Thermal conductivity investigation of R-227ea/R-134A (45/55) mixture in the vapor phase

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Abstract. Thermal conductivity of the gaseous R-227ea/R-134A (45/55) mixture was investigated by the coaxial cylinders method within the temperature range of 306–426 K and the pressure range of 0.1–1.6 MPa. Approximating dependence of thermal conductivity on pressure and temperature was obtained. Thermal conductivity on dew line and in ideal gas state was calculated.

1. Introduction
Presently, fluorohydrocarbons (HFC) have replaced fluorchlorine-containing hydrocarbons (HCIFC); the latter should gradually go out of use. To replace the forbidden chlorine-containing refrigerants, the search for and the development of the new mixtures have been undertaken. The relevance of new mixtures developing and their thermal conductivity studying is grounded by the continuous search for compositions with the optimal combination of high efficiency, availability, environmental safety and ease of use. For the active and large-scale implementation of the new mixtures, the exact thermophysical properties of such systems should be known.

In the present work a mixture of 45 mass % of 1,1,1,2,3,3,3-heptaffluoropropane, C₃HF₇ (R-227ea), and 55 mass % of 1,1,1,2-tetrafluorethane, C₂HF₄ (R-134a) is proposed; the mixture belongs to the ozone-safety refrigerant group with the ozone depletion potential ODP = 0. The values of the thermal conductivity in the vapor phase were experimentally obtained and the temperature dependence of the thermal conductivity in the ideal-gas state and on the dew line was calculated.

2. Experiments
The mixture was prepared by the weight technique; the limit weighing error was 0.1 g. The following refrigerant samples were applied: R-227ea produced by the “Prikladnaya Khimiya” (Applied Chemistry) Russian Research Center, 99.99% pure; and R-134a produced by Forane, France, 99.9% pure.

To measure the thermal conductivity of the mixture the stationary method of coaxial cylinders was used. The measurement technique and the experiment procedure are described in detail in [1–3]. The measuring cell consisted of two vertical coaxial nickel cylinders: the external, 140 mm long, and the internal, 101.3 mm. The width of the annular gap between the cylinders was equal to 0.366 ± 0.005 mm. To measure the temperature of the cylinders and the temperature difference between them copper–constantan thermocouples were used. The influence of the free ends on the thermal conductivity values was accounted by introducing the respective corrections [1]. The setup was calibrated against 99.998 vol. % pure argon. The divergence from the reference data was within 1%.
Before the experiment, the setup was vacuumed up to a pressure of 150–225 μPa. To avoid variations in the mixture composition, the measuring cell was filled up from the liquid phase. [2]. The error of the experimental data on the thermal conductivity was equal to 1.5–2.5%, while that on the temperature was 0.05 K and that on the pressure was within 4 kPa.

3. Results
R-227ea–R-134a mixture was investigated within temperature ranges of 306–426 K and pressure ranges of 0.1–1.6 MPa along seven quasi-isotherms. Table 1 presents the experimental thermal conductivity values.

| $T$, K | $p$, MPa | $\lambda$, mW/(mK) | $T$, K | $p$, MPa | $\lambda$, mW/(mK) |
|--------|----------|---------------------|--------|----------|---------------------|
| 306.83 | 0.129    | 13.45               | 366.79 | 1.263    | 19.38              |
| 306.21 | 0.330    | 13.70               | 386.29 | 0.133    | 19.50              |
| 306.72 | 0.749    | 14.46               | 386.46 | 0.321    | 19.70              |
| 324.23 | 0.136    | 14.85               | 386.26 | 0.584    | 19.95              |
| 324.23 | 0.396    | 15.13               | 386.10 | 0.909    | 20.35              |
| 324.15 | 0.678    | 15.56               | 386.23 | 1.122    | 20.55              |
| 323.68 | 1.132    | 16.58               | 386.14 | 1.326    | 20.84              |
| 326.19 | 1.324    | 17.20               | 386.14 | 1.326    | 20.85              |
| 350.60 | 0.174    | 16.81               | 407.95 | 0.106    | 21.26              |
| 350.66 | 0.204    | 16.91               | 407.88 | 0.407    | 21.52              |
| 350.62 | 0.346    | 17.03               | 407.27 | 0.635    | 21.71              |
| 350.64 | 0.609    | 17.23               | 407.44 | 0.956    | 22.04              |
| 350.56 | 1.191    | 18.15               | 407.76 | 1.093    | 22.19              |
| 350.52 | 1.517    | 18.88               | 407.69 | 1.339    | 22.43              |
| 350.58 | 1.548    | 18.95               | 425.98 | 0.112    | 22.73              |
| 346.09 | 1.610    | 19.01               | 426.03 | 0.372    | 22.99              |
| 367.78 | 0.196    | 18.11               | 426.31 | 0.583    | 23.14              |
| 366.94 | 0.413    | 18.38               | 426.26 | 0.873    | 23.38              |
| 366.97 | 0.672    | 18.64               | 426.25 | 1.046    | 23.47              |
| 366.88 | 0.974    | 19.00               | 426.04 | 1.338    | 23.83              |

