Density and speed of sound in refrigerant vapor
R-125 (31 wt. %) + R-134A (69 wt. %)

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Abstract. Using a constant volume piezometer and ultrasonic interferometer methods, the density and speed of sound in gaseous mixture R-125 (31 wt. %) + R-134a (69 wt. %) were measured within the temperature range from 293 to 393 K and at pressure from 0.18…0.47 to 2.5 MPa. The errors in the measuring temperature, pressure, density and speed of sound were ±20 mK, ±4 kPa, ± (0.15–0.3) %, ± (0.1–0.2) %, respectively. It was shown that the speed of sound values increase with temperature and decrease with pressure. The obtained results were compared with the calculations using the REFPROP software.

1. Introduction
The REFPROP program [1], developed by the U.S. Institute of Standards and Technology, is a generally accepted world standard for the thermophysical properties of individual and mixed refrigerants. Nevertheless, our previous study of the speed of sound (U) in a mixture of R-125 and R-134a refrigerant has shown that for the composition R-125 (63.9 wt. %) + R-134a (36.1 wt. %) the obtained experimental data for vapor phase exceed the results of calculations by REFPROP by values exceeding the measurement errors of the speed of sound [2]. At the same time, refrigerants of the R-125 / R-134a system are the basis of many modern mixed refrigerants and, for this reason, high requirements are imposed on the accuracy of data on their properties in a wide range of concentrations.

The aim of this work was to measure the density (ρ) and speed of sound in a vapor of the composition R-125 (31 wt. %) + R-134a (69 wt. %) in a wide range of the state parameters.

2. Experimental details
The measurements were carried out by the methods of a constant volume piezometer (296–393 K; 0.469–2.55 MPa) and an ultrasonic interferometer (293–393 K; 0.184–2.52 MPa). The errors in the measuring temperature, pressure, density and speed of sound were ±20 mK, ±4 kPa, ± (0.15–0.3) %, ±(0.1–0.2) %, respectively [3–5]. The refrigerants of the R-125 – R134a system were prepared by the gravimetric method with an error of no more than 0.05 wt. %. Refrigerant R-125 was supplied by China and was 99.5% pure. Refrigerant R-134a was from Forane (France) and had a purity of 99.9%. These components were used without further purification. Molecular mass of the mixture was 107.00 g mol⁻¹. Before the start of the experiment, the setup was vacuumed up to a pressure of (2–4) Pa. To avoid variations in the mixture composition, the measuring cell was filled up from the liquid phase.
3. Results and Discussion
The results of our measurements of the refrigerant density and speed of sound in the vapor phase are shown in figure 1, 2 and table 1, 2.

Table 1. Measured density of 31 wt. % R125 + 69 wt. % R134a refrigerant in the vapor phase.

| T (K) | p (MPa) | \( \rho \) (kg m\(^{-3}\)) | T (K) | p (MPa) | \( \rho \) (kg m\(^{-3}\)) |
|-------|---------|-----------------|-------|---------|-----------------|
| 296.51 | 0.4692  | 22.46           | 353.15 | 1.3070  | 55.57           |
| 313.15 | 0.8279  | 39.73           | 353.15 | 2.1114  | 103.94          |
| 313.15 | 1.0856  | 55.69           | 373.15 | 0.6163  | 22.37           |
| 313.17 | 0.5022  | 22.44           | 373.15 | 1.0449  | 39.61           |
| 333.15 | 0.5407  | 22.41           | 373.15 | 1.4106  | 55.52           |
| 333.15 | 0.9022  | 39.69           | 373.15 | 2.3368  | 103.84          |
| 333.15 | 1.8738  | 104.05          | 393.15 | 0.6532  | 22.35           |
| 333.20 | 1.1992  | 55.63           | 393.15 | 1.1138  | 39.57           |
| 353.15 | 0.5787  | 22.39           | 393.15 | 1.5121  | 55.46           |
| 353.15 | 0.9745  | 39.65           | 393.15 | 2.5522  | 103.73          |

Figure 1. Experimental quasi-iscochores of the refrigerant R-125 (31 wt. %) + R-134a (69 wt. %) vapor density.

