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Estimating the viscosity of pure refrigerants and their mixtures by free-volume theory

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ABSTRACT

In this work, the free-volume theory (FVT) was extended to modeling the viscosities of 24 hydrofluorocarbon refrigerants, and applied to predict the viscosities for the mixtures of hydrofluorocarbon refrigerants. It is the first time to apply the FVT to the viscosities of ternary mixtures of hydrofluorocarbon refrigerants. Hydrofluoro-olefins (HFOs) are a new class of refrigerants, which are identified as promising refrigerants because they have low global warming potential, were studied in this paper. For the viscosity of pure refrigerants, the average absolute relative deviations between the FVT calculation and experiment are less than 1.5%. When calculating the viscosities of the mixtures of hydrofluorocarbon refrigerants, three mixing rules without more parameters were tested and compared, the average absolute relative deviations between the FVT coupled with the best mixing rule and experiment are less than 6.5%.

Estimation de la viscosité de frigorigènes purs et de leurs mélanges à travers la théorie du volume libre

Mots clés : Viscosité ; Frigorigéne ; Mélanges ; Théorie du volume libre ; Calcul

1. Introduction

Thermophysical properties of refrigerants are necessary in the design of refrigeration equipments such as air conditioning, refrigerator, refrigeration storage and small refrigeration compressor. As one of the most important transport properties, viscosity has a direct and important effect on heat transfer coefficient, which is especially important for heat exchanger. Viscosity data are also essential for calculating pressure drops in the design of pump and piping (Viswanath et al., 2007). A large number of experimental studies have been carried out for viscosities of fluids, but limited in a special range of pressure and temperature. Therefore, there is a need to build a reliable and accurate model for viscosities of refrigerants. Many viscosity models have been proposed, such

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Nomenclature

η	Viscosity (mPa·s)
η_0	Dilute gas viscosity term (mPa·s)
η_r	Dense-state correction term for viscosity (mPa·s)
ρ	Density (kg·m^{-3})
T	Temperature (K)
p	Pressure (Pa)
M	Molecular weight (kg·mol^{-1})
R	Ideal gas constant (J·mol^{-1}·K^{-1})
l	Characteristic molecular length (m)
α	Barrier energy (J·m^3·mol^{-1}·kg^{-1})
B	Characteristic of the free-volume overlap
U	Uncertainty

Subscripts

0	Dilute gas term
r	Dense-state correction term
i	Component i
mix	Mixtures
AAD	Average absolute relative deviation
MD	Maximum deviation
lit	Value from literature
cal	Calculated value

Abbreviations

R11	Trichlorofluoromethane
R12	Dichlorodifluoromethane
R22	Chlorodifluoromethane
R32	Difluoromethane
R13	Chlorotrifluoromethane
R23	Trifluoromethane
R125	Pentafluoroethane
R134a	1,1,1,2-Tetrafluoroethane
R152a	1,1-Difluoroethane
R141b	1,1-Dichloro-1-fluoroethane
R142b	1-Chloro-1,1-difluoroethane
R143a	1,1,1-Trifluoroethane
R123	2,2-Dichloro-1,1,1-trifluoroethane
R124	1-Chloro-1,2,2,2-tetrafluoroethane
R113	1,1,2-Trichloro-1,2,2-trifluoroethane
R114	1,2-Dichloro-1,1,2,2-tetrafluoroethane
R227ea	1,1,1,2,3,3,3-Heptafluoropropane
R236ea	1,1,1,2,3,3-Hexafluoropropane
R236fa	1,1,1,3,3,3-Hexafluoropropane
R245fa	1,1,1,3,3-Pentafluoropropane
R245ca	1,1,2,2,3-Pentafluoropropane
R1234yf	2,3,3,3-Tetrafluoroprop-1-ene
R1234ze	Trans-1, 3,3,3-tetrafluoropropene
R13B1	Bromitrifluoromethane

as the corresponding states method (Klein et al., 1997), the hard sphere theory (Assael et al., 1995a), the modified Chapman–Enskog method (Sheng et al., 1989) and the friction theory (Quinones-Cisneros et al., 2000).

Recently, the free-volume theory (FVT) (Allal et al., 2001a, 2001b) has been proposed and is suitable for viscosities of fluids both in the liquid phase and the gas phase, which can directly utilize experimental density data to estimate the viscosity and just has three parameters. This model has been applied in alkanes, alkylbenzenes, cycloalkanes, alcohols, carbon dioxide and water successfully. Although the FVT has been applied for modeling the viscosity for hydrofluorocarbon refrigerants and their mixtures, the amount of contributions is still limited and nobody applied the FVT to the viscosities of ternary mixtures of refrigerants. Allal et al. (2001a) just used the FVT to model the viscosity of R152a, R11 and R12. Llovell et al. (2013) applied the FVT coupled with the soft-SAFT equation of state to reproduce the viscosities of R41, R23, R32, R125, R134a, R143a, R152a, R227ea, R236ea, R236fa, R245ca, R245fa and binary mixtures of R125 + R134a, R32 + R134a. In this method, the density, which is required for the calculation of the viscosity with FVT, is obtained from soft-SAFT equation of state. For the mixtures, they applied a linear Lorentz type mixing rule for the three parameters in the dense-state correction term, but the applicability of the mixing rule in predicting the viscosity for ternary mixtures of hydrofluorocarbon refrigerants needs to be validated.

In this work, we used the FVT to describe the viscosities of pure hydrofluorocarbon refrigerants and their mixtures. The number of the pure refrigerants is far beyond the work

Table 1 – The fitting result of Eq. (2) for pure refrigerants.

Compound	d_1 ×100	d_2 ×1000	AAD/%	MD/%	Compound	d_1 ×100	d_2 ×1000	AAD/%	MD/%
R11	−0.2556	0.4661	0.0	0.0	R123	−0.1474	0.3826	0.1	0.1
R12	−0.2510	0.4984	0.0	0.0	R124	−0.2392	0.4825	0.0	0.1
R22	−0.2525	0.5184	0.0	0.0	R113	−0.2590	0.4535	0.0	0.0
R32	−0.2529	0.5185	0.0	0.0	R114	−0.2571	0.4816	0.0	0.0
R13	−0.2366	0.5423	0.1	0.1	R227ea	−0.2371	0.4806	0.0	0.0
R23	−0.2546	0.5712	0.0	0.0	R236ea	−0.2513	0.4784	0.0	0.0
R125	−0.2299	0.5024	0.1	0.1	R236fa	−0.2444	0.4734	0.0	0.0
R134a	−0.1982	0.4502	0.1	0.2	R245fa	−0.2449	0.4591	0.0	0.0
R152a	−0.2322	0.4424	0.1	0.2	R245ca	−0.2501	0.4597	0.0	0.0
R141b	−0.2315	0.4208	0.0	0.0	R1234yf	−0.2668	0.5256	0.0	0.0
R142b	−0.1929	0.4142	0.3	0.5	R1234ze	−0.2660	0.5248	0.0	0.0
R143a	−0.2114	0.4470	0.0	0.1	R13B1	−0.2708	0.5980	0.0	0.1