system, the important problem is selection of suitable oil (or lubricant) on alternative refrigerant. 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.

One of the important issues in refrigeration systems for the reliability and the system life is oil return. Thus, much work has been done on this issue. The vertical suction line is considered for oil return because the refrigerant must overcome gravity to carry the oil vertically upward. Fukuta et al. [2] studied oil return characteristics for a suction line with vertical upward flow. Two-phase flow of the oil and air was used to examine basic characteristics of the oil film transport in vertical upward flow. The oil film thickness was measured by a capacitance sensor with air and oil flow rate, oil viscosity, and tube diameter. The average oil film thickness was shown to decrease with an increase in the air velocity and the pressure. Also, it was slightly decreased as the oil viscosity and flow rate are increased.

After HFC refrigerants were introduced as alternative refrigerants for CFCs and HCFCs, the miscibility between refrigerant and oil is an important issue in a low temperature component such as the evaporator or suction line. Fung et al. [3] studied oil return characteristics of R-404A with MO and POE oil. 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. Lee [4] proposed a model on oil retention in CO_2 air conditioning systems. PAG oil was used as the lubricant. 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. [5] studied oil retention in the evaporator, condenser, liquid and suction lines of R22 and R410A air conditioning systems. They plotted the cumulative oil retention in each component and measured an increase in the pressure drop due to oil retention.

While much work has been done on oil return characteristics for HFC/Oil mixtures, not much work have been given on CO2/Oil mixtures is insufficient. Therefore, this paper presents further experimental results of oil return in CO2 evaporator model with various conditions of CO2/PAG oil and CO2/POE oil.

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 an evaporator model, oil injection, magnetic refrigerant pump, a mass flow meter and densimeter. 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 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. A sight flow indicator for the observation of the phase behavior consists of Pyrex glass of 20 mm diameter, 10 mm thickness established on front and back surface. T-type thermocouples and absolute pressure transducers were connected into the tube.

