

Simultaneous Viscosity-Density Measurements of Gases over a Wide Range of Temperature and Pressure Using a Vibrating-Wire Viscometer and a Single-Sinker Densimeter

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Outline

1 Motivation and Tasks

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- Vibrating-Wire Viscometer
- Single-Sinker Densimeter
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3 Results of the Measurements

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- Normal Butane
- Isobutan

4 Conclusions and Outlook

Motivation and Tasks

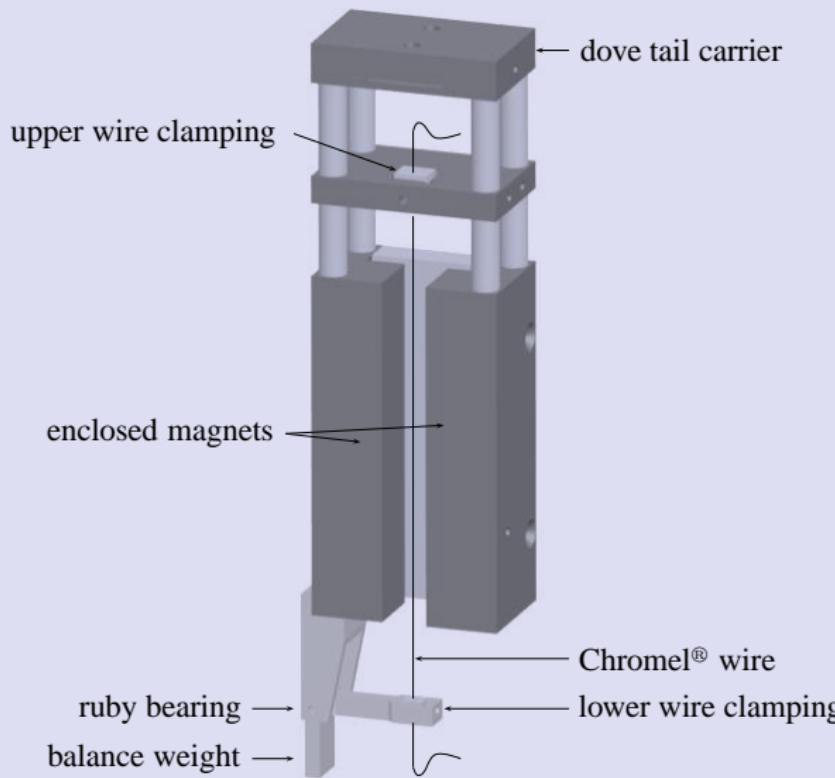
Motivation

- Shortage of fossil fuels → more economic use essential
 - Higher energy conversion efficiency needs better design of machines and facilities
 - Reduction of CO₂ emission → new technologies required
- ⇒ precise thermophysical properties of industrially and ecologically important fluids needed, e.g., normal butane, isobutane, etc.

Tasks

- Test and calibration of an appropriate combined apparatus
- Measurement of new precise $\eta \rho p T$ data in large temperature and pressure ranges

Vibrating-Wire Viscometer



- Wire:
 $L_W = 9 \text{ cm}$
 $f = 280 \text{ Hz}$
 $D = 25 \mu\text{m}$
Ni90/Cr10
- Magnets:
 $L_M = 6 \text{ cm}$
Sm₂Co₁₇

Vibrating-Wire Viscometer

Implementation

- ① Initialization of a vibration of the clamped wire in a homogeneous magnetic field by means of a sinusoidal voltage pulse
- ② Magnetic induction of a voltage in the moving wire
- ③ Detection of the damped harmonic oscillation via measuring the voltage as function of time
- ④ Determination of the logarithmic decrement and of the frequency using a non-linear fit
- ⑤ Iterative calculation of the viscosity including the density measured simultaneously

Calibration

- Iterative adjustment of the wire radius by comparing the viscosity in the limit of zero density of a measurement on helium with a theoretically calculated value (Bich *et al.*¹)

¹ Bich, E.; Hellmann, R.; Vogel, E.: *Mol. Phys.* **105**, 3035-3049 (2007).

Single-Sinker Densimeter

Implementation

- Use of the buoyancy principle of Archimedes
(Ruhr-Universität Bochum, Brachthäuser *et al.*²)
- Difference between the weight in vacuo and the weight under the influence of the buoyancy force on the sinker due to the fluid
- Calibration of the balance and determination of the sinker volume
- Density of the fluid:

$$\rho = \frac{F_{w,s,\text{vac}}(T) - F_{w,s,\text{fluid}}(p, T)}{g V_s(p, T)}$$

- Magnetic-suspension coupling (Lösch³):
Contactless power transmission from the measuring cell to the balance situated under ambient conditions

² Brachthäuser, K.; Kleinrahm, R.; Lösch, H. W.; Wagner, W.: Fortschr.-Ber. VDI, Reihe 8, Nr. 371, VDI-Verlag: Düsseldorf (1993).

