1992

A Novel Approach to Instrumentation and Application for OCR Measurement in Refrigeration System

A. Wada
Jasco Corporation

M. Nomura
Jasco Corporation

K. Tsuboi
Jasco Corporation

K. Kutsuna
Nippondenso Company

T. Nabeta
Nippondenso Company

A NOVEL APPROACH TO INSTRUMENTATION AND APPLICATION FOR OCR MEASUREMENT IN REFRIGERATION SYSTEM

A. Wada, M. Nomura, and K. Tsuboi
Jasco Corporation

K. Kutsuna and T. Nabeta
Nippondenso Co., Ltd.

ABSTRACT

A new instrument has been developed for an on-line real-time measurement of oil circulating rate in refrigeration system utilizing a ultra-violet light absorption behavior of oil. A dual optical path configuration was introduced to the flow cell of this instrument, and it allows the instrument to perform dual beam absorbance measurement which contributes to provide quite stable and precise result. This instrument was applied on OCR measurement on several refrigeration systems in transient state.

INTRODUCTION

The oil circulating rate(OCR) is a quite important characteristic which indicates performance and durability of the compressor, and it is strongly required to evaluate in developments, improvements, and reliability test of the refrigeration system. This measurement was carried out by a method specified by the ASHRAE STANDARD[1]. It is the so called weight measurement method, where the weight is taken from the remainder of the mixture after allowing for refrigerant evaporation from the liquid phase refrigerant/oil sample from the refrigerating cycle. This method has, however, several shortcoming of a lack in accuracy, impracticality in a measurement on the transient characteristics, a long time needed to manipulation, etc., and new method was desired to permit the on-line real time measurement.

J. J. Baustian et al. carried out researches with support of ASHRAE, and suggested several prospective methods[2,3]. These are the method utilizing, 1) density measured with the natural frequency of U-tube holding refrigerant/oil mixture, 2) viscosity of the mixture, 3) ultrasonic velocity, however, they have not come to the practical usage yet.

K. Kutsuna et al. succeeded in developing a new method utilizing ultraviolet(UV) light absorption of oil[4]. Based on this study, the authors have introduced a new oil concentration meter, NUVOM-1a, which is designed for on-line measurement of the OCR with its flow cell installed at the liquid line of the cycle. This paper describes as instrumentation and some application of this meter.

PRINCIPLE OF MEASUREMENT

A liquid refrigerant shows no ultra-violet(UV) light absorption over a wavelength region of down to 250 nm, while almost all the lubricating oil do in this region. This enables us to measure a concentration of the oil circulating with a liquid refrigerant by its absorption of UV light. Lambert-Beer's law allows a relation between light intensities before and after passing through a medium to be expressed as:

$$\log(I_o/I) = e \cdot c \cdot l \qquad (1)$$

Where: Io and I = Intensities of incident and transmitted light
c = Oil concentration
l = Length of the medium
e = Absorption coefficient

This equation indicates that the value of log(Io/I), which is called as absorbance, is directly proportional to the concentration, since "e" and "l" are both constants here. The proportional constant "e·l" is preliminarily determined from the absorbances observed on oil samples prepared for controlled concentration. The oil concentration is evaluated from the observed absorbance at refrigerating cycle by this equation. The oil circulating rate(OCR) is equivalent to this concentration at liquid phase line of a refrigerating cycle where the oil is uniformly mixed with the liquid refrigerant.

INSTRUMENTATION

The meter consists of three components, a main unit, a flow through cell and a printer/plotter unit. The main unit includes an optics, an electronics and a data processing unit.

