

Experimental Investigation of the Thermal Conductivity Behavior of Ne-Ar, Ne-N₂ and Ar-N₂ Binary Gas Mixtures

*Svenja Jung^{1,2}, Mike Benkendorf¹, Hans-Fridtjof Pernau¹, Markus Graf^{2,3},
Laura Maria Comella², Jürgen Wöllenstein^{1,4}, Katrin Schmitt^{1,4}*

¹ *Fraunhofer Institute for Physical Measurement Techniques IPM, Georges-Köhler-Allee 301, 79110 Freiburg im Breisgau, Germany,*

² *University of Applied Sciences Karlsruhe, Moltkestraße 30, 76133 Karlsruhe, Germany,*

³ *University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany,*

⁴ *Albert-Ludwig-University Freiburg, Georges-Köhler-Allee 102, 79110 Freiburg im Breisgau, Germany
svenja.jung@ipm.fraunhofer.de*

Summary

Binary gas mixtures provide a basis for the investigation of the thermal conductivity behavior and create a starting point for extending the analysis to more complex gas mixtures. Nonlinear behavior already appears in fundamental binary gas mixtures, indicating that even simple systems exhibit complex composition-dependent interactions. Improved prediction of these nonlinearities enables enhanced simulation and calibration of thermal conductivity detectors.

Keywords: Thermal conductivity, binary gas mixtures, nonlinear mixing behavior, thermal conductivity detector, lock-in amplifier

Introduction

Precise theoretical prediction of the properties for gas mixtures is challenging because intermolecular interactions depend on the molecular model, temperature, and pressure, and determine the energy transfer between translational and internal degrees of freedom [1]. Therefore, the thermophysical properties of each pure component in the binary gas mixture are analyzed to assess its influence on transport and thermal behavior. Even in binary mixtures of monatomic gases, nonlinear thermal conductivity behavior is observed. Consequently, the concentration-dependent nonlinearity of the thermal conductivity of binary gas mixtures requires experimental determination, as a precise theoretical prediction remains complex, but is crucial to understand more complex gas mixtures, e.g. air. In this paper, the binary gas mixtures of Ne-Ar, Ne-N₂ and Ar-N₂ are considered, enabling a fundamental investigation of the nonlinearity.

Experimental method

Most advanced, precise gas measurements via thermal conductivity are based on variations of the hot-wire method. This method uses a simple and robust tungsten wire as a thermal conductivity detector (TCD), which simultaneously serves as a heating element and temperature sensor, configured as Wheatstone half bridge. The TCD's reference elements adjust to the ambient gas temperature, thus compensating for

temperature influences. Since cross-sensitivity to temperature and humidity affects thermal conductivity, this was additionally measured to assess its potential for use in compensation. The schematic of the TCD measurement for a controlled binary gas mixture is shown in Fig. 1. The increased measurement requirements are met by the lock-in amplifier principle, which are composed of an advanced, compact microcontroller electronic and a benchtop lock-in amplifier.

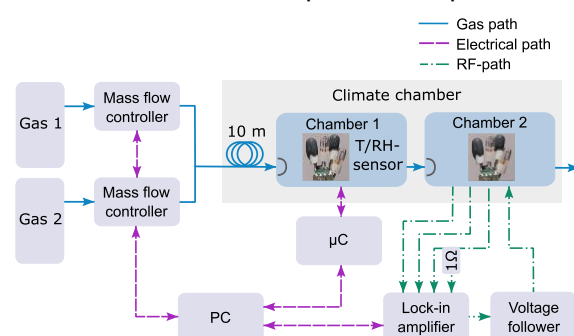


Fig. 1. TCD measurement setup for controlled binary gas mixture measurements. The mixed gas is passed through a 10 m long extended thermalization unit to both measurement chambers with an additional temperature/humidity sensor ScioSense (ENS210), which are located inside the climate chamber. The TCDs operate through a microcontroller electronic and a lock-in amplifier (Zurich Instruments HF2LI) with external voltage follower and a 1 Ω shunt-resistor for current measurement.

Results

Literature values on the nonlinear behavior of the binary gas mixtures Ne-Ar, Ne-N₂ and Ar-N₂ were compiled from various sources [1,2], as no systematic compilation exists that considers the influence of temperature. Therefore, Ne-Ar, Ne-N₂ and Ar-N₂ measurements were performed to investigate the influence of the nonlinear behavior at 25 °C and 38 °C for atmospheric pressure. The bridge voltage measurement using constant gas steps was carried out to determine the nonlinear behavior of the noble gases Ne-Ar (Fig. 2).