³ Lösch, H. W.: Fortschr.-Ber. VDI, Reihe 3, Nr. 138, VDI-Verlag: Düsseldorf (1987).

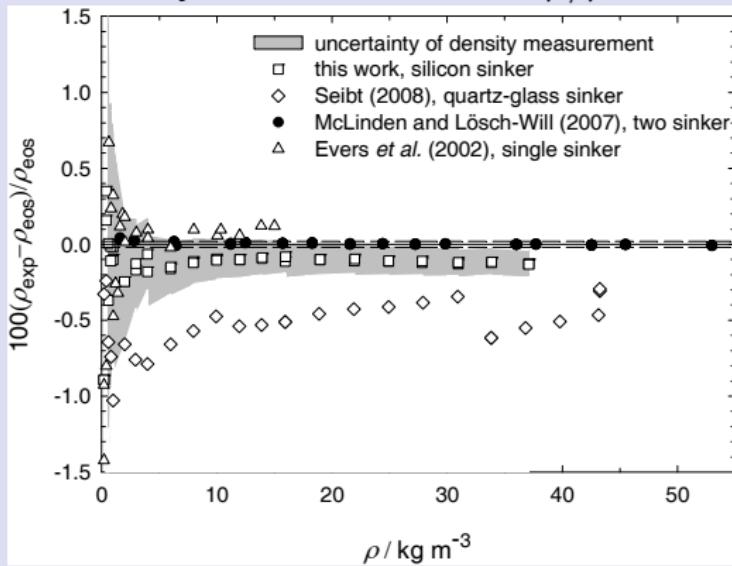
Combined Viscosity-Density Measuring System



Results and Comparisons

Density of Helium

Comparison of the new density data ρ_{exp} with ρ_{eos} of Ortiz Vega⁴
 Uncertainty of the new data: $\Delta\rho/\rho \leq 0.1\%$ for $\rho \geq 10 \text{ kg m}^{-3}$



- No adsorption with new silicon sinker
- Uncertainty in accordance with that of EOS

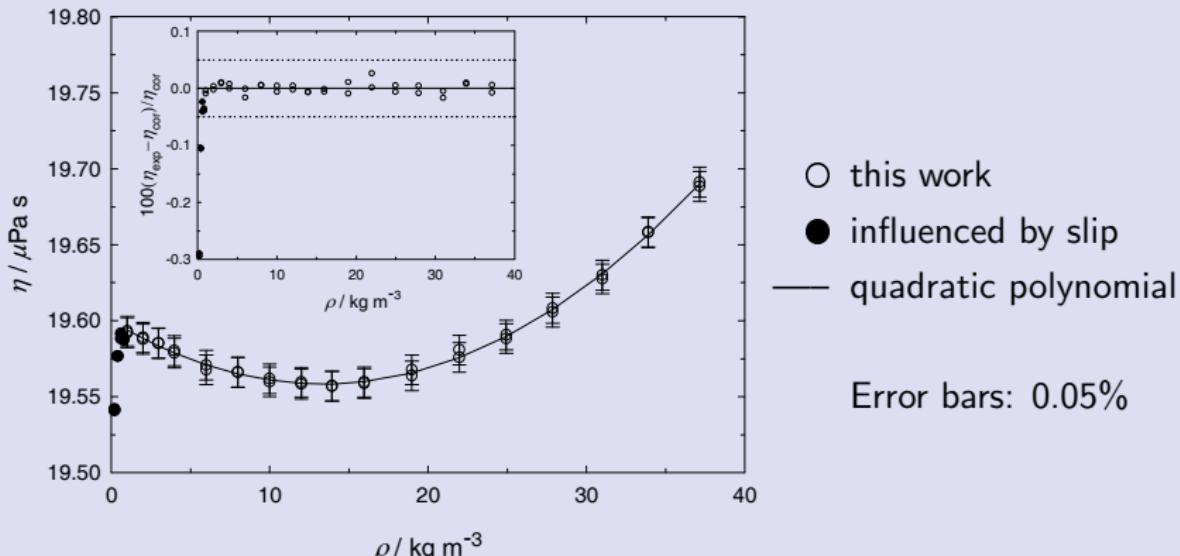
⁴ Ortiz Vega, D. O.: Dissertation, Texas A&M University, Office of Graduate Studies, College Station, TX, USA (2013).

