

Viscosity of R134a, R32, and R125 at Saturation

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This paper reports the results of the measurement of the viscosity of R134a close to the saturation line in the vapor phase. The new measurements were carried out in a vibrating-wire viscometer specially constructed for the purpose, and the results have an accuracy of $\pm 2\%$. In addition, the opportunity is taken to present a reevaluation of earlier measurements along the saturation line of the viscosity of R32 and R125. Improved equations of state for these fluids are now available and can be employed to generate improved values for the viscosity.

KEY WORDS: R134a; R32; R125; refrigerants; vibrating-wire viscometer; viscosity.

1. INTRODUCTION

There have been a number of measurements of the viscosity of the liquid and vapor phases of refrigerants less damaging to the environment in the last 8 years. The most recent summary of the data for R134a was prepared by Laesecke [1] in cooperation with the Subcommittee on Transport Properties of IUPAC Commission I.2. Among these measurements there remain some discrepancies between the results of various authors which lie outside of the bounds of mutual uncertainty. Moreover, while there are many measurements of the viscosity in the liquid phase at saturation, there are fewer results in the saturated vapor phase. For these reasons we have performed new measurements of the viscosity of R134a in the saturated

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vapor phase and we report them here for the temperature range 242 to 343 K.

We have previously reported viscosity data in the saturated vapor of R32 and R125 [2] carried out with an instrument similar to that employed here for R134a. At the time of these early measurements the equations of state available for the two fluids were not very reliable, being based upon scant experimental data. Since that time, much more accurate equations of state of R32 and R125 [3] have been produced. These new equations of state yield densities at saturation, in the range of temperatures of interest, that differ by up to 5% from those calculated earlier. Since the density of the fluid enters directly into the working equation for the evaluation of the viscosity, it follows that there must have been systematic errors introduced into the viscosity data previously reported. We have therefore recalculated our earlier results for the viscosity of R32 and R125 from the original raw data using modern equations of state for the density, and we report the results here.

2. EXPERIMENTAL

The measurements have been carried out in the vibrating-wire viscometer described in detail elsewhere [2]. The vibrating wire was made from tungsten, with a diameter of $7.2\text{ }\mu\text{m}$. Saturation conditions in the vapor phase were achieved by means of a pool of liquid refrigerant formed below the vibrating-wire assembly inside the pressure vessel. Saturated vapor conditions could not be maintained within the entire pressure vessel because of the need to maintain a positive temperature gradient upward in the vessel in order to suppress natural convection. Although this gradient never led to a difference of more than 0.5 K over the length of the vessel, it means that the measurements were conducted near the saturation line rather than on it. The effect upon the viscosity of the consequent change in the density is negligible, but there is a direct uncertainty of $\pm 0.2\text{ K}$ in the temperature at which the measurement was conducted and, therefore, an uncertainty of $\pm 0.4\%$ in the saturated vapor density. The vapor pressure of the sample was measured continuously for a comparison with independent values, while the temperature was measured with a precision of $\pm 0.1\text{ K}$ by mean of a platinum resistance thermometer. The samples of the refrigerants were supplied by ICI Chemicals and Polymers Ltd. The sample of R134a was that employed for a special round-robin test [4], and the samples of R32 and R125 had a purity in excess of 99.9%, which was confirmed after the measurements.

The viscometer was calibrated to determine the wire radius with the aid of measurements of the viscosity of nitrogen and helium at two temperatures

using the viscosity data of Kestin et al. [5, 6] and the density from the equations of state recommended by IUPAC [7, 8]. The calibration did not account for the surface roughness of the wire or for any magnetic damping in the manner recently reported by Vogel et al. [9]. For these reasons, whereas the precision of the viscosity measurements is still of the order of $\pm 0.5\%$, it seems prudent to be more conservative in the claimed accuracy and to ascribe a figure of $\pm 2\%$ to it.

The analysis of the viscosity measurements on R134a was carried out with the equation of state proposed by Saltoh et al. [10]. For the conditions of interest, this yields density values negligibly different from those using the recent equation of Tillner-Roth et al. [11].

For R32 and R125 the density required in order to evaluate the viscosity has now been taken from the equation of state of McLinden et al. [3] and the density has an uncertainty of $\pm 0.5\%$ near saturation.

3. RESULTS

Tables I, II, and III report the viscosity data for R134a, R32, and R125 respectively, in the temperature range of 223 to 343 K. In the case of R134a the results are presented here for the first time. For R32 and R125 the data contained in the tables were recalculated from our original results using the newer and more accurate values for the density. For R32 the differences in the density near saturation between the previous data and those

Table I. Viscosity of R134a in the Vapor Phase, Near Saturation

Temperature T (K)	Pressure P (MPa)	Density ρ ($\text{kg} \cdot \text{m}^{-3}$)	Viscosity η ($\mu\text{Pa} \cdot \text{s}$)
242.96	0.084	4.42	10.4
251.44	0.120	6.14	10.6
258.26	0.159	8.00	10.8
263.74	0.185	9.32	11.0
266.95	0.224	11.08	11.1
273.43	0.287	14.05	11.3
283.26	0.409	19.83	11.6
283.29	0.409	19.83	11.6
298.06	0.652	31.46	12.2
303.32	0.758	36.62	12.4
313.12	0.985	47.90	12.9
323.06	1.290	64.17	13.4
332.40	1.631	83.75	13.9
342.77	2.071	111.60	14.6

