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A CORRELATION TECHNIQUE FOR PREDICTING THE VISCOSITY OF FREON-12 AND FREON-22 VAPOURS

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The paper presents correlations which fit the experimental viscosity data over a wide temperature and pressure range of Makita and a method for predicting the viscosity at any temperature and pressure of Freon-12 and Freon-22 vapours.

Introduction

The correlation of experimental viscosity data of Freon-12 (CCl_2F_2) vapour and Freon-22 ($CHClF_2$) vapour at a nominal pressure of one atmosphere has been presented by a number of investigators[1)~3)]. The data have usually been represented by an equation of the form

$$\left.\begin{aligned} &\mu = E\sqrt{T} - F \\ \text{or}\qquad &\mu = E'\sqrt{T}e^{-\frac{F'}{T}}, \end{aligned}\right\} \quad (1)$$

where E, F and E', F' are pressure dependent coefficients. However, there is need for predicting the viscosity at high pressures.

It may be realized from the experimental investigations of Makita[1)], Benning and Markwood[2)] and Kamien and Witzell[3)] that viscosity data at high pressures are scarce and large gaps exist in the range of pressures investigated. It may be noted that Makita's[1)] experimental data for Freon-12 and Freon-22 vapours cover a wider range of pressures at constant temperatures than the data of Benning and Markwood[2)] or Kamien and Witzell[3)].

Theory

The representation of experimental viscosity measurements by a viscosity-density relation greatly simplifies prediction of viscosity at the temperature and pressure conditions of practical interest. Since there is no generally acceptable method for the representation of experimental viscosity data of Freon vapour over a wide range of temperatures and pressures, the "excess viscosity" concept described by Iwasaki and Kestin[4)] may be extended to Freon-12 and Freon-22 vapours.

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1) T. Makita, *This Journal*, **24**, 74 (1954)
2) A. F. Benning and W. H. Markwood, Jackson Laboratories, E. I. duPont de Nemours and Company, B-10, Reprinted from the April, 1939 issue of Ref. Eng.
3) C. Z. Kamien and O. W. Witzell, *ASHRAE TRANSACTIONS*, **65**, 663 (1959)

The excess viscosity defined as the difference between the viscosity, μ, at a particular temperature and density and the viscosity, μ_0, at the same temperature but at zero-density is a unique function of density of the form

$$\mu-\mu_0=B\rho+C\rho^2, \qquad (2)$$

where $\mu=\mu(\rho, T)$

and $\mu_0=\mu(0, T)$.

The coefficients, B and C, which depend on the nature of the vapour are only mildly varying functions of temperature[5].

Calculations and Correlations

The first step in the computational technique is to determine the zero-density values of viscosity from the experimental data on viscosity presented by Makita[1] at temperatures 25, 50, 100, 150 and 200°C covering a wide range of pressures at each temperature. The viscosity at any temperature is plotted *versus* density and the data is correlated by the least square method using the expression

$$\mu=\mu_0+b\rho+c\rho^2. \qquad (3)$$

Table 1 Zero-density viscosity, μ_0, coefficients, b, c and reliability information for Freon-12 and Freon-22 vapours based on Makita's[1] experimental data

Temp. °C	Coefficient $\mu_0\times10^2$ Poise	Coefficient $b\times10^2$ Poise/(gm/cm³)	Coefficient $c\times10^2$ Poise/(gm/cm³)²	Standard deviation $\sigma\times10^6$ Poise	Greatest error $\times10^6$ Poise	Per cent greatest error
			FREON-12			
25	0.012467	0.0027	1.5921	0.0623	0.0973	0.074
50	0.012938	0.0393	0.1034	0.0070	0.0094	0.007
100	0.014220	0.0251	0.2156	0.7938	1.1860	0.801
150	0.015655	0.0250	0.1989	0.8653	1.2430	0.748
200	0.017197	0.0166	0.2506	0.3004	0.4898	0.278
			FREON-22			
25	0.012651	0.0677	0.6494	0.4807	0.6980	0.515
50	0.013472	0.0577	−0.0223	0.2937	0.4465	0.308
100	0.015372	0.0184	0.4710	0.2718	0.4446	0.279
150	0.016931	0.0178	0.3765	0.2939	0.4458	0.247
200	0.018588	0.0128	0.4917	0.1720	0.2892	0.149

The zero-density values of viscosity, μ_0, so obtained, as well as the coefficients, b and c, are presented in Table 1. The standard deviation, σ, defined in standard texts on statistical methods[6] is calculated