(1)–(4): 22.4; 39.7; 55.6; 104.0 kg m\(^{-3}\).

It is seen that the value \( U \) increases with temperature and decreases with pressure (figure 2). To confirm the reported error in the measuring speed of sound, initial data for each isotherm were approximated by polynomials of the second degree on pressure (total average absolute deviation AAD=0.07%), and by extrapolating \( U \) their values at zero pressure (\( U_0 \)) were obtained. These values, according to the well-known formula [3], were recalculated in the ideal-gas heat capacity (\( C_\rho \)), which is an additive value relative to pure components. Its comparison with the ideal gas heat capacity according to [2] has shown that the average absolute deviation is 3% or in terms of \( U_0 - 0.15\% \). The
latter value, taking into account the extrapolation performed, corresponds to our error in measuring the speed of sound.

Table 2. Measured speed of sound of 31 wt. % R125 + 69 wt. % R134a refrigerant in the vapor phase.

|   T (K)   |   p (MPa)   |   U (m s⁻¹)   |   T (K)   |   p (MPa)   |   U (m s⁻¹)   |
|----------|-------------|---------------|----------|-------------|---------------|
| 293.15   | 0.1835      | 154.32        | 333.15   | 1.8493      | 127.21        |
| 293.17   | 0.6952      | 138.65        | 353.15   | 0.2226      | 169.88        |
| 293.92   | 0.7273      | 137.48        | 353.15   | 0.4600      | 166.62        |
| 294.14   | 0.7169      | 138.51        | 353.15   | 0.8883      | 159.98        |
| 294.79   | 0.3641      | 150.15        | 353.15   | 1.3923      | 151.27        |
| 294.94   | 0.7416      | 137.65        | 353.15   | 1.6986      | 145.47        |
| 295.40   | 0.6969      | 140.03        | 353.15   | 2.0829      | 137.24        |
| 313.15   | 0.1962      | 159.43        | 373.15   | 0.4890      | 172.00        |
| 313.15   | 0.7577      | 146.65        | 373.15   | 0.9518      | 166.08        |
| 313.15   | 1.1454      | 135.19        | 373.15   | 1.5080      | 158.30        |
| 313.15   | 1.2010      | 133.21        | 373.15   | 1.8533      | 153.27        |
| 313.15   | 1.2128      | 132.74        | 373.15   | 2.3029      | 146.19        |
| 313.19   | 0.4021      | 155.57        | 393.15   | 0.2371      | 179.59        |
| 313.19   | 1.1494      | 135.09        | 393.15   | 0.2494      | 179.49        |
| 333.15   | 0.2005      | 165.26        | 393.15   | 0.5178      | 177.02        |
| 333.15   | 0.2092      | 164.70        | 393.15   | 1.0138      | 171.66        |
| 333.15   | 0.4306      | 161.07        | 393.15   | 1.6193      | 164.80        |
| 333.15   | 0.8263      | 153.59        | 393.15   | 2.0035      | 160.45        |
| 333.15   | 1.2739      | 143.51        | 393.15   | 2.5149      | 154.22        |

Figure 2. Speed of sound isotherms in the refrigerant R-125 (31 wt. %) + R-134a (69 wt. %). From bottom to top: 313.15 K; 333.13K; 353.13K; 373.15K; 393.15 K. Dots are experimental data, lines are approximation.
Comparison of the obtained data with calculations using the REFPROP program has shown that the average absolute deviation does not exceed 0.19% for density and 0.085% for the speed of sound. These values are within the limits of our experimental errors.

Figure 3. Relative deviations of our experimental speed of sound from data [1].

Conclusions
Experimental data on the density and speed of sound in the vapor of R-125 (31 wt. %) + R-134a (69 wt. %) refrigerants have been obtained for the first time. The measurement results show good agreement between the experimental data and the existing calculations. This suggests that the models and data included in REFPROP allow describing the thermal properties of refrigerants of the R-125 / R-134a system for compositions containing less than 50 wt. % R-125 with an experimental data error.

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