Table II. Viscosity of R32 in the Vapor Phase, Near Saturation

Temperature T (K)	Pressure P (MPa)	Density ρ ($\text{kg} \cdot \text{m}^{-3}$)	Viscosity η ($\mu\text{Pa} \cdot \text{s}$)
223.17	0.136	4.04	10.3
238.87	0.259	7.38	10.4
251.88	0.416	11.57	10.7
268.68	0.705	19.18	11.2
273.50	0.798	21.61	11.4
278.81	0.899	24.10	11.7
292.81	1.411	38.68	12.3
297.97	1.555	42.48	12.6
303.11	1.914	54.25	13.0
313.25	2.489	73.67	13.8
323.05	3.158	99.44	14.6
335.13	4.047	140.64	16.0
343.23	4.849	194.43	17.1

now employed exceed 5% in some cases and are frequently large. For R125 the situation is not quite so extreme, but even so, differences of about 2% in the density arise. Naturally, these density differences produce a large change in the viscosity values derived from the measurements. The new values listed in Tables II and III therefore supersede those provided earlier [2]. In extreme cases, the changes in the value of the viscosity amount to $\pm 3\%$.

Table III. Viscosity of R125 in the Vapor Phase, Near Saturation

Temperature T (K)	Pressure P (MPa)	Density ρ ($\text{kg} \cdot \text{m}^{-3}$)	Viscosity η ($\mu\text{Pa} \cdot \text{s}$)
223.99	0.108	7.28	10.1
232.44	0.143	9.38	10.3
244.04	0.250	16.01	10.8
253.66	0.330	20.80	11.2
263.23	0.473	29.67	11.7
273.48	0.675	42.51	12.2
284.24	0.968	62.19	12.9
293.61	1.208	78.23	13.5
298.11	1.413	93.91	13.9
303.24	1.579	106.10	14.3
313.45	2.026	143.48	15.4
323.18	2.424	180.73	16.5
331.99	2.913	244.26	17.7

4. COMPARISONS

4.1. R134a

The transport properties of R134a were the subject of an early review by Krauss et al. [12]. That review and subsequent analysis of the data revealed discrepancies of a major kind between various sets that were beyond estimated experimental uncertainties. As a result, based upon the hypothesis that purity of the samples was the source of the difficulty, a round-robin test [4] using a single sample of the material was organized in which measurements of the viscosity were made in a number of independent laboratories. This test led to improved agreement among the results of the new experiments and generated a much larger body of data. Thus, it has now been deemed appropriate to prepare a revised representation of the transport properties of R134a [1]. This most recent survey confirms that the present results form the only set of information below a temperature of 273 K in the vapor phase and that they are part of a rather small group of results for saturation conditions at any temperature. They, therefore, make a significant contribution to the available experimental information.

In this paper it is not our intention to produce a revised correlation for the viscosity of R134a. Thus, we simply present in Fig. 1 a plot of the viscosity of R134a as a function of the density along the isotherms covered in the present work for which there are other independent measurements. We include the measurements of Nabizadeh and Mayinger [13] with an oscillating disk viscometer, Assael and Polimatidou [14] with a vibrating-wire viscometer, Vogel and Wilhelm [15] with an oscillating-disk viscometer, and Dowdell and Mathews [16] with a capillary viscometer. We omit the results of Takahashi et al., since they are significantly different from all other results [4]. The figure also contains the results of the empirical correlation developed by Krauss et al. [12] for the range of conditions for which it is valid.

It can be seen from Fig. 1 that the data within the region between the low density limit and saturation is rather scarce. Thus, whereas the data of Vogel and Wilhelm indicate a negative first density coefficient of viscosity at low temperatures, there are few data that overlap that region and the viscosity at higher densities generally increases with density at any temperature. At the level of ± 2 to 4%, all of the data contained in Fig. 1 for the viscosity of R134a in the vapor phase are mutually consistent. Closer inspection within this difference is only possible by linear interpolation of our data to intermediate temperatures. The open symbols in Fig. 1 represent the results of this process. It can be seen that the results of Assael et