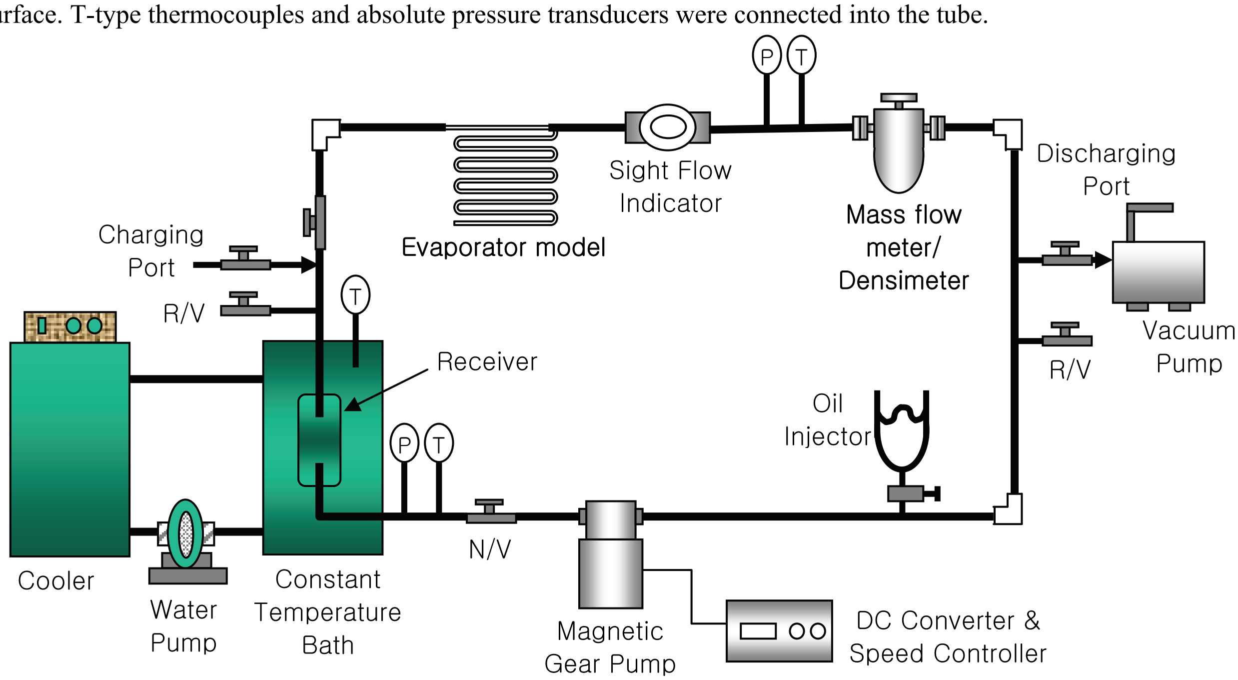

Fig. 1 Schematic diagram of an experimental system

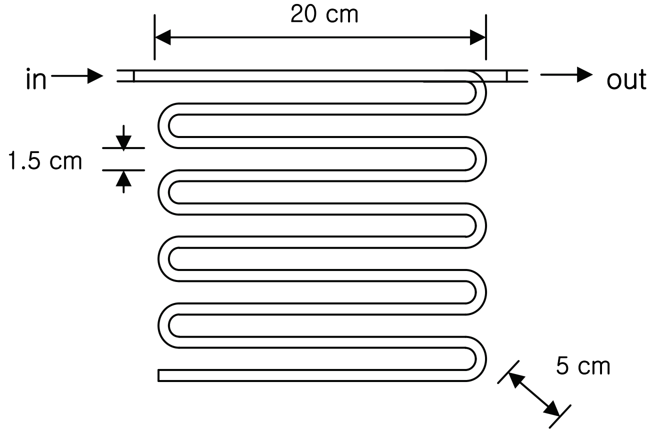

Fig. 2 Schematic diagram of an evaporator model

The coolant flow loop contains a constant-temperature bath, a cooler and a water pump. The temperature of CO2/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 an evaporator model, which was made of stainless steel to endure the high pressure and insulated to minimize heat loss. The diameter of the evaporator tube is 1/4 inch.

3. EXPERIMENTAL CONDITIONS AND PROCEDUER

Several key properties should be evaluated, including solubility, miscibility and stability to select the proper oil for CO2 refrigeration systems. PAG oil has excellent lubricity, good low-temperature fluidity and good compatibility with most elastomers and POE oil shows good miscibility characteristics with CO2. PAG and POE oils were studied in this paper as a lubricant candidate for CO2 refrigerant. Table 1 shows the typical properties of the lubricant oils.

An evaporator model is employed to simulate the evaporator of a CO_2 refrigeration system. Oil return characteristics has been investigated for CO_2/PAG and CO_2/POE mixtures 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 60 bar and mass flow rate is at 2.0 kg/min. Also, Oil return characteristics has been investigated in the range of mass flow rate 1.4 kg/min to 2.0 kg/min at operating pressure 60 bar and temperature 10 ℃.

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 CO2 m_R is injected into the system through a charging port. The oil concentration (OC) is defined by eqn. (1).

$$OC = \frac{m_O}{m_R + m_O} \qquad (1)$$

There are three kinds of refrigerants that are pure CO2, CO2/PAG oil mixture and CO2/POE oil mixture. The density is measured for various temperatures, oil concentrations and mass flow rates by the densimeter when the evaporator model is attached or not. The oil return ratio (OR) is defined by eqn. (2).

$$OR = \frac{\rho_{evap} - \rho_o}{\rho_{no-evap} - \rho_o} \qquad (2)$$

Table 1 Typical property of oils

Oil	PAG	POE
Company	CPI	MOBIL
Model	RPAG-100	EAL Arctic-100
Specific gravity at 15 ℃	1.007	0.962
Pour point (℃)	-40	-30
Flash point (℃)	168	254
Viscosity at 40 ℃ (cSt)	100	100

4. RESULTS AND DISCUSSION

Figure 3 shows the density of CO2/PAG oil mixture at various oil concentrations and temperatures before and after the evaporator model was attached. The solid dotted data in Figure 3 represents the density of CO2/PAG oil mixture when the evaporator model was not installed, and the blank dotted data shows the density of CO2/PAG oil

