Viscosity of Isobutane

MARIO H. GONZALEZ and ANTHONY L. LEE
Institute of Gas Technology, Chicago, Ill.

Experimental viscosity data for isobutane are presented for temperatures from 100° to 340° F. and pressures from 100 to 8000 p.s.i.a. Experimental density values are reported for temperatures from 100° to 340° F. at 8000 p.s.i.a. The method for correlating the data is discussed, and the data are compared with literature values. A table of recommended viscosity values is presented.

DATA on the effects of temperature and pressure on the viscosity of isomeric paraffins are scarce. The effects of temperature on the viscosity of these compounds have been noted by Evans (*3*), Lambert *et al.* (*7*), Lipkin, Davidson, and Kurtz (*10*), Titani (*15*), Ishida (*6*), and Sage, Yale, and Lacey (*12*). The only data that report the pressure effect on viscosity are those presented by Sage, Yale, and Lacey (*12*) for the isobutane system.

Extensive study has been carried out on the viscosity of normal paraffins up to 10 carbons in chain length and for some of their binary mixtures (*8*). The study of the isomers of these hydrocarbons could be critical in the determination of the molecular configuration dependence of viscosity. This dependence appears to be an important factor in the behavior of mixtures of compounds with completely dissimilar configurations, as in the methane–*n*-decane system (*5,8*).

This paper presents experimental and recommended values for isobutane at temperatures from 100° to 460° F. and pressures from atmospheric to 8000 p.s.i.a. Experimental density data are reported for temperatures from 100° to 340° F. at 8000 p.s.i.a.

APPARATUS AND MATERIALS

The instrument used is a modified version of one described previously (*4*). A magnetically driven mixing pump and stainless steel pycnometers for density determinations have been added to the system.

The isobutane is a Phillips Petroleum Co. pure grade. Mass spectrometric analysis showed a composition of 99.7% *iso*-C_4, 0.2% N_2, and 0.1% O_2.

EXPERIMENTAL DATA

Most of the experimental data were obtained for the liquid phase, as only two of the isotherms investigated were above the critical temperature of isobutane. The determinations at 160° and 220° F. were extended to the saturated liquid locus. Isobars of viscosity are presented in Figure 1, and a cross-plot of viscosity *vs.* pressure is shown in Figure 2. The reported values are believed to be within ±1% of the true isobutane viscosity values at the 95% level of confidence (*5*).

The residual correlation represented all data satisfactorily. The determinations for the 100° and 160° F. isotherms were carried up to 8000 p.s.i.a., which defined the high-density section of the residual curve. The other isotherms were then studied only to the extent of defining the remaining section of the curve. Density values by Sage and Lacey (*11*) were used for pressures up to their highest reported values of 5000 p.s.i.a. To extend the residual correlation of all isotherms to 8000 p.s.i.a., density values were determined at these conditions. Table I presents the experimental

