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Real-time measurement of mixing ratio of refrigerant/refrigeration oil mixture

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Abstract

The mixing of refrigeration oil with refrigerant in a refrigeration cycle has great influence on cycle performance. A sampling method is the most general way to measure the mixing ratio of refrigerant and refrigeration oil. Since the sampling method is time-consuming and reduces the amount of refrigerant and oil in the cycle, a real-time measurement is desirable. In this study, a refractive index measurement was applied to measure the mixing ratio of refrigerant/oil mixture. A laser displacement sensor was used to detect any change in optical path which results from changes of the refractive index of refrigerant/oil mixture. For the practical application of real-time measurement of the oil circulation ratio (OCR) in the refrigeration cycle, a correlation between the refractive index and the mixing ratio was developed. In addition, the changes of the refractive index in a range of a few percentages of the oil concentration and under subcooled conditions were measured. Finally, a transient measurement of the OCR in a practically operating refrigeration cycle was carried out successfully.

Keywords: Refrigeration system; Process; Measurement; Continuous flow; Binary mixture; Oil; Refrigerant

Mesures en temps réel de la composition des mélanges frigorigène/huile

Mots clés : Système frigorifique ; Procédé ; Mesure ; Écoulement continu ; Mélange binaire ; Huile ; Frigorigène

1. Introduction

Refrigeration oil is used in refrigerant compressors for lubrication, sealing and cooling. The mixing of refrigerant with oil has a great influence on the reliability of the compressor and on the cycle performance. A certain amount of refrigeration oil is discharged with refrigerant from the compressor and circulates with the refrigerant in the cycle. Since the oil concentration in the refrigerant circulating in the cycle, which is termed oil circulation ratio (OCR), affects pressure drop and the heat transfer characteristics of the heat exchangers, measurement of the OCR in the cycle is very important. The most general way to measure the mixing ratio of refrigerant/oil mixture is a sampling method [1]. High pressure liquid chromatography [2] is also used for

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Nomenclature

c	coefficient in Eq. (3)	β	volume fraction of refrigerant
k	coefficient in Eq. (4), Pa^{-1}	ρ	density, $kg\ m^{-3}$
m	mass, kg	*Subscript*	
n	refractive index	o	oil
T	temperature, °C	r	refrigerant
x	mass fraction of refrigerant		

precise measurement. However, these measurements are time-consuming and reduce the amount of refrigerant in the cycle and oil in the compressor. A real-time measurement of the mixing ratio of refrigerant/refrigeration oil mixture is therefore desirable.

Several sensors and principles for the real-time measurement of the mixing ratio of refrigerant/oil mixture have been proposed, and they detect viscosity [3,4], acoustic velocity [3,5–9], density [3,9–11], absorption of light [12–14] or dielectric constant [12,15,16], respectively. Refractive index [12,17,18] is one of the properties which changes according to the mixing ratio of refrigerant/oil mixture. The authors [19] developed a refractive index sensor and proposed to use the sensor for the measurement of concentration of refrigerant/oil mixture. It was shown in the previous paper that the difference of refractive index between the refrigerant and refrigeration oil is large enough to detect the mixing concentration of refrigerant/oil mixture and that the refractive index changes almost linearly according to the mixing ratio. The sensor developed in the previous study has enough accuracy to detect the concentration of refrigerant/oil mixture with an uncertainty of about 0.2%. In this study, data arrangement of the refractive index and development of a correlation curve between the refractive index and the concentration of the mixture are discussed. In order to apply this method to the measurement of OCR in practical refrigeration cycles, a change of the refractive index of around 1% of oil concentration needs to be measured precisely. Furthermore, since a liquid line in the refrigeration cycle is generally under subcooled conditions, the refractive index under the subcooled condition is also examined. Finally, an attempt to measure the transient change of the OCR is carried out in a practically operating refrigeration cycle.

2. Experiment

2.1. Refractive index sensor unit

There are three methods to detect the refractive index mainly. The first is to detect a change in light intensity through a sensor [20,21], the second is to detect a change of optical path [17,22,23] and the third is to detect the critical angle [12,18,24]. In the previous paper [19], the authors developed a refractive index sensor which detects the change of optical path using a laser displacement sensor. As a detailed description was provided in the previous paper, only a simple outline is explained in this paper. Fig. 1 shows the principle of the refractive index measurement. The test medium, namely a refrigerant/oil mixture, is filled in a pressurized chamber that has a glass window. The incident light enters the test medium through the glass window and reflects off the surface of a base plate. When the incident beam passes through the interface between the air and glass, and the interface between the glass and the test medium, refraction occurs due to the different refractive indices of air, glass and the test medium. The optical path changes according to the refractive index of the test medium as shown in Fig. 1. The laser displacement sensor, having a measuring range from 25 to 35 mm with a resolution of 1 μm, was used to detect the change of optical path. It has a semiconductor type laser with a wave length of 670 nm. A photograph of the refractive index sensor unit (measuring unit) incorporating the laser displacement sensor is shown in Fig. 2. Based on the measuring principle, the sensor is applicable to miscible combinations of refrigerant and oil.

2.2. Experimental setup

Fig. 3 shows the schematic diagram of an experimental setup. The measuring unit is connected to a mixture storage tank and the test chamber is filled with the refrigerant/oil mixture under a saturated condition. The test medium is circulated by a gear pump and the temperature is controlled by an electric heater. The concentration of refrigerant/oil mixture is checked using the sampling method. In the experiments, the concentration of refrigerant ranges from 0 to 100% and the temperature from 30 to 50 °C. Refrigerants

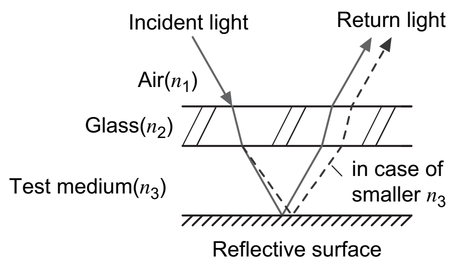

Fig. 1. Principle of measurement.