Results and Comparisons

Viscosity of Helium - Calibration

Comparison of the new experimental viscosity data for helium at 293.15 K to a quadratic polynomial

- Reproducibility within $\pm 0.05\%$ (inset)
- Calibration using a high-precision value by Bich *et al.*: $19.600 \mu\text{Pa s}$

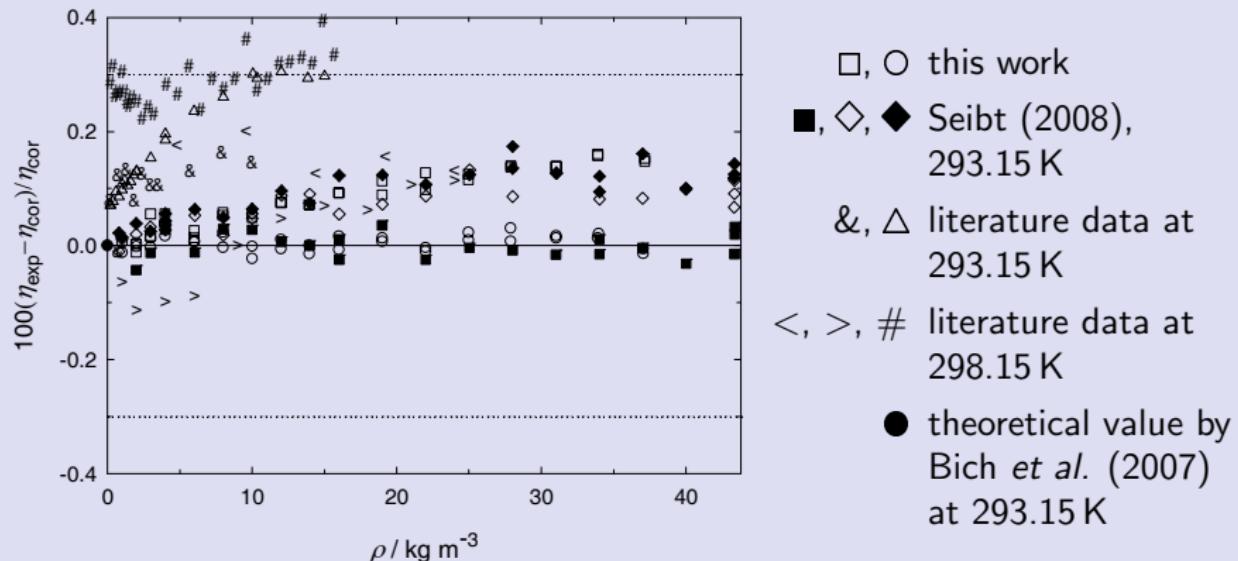


Results and Comparisons

Viscosity of Helium - Comparison to Data from Literature

Comparison of the new viscosity data at 293.15 K, fitted to a quadratic polynomial

- Extension of density range with new results
- New data consistent within $\pm 0.1\%$



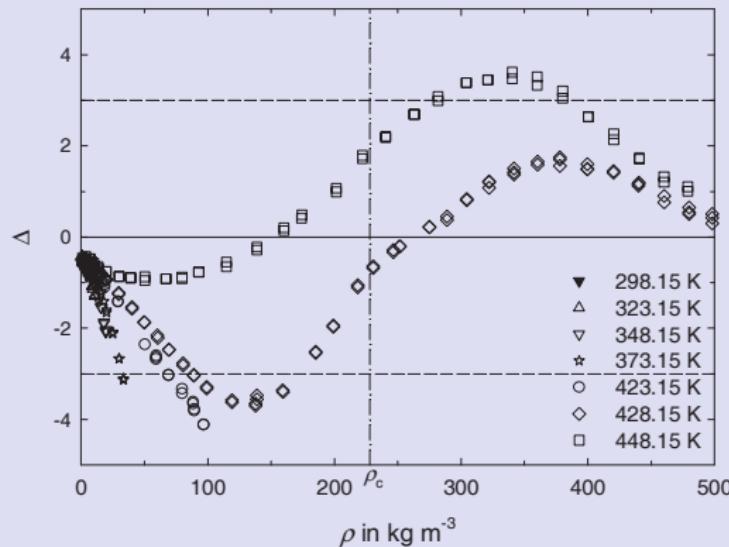
Results and Comparisons

Viscosity of Normal Butane

Comparison of the new data η_{exp} with η_{cor} of Vogel et al.⁵

Uncertainty of the new data: $\Delta\eta/\eta \leq 0.5\%$

- Deviations up to $\pm 4\%$



$$\Delta = 100 \frac{\eta_{\text{exp}} - \eta_{\text{cor}}}{\eta_{\text{cor}}}$$

Critical parameters:

$$T_c = 425.125 \text{ K}$$

$$p_c = 3.796 \text{ MPa}$$

$$\rho_c = 228.0 \text{ kg m}^{-3}$$

⁵ Vogel, E.; Küchenmeister, C.; Bich, E.: *High Temp.-High Pressures* **31**, 173-186 (1999).