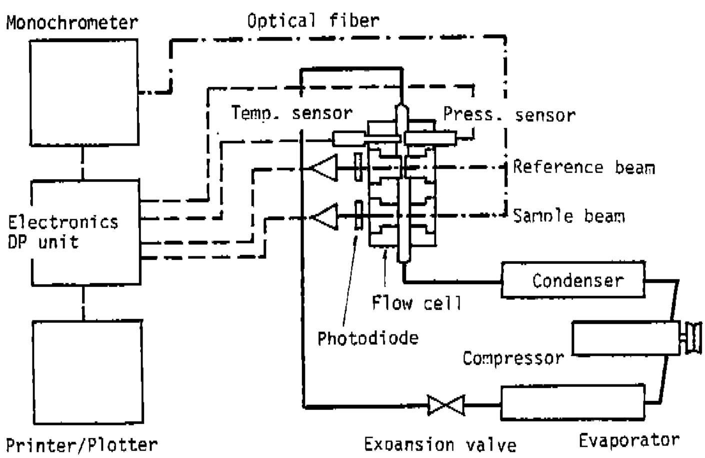


Fig. 1 Schematic diagram of the apparatus

The meter employs deuterium discharge lamp for the UV light source. The UV light from this lamp is focused on an entrance slit, dispersed with a grating, monochronized through a exit slit, and then it enters an optical fiber. The optical fiber is split into two optical paths at the flow cell. The flow cell is installed for measurement at a liquid phase line located between the condenser and the expansion valve of refrigerating cycle.

Figure 2 shows the diagram of this flow cell. These two optical paths possess a different path length from each other. The intensities of light beam passing through these paths are detected by the silicon photocells located just past the cell windows. This flow cell also includes sensors for temperature and pressure detection which permit the instrument to measure them in the same time and close to the detection of the light intensity. Data acquisition is carried out for every 25 msec. on light intensity, simultaneously with the temperature and pressure. The OCR is evaluated from this data at the data processing unit, displayed on the

LCD, and plotted out on the printer/plotter unit.

The flow cell possesses two optical paths with different path lengths. Lambert-Beer's law allows the intensities of transmitted lights I1 and I2 to be expressed by the following equations:

$$I1 = Io \cdot 10^{-ecl1}, \quad I2 = Io \cdot 10^{-ecl2} \qquad (2)$$

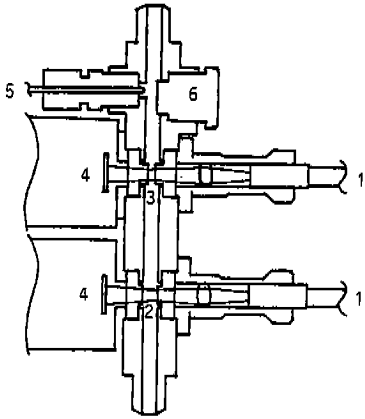
Where: l1 and l2 = Path lengths
e = Absorption coefficient of the oil
c = Concentration of oil
Io = Intensity of incident light

A ratio of these two equations gives:

$$I2/I1 = 10^{ec(l1-l2)} \qquad (3)$$

And a logarithm of this ratio gives an absorbance "Abs" proportionated to the optical path length difference of l1 - l2. These "Abs" values are in proportion to the oil concentration as shown in the equation(4).

$$Abs = e \cdot c \cdot (l1 - l2) = \log(I2/I1) \qquad (4)$$



1 Optical fiber
2 Optical path for sample
3 Optical path for reference
4 Silicon photocell
5 Tempereture sensor
6 Pressure sensor

Fig. 2 Flow cell details

Usually, the lamp embodies some fluctuation in its light energy, and cell windows may become dim after working a long time. They will effect the detected intensity I1 and I2. The former will force the intensity of incident light to be expressed as Io(t) instead of Io, and the later gives an extinction of q to the intensities of transmitted lights, respectively. These effects induce a modification on the equations (2) as:

$$I1 = q \cdot Io(t) \cdot 10^{-ecl1}, \quad I2 = q \cdot Io(t) \cdot 10^{-ecl2} \qquad (5)$$

However, taking a ratio of I1 and I2 can eliminate the effect, and give quite a same result as equation (3).