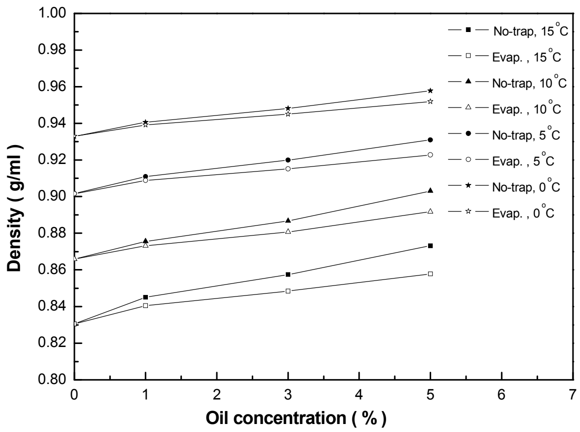

Fig. 3 Density of CO2/PAG oil mixture for oil concentration and temperature

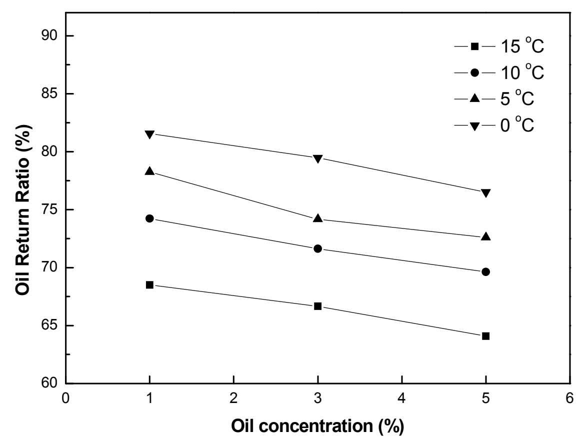

Fig. 4 Effect of the oil concentration on PAG oil return ratio

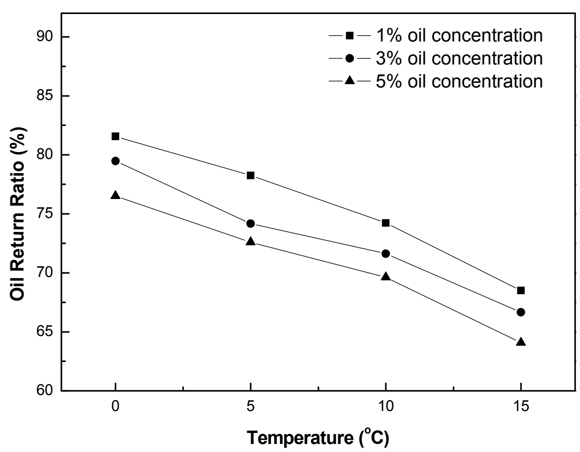

Fig. 5 Effect of the temperature on PAG oil return ratio

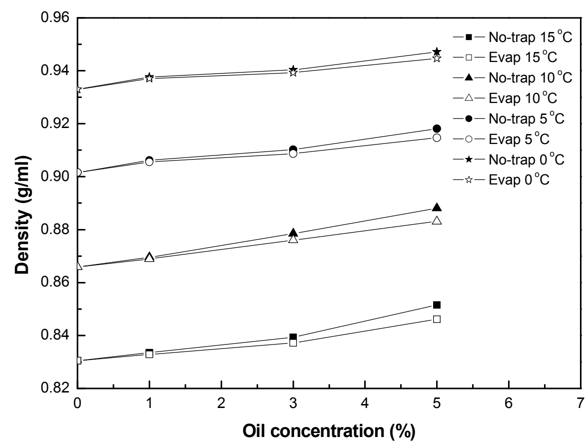

Fig. 6 Density of CO2/POE oil mixture for oil concentration and temperature

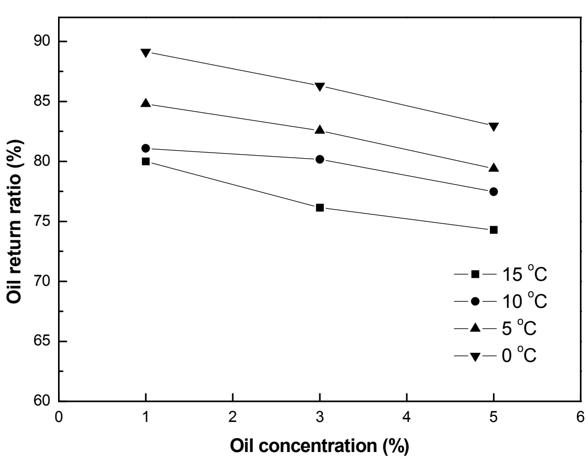

Fig. 7 Effect of the oil concentration on POE oil return ratio

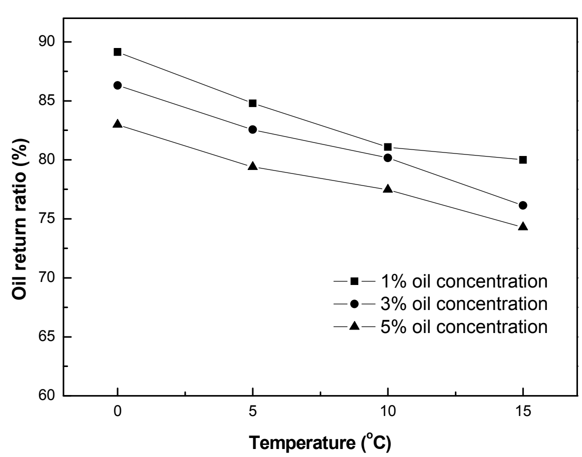

Fig. 8 Effect of the temperature on POE oil return ratio

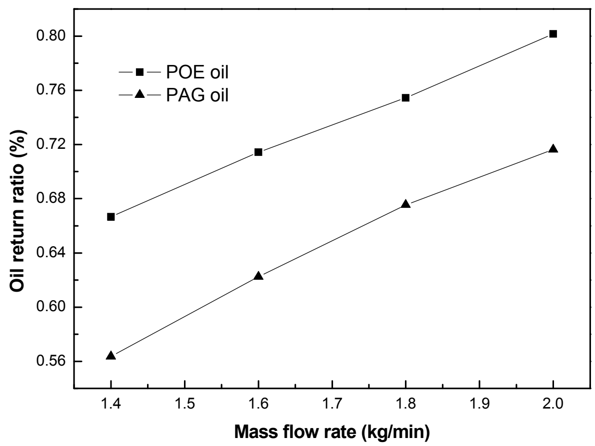

Fig. 9 Effect of the mass flow rate on PAG and POE oils return ratio at 10 ℃, 3 wt.%

mixture when the evaporator model was installed. Therefore, the oil return ratio in evaporator model can be estimated by the difference between the two fitted curves.

