VISCOSITY PREDICTION OF REFRIGERANTS UNDER SUBCRITICAL/SUPERCRITICAL CONDITIONS

by

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Viscosity is an important thermophysical property of fluids. Viscosities of refrigerants were predicted based on friction theory combined with the Lemmon and Span short reference equation of state. This model is valid for the temperature up to 397 K and pressure up to 40 MPa, which cover both the subcritical and supercritical regions. Experimental data were further used to validate the model. Under all test conditions, the accuracy is better than 6%, which is acceptable in most practical applications.

Key words: *refrigerants, viscosity, friction theory*

Introduction

As one of the most important transport properties, viscosity is indispensable for the equipment design and simulation in refrigeration areas. However, the experiment viscosity values of new refrigerants, such as R141b (1,1-dichloro-1-fluoroethane), R142b (1-chloro-1,2-difluoroethane), and R245fa (1,1,1,3,3-pentafluoropropane), which can be used in refrigeration systems, heat pumps, and other applications are scarce. Therefore, reliable viscosity calculation and prediction models for these refrigerants are essential.

In recent years, Quinones-Cisneros *et al.* [1, 2] proposed a friction theory viscosity model, which can be applied to the entire phase range, and can be further used to calculate the viscosity of alcohols and *n*-alkanes. The principle and calculation process were relatively simple, and the accuracy was very good. In this paper, the study of the friction theory combined with the Lemmon and Span short reference equation of state was proposed and further applied to the prediction of viscosities for R141b, R142b, and R245fa (fig. 1).

The friction theory

In general terms, the generalized friction theory model can be written as [1]:

$$\eta = \eta_0 + \eta_i + \eta_f = \frac{0.021357(MT)^{1/2}}{\sigma \xi_\eta^*(T^*)} + \rho B_\eta \eta_0 + \eta_f \tag{1}$$

$$\ln x_h^*(T^*) = \sum_0^4 x_i (\ln T^*) \tag{2}$$

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$$\frac{B_\eta}{N_A\sigma^3} = \sum_{i=0}^{6} \beta_i T^{*-0.25i} + \beta_7 T^{*-0.25} + \beta_8 T^{*-5.5} \tag{3}$$

where η_0 [Pa·s] is the viscosity at the zero-density limit [3], η_i [Pa·s] – the initial density dependency, and η_f [Pa·s] – the residual friction viscosity term; M – the molar mass, σ – the length of the size parameter, T^* – the reduced temperature, the coefficient, x_i can be obtained from fitting the dilute gas viscosity, and the results of the coefficients are presented in tab. 1; $T^* = k_B T/\varepsilon$, N_A [mol^{-1}] is Avogadro's Number , σ – the length scaling parameter, ε/k_B – the energy scaling parameter; β_i – the second viscosity virial coefficient obtained from the Lennard-Jones fluid theoretically [4].

Table 1. Dilute gas viscosity constants

	x_0	x_1	x_2	x_3	x_4	AAD%
R141b	1.274293	–0.65497	0.268848	0.074635	–0.02519	$8.280\cdot10^{-4}$
R142b	1.274239	–0.65601	0.253169	0.058121	–0.09047	$1.226\cdot10^{-3}$
R245fa	1.274217	–0.65637	0.259078	0.037966	–0.08469	$4.975\cdot10^{-3}$

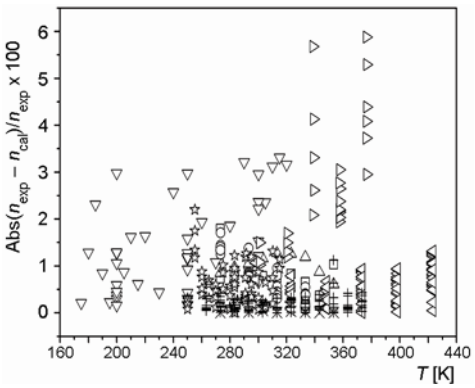

Figure 1. Deviations of the primary data from the friction theory of R141b, R142B and R245fa as a function of temperature □R141b [6], ○R141b [7], ΔR141b [8], ▽R141b [9], ·R142b [6], R142b[10], ▷R245fa [11], ☆R245fa [12], ＋R245fa [13]

