An investigation on the in si · tu measurement of the oil-concentration

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Key word : Concentration, Refrigerant/oil mixture, Specific gravity, Densimeter

Abstract

In order to predict thermodynamic peformance of refrigeration system, it is required to know the oil concentration of the refrigerant/oil mixture. The current method is to extract the working mixture and then to measure the oil weight. In this study, oil concentration is measured in si.tu way without any extraction of the working fluid. Based on the measurement, a working equation is presented as follows.

$C = a + b \times t + c \times t^2 + (d + e \times t + f \times t^2) \times SG$

C is oil concentration, t is temperature(℃), SG is specific gravity of mixture and a~f is coefficients. The oil concentration ranges over 0~12 wt% and the temperature ranges over 20~50℃. The specific gravity and temperature are measured using the on-line densimeter and thermometer. This working equation enables to predict the oil concentration without any extraction of the mixture. This equation can be applied for R-12/Naphthenic oil and R-134a/POE oil liquid mixtures.

Nomenclature

a, b, c, d, e, f : Coefficient

A, B : Coefficient

$B_{0\sim8}$: Coefficient

C : Oil concentration

SG : Specific gravity

t : Temperature(℃)

T : Temperature(K)

Greek letters

θ : Nondimensional temperature

Subscripts

ref : Reference

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1 Introduction

The oil concentration may have a significant effect on the hydrodynamic and heat transfer performance of refrigeration system components, such as condensers and evaporators, because of changes in the thermodynamic and transport properties[1]. To account for these effects of oil on a refrigeration system, the mass fraction of oil dissolved in an oil-refrigerant mixture flow is required.

In the normal operation of a vapor-compression refrigeration system, a portion of the compressor lubricating oil circulates with the refrigerant. The mass fraction of the circulating oil is necessary for the accurate calculation of refrigeration system capacity, estimation of the thermal and hydrodynamic performance of system components, prediction of fluid properties in the system, and prevention of operational problems caused by excessive oil circulation.

The present standard method[2] for measuring the circulating oil concentration is in sequence of sample of the oil-refrigerant mixture from the liquid line, weighing the sample, boiling off the refrigerant component, and weighing the residue.

In this study, in-line method is developed. The in-line method would be a clear improvement over the sample-removal method, especially for measurements in small systems and for the study of transient oil migration.

Several investigators have studied the prediction of oil concentration. Baustian et al. investigated thermophysical, transport[3], electrical, and optical properties[4] of oil-refrigerant liquid mixtures. They recommended several oil concentration sensors; density measurement, acoustic velocity measurement, capacitance measurement, and refractive index measurement. They evaluated a commercially available vibrating U-tube densimeter as a sensor for measuring the concentration of oil in the liquid line of a refrigeration system[5]. They conducted calibration and performance tests under simulated liquid-line conditions for R-12/naphthenic oil, R-22/naphthenic oil, and R-502/alkylbenzene oil mixtures over 0 to 30 weight-percent. They presented a temperature-concentration-density correlation using the experimental data. And they concluded the densimeter could be used to measure the flowing oil concentration with an uncertainty of 2 weight-percent for liquid-line temperatures below approximately 32.3 ℃. They assumed the flowing oil concentration was equal to the injected oil concentration. But the flowing oil concentration is not the same as the injected oil concentration. Therefore their correlation is not reliable.

Kutsuna et al.[6] developed a method of real time oil concentration measurement utilizing the effect of ultraviolet light absorption by lubricating oil in the liquid refrigerant line of an automotive air conditioning system. They used CFC-12 with mineral oil and HFC-134a with PAG oil. They said that this method has an accuracy of 0.1 weight percent at an oil concentration of 1 weight percent.