The volume of an amount of liquid refrigerant depends greatly on its temperature and pressure. When the volume changes, the absorbance changes even if the oil concentration is kept unchanged, because the absorbance is in proportion to the weight/volume concentration but not to weight/weight concentration. In this meter, the measurement of absorbance is accompanied with that of the temperature and pressure, and it permits the observed absorbance to be compensated against the change in temperature and the pressure.

The meter incorporates the compensation factors expressed as:

$$Abs(true) = Abs(obs)/[f(T) \cdot g(P)] \qquad (6)$$

Where Abs(obs) and Abs(true) = Observed and compensated absorbance
f(T) and g(P) = Compensation factors expressed in terms of temperature T and pressure P as the following quadratic equations:

$$f(T) = a0 + a1 \cdot T + a2 \cdot T^2$$

$$g(P) = b0 + b1 \cdot P + b2 \cdot P^2 \qquad (7)$$

Here, the coefficients from a0 to b2 are determined for each refrigerant by a least-squares calculation on the absorbance data of known concentration samples observed at several temperatures and pressures.

In the equation (3), "e" depends on an oil and a measuring wavelength, and it should be determined for each oil individually. The proportional relation between "Abs" and "c" usually includes some deviations caused by an effect from a spectral band width of measuring light and a limitation in the dynamic range of the detector, etc., even though the Lambert-Beer's law assures this proportional relation. This requires that a equation for calibration can also represent non-linear relations.

The meter employs a calibration curves expressed by the following quadratic equation to calculate OCR from the compensated absorbance:

$$\ln(c) = W \cdot \{\ln[Abs(true) - Z]\}^2 + X \cdot \{\ln[Abs(true) - Z]\} + Y \qquad (6)$$

Where W, X, Y, Z = coefficients

Here, we take a natural logarithm of both concentration and absorbance, and it permits the calibration curve to provide the OCR values with the same reliability over all its range.

CALIBRATION

Firstly, the calibration curves were calculated for CFC12 and HFC134a systems, which are a current refrigerant for car air conditioner and its alternative, respectively.

Oil samples were prepared with a mineral oil and a PAG(Polyalkylene Glycol) oil dissolved in CFC11, respectively, and then forwarded for measurement by an UV-Vis spectrophotometer. The observed absorption spectra were shown in figure 3, and they reveal that wavelength of 350 nm and 272 nm are proper for the measurement of mineral oil and PAG oil, respectively, under consideration on both linearity and sensitivity. Next, a mixture of oil and refrigerant were prepared in several controlled weight/weight concentration in pressure reservoirs for both mineral oil/CFC12 and PAG/HFC134a systems.

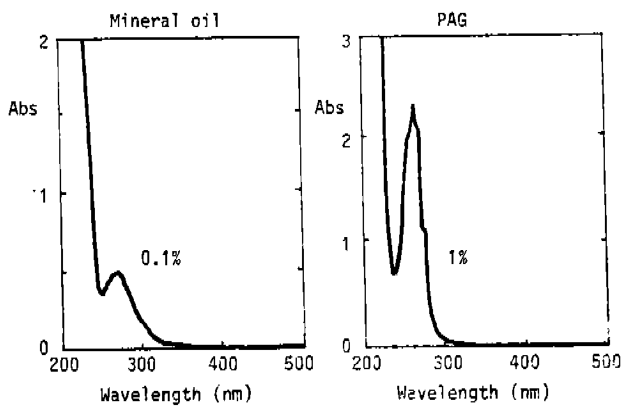


Fig. 3 Absorption spectra of oils

They were delivered into the flow through cell kept it in liquid phase using a HPLC pump with some modifications, and the absorbances were measured. Measurement was carried out under several controlled temperatures and pressures.

The compensation factors and the coefficients of calibration curve were calculated from the data sets of absorbance, concentration, temperature and pressure, and memorized in the instrument and utilized for actual refrigerating cycle. Figures 4 to 6 show these results.