The residual friction term can be written as:

$$\eta_f = \kappa_a p_a + \kappa_r \Delta p_r + \kappa_{aa} p_a^2 + \kappa_{rr} p_r^2 \tag{4}$$

where κ_a, κ_r, κ_{aa}, and κ_{rr} are the friction coefficients, ρ [kgm^{-3}] – the density, p_a [Pa] – the attractive pressure term, and p_r [Pa] – the repulsive pressure term. To calculate p_a and p_r, the Lemmon *et al.* [5] short reference equation of state is selected. In the friction theory, this can be achieved by using the internal pressure (π_T) concept according to the equation:

$$P = P_r + P_a = P_{id} + \Delta P_r - p_T \tag{5}$$

where P_{id} is the ideal part, and ΔP_r – the residual part. The temperature-dependent coefficients can be written:

$$\kappa_a = (a_0 + a_1\psi_1 + a_2\psi_2)\frac{T_c}{T} \tag{6}$$

$$\kappa_r = (b_0 + b_1\psi_1 + b_2\psi_2)\frac{T_c}{T} \tag{7}$$

$$\kappa_{aa} = (A_0 + A_1\varphi_1 + A_2\varphi_2)\left(\frac{T_c}{T}\right)^3 \tag{8}$$

$$\kappa_{rr} = (B_0 + B_1\varphi_1 + B_2\varphi_2)\left(\frac{T_c}{T}\right)^3 \tag{9}$$

where, $\varphi_i = \exp[(T_c - T)^i]$, a_i , b_i , A_i , and B_i are the parameters of the viscosity model, and T_c [K] is the critical temperature.

Results and discussions

In this paper, the Lemmon *et al.* [5] short reference equation of state is used to correlate the studied refrigerants, and the results are given in tab. 2. To evaluate the performance of the friction theory viscosity model, the average deviation (AAD) and the maximum deviation (MAD) were calculated. The AAD and MAD are 1.089% and 3.499% for R141b, 0.547%, and 1.473% for R142b, and 0.6493%, and 5.598% for R245fa. It was found that when the temperature and pressure are near the critical point of the pure mass composition, the calculation error for the viscosity is higher because the thermal physical properties near the critical point change dramatically.

Conclusions

In this paper, viscosity for R141b, R142b, and R245fa were predicted by combining friction theory with the Lemmon *et al.* [5] short reference equation of state. The results show that in the fitting range the average absolute deviations between the reference data and the calculated values are less than 6%, which is accurate enough to be applied into engineering calculation.

Table 2. Parameters of the friction theory model

	a_0	a_1	a_2	b_0	b_1	b_2
R141b	$8.661\cdot10^{-12}$	$-3.764\cdot10^{-12}$	$-2.297\cdot10^{-13}$	$1.562\cdot10^{-11}$	$-6.596\cdot10^{-12}$	$-2.439\cdot10^{-13}$
R142b	$3.220\cdot10^{-11}$	$-1.463\cdot10^{-11}$	$9.665\cdot10^{-13}$	$4.998\cdot10^{-11}$	$-1.927\cdot10^{-11}$	$-1.281\cdot10^{-12}$
R245fa	$-7.565\cdot10^{-13}$	$1.325\cdot10^{-12}$	$-2.063\cdot10^{-12}$	$2.320\cdot10^{-12}$	$1.019\cdot10^{-12}$	$-2.958\cdot10^{-12}$
	A_0	A_1	A_2	B_0	B_1	B_2
R141b	$3.107\cdot10^{-21}$	$-1.159\cdot10^{-21}$	$-3.439\cdot10^{-23}$	$4.332\cdot10^{-21}$	$1.461\cdot10^{-21}$	$3.556\cdot10^{-23}$
R142b	$-1.447\cdot10^{-18}$	$1.025\cdot10^{-18}$	$-4.457\cdot10^{-19}$	$1.437\cdot10^{-18}$	$-1.017\cdot10^{-18}$	$4.466\cdot10^{-19}$
R245fa	$3.842\cdot10^{-21}$	$-9.957\cdot10^{-22}$	$-3.087\cdot10^{-22}$	$-2.724\cdot10^{-21}$	$2.184\cdot10^{-21}$	$6.629\cdot10^{-22}$

Acknowledgments

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