Grebner and Crawford[7] presented equilibrium pressure-temperature-concentration data experimentally measured for R-12/naphthenic mineral oil, R-12/paraffinic mineral oil, R-134a/ester oil, and R-134a/polyalkylene glycol (PAG) mixtures. Using the experimental data, empirical models are developed to predict the solubility for each mixture at equilibrium. Raoults Rule and Flory-Huggins theory are also used to predict mixture behavior. These equilibrium models are also used to determine the amount of liquid refrigerant as the re-

Table 1 Typical properties of oils for testing and evaluation

List \ Class	Naphthenic Mineral Oil	POE Oil
Products	RO 68	SOLEST 68
Specific gravity 20℃	0.905	0.945
Viscosity(cSt) 40℃	63.8	64.0
Flash point(℃)	193.3	296
Pour point(℃)	-37.2	-43.0
Specific gravity	$SG = 0.98193 - 2.99489 \times 10^{-4} \times T$	$SG = 1.03307 - 0.00026 \times T$

frigerant in an evaporator boils. Hughes et al.[8] presented pressure-enthalpy charts for R-12/oil mixtures. They studied the effect of oil on the heat transfer and COP and presented oil-refrigerant curves for an 8% oil mixture. They reported that COP and the heat transfer at the evaporator are degraded because of the oil effect.

The conventional method is sampling and weighing method. It can not be applied to the continuous and transient measurements. The purpose of this study is to develop a new way to estimate the oil concentration. It is based on the measurement of density of refrigerant-oil mixture.

2. Experiment

2.1 Selection of refrigerant and oil

R-12 was widely used refrigerants in commercial and residential refrigerator and air-conditioning. It will be phased out. R-134a is used in car air-conditioning and domestic refrigerator as R-12 alternative[9]. These two are typical refrigerant. So R-12 and R-134a are used in the experiment. Naphthenic and POE oils are also used. The properties of refrigerants and oils are listed in the Table 1

2.2 Experimental apparatus

Figure 1 is schematics of experimental set-up[10]. The apparatus consists of the circulating pump, pressure vessel, isothermal bath, oil injection and sampling unit, and heat exchanger. The densimeter is installed between isothermal bath and sampling unit. Thermocouples and pressure transducers are located at the inlet and outlet of the densimeter. The sight glass is before the densimeter inlet. The state of mixture is checked by the sight glass. The pump circulates the refrigerant and oil mixture. The maximum flow rate is 3 l/min at 30 bar discharge pressure. The drive motor is 1/2 HP and 3 phase, which is controlled by inverter.

The pressure vessel is installed at the highest point. It controlls the total pressure of the system. Also it regulates the pulse generated by the circulating pump. The state of liquid line is confirmed by the liquid level.

The oil injection and sampling unit is two-way pipe system. The stainless steel cylinder is used to inject oil and to sample the mixture. Its volume is 75 ml. A copper coil is used to separate refrigerant from the sampled refrigerant/oil mixtures. The length of the coil is 150 mm, and diameter is 9.525 mm.

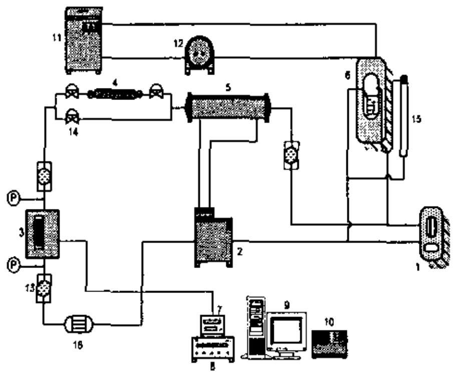
The temperature of the experimental apparatus is controlled by the isothermal bath and heat exchanger. Heat exchanger is connected the isothermal bath. The density and temperature of refrigerant/oil mixture are measured by the U-tube densimeter. The precision of densimeter and temperature is 0.002 g/cc and 0.1C, respectively. The densimeter is calibrated with air and water by manufacturer. The deviation of density of water is within 0.15%. A Coriolis effect mass flow meter is used to measure the mass flow rate. T-type thermocouples are used to measure the temperature. The pressure is measured with pressure transducers with a precision of 1.0 kPa. The temperature and pressure signals are transferred to PC through data acquisition system by RS-232C communication. The specifications of measuring devices are listed in the Table. 2

2.3 Experimental condition

In general, refrigerator operates over the temperature range from -23 to 54℃ and car air-conditioning does from 10 to 40℃. The temperature of condenser is between 55℃ and 40℃. Therefore in this study the temperature ranges from 20 to 50 ℃. The oil concentration ranges from 0 to 12%