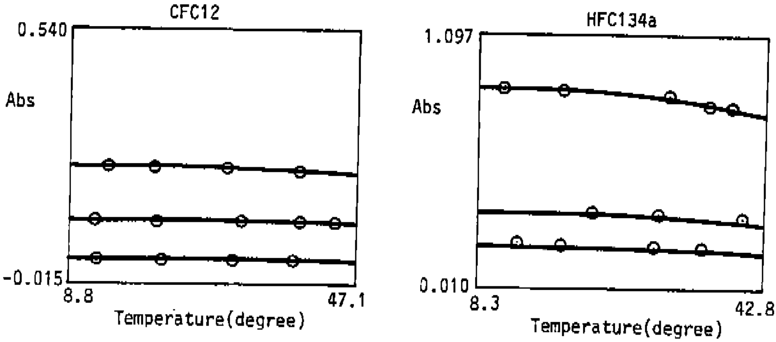


Fig. 4 Temperature dependency of absorbance

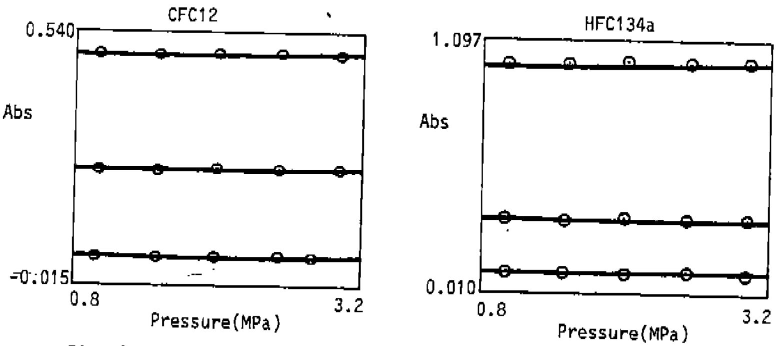


Fig. 5 Pressure dependency of absorbance

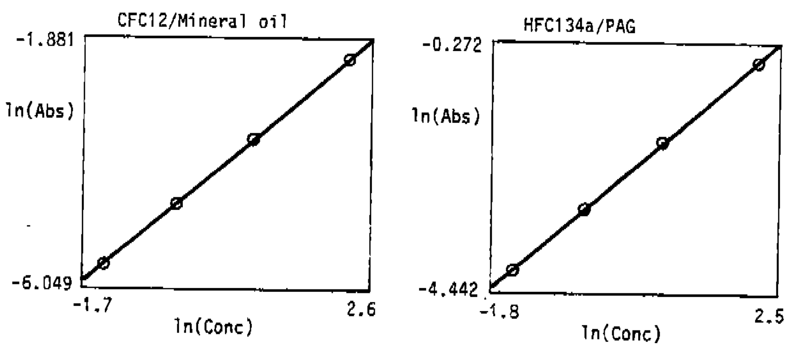


Fig. 6 Calibration curve

APPLICATION

The meter was applied on the measurement in a refrigeration cycle of automotive air conditioner with CFC12/mineral oil. In this data, oil concentration is expressed in scale being relative to the concentration at compressor speed of 1800 rpm. The oil concentration fluctuates when the compressor speed changes rapidly, but it will stabilize in approximately 2 to 3 minutes. Minor fluctuation are also observed during compressor speeds of 600 rpm and 1800 rpm, and this is considered to result from changes in the refrigerant flow rate due to the hunting phenomenon in the expansion valve.

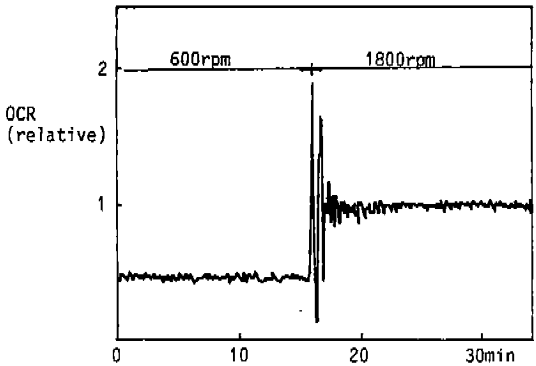


Fig. 7 OCR in automotive air conditioner

Figure 8 shows the behavior of an OCR observation for a unit with insufficient refrigerant in comparison with a unit operated under normal condition. Under former condition, it appears large scale fluctuation in OCR than normal condition. It also appears spike noise due to the existence of bubbles within refrigerant flow. When the unit goes into an extremely insufficient refrigerant condition, the intermittent flow appears in the sight glass, and the meter shows "over scale phenomenon".

