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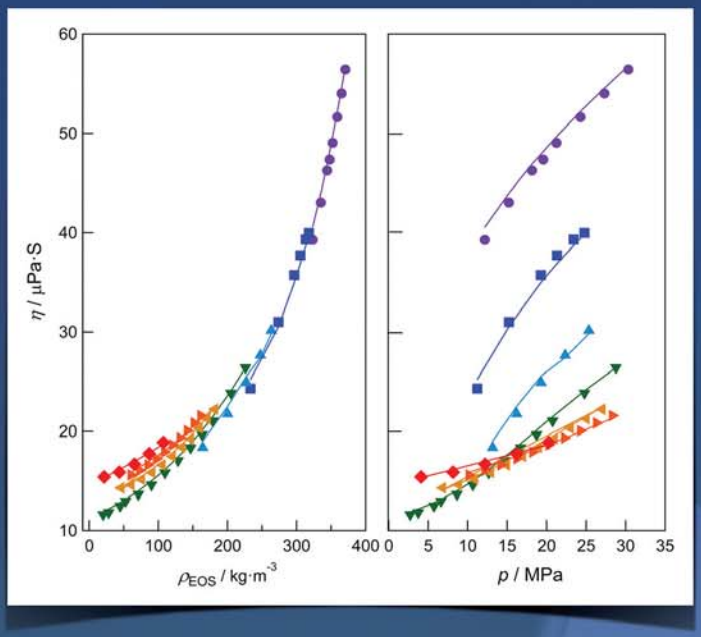

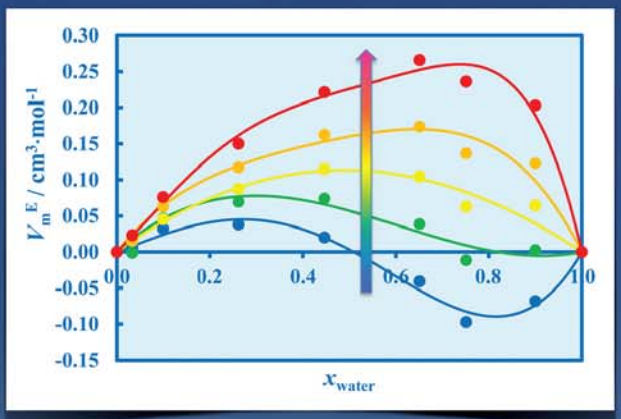

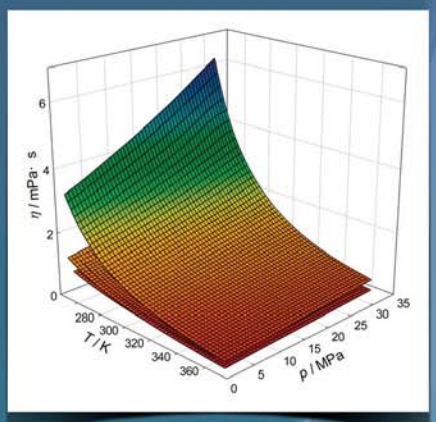

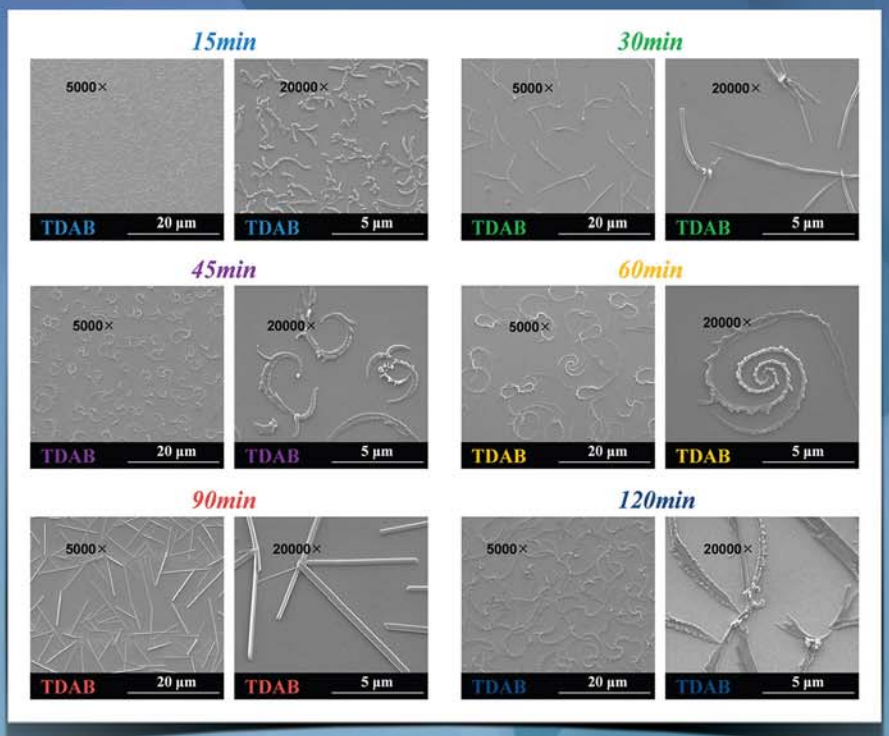

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Viscosity and Density of Normal Butane Simultaneously Measured at Temperatures from (298 to 448) K and at Pressures up to 30 MPa Incorporating the Near-Critical Region