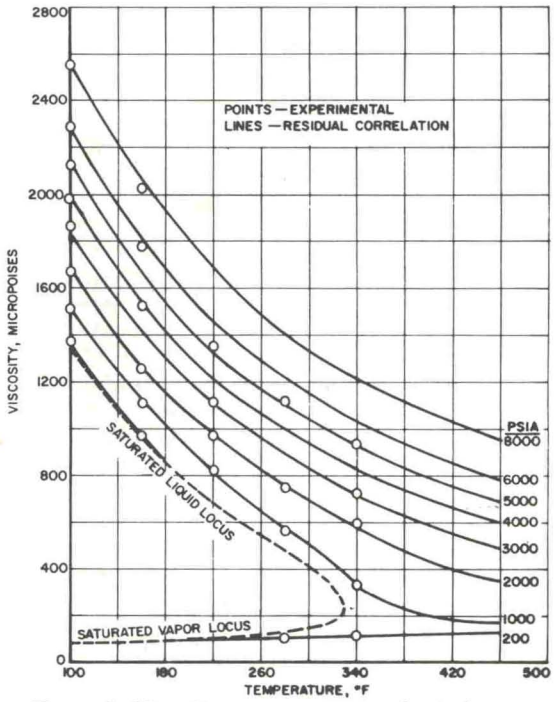

Figure 1. Viscosity *vs.* temperature for isobutane

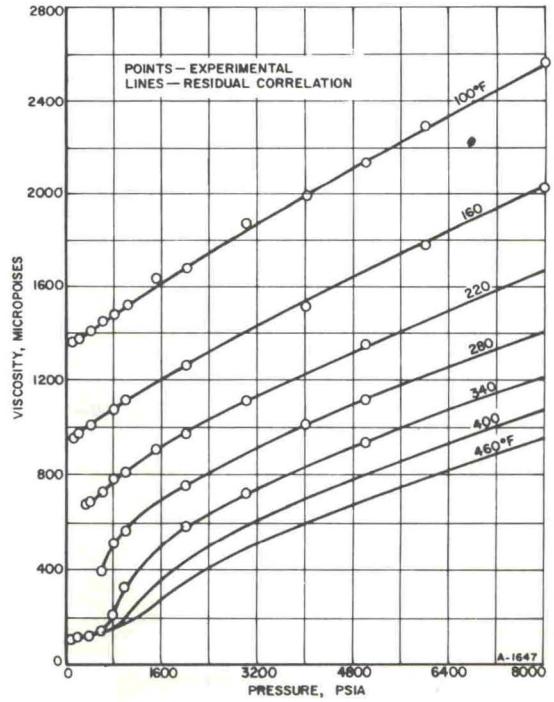

Figure 2. Viscosity *vs.* pressure for isobutane

density values obtained. The standard deviation of the experimental density values was ±1.6%.

Detailed tables of experimental data have been prepared and are available from ADI.

COMPARISON WITH LITERATURE

The only available data on the viscosity behavior of isobutane for the range of temperatures and pressures studied in this paper are those reported by Sage, Yale, and Lacey (*12*). These authors reported data for isobutane for temperatures from 100° to 220° F. and pressures from atmospheric to 2000 p.s.i.a. which are consistently lower than those obtained in this investigation. Data are compared in Figure 3.

Values of isobutane viscosity were calculated with the equation proposed by Lee *et al.* (*9*), using the density data of Sage and Lacey. The resulting values had a standard deviation of −9% from the experimental points. This indicates a configuration effect which is not taken into consideration by the formula. This effect has been analyzed by the authors.

A survey of the literature shows that the reported values of the viscosity of isobutane at atmospheric pressure vary widely among authors. Data presented by Lambert *et al.* (*7*), the Thermophysical Properties Research Center "Data Book" (*14*), Sage *et al.* (*12*), Svehla (*13*), and values calculated with the equation of Lee *et al.* (*9*) were plotted. The μ_0 values used in the residual correlation were obtained from a least squares fit of the experimental data to Sutherland's equation. The small curvature of the calculated values at low temperatures was neglected since its effect on the recommended values was on the order of ±0.1%. The values used and the experimental data are shown in Figure 4.

Table I. Density of Isobutane at 8000 P.S.I.A.

Temp., ° F.	Density, G./Cc.
100	0.6126
160	0.5882
220	0.5695
280	0.5451
340	0.5192

