Experimental study of R-32/R-125 (75/25 wt.%) thermal conductivity in the vapor phase

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Abstract. The article presents the investigation of the thermal conductivity of binary mixture R-32/R-125 (75/25) in the gas state. Measurements were taken with a coaxial cylinders method in the temperature range of 305-426 K and the pressure range of 0.1-1.8 MPa. The dependence of thermal conductivity on pressure and temperature was discussed. The equations for thermal conductivity on the dew line and in the ideal gas state were obtained.

1. Introduction
Nowadays there is a trend towards the search for new refrigerant compositions. This is due to the variety of refrigeration, power, and heat pumping equipment, different actual operating conditions, as well as restrictions related to the impact on the ozone layer and global warming. By selecting the composition of refrigerants, one can ensure the maximum efficiency of devices and installations. Binary mixtures R-32/R-125 are an alternative to R-22 Freon in refrigeration, heat pumps, and air conditioning since the ozone-depleting potential of these mixtures is zero. They are low toxic, non-explosive, and show high efficiency. A blend of refrigerants 75 wt.% R-32 (difluoroethane) and 25 wt.% R-125 (pentafluoroethane) was studied in this work. The thermal conductivity values for this mixture in the vapor phase were obtained experimentally. Besides, the temperature dependence of the thermal conductivity in the state of an ideal gas and on the dew, line was found.

2. Experiments
The R-32/R-125 (75/25) composition was blended in the laboratory by the weight technique. Samples of R-32 refrigerants produced in Russia with a purity of 99.9% and R-125 produced in China with a purity of 99.5% were tested. These components were used without further purification. The composition of the gas mixture was determined by alternately weighing the filling cylinder. The balloon was weighed before filling, after filling with the first component, and after filling with the second component. The limit composition error was 0.05 wt.%.

A stationary method of coaxial cylinders in a relative version was implemented employing the setup for measuring thermal conductivity. The model has been detailed in recent publications [1–3]. The main element of the experimental setup was the measuring cell. It consisted of an inner cylinder and an outer cylinder with an annular gap of 0.366 ± 0.005 mm. The inner cylinder was accurately in line with the outer cylinder. The lengths of the outer and inner cylinders were 140 and 101.3 mm, respectively. The setup was equipped with systems for evacuation, pressure measurement, regulation, and temperature measurement. Thermometry was carried out using copper-constantan thermocouples.
A distinctive feature of this setup for measuring the thermal conductivity of gases is the absence of any security heaters and other devices designed to compensate for heat leaks from the ends of the inner cylinder and equalize the temperature field along its length. The effect of the free ends is taken into account by introducing appropriate corrections to the calculation formula for thermal conductivity [1]. The accuracy of the obtained results is based on the use of approved experimental techniques, detailed estimation of measurement errors, the carrying out of a set of test and calibration experiments, their reproducibility, and comparison of results with the literature data of other authors. The reliability of the unit has been repeatedly verified and confirmed by the results of numerous experiments including studies of pure gases and their mixtures. The setup allows measuring the thermal conductivity of the gas phase with an accuracy of 1.5-2.5%.

3. Results
The point-by-point measurements of the binary mixture R-32/R-125 (75/25) thermal conductivity covered the temperatures range of 305-426 K and pressures of 0.1-1.8 MPa. These data are accumulated in table 1.