The measurement results were approximated by the empirical dependency [2, 3]:

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

(1)

where $T$ is the temperature in K, $p$ is the pressure in MPa, and $\lambda$ is in mW/(m K). The values of the $a_{ij}$ parameters are presented in table 2. The standard deviation of the obtained experimental data from those smoothed fitted according to equation (1) is within 0.4 %.

| Coefficient indices, $ij$ | 0   | 10  | 20  | 11  | 21  | 12  | 22  |
|--------------------------|-----|-----|-----|-----|-----|-----|-----|
| Coefficient value, $a_{ij}$ | -25.617 | 9.844 | 27.086 | 0.0958 | 1.797 | -0.307 | 5.379 |
Figure 1 shows the experimental data reduced to the same temperatures (isotherms) and fitted according to equation (1). It should be noted that the thermal conductivity of the investigated mixture along the isotherms increases in fact linearly with the pressure increase.

The thermal conductivity on the condensation line, \( \lambda_d \), and the ideal-gas thermal conductivity, \( \lambda_0 \) (at \( p_0 = 0.101325 \) MPa), were calculated by two methods: by extrapolating isotherms of the thermal conductivity of R-227ea–R-134a (45/55) vapor to the dew line and by calculation according to the generalizing equation (1). The data on the vapor pressure on the condensation line were taken from [4]. The comparison shows that the thermal conductivity values obtained using these two methods coincide within the limits of random error of 0.4–2.3% for the \( \lambda_d \) and 0.03–0.75% for the \( \lambda_0 \). Hereafter, in order to maintain the uniformity of the description of the properties within the whole parameter range the second calculation method was selected. The calculated \( \lambda_d \) values are approximated by the dependence

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

where \( b_1 = 54.272 \), \( b_2 = -0.3696 \), \( b_3 = 7.833 \times 10^{-4} \). The values of the vapor pressure and the thermal conductivity on the dew line are given in table 3.

Table 3. R-227ea–R-134a (45/55) thermal conductivity on the dew line.

|   |   |   |
|---|---|---|
|   |   |   |
| T, K | \( p_{dl} \), MPa | \( \lambda_{dl} \), mW/(mK) |
| 300 | 0.6490 | 13.89 |
| 310 | 0.8616 | 14.97 |
| 320 | 1.1225 | 16.20 |
| 330 | 1.4385 | 17.59 |
| 340 | 1.8171 | 19.15 |
| 350 | 2.2670 | 20.87 |
| 360 | 2.7990 | 22.75 |
For $\lambda_0$, from equation (1), the following dependence was obtained

$$\lambda_0 = c_1 + c_2 T + c_3 / T,$$

where $c_1 = -25.617$, $c_2 = 0.0985$, $c_3 = 2732.3$. Figure 2 shows thermal conductivity of R-227ea–R-134a (45/55) mixture in ideal-gas state.

The $\lambda_0$ value for the investigated mixture was calculated in the additive approximation on the basis of the experimental data according to the ideal-gas thermal conductivity of the pure components, R-227ea [1] and R-134a [4] (figure 2). The relative discrepancies between the calculated values and the experimental ones are within 0.1–1.7%.

4. Conclusions

The experimental data of the R-227ea–R-134a (45/55) refrigerant thermal conductivity in the vapor state within the temperature range of 306–426 K and the pressure range of 0.1–1.6 MPa have been obtained, and the measurement errors have been estimated. It has been found that the approximating equation (1) describes thermal conductivity of R-227ea–R-134a (45/55) mixture in a wide range of the state parameters: from ideal gas up to dew line.

References

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