2.4 Experimental method and procedure

The experimental procedure is as follows. At first the refrigerant is charged into the experimental system. The refrigerant is weighed by scale with a precision of o.1 g. The temperature of pressure vessel is maintained at a setting value. After the liquid refrigerant is confirmed by the liquid level, the circulating pump starts. The system is run more than 2 hours until it reaches to a steady state. After the system reaches to a steady state, the density, temperature, and pressure of the refrigerant are recorded. Then, oil is injected. The system is run sufficiently enough until refrigerant and oil are completely mixed and it reaches to a steady state again. After the system reaches to a steady state, the density,



1	Pump	9	Computer
2	Constant Temperature Bath	10	Data Acquisiton System
3	Flowmeter/ Densimeter	11	Constant Temperature Bath
4	Oil Injector/Sampler	12	Water Circulation Pump
5	Heat Exchanger	13	Sight Glass
6	Pressure Vessel	14	Valve
7	Density Monitoring System	15	Liquid Level Gauge
8	HP Power Supply	16	Filter Dryer

Fig. 1 Schematic diagram of experimental apparatus.

Table 2 Specifications of measuring equipments

Equipments	Specification
Densimeter System	Model : DMS OVAL Electric Corp. Range : 0~6.0000 g/cc Accuracy : ±0.002 g/cc, 0.1℃ Output Density&Temp. : 4~20 mA
Portable Pressure Indicator/Calibrator	Model : DPI601, Druck Range 70(mbar) to 35(bar)(±0.05%fs) Accuracy : 0.05%(35 to 75bar[0.1%])
Data Acquisition Terminal	Model : DA2500E Yokogawa Electric Corp. Range TC : -200 to 2315 (℃) Resolution TC : 0.1 to 0.2, RTD:0.1
HP-IB DC Power supply	Model : HP 6674A Volt Ampere Output Range : 0-60V, 0-35A Programming Accuracy : 60mV,25mA
Micro Motion Mass Flowmeter	Model : N25-1811KP, OVAL Range : 0-600g/h Accuracy : 0.1% of full scale

temperature, and pressure of the refrigerant/oil mixture are recorded. As soon as the recording is finished, the refrigerant/oil mixture is taken into the cylinder for sampling of mixture. The cylinder is separated from the experimental apparatus. The copper coil is connected to the cylinder. The tube and cylinder are weighed. The cylinder valve is opened very slowly to evaporate the refrigerant. The refrigerant is evaporated while passing the copper coil. After the refrigerant is removed completely, the cylinder is weighed. The above procedures are repeated over the temperature range from 20℃ to 50℃ at 5℃ or 10℃ intervals. One process of the above is finished. Then the oil is injected again into the system and the above procedures are repeated until the maximum oil concentration is obtained.

After the experiment is finished for an oil, the experimental system is cleaned. The cleaning procedure is as follows. At first the residual refrigerant/oil mixture is flushed by the high pressure N_2 gas. Then the apparatus is evacuated enough. The solvent is charged into the experimental apparatus. The circulating pump is run to clean the experimental apparatus. After the pump is run enough, the solvent is removed in the experimental apparatus. The experimental apparatus is evacuated again.

3. Results and discussion

3.1 Calibration of the system

The densimeter is calibrated with air and water by manufacturer. Also the overall system is calibrated with a pure refrigerant. Figure. 2 shows measured specific gravity and REFPROP's specific gravity for a pure refrigerant R-12 and R-134a. Specific gravity differences between two data are nearly con-

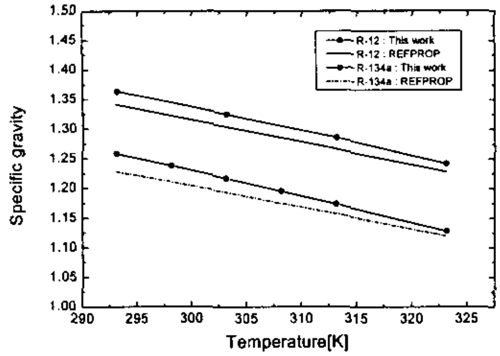


Fig. 2 Comparison of specific gravity of the liquid refrigerant R-12 and R-134a with reference value.