| Table 1. Experimental thermal conductivity of R-32/R-125 mixture. |
|---------------------------------------------------------------|
| \( T \) (K) | \( p \) (MPa) | \( \lambda \) mW/(mK)\(^{-1} \) | \( T \) (K) | \( p \) (MPa) | \( \lambda \) mW/(mK)\(^{-1} \) | \( T \) (K) | \( p \) (MPa) | \( \lambda \) mW/(mK)\(^{-1} \) |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 306.03          | 0.125           | 13.49           | 351.29          | 0.492           | 17.15           | 398.19          | 0.318           | 21.05           |
| 305.99          | 0.168           | 13.56           | 351.31          | 0.697           | 17.36           | 396.71          | 0.347           | 20.83           |
| 305.70          | 0.341           | 13.82           | 351.36          | 0.962           | 17.63           | 396.85          | 0.468           | 20.91           |
| 306.05          | 0.415           | 13.82           | 351.31          | 1.244           | 17.97           | 396.78          | 0.603           | 21.04           |
| 306.07          | 0.537           | 13.99           | 351.28          | 1.479           | 18.27           | 396.82          | 0.631           | 21.00           |
| 305.76          | 0.568           | 14.12           | 351.26          | 1.722           | 18.62           | 396.87          | 0.885           | 21.21           |
| 305.76          | 0.823           | 14.51           | 368.25          | 0.123           | 18.27           | 396.82          | 1.219           | 21.47           |
| 305.74          | 0.968           | 14.80           | 368.25          | 0.300           | 18.40           | 396.74          | 1.370           | 21.62           |
| 323.60          | 0.152           | 14.66           | 368.26          | 0.502           | 18.56           | 396.72          | 1.650           | 21.88           |
| 323.55          | 0.301           | 14.87           | 368.25          | 0.795           | 18.80           | 411.21          | 0.129           | 22.07           |
| 323.49          | 0.548           | 15.15           | 368.09          | 1.074           | 19.02           | 411.24          | 0.299           | 22.20           |
| 322.83          | 0.709           | 15.45           | 368.04          | 1.348           | 19.27           | 411.21          | 0.400           | 22.28           |
| 322.83          | 0.887           | 15.68           | 368.01          | 1.604           | 19.56           | 411.24          | 0.662           | 22.46           |
| 322.83          | 1.085           | 16.01           | 368.01          | 1.695           | 19.68           | 411.29          | 0.969           | 22.67           |
| 322.92          | 1.234           | 16.23           | 368.06          | 1.697           | 19.69           | 411.24          | 1.090           | 22.77           |
| 322.84          | 1.507           | 16.80           | 381.18          | 0.123           | 19.33           | 422.24          | 1.316           | 22.93           |
| 322.82          | 1.683           | 17.22           | 381.21          | 0.264           | 19.43           | 421.25          | 1.561           | 23.15           |
| 335.20          | 0.153           | 15.56           | 380.99          | 0.304           | 19.52           | 428.91          | 0.123           | 23.55           |
| 335.09          | 0.282           | 15.71           | 381.01          | 0.455           | 19.55           | 426.63          | 0.125           | 23.34           |
| 335.05          | 0.524           | 15.99           | 380.96          | 0.643           | 19.76           | 429.00          | 0.284           | 23.65           |
| 335.05          | 0.705           | 16.26           | 381.01          | 0.835           | 19.90           | 429.15          | 0.53            | 23.80           |
| 335.06          | 0.870           | 16.35           | 381.00          | 1.020           | 20.07           | 429.26          | 0.790           | 23.99           |
| 335.14          | 1.014           | 16.53           | 380.97          | 1.212           | 20.32           | 429.33          | 1.146           | 24.49           |
| 335.13          | 1.265           | 16.90           | 381.07          | 1.427           | 20.42           | 429.48          | 1.298           | 24.39           |
| 335.10          | 1.545           | 17.32           | 381.03          | 1.764           | 20.78           | 429.16          | 1.417           | 24.50           |
| 335.11          | 1.776           | 17.76           | 381.06          | 1.831           | 20.85           | 429.21          | 1.703           | 24.69           |
| 351.39          | 0.128           | 16.81           | 396.77          | 0.135           | 20.66           | 20.66           | 20.66           | 20.66           |
| 351.34          | 0.310           | 16.97           | 398.18          | 0.151           | 20.93           | 20.93           | 20.93           | 20.93           |
To approximate the measurement results an empirical relationship between thermal conductivity and pressure-temperature was used [2, 3]:

$$\lambda(T, p) = a_0 + a_{10} \frac{T}{100} + a_{20} \frac{T}{100} + p\left(a_{11} \frac{T}{100} + a_{21} \frac{100}{T}\right) + p^2\left(a_{12} \frac{T}{100} + a_{22} \frac{100}{T}\right).$$

