ON THE VISCOSITY OF NATURAL GAS

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Abstract
The existing measurements of the viscosity of gaseous systems can be extended if use is made of statistical mechanics. In this work, we confine ourselves to the measurements of the viscosity of multicomponent mixtures of low-density gases. The method is applied to one sample of natural gas.

Introduction

Knowledge of viscosity is needed for the calculation of pressure losses in pipelines, efficiency of fluid-flow machines, and the calibration of flowmeters. An extended law of corresponding states, developed by Kestin et al. [1], together with their empirically optimized collision integrals has been tested by Boushehri et al. [2] for quaternary mixtures of polyatomic gases. The method is applied to one sample of natural gas chosen from Shiraz pipeline, where no previous experimental data was available. Apart from their intrinsic importance, such experimental results can provide a test of the kinetic-theory expressions and of the adequency of the extended law of corresponding states. The expression

for the viscosity of a ν-component mixture of gases is given by [3]:

where

$$\eta_{mix} = - \frac{\begin{vmatrix} H_{11} & H_{12}...H_{1\nu} & x_1 \\ H_{21} & H_{22}...H_{2\nu} & x_2 \\ \vdots & \vdots & \vdots \\ H_{\nu 1} & H_{2}...H_{\nu\nu} & x_\nu \\ x_1 & x_2...x_\nu & 0 \end{vmatrix}}{\begin{vmatrix} H_{11} & H_{12}...H_{1\nu} \\ H_{21} & H_{22}...H_{2\nu} \\ \vdots & \vdots \\ H_{\nu 1} & H_{\nu 2}...H_{\nu\nu} \end{vmatrix}} \qquad (1)$$

$$H_{ii} = \frac{x_i^2}{\eta_i} + \sum_{\substack{k=1 \\ k \neq i}}^{\nu} \frac{2x_i x_k}{\eta_{ik}} \frac{m_i m_k}{(m_i + m_k)^2} [\frac{5}{3A_{ik}^*} + \frac{m_k}{m_i}], \qquad (1\text{-a})$$

$$H_{ij}(i \neq j) = -\frac{2x_i x_j}{\eta_{ij}} \frac{m_i m_j}{(m_i + m_j)^2} [\frac{5}{3A_{ij}^*} - 1], \qquad (1\text{-b})$$

$$\eta_{ij} = \frac{5}{16} [[\frac{2m_i m_j}{m_i + m_j}] \frac{kT}{\pi}]^{1/2} \frac{1}{\sigma_{ij}^2 \Omega_{ij}^{(2,2)*}(T_{ij}^*)}, \qquad (1\text{-c})$$

$$\eta_i = \frac{5}{16} [\frac{m_i kT}{\pi}]^{1/2} \frac{f_\eta}{\sigma_{ii}^2 \Omega^{(2,2)*}}, \qquad (1\text{-d})$$

In these equations, x_i stands for the mole-fraction of component i; m_i is the mass of molecule i; and σ_{ij} represents a characteristic scaling parameter. The collision integral $\Omega_{ij}^{(2,2)*}$ is a function of the reduced temperature, $T^* = kT/\varepsilon_{ij}$, with ε_{ij} denoting an energy scaling factor. The pair σ_{ij} and ε_{ij} are taken from Ref. 1. The equations for the functionals are given as [1]:

$$\Omega_{22} = \Omega^{(2,2)*}/f_\eta = \exp [0.45667 - 0.53955 (\ln T^*)$$

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$+0.18265 \, (\ln T^*)^2 - 0.03629 \, (\ln T^*)^2$

$+0.00241 \, (\ln T^*)^4], \quad 1 < T^* < 90,$ (2-a)

$\Omega^{(1,1)*} = \exp [0.347 - 0.444 \, (\ln T^*)$

$+0.093 \, (\ln T^*)^2 - 0.010 \, (\ln T^*)^3],$

$\quad 0.5 < T^* < 25,$ (2-b)

where f_η is a higher-order correction to the viscosity, and

$A^* = \Omega^{(2,2)*} / \Omega^{(1,1)*} = \Omega_{22} / \Omega^{(1,1)*}.$ (2-c)

Expression (1) is only a first approximation, but accurate results can be obtained if the single-component viscosities η_i are calculated according to Eq. (1-d).

Experimental Section

The measurements reported here were made with a constant-volume gas viscometer similar to that of McCoubrey and Singh [4]. The viscometer consisted of an approximately 1-liter bulb connected on one side to a capillary (Pyrex thick-wall tubing of 28.6 cm length and 0.039 cm i. d.), and on the other to a mercury manometer. The exit side of the capillary was continuously evacuated via a liquid-nitrogen trap by means of a mercury diffusion pump in conjunction with a mechanical vacuum pump. The viscometer bulb and capillary were thermostatted by means of an oil bath (up to 120°C). The bath temperature was controlled within ±0.1°C. The temperature was obtained using a five-junction thermocouple in conjunction with a Leeds-Northrup potentiometer (±1 μv). Times were measured with a precision stopwatch

(calibrated in tenths of a second), and the pressure with a traveling microscope reading to 0.05 mm. It should be noted that, at each temperature, the gas-viscosity coefficients were determined from the well-known Poiseuille equation modified for the slip correction. The apparatus constant was determined at each temperature using nitrogen, and checked with oxygen (the pressure range of these measurements was 22-11 cm mercury). Nitrogen was obtained from Matheson Co. Oxygen was supplied by the Fluka Co. The minimum purities of N_2 and O_2 were 99.9 and 99%, respectively. In every determination of a viscosity coefficient, results at each temperature were averaged from at least three runs.

Results and Discussion

In Table 1, viscosities of the natural gas of Iran (Shiraz pipeline) are presented in the temperature range of 20-120°C as measured by the capillary flow method. The experimental values of viscosity are compared with the theoretical values obtained from the kinetic theory with the aid of the extended law of corresponding states proposed by Kestin *et al.* We neglected all components with mole fractions of less than 0.003 after substituting n-butane for all heavier hydrocarbons. The comparison shows that good agreement exists between measured values and theoretically calculated results.

In summary, we have used standard formulas to calculate the viscosity of one gas mixture at six temperatures and we have compared our calculations [5] with experimental data. The agreement is excellent, as was more or less to be expected.

Acknowledgements

Table 1. Viscosity of natural gas

Compn (mole fraction)						Temp °C	Viscosity, μp		
CH_4	C_2H_6	C_3H_8	n-C_4H_{10}	N_2	CO_2		exptl	calcd	dev[a],%
0.8604	0.0760	0.0428	0.0105	0.0064	0.0039	20	106.25	106.03	0.21
						40	112.53	112.53	0.00
						60	118.80	118.85	-0.04
						80	124.85	125.02	-0.14
						100	130.66	131.04	-0.29
						120	135.10	136.93	-1.34

[a] Standard deviation = 0.55%

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