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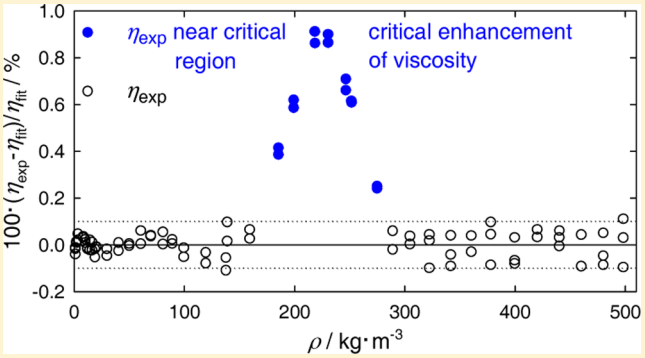
ABSTRACT: A vibrating-wire viscometer and a single-sinker densimeter were simultaneously used to determine accurate $\eta\rho pT$ data for normal butane. Seven isotherms were measured between (298.15 and 448.15) K up to maxima of 91 % of the saturated vapor pressure for the subcritical and of 30 MPa for the supercritical isotherms. The combined expanded uncertainty (k = 2) in density is 0.2 %, except for the low-density region. The data agree within ±0.4 % with densities for the equation of state by Bücker and Wagner, excluding the near-critical region due to the strong influence of allocation errors for temperature and pressure. The deviations for the near-critical isotherm 428.15 K amount to +8.5 %, distinctly higher than the total expanded uncertainty of the density data (2.4 %). The viscosity measurement is less influenced in the near-critical region by allocation errors for temperature and density so that the total expanded uncertainty is 0.6 %. The new data were compared with viscosity correlations of Younglove and Ely, Vogel et al., and Quiñones-Cisneros and Deiters. Maximum deviations between +16 % and −7 % at 428.15 K and densities 150 < ρ/kg·m^{-3} < 300 exceed seriously the expanded uncertainties of 6.0 % for the three correlations. The effect of about +1 % for the critical enhancement is obvious for 428.15 K. The present data should be used to generate a new viscosity correlation.



1. INTRODUCTION

Normal butane, also known as R-600, is an important working fluid in the petrochemistry and in the natural gas industry. It is of importance as power gas in aerosols, as fuel gas in its liquified state, and as refrigerant in the cooling industry due to its low global warming and negligible ozone depletion potentials. Reliable thermophysical properties of normal butane are required when technical objects are designed, operated, maintained, or retrofitted and where this substance is concerned. Experimentally determined thermophysical properties are significant not only for process simulations and for computational fluid dynamics but also for a comparison with theoretically computed values. Moreover, exactly measured data are strongly needed for a reference equation of state[1] and a reliable viscosity surface correlation.[2]

The equipment designed by Seibt[3] for the simultaneous determination of viscosity and density in this work was first applied by Seibt et al.[4] for measurements on helium and nitrogen. The used vibrating-wire viscometer represents an advanced version of an instrument developed and employed for measurements on gases by Wilhelm et al.[5,6] To infer the viscosity from the observed damped oscillation curves of the vibrating wire on the basis of the respective working equation, density values of an uncertainty as low as possible are necessary. Although the evaluation of the parameters of the recorded oscillation curves enables, in principle, deduction of viscosity and density simultaneously, the resulting density values are characterized by a comparably large uncertainty. The needed density values were calculated using concurrently measured values for pressure and temperature in combination with a reliable equation of state. The uncertainties of the measured temperatures and pressures influence not only the calculated densities but also the uncertainty of the finally derived viscosity values. Seibt et al. improved the experimental equipment of Wilhelm et al. by integrating an accurate single-sinker densimeter and, in so doing, they reduced the impact of an increased uncertainty in density, particularly in the near-critical region. Finally, the relative combined standard uncertainty (k = 1) of the density measurement amounts to 0.1 % so that the relative combined standard uncertainty in the viscosity is 0.3 %, with the exception of the low-density and the near-critical regions.

A program concerned with the investigation of the thermophysical properties density and viscosity of alkanes, using the measuring equipment under discussion, was initiated. Within the framework of this program, Seibt et al.[7] performed

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