4) H. Iwasaki and J. Kestin, *Physica*, **29**, 1345 (1963)
5) S. K. Kim and J. Ross, *J. Chem. Phys.*, **42**, 263 (1965)
6) C. C. Peters and W. R. Van Voorhis, "Statistical Procedures and their Mathematical Bases", McGraw-Hill Book Company, Inc., New York and London (1940)

by the following equation

$$\sigma=\left[\frac{1}{N}\sum_{i=1}^{N}(\mu_i-\bar{\mu}_i)^2\right]^{1/2}. \tag{4}$$

The "greatest error" signifies the maximum difference between the experimental and correlated value of viscosity. The per cent greatest error is calculated on the basis of the experimental viscosity value.

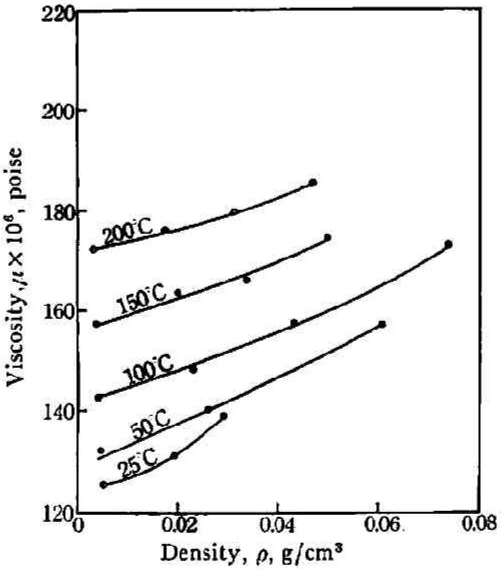

Fig. 1 Variation of viscosity of Freon-12 vapour with density
⊙ : experimental data of Makita[1)]
— : present correlation

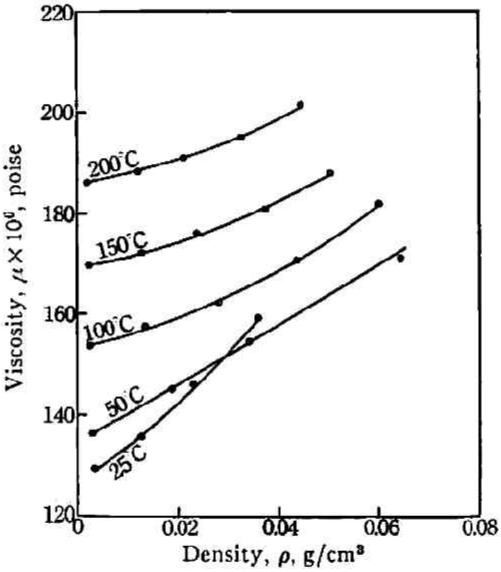

Fig. 2 Variation of viscosity of Freon-22 vapour with density
⊙ : experimental data of Makita[1)]
— : present correlation

Figs. 1 and 2 respectively show the variation of viscosity of Freon-12 and Freon-22 vapours with density.

Using the zero-density values of viscosity, μ_0, given in Table 1 and the experimental viscosity values of Makita, the excess viscosity, $(\mu-\mu_0)$, is plotted *versus* density at any temperature and pressure. For Freon-12 and Freon-22 vapours, it is found that the excess viscosity is a unique function of density. The plot of excess viscosity *versus* density is correlated using equation (2) by the least

Table 2 Coefficients, B, C and reliability information for Freon-12 and Freon-22 vapours based on Makita's[1)] experimental data

Refrigerant	Coefficient	Coefficient	Standard deviation	Probable error
	$B\times 10^2$ Poise/(gm/cm³)	$C\times 10^2$ Poise/(gm/cm³)²	$\sigma\times 10^6$ Poise	P. E. $\times 10^6$ Poise
Freon-12	0.0252	0.2358	2.2240	1.5090
Freon-22	0.0218	0.4376	2.8080	1.8940

square method. The values of B and C, so obtained, are given in Table 2 with the standard deviation, σ, and the probable error, P. E., calculated by the equation

$$\text{P. E.}=0.6745\sigma. \tag{5}$$

In Fig. 3, the excess viscosity of Freon-12 and Freon-22 vapours is plotted *versus* density.

Zero-density viscosity of Freon-12 and Freon-22 vapours

It is important to realize that the determination of viscosity at any temperature and density requires information regarding the temperature dependence of zero-density viscosity. The temperature dependence of zero-density viscosity may be represented by an equation of the form

$$\mu_0=B_0\sqrt{T}-C_0, \tag{6}$$

where the constants, B_0 and C_0, depend on the nature of the vapour.