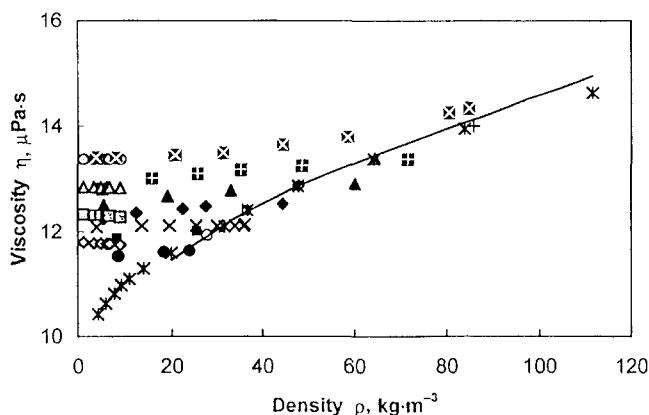


Fig. 1. Viscosity of R134a in the vapor phase, near saturation, as a function of density. *, This work; —, Krauss et al. correlation [12]; Assael et al. [14] (●, $T=293.15$ K; ■, $T=303.15$ K; ◆, $T=313.15$ K; ▲, $T=323.15$ K; ■, $T=333.15$ K); Nabizadeh et al. [13] (×, $T=303.15$ K; ✕, $T=313.15$ K); Vogel et al. [15] (◇, $T=297.48$ K; □, $T=310.95$ K; △, $T=324.79$ K; ○, $T=338.73$ K; ▼, Dowdell and Mathews [16]. The open symbols (○, □, ◇, △, and +) represent our data at the temperatures used by Assael et al. [14]; these data were obtained by linear interpolation of the present experimental data.

al. [14] at saturation are always below the present results by a few percent. There is no obvious explanation for these discrepancies.

4.2. R32

Figure 2 contains a plot of the vapor phase viscosity of R32 as described in this work near saturation together with the results of other workers [17]. In this case it can be seen that the data are even scarcer. They are, however, no less consistent now that our earlier measurements have been recalculated with better density data.

4.3. R125

Figure 3 contains a plot of the viscosity of R125 near saturation as a function of density. As well as the present results, we include those of Assael and Polimatidou [14]. It can be seen that the amount of data is really very small. The figure again shows the mutual consistency of the two sets of data. It should be noted that this conclusion contrasts with the conclusion of Assael et al. reported earlier. It has been verified that the

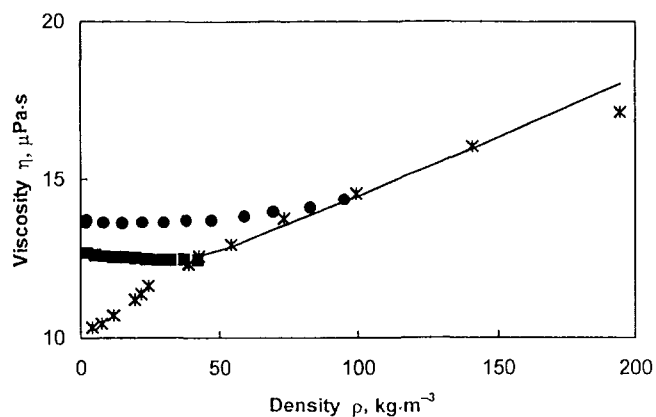


Fig. 2. Viscosity of R32, in the vapor phase, near saturation, as a function of density. *, This work; Takahashi et al. [17] (—, proposed correlation; ■, $T = 298.15$ K; ●, $T = 323.15$ K).

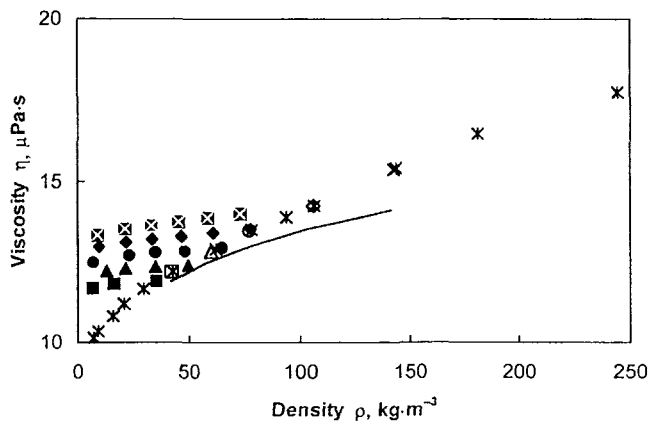


Fig. 3. Viscosity of R125 in the vapor phase, near saturation, as a function of density. *, This work; Assael et al. [14] (■, $T = 273.15$ K; ▲, $T = 283.15$ K; ●, $T = 293.15$ K; ◆, $T = 303.15$ K; ◻, $T = 313.15$ K; —, proposed extrapolation to the saturation line). The open symbols (○, □, ◇, △, and ×) represent our data at the temperatures of Assael et al. [14]; these data were obtained by linear interpolation of the present experimental data.

apparent discrepancy between the two sets of vibrating-wire viscosity data reported earlier [2, 14] arises from two different sources. First, in our earlier work, we were forced to use inaccurate density data. Second, the density extrapolation of the data of Assael et al. [14] to saturation in order to permit the comparison was probably too simplistic. Figure 3 reveals significant differences between the values derived earlier for saturation for the viscosity of R125 and those reported here. On the other hand, Fig. 3 shows that the interpolation of the present results at saturation for the temperatures employed by Assael et al. [14] indicates that, in reality, the agreement is rather good (within a few percent), although again the results of Assael et al. [14] are systematically below the present results.

5. CONCLUSIONS

The measurements reported here for the viscosity of R134a, R32, and R125 in the vapor phase near saturation add to the data for these fluids in a region where few other results exist. It is hoped that the data will aid the formulation of new correlations of the transport properties of these fluids.

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