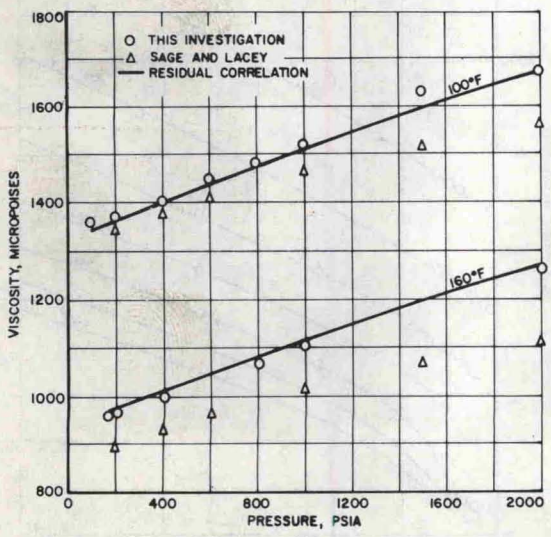

Figure 3. Comparison of viscosity values of isobutane

CORRELATION

The problem of predicting viscosity values that would agree with the experimental results, and for temperatures and pressures outside the range of experimental investigation, was solved by the correlation based on the residual viscosity concept (*1*). This correlation is defined as the difference between viscosity of a given pressure and temperature and μ_0, the viscosity at 1 atm. and the same temperature, plotted against the density corresponding to the given temperature and pressure. The residual viscosity concept has been discussed in detail (*1,2*) and has predicted the viscosity of a number of materials which include the normal paraffins up to decane and at least the isomer reported in this investigation. The residual correlation of the isobutane data is shown in Figure 5.