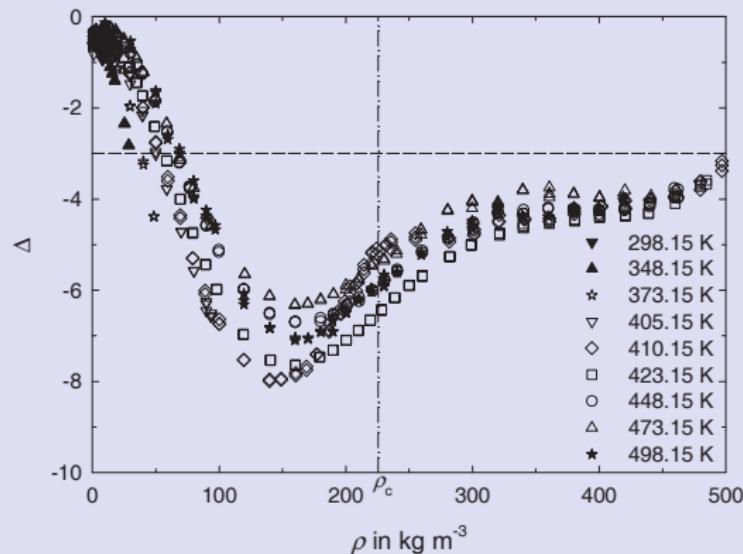
Results and Comparisons

Viscosity of Isobutane

Comparison of the new data η_{exp} with η_{cor} of Vogel et al.⁶

Uncertainty of the new data: $\Delta\eta/\eta \leq 0.5\%$

- Deviations down to -8%



$$\Delta = 100 \frac{\eta_{\text{exp}} - \eta_{\text{cor}}}{\eta_{\text{cor}}}$$

Critical parameters:

$$T_c = 407.81 \text{ K}$$

$$p_c = 3.629 \text{ MPa}$$

$$\rho_c = 225.5 \text{ kg m}^{-3}$$

⁶ Vogel, E.; Küchenmeister, C.; Bich, E.: *Int. J. Thermophys.* **21**, 343-356 (2000).

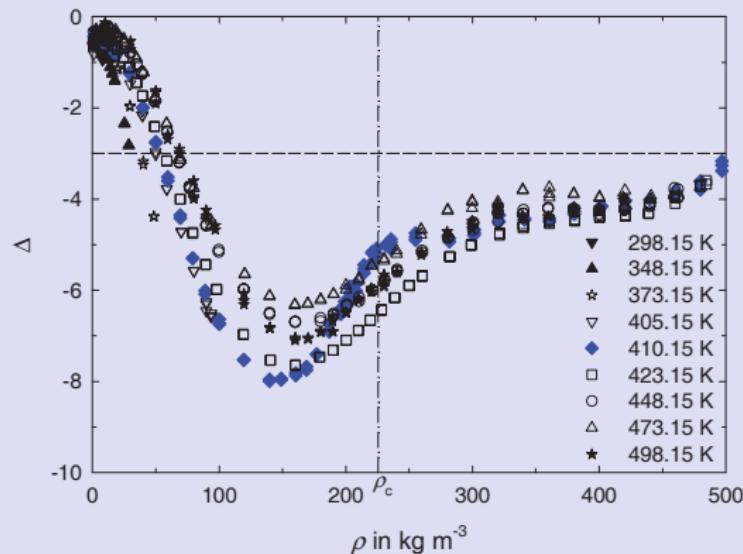
Results and Comparisons

Viscosity of Isobutane

Comparison of the new data η_{exp} with η_{cor} of Vogel et al.⁶

Uncertainty of the new data: $\Delta\eta/\eta \leq 0.5\%$

- Deviations down to -8%



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Conclusions and Outlook

- Simultaneous viscosity-density measurements on gases using a combined apparatus in larger temperature and pressure regions
 - Calibration of the vibrating-wire viscometer using a measuring series on helium
 - Application of a combined apparatus on industrial important fluids
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- New precise viscosity data are available for helium, normal butane, and isobutane to update current viscosity-surface correlations of these fluids
 - New viscosity data for normal butane and isobutane include data for the near-critical region → this region can be modeled within a new correlation now

Slides available at: www.thermodynamics-zittau.de