Sound velocity in the vapor phase of the binary mixture
R-125 (63.9 wt.%) – R-134a (36.1 wt.%)

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Abstract. Using an ultrasonic interferometer method, the sound velocity in gaseous mixture R-125 (63.9 wt.%) - R-134a (36.1 wt.%) was investigated in the temperature interval 303-393 K and pressure up to 0.95 MPa. The temperature measurement error was 20 mK, pressure 4 kPa, and sound velocity (0.2–0.3) %. It was shown that the sound velocity values increase with temperature and decrease with pressure. Comparison of our data with the calculations using the REFPROP software was performed.

1. Introduction
Refrigerants R-125 (1,1,2,2-Pentafluoroethane, C₃H₃F₅) and R-134a (1,1,2-Tetrafluoroethane, C₃H₂F₃) with zero ozone depletion potential are the main components of a large number of modern organic coolants (R-404a, R-417a (b), R-419a, R-422 (ad), R-437a, etc.) that make up the composition of R-421 (a, b). All of them are designed to replace R-22 and R-502 refrigerants in various refrigeration equipment and heat pumps. With these refrigerants there is no need to change the oil. For this reason, the study of the properties of the R-125 - R-134a system is necessary for solving various scientific and applied tasks.

At present, it is generally accepted to carry out a thermodynamical description of refrigerants using Helmholtz free energy [1]. The basis for its development is the $pVT$-properties and the temperature dependence of heat capacity of the ideal gas of the substance. This justifies the importance of obtaining experimental data on these properties. To test the Helmholtz equation, data on the sound velocity play an important role, since it depends on both thermal and caloric properties and, thus, allows us to control the agreement of dissimilar data on thermophysical properties. The aim of our study is to measure the sound velocity of the gaseous R-125 (63.9 wt.%) - R-134a (36.1 wt.%) refrigerant in a wide range of temperatures and pressures.

2. Experimental details
An ultrasonic interferometer [2] was used for the measurement of the sound velocity in a R-125 (63.9 wt.%) – R-134a (36.1 wt.%) refrigerant (303-393 K, 0.14-0.95 MPa). The operating frequency of the interferometer was about 1.9 MHz. Experimental installation was made from 12Kh18N10T steel. The liquid thermostat and platinum PTS-10 resistance thermometers, calibrated with an error of 0.02 K were used. During the measurements, the temperature in the thermostat was maintained with an accuracy of 5 mK. Pressure $p$ was measured with a quartz manometer, which was previously calibrated with a piston gage. A hot stainless steel membrane null indicator was used. The temperature measurement error was 20 mK, pressure 4 kPa, and sound velocity (0.2–0.3) % [3-5]. The
concentration of the R-125 - R134a refrigerant was determined by weighing pure components. The error of its determination did not exceed 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 112.84 g mol$^{-1}$.

Before the filling of the installation with refrigerant, it was evacuated to a pressure of 2-3 Pa, and the filling itself was carried out from the liquid phase in order to maintain the original composition of the mixture.

3. Results and Discussion

Figure 1 and table 1 show the results of measurements of the refrigerant sound velocity in the vapor phase. It is seen that the value $U$ increases with temperature and decreases with pressure. For each isotherm, the initial data are approximated by polynomials of the first or second degree of pressure:

$$U(p) = A_0 + A_1 p + A_2 p^2$$  \hspace{1cm} (1)

where $p$ is the pressure in MPa and $U$ is the sound velocity in m s$^{-1}$. The average absolute deviation of experimental points from (1) is 0.05 \% (figure 2). On average, our data are 0.35\% higher (figure 3) than results of calculations using REFPROP software [6]. This difference, in principle, does not exceed the estimated measurement errors; nevertheless, experimental data may be applied to refine the theoretical models used in the REFPROP software.

### Table 1. Experimental sound velocity in the vapor phase of 63.9 wt.% R125 – 36.1 wt.% R134a refrigerant.

| $T$ (K) | $p$ (MPa) | $U$ (m s$^{-1}$) | $T$ (K) | $p$ (MPa) | $U$ (m s$^{-1}$) |
|--------|-----------|-----------------|--------|-----------|-----------------|
| 303.15 | 0.1383    | 154.24          | 353.15 | 0.4852    | 163.16          |
| 303.15 | 0.4075    | 148.72          | 353.15 | 0.6239    | 160.78          |
| 303.15 | 0.5156    | 146.13          | 353.15 | 0.7360    | 159.12          |
| 303.15 | 0.6900    | 144.10          | 353.15 | 0.8323    | 157.84          |
| 303.15 | 0.6872    | 142.10          | 373.15 | 0.5150    | 167.80          |
| 313.15 | 0.5419    | 149.11          | 373.15 | 0.6643    | 166.34          |
| 313.15 | 0.6353    | 147.14          | 373.15 | 0.7859    | 164.86          |
| 313.18 | 0.7107    | 145.98          | 373.15 | 0.8897    | 163.68          |
| 333.15 | 0.1520    | 162.07          | 393.15 | 0.1796    | 175.36          |
| 333.15 | 0.4543    | 157.32          | 393.15 | 0.5443    | 172.53          |
| 333.15 | 0.6846    | 153.63          | 393.15 | 0.7040    | 171.06          |
| 333.15 | 0.7720    | 151.92          | 393.15 | 0.8332    | 169.82          |
| 353.15 | 0.1615    | 166.57          | 393.15 | 0.9447    | 168.86          |

Using the approximation equations (1), we calculated the sound velocity at zero pressure $U_0(T)$ and then, similar to [5], the heat capacity of ideal gas of mixtures R-125 (63.9 wt.%) - R-134a (36.1 wt. %). Approximation of the obtained data gave the equation:

$$\frac{C_p^0(T)}{R} = 2.45 + 2.742 \times 10^{-2} T,$$  \hspace{1cm} (2)

where $T$ is the temperature in K, and $R = 8.314472$ J (mol K)$^{-1}$ is the universal gas constant.
Figure 1. Experimental sound velocity isotherms. Dots are experimental data, and lines are approximation. From bottom to top: 303.15 K, 313.15 K, 333.15 K, 353.15 K, 373.15 K, 393.15 K.

Figure 2. Relative deviations of our sound velocity measurements from approximation (1).
Figure 3. Relative deviations of our sound velocity measurements from data [6].

The calculation of heat capacity of the ideal gas according to (2) differs from the data of [6] by no more than 2.6%, with an average absolute deviation of 1.6%. This agreement confirms the estimated accuracy of our measurements of the sound velocity and the claimed concentration of the mixture components, because the error $U_0$ for the given composition is 20–25 times less than the error of $C_P^0$.

**Conclusion**

Experimental data on the sound velocity in a vapor of R-125 (63.9 wt.% - R-134a (36.1 wt.%) refrigerant have been obtained for the first time. By comparing the calculated ideal gas heat capacity with its determination through the ideal gas heat capacity of the components, the claimed accuracy of sound velocity measurements has been confirmed. A fairly good agreement of the measurement results with the calculation of the sound velocity using the REFPROP software has been shown.

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