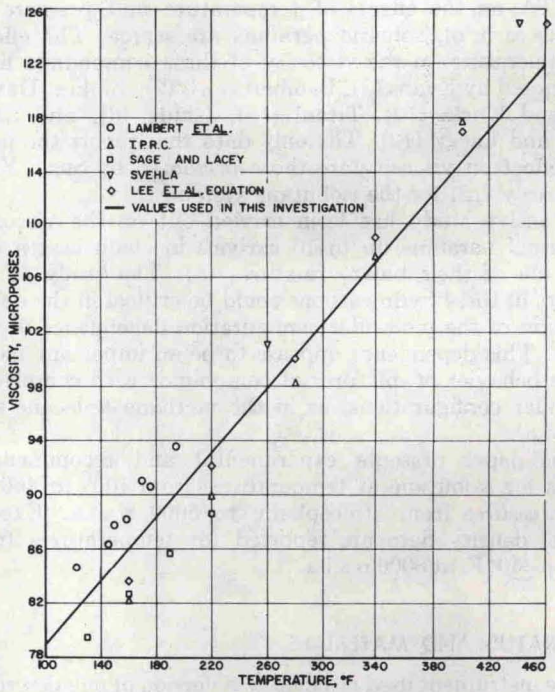

Figure 4. Viscosity of isobutane at atmospheric pressure

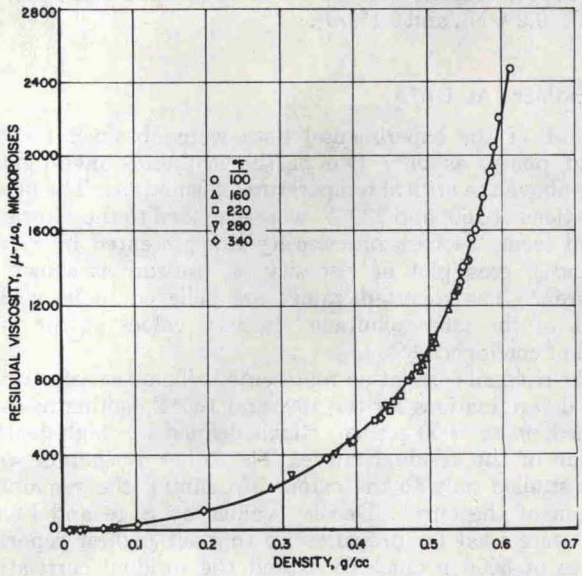

Figure 5. Residual viscosity *vs.* density for isobutane

Table II. Viscosity of Isobutane

Pressure, P.S.I.A.	100° F.		160° F.		220° F.		280° F.		340° F.		400° F.		460° F.	
	Density, g./cc.	Viscosity, micropoises	Density, g./cc.	Viscosity, micropoises	Density, g./cc.	Viscosity, micropoises	Density, g./cc.	Viscosity, micropoises	Density, g./cc.	Viscosity, micropoises	Density, g./cc.	Viscosity, micropoises	Density, g./cc.	Viscosity, micropoises
14.7	0.0023	79	0.0021	86	0.0011	93	0.0017	101	0.0016	108	0.0015	115	0.0014	122
100	0.5378	1343(1358.4)	0.0159	91	0.0139	96	0.0155	106 (106.1)	0.0114	113(115.3)	0.0105	117	0.0097	123
165	...	...	0.4880	971 (959.9)	...	...	...	...	...	...	...	...	...	...
200	0.5397	1362(1368.3)	0.4887	974 (967.0)	0.0314	100	0.0271	107 (106.7)	0.0242	116(118.4)	0.0220	119	0.0201	126
300	0.5416	1379	0.4918	994	0.0570	108	0.0450	111	0.0387	117	0.0345	123	0.0312	129
310	...	...	...	...	0.4218	661 (680.6)	...	...	...	...	...	...	...	...
400	0.5435	1402(1401.7)	0.4950	1014(1002.2)	0.4276	681 (681.4)	0.0692	120 (119.6)	0.0557	123(124.7)	0.0483	127	0.0431	132
500	0.5448	1414	0.4976	1031	0.4346	709	0.1122	139	0.0766	130	0.0638	132	0.0559	136
600	0.5464	1433(1449.3)	0.5003	1048	0.4404	733 (731.9)	0.3117	365 (397.4)	0.1037	142(145.2)	0.0812	138	0.0698	141
800	0.5496	1469(1478.4)	0.5054	1081(1069.5)	0.4506	777 (781.6)	0.3730	509 (508.7)	0.1920	202(210.6)	0.1241	159	0.1009	154
1000	0.5528	1509(1514.1)	0.5099	1116(1106.3)	0.4588	818 (817.6)	0.3927	566 (562.3)	0.2847	322(329.0)	0.1780	197	0.1361	173
1250	0.5565	1549	0.5152	1154	0.4667	857	0.4105	627	0.3279	405	0.2444	268	0.1833	209
1500	0.5598	1594(1629.4)	0.5201	1194	0.4745	902 (901.7)	0.4243	675	0.3582	475(489.2)	0.2882	335	0.2271	254
1750	0.5629	1634	0.5248	1231	0.4811	937	0.4340	716	0.3783	530	0.3204	395	0.2630	302
2000	0.5653	1669(1670.6)	0.5287	1266(1259.0)	0.4884	973 (973.0)	0.4431	755 (755.0)	0.3940	578(586.0)	0.3412	442	0.2909	348
2500	0.5705	1750	0.5366	1341	0.4981	1041	0.4577	819	0.4160	653	0.3724	521	0.3299	423
3000	0.5754	1829(1860.5)	0.5432	1401	0.5068	1107(1107.0)	0.4700	883	0.4322	716(721.6)	0.3945	586	0.3582	490
3500	0.5804	1919	0.5489	1466	0.5149	1161	0.4806	941	0.4450	768	0.4105	641	0.3791	547
4000	0.5852	1999(1983.1)	0.5542	1533(1518.4)	0.5222	1217	0.4905	1001(1008.0)	0.4575	826	0.4251	695	0.3955	597
4500	0.5889	2074	0.5595	1598	0.5293	1274	0.4989	1055	0.4681	879	0.4381	747	0.4092	642
5000	0.5926	2142(2125.8)	0.5639	1660	0.5350	1333(1344.8)	0.5065	1111(1117.0)	0.4777	931(936.9)	0.4498	798	0.4220	690
6000	0.5985	2275(2282.5)	0.5720	1784(1774.4)	0.5470	1453	0.5208	1215	0.4944	1034	0.4682	886	0.4430	776
7000	0.6063	2424	0.5795	1910	0.5560	1560	0.5318	1310	0.5057	1108	0.4845	977	0.4616	860
8000	0.6126	2550(2550.4)	0.5860	2030(2021.5)	0.5648	1670	0.5410	1400	0.5192	1208	0.4990	1069	0.4775	946

RECOMMENDED VALUES

Recommended values for viscosity of isobutane for temperatures from 100° to 460° F. and pressures from atmospheric to 8000 p.s.i.a. are presented in Table II, which also shows experimental data in parentheses. The recommended values are believed to be within ±2% of the true isobutane viscosity values over the entire ranges of temperature and pressure reported. These values were determined from smoothed large-scale viscosity-temperature, and residual viscosity–density plots based on the authors' experimental data.