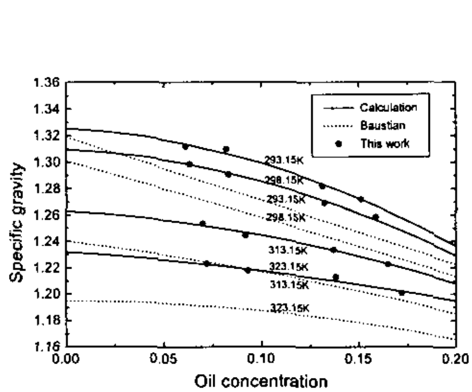


Fig. 3 Comparison of specific gravity of calculation and Baustian et al.[(5)] for R-12/Naphthenic oil mixture.

stant. The difference results from the system error which is combined effect of the densimeter, the thermometer, the pressure gauge. Therefore, measured specific gravity is corrected by the amount of the system error.

3.2 Comparison with Baustian et al.

Figure. 3 compares the specific gravity of R-12/VG68 Naphthenic lubricant mixtures which is measured in this study with the specific gravity of R-12/VG32(150 sus) Naphthenic lubricant mixtures in Baustian et al[(5)]. A solid line is fitting the data of R-12/VG68 Naphthenic lubricant mixtures which is measured in this study. A dotted line is Baustian's calculation for R-12/VG32 Naphthenic lubricant mixtures. The Baustian's correlation is as follow.

$$SG = b_0 + b_1 C + b_2 \theta + b_3 C^2 + b_4 C\theta + b_5 \theta^2 + b_6 C^2 \theta + b_7 C \theta^2 + b_8 C^2 \theta^2 \qquad (1)$$

where θ is Tref/T, bi (I=1,8) is coefficient, Tref is 291.15K, SG is a specific gravity of refrigerant/lubricant mixtures, and C is oil concentration. Because specific gravity and viscosity of the sample material are different from each other, direct comparison is not possible. But qualitative comparison is possible. Baustian et al[(5)]. obtained the equation on the assumption that oil concentration of refrigerant/lubricant mixtures flowing the system is equal to the concentration of lubricant injected into the system. However, because solubility may change with temperature and oil may accumulate in the apparatus, flowing oil concentration is not equal to the injected oil concentration. In this study, it is confirmed. Specific gravity refrigerant/lubricant mixtures 293.15K, 298.15K, 313.15K and oil concentration increase. Specific gravity R-12/VG 68 Naphthenic lubricant mixtures decrease along quadratic curve. The specific gravity from Baustian et al[(5)]. decreases in a linear line for R-12/VG 32 Naphthenic lubricant mixtures. The specificgravity of R-12 at 293.15K is about 0.3335. The specific gravity of R-12/VG 68 Naphthenic lubricant mixtures at 0 % concentration is about 0.3325. On the other hand, specific gravity of R-12/VG 32 Naphthenic lubricant mixtures in Baustian et al[(5)]. is about 0.3195 at 0 % concentration. It is revealed that there is a quite difference between the value

Table 3 Coefficients to equation (1) for R-12/ Naphthenic oil mixture

Coefficients	Mixtures	
	Baustian VG 32	This work VG 68
b_0	0.624438	2.28668
b_1	8.662384	-0.05715
b_2	2.407836	-0.99812
b_3	-22.505005	-8.20542
b_4	-21.507901	0.1030045
b_5	-1.706437	0.04316325
b_6	48.802555	-0.00002911
b_7	12.346718	-0.128582
b_8	-26.296189	6.31417
Correlation	0.99	0.99

of Baustian's and REFPROP. This difference results from the fact that Baustian's correlation is based on the injected oil concentration. Therefore, a new correlation is needed and it should be based on the flowing oil concentration. There are coefficients in Table 3 that Baustian et al. presented for R-12 /VG32 Naphthenic lubricant mixtures.