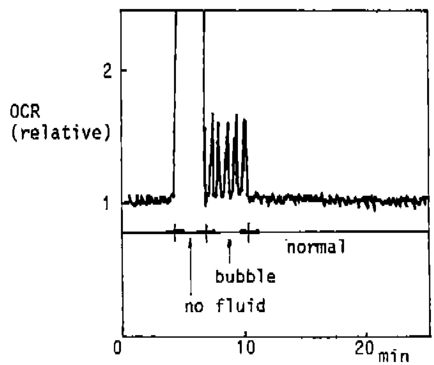


Fig. 8 OCR observation for a unit with insufficient refrigerant

The meter was also applied to observe the behavior of an OCR of room air conditioner in a transient state. Figure 9 shows this result. It took about 3 minutes to condense the refrigerant into liquid from starting up the refrigeration system. During this period, the refrigerant in gaseous phase gave off bubbles and prevented the measurement system from providing a correct OCR. A large amount of oil was observed circulating momentarily just after the refrigerant was fully condensed, while it soon decreased, and the refrigeration system became stable in about 5 minutes.

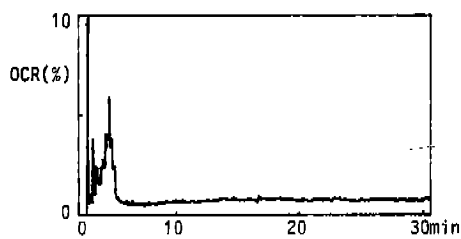


Fig. 9 OCR in room air conditioner

CONCLUSION

We have developed an instrument to measure the concentration of oil circulating with the refrigerant in a refrigeration cycle by utilizing the phenomena that the oil absorbs UV light. It comprises a flow cell which is installed in the liquid phase line of a refrigerating cycle, and monochronized UV light is introduced through an optical fiber. through measurement of light absorption by the oil, its concentration can be evaluated. It incorporates facilities to compensate for the change in the volume of the liquid refrigerant against the changes in temperature and pressure.

This meter provides a marked improvement in the accuracy and precision in oil concentration measurement over a conventional capture method. In addition, it permits us to observe the OCR under not only stationary but also transient state.

It was thought that fleons are quite safe and harmless to man and animals, and they have been used in large quantities as a refrigerant and a washing solvent. However, it was found that the fleons are harmful to the ozone layer, and the restrictions on their production or consumption were introduced by the Treaty of Vienna(1985), by the Protocol of Montreal(1987), and the Conference in London(1990). It may be impossible for us human race to part with the comfortable environment created by the climate control, and great efforts are exerted to develop alternatives to current refrigerants and refrigeration systems for adoption as alternatives. We expect the meter, NUVOM-1a, will promote these developments and contribute to the conservation of nature and a good environment.

REFERENCES

1) ASHRAE, "Standard Measurement Guide, Measurement of Proportion of Oil in Liquid Refrigerants", 1975
2) J.J.Baustian et al., Real Time Determination of Concentration of Oil Dissolved Refrigerant Flow Stream without Sample Removal. Final Report, College of Engineering Iowa State Univ., 1987
3) D.E.Finchbaugh et al., Method of and System for Determining Refrigerant/ Lubricant Ratio within Enclosed Flow Apparatus. U.S.Patent 4,916,915, 1990
4) K.Kutsuna et al., Real Time Oil Concentration Measurement in Automotive Air Conditioning by Ultraviolet Light Absorption, SAE paper 910222, 1991