The constants, B_0 and C_0, for Freon-12 and Freon-22 vapours are evaluated by matching equation (6) to the zero-density viscosity-temperature data presented in Table 1 using the method of least squares. The values of B_0 and C_0, so obtained, are given in Table 3. The standard deviation is calculated by equation (4) and the probable error by equation (5).

Table 3. Constants, B_0, C_0 and reliability information for Freon-12 and Freon-22 vapours based on zero-density viscosity data given in Table 1

Refrigerant	Constant $B_0\times10^6$ Poise/°K$^{\frac{1}{2}}$	Constant $C_0\times10^6$ Poise	Standard deviation $\sigma\times10^6$ Poise	Probable error P. E.$\times10^6$ Poise
Freon-12	10.57	59.77	1.6643	1.1226
Freon-22	13.25	102.65	0.5334	0.3598

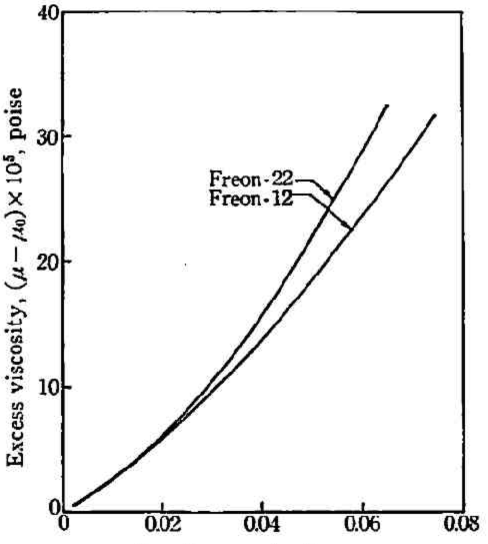

Fig. 3 Variation of excess viscosity of Freon-12 and Freon-22 vapours with density

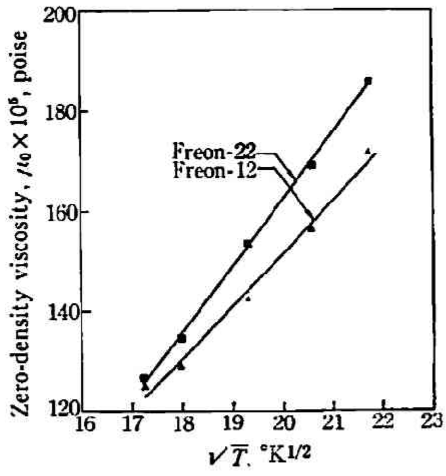

Fig. 4 Zero-density viscosity of Freon-12 and Freon-22 vapours

In Fig. 4 is presented a plot of μ_0 *vs.* $\sqrt{T}$ for Freon-12 and Freon-22 vapours.

Results and Discussions

It is evident from Tables 1. 2 and 3 that equations (2), (3) and (6) provide the best fit to the experimental data of Makita[1] and the zero-density viscosity.

A plot of viscosity *versus* density of Freon-12 and Freon-22 vapours represented respectively in Figs. 1 and 2 signifies that the viscosity isotherms are parallel curves. The significance of this is that it greatly simplifies the measurement, as viscosity over wide range of temperatures and pressures may be predicted from the viscosity data at atmospheric pressure for wide range of temperatures and from the viscosity data at atmospheric temperature for wide range of pressures.

It can be seen in Fig. 3 that the excess viscosity-density data of Freon-12 and Freon-22 vapours are represented by a single curve for each vapour. The ability to predict excess viscosity from a single curve greatly simplifies the evaluation of viscosity from a knowledge of the zero-density viscosity and density.

Fig. 4 indicates a linear relationship between μ_0 and $\sqrt{T}$. The zero-density viscosity, μ_0, at any temperature of Freon-12 and Freon-22 vapours may, therefore, be satisfactorily determined by equation (6).

Conclusion

The present correlations facilitate design of engineering systems as viscosity information on Freon-12 and Freon-22 vapours may, readily, be obtained by equations (2) and (6) from a knowledge of density, ρ, coefficients, B, C, and constants, B_0, C_0. The density of Freon-12 vapour or Freon-22 vapour may be obtained from tables given in standard texts[7]. The coefficients, B, C, and constants, B_0, C_0, are to be taken from Tables 2 and 3 respectively.

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7) N. Sharpe, "Refrigerating Principles and Practices", McGraw-Hill Book Company, Inc., New York and London (1949)