3.3 A new correlation

Baustian's correlation is not correct and is not convenient because of its nonlinearity in terms of specific gravity. Therefore a new correlation is tried to meet two conditions. The first one is that the correlation should be on the basis of flowing oil concentration. The second is that the correlation should be an explict function of the specific gravity. Because there are linear relations between oil concentration and specific gravity of mixtures a linear relation equation is presented as follows:

Table 4 Coefficients to equation (3)

Coefficient	Mixtures	
	R-12 /naphthenic oil	R-134a /POE oil
a	-0.1404872	-0.02575
b	0.1521228	0.250795
c	-0.0008843	-0.0013572
d	0.2395017	0.11581
e	-0.1175216	-0.201888
f	0.0005615	0.00075974
Correlation	0.9868	0.9867

$$C = A + B \times SG \quad (2)$$

Where C is the concentration of oil extracted and measured, SG is the specificgravity of mixtures, A and B are coefficients. And then the effect of the temperature is considered, and the following correlation is suggested.

$$C = a + b \times t + c \times t^2 + (d + e \times t + f \times t^2) \times SG \quad (3)$$

where t is the temperature in ℃. Coefficients are calculated by using data of the temperature, oil concentration and specificgravity for R-12/VG 68 Naphthenic refrigerant mixture and R-134a/VG 68 POE lubricant mixtures. They are presented in Table. 4. The oil concentration calculated from Eq. 3 is compared with data measured for R-12/VG 68 Naphthenic lubricant mixtures and R-134a/VG 68 POE lubricant mixtures in Figure 4 and Figure 5, respectively. The Eq.(3) is valid over the temperature 20 - 50℃ and concentration 0 - 20%. This correlation can predict oil concentration of mixtures flowing in an apparatus.

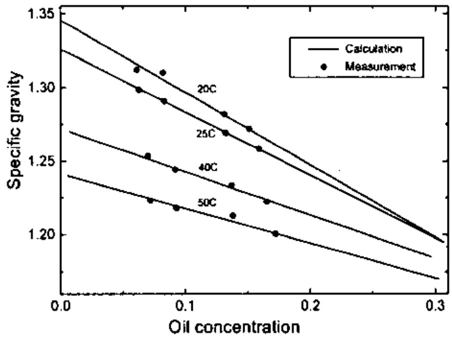


Fig. 4 Best fit curve for R-12/VG 68 Naphthenic oil mixture.

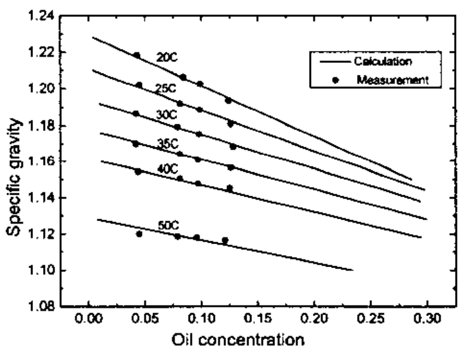


Fig. 5 Best fit curve for R-134a/VG 68 POE oil mixture.

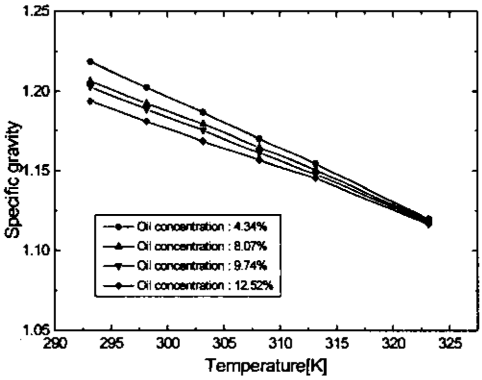


Fig. 6 Specific gravity for R-134a/VG68 POE oil mixture with respect to temperature.

4. Conclusion

A densimeter method is developed to predict the flowing oil concentration without extraction. This method is applied to the R-12/VG68 Naphthenic lubricant mixtures and the R-134a/VG68 POE lubricant mixtures. A correlation is derived as follows

$$C = a + b \times t + c \times t^2 + (d + e \times t + f \times t^2) \times SG$$

where t is temperature in ℃ and SG is the specificgravity. This equation is valid over the temperature 20-50℃ and concentration 0-20%.

With this correlation, a flowing oil concentration can be predicted by measuring the specific gravity, temperature of the flowing mixtures without any extraction. The correlation is quite accurate and extended to any other refrigerant/oil mixtures.

Acknowledgements

This study was supported by Korea Science and engineering Foundation under contact No. 971-1006-034-1 and the support is gratefully acknowledged

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