Figure 4 represents the PAG oil return ratio in the evaporator model at various oil concentration 0 to 5 weight-percent. In the case of the temperature of 10 ℃ and the mass flow rate of 2 kg/min, the oil return ratio was 74 % at the oil concentration of 1 wt.%, the oil return ratio was 69 % at that of 3 wt.% and the oil return ratio was 67 % at that of 5 wt.%. The oil return ratio is decreased with an increase in PAG oil concentration at given temperatures.

Figure 5 shows the PAG oil return ratio in the evaporator model at various temperature 0 to 15 ℃. In the case of the oil concentration of 3 wt.% and the mass flow rate of 2 kg/min, the oil return ratio was 79 % at the temperature of 0 ℃, the oil return ratio was 74 % at that of 5 ℃, the oil return ratio was 71 % at that of 10 ℃ and the oil return ratio was 66 % at that of 15 ℃. The oil return ratio is decreased with an increase in the temperature at given PAG oil concentrations. Consequently, the oil return ratio is decreased with an increase in the oil concentration and mixture temperature for PAG oil due to the miscibility of CO2/PAG oil mixture.

The density of CO2/POE oil mixture is shown in Figure 6 at various oil concentrations and temperatures before and after the evaporator model was attached. Figure 7 represents the POE oil return ratio in the evaporator model at various oil concentration 0 to 5 weight-percent. In the case of the temperature of 10 ℃ and the mass flow rate of 2 kg/min, the oil return ratio was 81 % at the oil concentration of 1 wt.%, the oil return ratio was 80 % at that of 3 wt.% and the oil return ratio was 77 % at that of 5 wt.%. The oil return ratio is decreased with an increase on POE oil concentration at given temperatures.

Figure 8 shows the POE oil return ratio in the evaporator model at various temperature 0 to 15 ℃. In the case of the oil concentration of 3 wt.% and the mass flow rate of 2 kg/min, the oil return ratio was 86 % at the temperature of 0 ℃, the oil return ratio was 82 % at that of 5 ℃, the oil return ratio was 80 % at that of 10 ℃ and the oil return ratio was 76 % at that of 15 ℃. The oil return ratio is decreased with an increase on the temperature at given PAG oil concentrations. Consequently, the oil return ratio is decreased with an increase in the oil concentration and mixture temperature for POE oil due to the miscibility of CO2/POE oil mixture.

Figure 9 represents the oil return ratio in the evaporator model in the range of mass flow rates 1.4 to 2.0 kg/min. In the case of the temperature of 10 ℃ and the oil concentration of 3 wt.%, the oil return ratio is increased with an increase in the mass flow rate for both POE and PAG oils. The trend on oil return ratio is similar for both POE and PAG oils. However, POE oil is seen to be superior to PAG oil in terms of oil return in an evaporator of a CO2 refrigeration system.

5. CONCLUSIONS

An experimental study has been carried out to investigate the oil return in CO2 evaporator model for various operating conditions of CO2/PAG oil mixture and CO2/POE oil mixture. The Characteristics of oil return depend on the oil concentration, the temperature and mass flow rate. The oil return ratio is decreased as the temperature is increased. The oil return ratio is decreased with an increase in the oil concentration. The oil return ratio is increased as the mass flow rate is increased for both PAG and POE oil mixtures. Consequently, the trend on oil return ratio is similar for both POE and PAG oils. However, POE oil is seen to be quantitively superior to PAG oil in terms of oil return in an evaporator of a CO2 refrigeration system due to the miscibility of CO2/ oil mixture.

NOMENCLATURES

Roman Symbol

HCFC	Hydrochlorofluorocarbon	
HFC	Hydrofluorocarbon	
MO	Mineral Oil	
OC	Oil Concentration	wt.%
OR	Oil Return Ratio	%
PAG	Polyalkylene Glycol	
POE	Polyolester	

Greek Symbol

ρ_o	Density of pure CO2	g/l
ρ_{evap}	Density of CO2/ oil mixture with evaporator	g/l
$\rho_{no-evap}$	Density of CO2/ oil mixture without evaporator	g/l

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