The density values presented in Table II are those of Sage and Lacey for pressures up to 5000 p.s.i.a. The densities for higher pressures were read from large-scale density-pressure plots in which smooth isotherms connecting Sage and Lacey's data and the experimental values at 8000 p.s.i.a. were drawn. The 400° and 460° F. isotherms were extended to 8000 p.s.i.a. with large-scale cross-plots of density-temperature . The resulting densities were checked further by comparing viscosities obtained from the residual plot with those values giving smooth curves in the viscosity-pressure and viscosity-temperature plots. The densities obtained are believed to be within ±5% of true isobutane density values.

ACKNOWLEDGMENT

This investigation was part of a continuing study of hydrocarbon physical and thermodynamic properties under the basic research program of the Institute of Gas Technology. The work was supported in part by IGT members and contributors and in part by the American Petroleum Institute through Project No. 65. R.S. Prokopek and D.C. Chang assisted in the experimental program.

LITERATURE CITED

(1) Brebach, W.J., Thodos, G., *Ind. Eng. Chem.* **50**, 1095–1100 (1958).
(2) Dolan, J.P., Starling, K.E., Lee, A.L., Eakin, B.E., Ellington, R.T., J. CHEM. ENG. DATA **8**, 396–9 (1963).
(3) Evans, E.B., *J. Inst. Petroleum Technol.* **24**, 321–23 (1938).
(4) Feldkirchner, H.L., Lee, A.L., Johnson, J.L., Eakin, B.E., "Novel Laboratory Equipment for Physical Property and Reaction Kinetic Studies," presented at A.I.Ch.E. Meeting, Memphis, Tenn., February 1964.
(5) Gonzalez, M.H., unpublished Master's thesis, Institute of Gas Technology, Chicago, 1966.
(6) Ishida, Y., *Phys. Rev.* **21**, 550–63 (1923).
(7) Lambert, J.D., Cotton, K.J., Pailthorpe, M.W., Robinson, A.M., Scrivins, J., Vale, W.R.F., Young, R.M., *Proc. Roy. Soc. (London)* **A 231**, 380–90 (1955).
(8) Lee, A.L., "Viscosity of Light Hydrocarbons," American Petroleum Institute, New York, 1965.
(9) Lee, A.L., Starling, K.E., Dolan, J.P., Ellington, R.T., *A.I.Ch.E. J.* **10**, 694–97 (1964).
(10) Lipkin, M.R., Davidson, J.A., Kurtz, S.S., *Ind. Eng. Chem.* **34**, 976–8 (1942).
(11) Sage, B.H., Lacey, W.N., "Thermodynamic Properties of the Lighter Paraffin Hydrocarbons and Nitrogen," American Petroleum Institute, New York, 1950.
(12) Sage, B.H., Yale, W.D., Lacey, W.N., *Ind. Eng Chem.* **31**, 223–6 (1939).
(13) Svehla, R.A., *NASA.* **TR R-132**, 119, 1962.
(14) Thermophysical Properties Research Center, "Data Book, Vol. **II**," Table 2057, Purdue University, Lafayette, Ind., 1963.
(15) Titani, T., *Bull. Chem. Soc. Japan* **5**, 98–108 (1930).

RECEIVED for review January 10, 1966. Accepted May 18, 1966. Material supplementary to this article has been deposited as Document number 8919 with the ADI Auxiliary Publications Project, Photoduplication Service, Library of Congress, Washington 25, D. C. A copy may be secured by citing the Document number and by remitting $1.25 for photoprints, or $1.25 for 35-mm. microfilm. Advance payment is required. Make checks or money orders payable to: Chief, Photoduplication Service, Library of Congress.