(1)

where $T$ is the temperature in K, $p$ is the pressure in MPa, and $\lambda$ is the thermal conductivity in mW(m K)$^{-1}$. The values of the $a_{ij}$ coefficients are summarized in table 2. The standard deviation of the obtained experimental data from equation (1) is within 0.5%.

| Coefficient indices, $ij$ | 0   | 10  | 20  | 11  | 21  | 12  | 22  |
|--------------------------|-----|-----|-----|-----|-----|-----|-----|
| Coefficient value, $a_{ij}$ | -48.290 | 13.240 | 64.782 | -0.046 | 3.822 | -0.138 | 2.212 |

The experimental thermal conductivity values are illustrated in figure 1. These data are smoothed along the isotherm. Also, data fitted according to equation (1) are shown by lines in figure 1. The thermal conductivity of the mixture under study increases linearly along isotherms with the increase in pressure, as indicated by figure 1.

![Figure 1. The thermal conductivity of binary mixture R-32/R-125 (75/25) vapors. The points are the experimental values; the lines correspond to equation (1).](image)

**Figure 1.** The thermal conductivity of binary mixture R-32/R-125 (75/25) vapors. The points are the experimental values; the lines correspond to equation (1).

In the discussions that follow, the calculations based on the experimental data are done. The thermal conductivity on the condensation line ($\lambda_d$) initially was determined. The calculations were performed in two ways. In the first, the thermal conductivity of the vapors of the R-32/R-125 (75/25) mixture on isotherms was extrapolated to the pressure on the condensation line. In the second method, the calculations were performed according to the generalizing equation (1). The missing dew line pressure data were taken from [4]. A comparison of the calculations with the two methods mentioned above showed that the values coincide within the random error of 0.07-1.6% for $\lambda_d$. Similar calculations for thermal conductivity in an ideal gas state ($\lambda_0$, at a pressure $p_0 = 0.101325$ MPa)
showed discrepancies from 0.03 to 0.95%. To ensure uniformity of the description of properties in the entire range of parameters, the second calculation method was chosen.

The \( \lambda_d \) values were approximated by the following temperature dependence

\[
\lambda_d = b_1 + b_2 T + b_3 T^2 ,
\]

where \( b_1 = 84.239, b_2 = -0.601, b_3 = 0.00125 \).

### Table 3. Thermal conductivity of R-32/R-125 (75/25) on the dew line.

| T (K) | \( p_d \) (MPa) | \( \lambda_d \) mW(mK)\(^{-1} \) |
|-------|------------------|-----------------------------|
| 300   | 1.770            | 16.04                       |
| 305   | 2.015            | 16.81                       |
| 310   | 2.285            | 17.63                       |
| 315   | 2.582            | 18.52                       |
| 320   | 2.907            | 19.48                       |
| 325   | 3.263            | 20.49                       |
| 330   | 3.652            | 21.57                       |
| 335   | 4.077            | 22.71                       |
| 340   | 4.541            | 23.91                       |
| 345   | 5.051            | 25.17                       |

For \( \lambda_0 \), the following relation was obtained from equation (1)

\[
\lambda_0 = c_1 + c_2 T + c_3 / T ,
\]

where \( c_1 = -48.290, c_2 = 0.1323, c_3 = 6519.2 \). Additionally, calculations of the thermal conductivity in ideal gas were carried out in the additive approximation. For this, we used the \( \lambda_0 \) values for pure components from [4]. The relative discrepancies between the calculated values \( \lambda_0 \) for the mixture under study and the experimental ones are within 0.1-2.9%.

### 4. Conclusions

Experimental thermal conductivity data of binary mixture R-32/R-125 (75/25) in the vapor state within the temperature range of 305-426 K and the pressure range of 0.1-1.8 MPa have been obtained for the first time, and the measurement errors have been estimated. It was found that the generalized equation (1) is adequate for calculating the thermal conductivity of an R-32/R-125 (75/25) mixture within a wide range of the state parameters: from ideal gas to the dew line.

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