

Dynamic viscosity of liquid mixture

Liquid dynamic viscosity is transport property needed in dimensioning process equipment. As described in Gmehling *et al.* [1], one of the models in commercial process simulators utilizes mole fraction weighting mixing rule to calculate dynamic viscosity of liquid mixture of several compounds:

$$\ln \frac{\eta_{\text{mix}}}{\text{cP}} = \sum_i x_i \ln \frac{\eta_i}{\text{cP}}$$

In fact, this model, which was default in the selected thermodynamic method, was used in an industrial case for which liquid mixture experimental data was not initially available. The mixture consisted of weakly polar component A and water (B), for which pure component data is as follows:

$$\begin{aligned}\eta_A &\sim 10 \text{ cP} \\ \eta_B &= 0.47 \text{ cP} \\ M_A &\sim 1000 \text{ g/mol} \\ M_B &= 18 \text{ g/mol}\end{aligned}$$

Mass fraction of water (B) in this mixture was 1 wt.-%.

First, the mole fractions for components A and B were calculated:

$$x_A = \frac{\frac{w_A}{M_A}}{\frac{w_A}{M_A} + \frac{w_B}{M_B}} = \frac{\frac{0.99}{1000}}{\frac{0.99}{1000} + \frac{0.01}{18}} = 0.64; \quad x_B = 1 - 0.64 = 0.36$$

Then the dynamic viscosity of the liquid mixture was obtained:

$$\begin{aligned}\ln \frac{\eta_{\text{mix}}}{\text{cP}} &= x_A \ln \frac{\eta_A}{\text{cP}} + x_B \ln \frac{\eta_B}{\text{cP}} = 0.64 \cdot \ln 10 + 0.36 \cdot \ln 0.47 = 1.2 \\ \eta_{\text{mix}} &= \exp(1.2) \text{ cP} = 3.3 \text{ cP}\end{aligned}$$

Calculations, using the mole fraction mixing rule, suggest that the liquid mixture viscosity is only 3.3 cP. Since this value seemed so low in comparison to the pure component liquid viscosity of component A, another mixing rule, utilizing mass fraction weighting, was selected in the simulator:

$$\ln \frac{\eta_{\text{mix}}}{\text{cP}} = \sum_i w_i \ln \frac{\eta_i}{\text{cP}}$$

With this model the resulting liquid mixture viscosity was 9.7 cP. Experimental work carried out some time afterwards indeed validated that the mass fraction weighting gives more accurate result for this kind of mixture.

In general, one would expect that adding even small amount of lighter fluid would considerably decrease the viscosity of a more viscous component. For this particular mixture, this was not the case and only a small reduction in viscosity was observed.

The simple mixing rules for viscosity are empirical, with no theoretical justification, and are primarily used as a quick way of estimating the viscosity of a fluid mixture. As it is illustrated in Gmehling *et al.* [1], they are not suitable for all systems. In fact, Gmehling *et al.* writes: “*This is one of the weakest areas in the process simulation...*” “*...more than the correct order of magnitude can hardly be obtained*”. “*In most cases, the values obtained for the mixture viscosity are too low...*”

There exists a plethora of more sophisticated methods of estimating the viscosity [2,3]. However, some of them require more comprehensive input data that might not be available for the mixture of interest. If you are going to use simple mixing rules, which is generally not recommended, make sure that there is experimental evidence that they work for the mixture you are dealing with.

References:

- [1] J. Gmehling, B. Kolbe, M. Kleiber, and J. Rarey, Chemical Thermodynamics for Process Simulation, 2nd edition, Wiley-VCH Verlag GmbH & Co. KGaA, 2019
- [2] B.E. Poling, J.M. Prausnitz, J.P. O'Connell, The Properties of Gases and Liquids, 5th edition., McGraw-Hill Companies, New York, 2001.
- [3] M.J. Assael, A.R.H. Goodwin, V. Vesovic and W.A. Wakeham, Eds., Advances in Transport Properties, Experimental Thermodynamics Series, Vol. IX, The Royal Society of Chemistry, Cambridge, 2014.