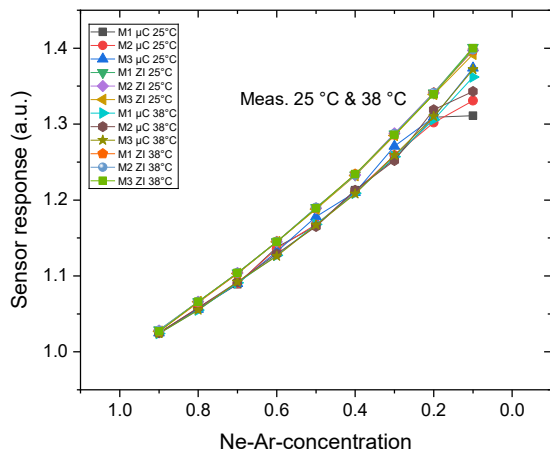


Fig. 2. Nonlinear behavior of Ne-Ar gas steps at 25 °C and 38 °C with 0 % RH. The TCDs were driven via the microcontroller electronic (μC) and the lock-in amplifier (ZI).

The nonlinear behavior is determined by dividing the bridge voltage difference by the corresponding linear gas concentration factor. The relationship at 25 °C and 38 °C shows a nonlinear increase up to a factor of 1.4. The pronounced nonlinearity results from the large difference in the thermal conductivity of Ne-Ar, with a ratio of 49:17.7. The binary gas mixtures of Ne-N₂ (Fig. 3) show a similar nonlinearity as Ne-Ar.

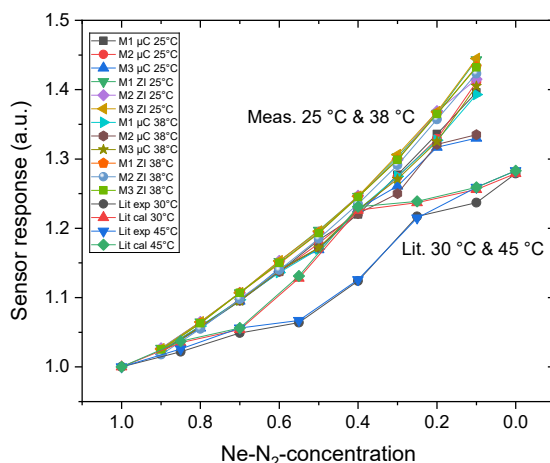


Fig. 3. Nonlinear behavior of Ne-N₂ gas steps at 25 °C and 38 °C, which are compared with the literature of Barua [2] at 30 °C and 45 °C.

The difference in the thermal conductivity of Ne and N₂ (49:25.8) increases up to a factor of 1.45. The literature data of Barua [2] are below the measured values and exhibit irregular behavior. The binary gas mixtures of Ar-N₂ (Fig. 4) show a lower nonlinear behavior as observed for Ne.

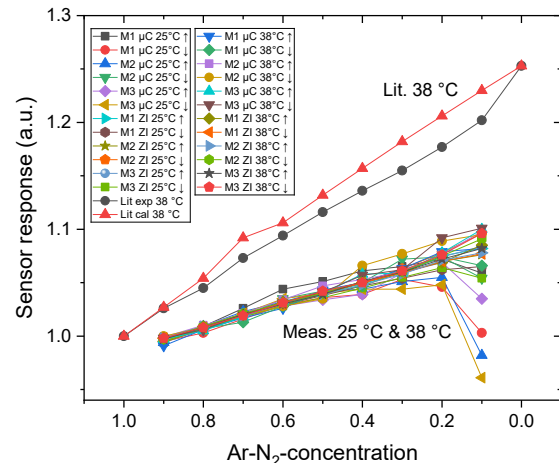


Fig. 4. Nonlinear behavior of Ar-N₂ gas steps at 25 °C and 38 °C, which are compared with the literature of Srivastava and Srivastava [1] at 38 °C.

The difference in the thermal conductivity of Ar and N₂ (17.7:25.8) increases nearly linearly up to a factor of 1.1, whereas the literature data of Srivastava and Srivastava [1] reach up to 1.25, with a significantly steeper increase. The two readout electronics are located close together and the small temperature difference between 25 °C and 38 °C with atmospheric pressure is for the gas combinations not noticeable.

Conclusion

The experimental results of the binary gas mixtures for Ne-Ar, Ne-N₂ and Ar-N₂ at 25 °C and 38 °C with atmospheric pressure show a pronounced concentration-dependent nonlinearity. The nonlinear behavior for Ne-Ar and Ne-N₂ can be attributed to the larger thermal conductivity difference. The marked nonlinearities in binary gas mixtures indicate that simple linear models are inadequate for accurately describing the physical behavior, which is a critical factor for the accurate calibration and reliable operation of TCDs.

References

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