MEASUREMENTS OF VISCOSITY AND DENSITY OF N-ALKANE AND THEIR MIXTURES

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Abstract

In this study, we present data for viscosity and density of n-alkanes(C_9, C_{10}, C_{11}, C_{12}, C_{13}, C_{15}, C_{20}, C_{24}, C_{28}, C_{32}, C_{36}, C_{40}, C_{44}) and their mixtures (quantitative n-alkane mixtures;C_6-C_{44}, petroleum waxes and polywax). Viscosity (dynamic (η), (kinematic (ν)), rheological properties (shear rate, shear stress) and density (ρ) were measured by Anton Paar SVM 3000 Stabinger Viscometer according to ASTM D7042-04. Viscosity and density measuring values' reproducibilities were 0.28% and 0.02%, respectively. The measuring data were compared with other experimental data; API 42, 44 and Yaws over a wide range of temperatures (293-373 K). The results obtained by this measuring system were highly satisfactory.

Key Words: viscosity and density, n-alkane mixtures, n- paraffin, wax

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1. Introduction

The dynamic viscosity (η) and density (ρ) are very important thermophysical properties in the chemical and petrochemical industries. Petroleum fractions include complex mixtures of acyclic (paraffins or alkanes, isoalkanes, alkenes, isoalkenes) and cyclic (aromatics and naphthalenes) hydrocarbons. This different organic structure of hydrocarbons causes change of some physical (density) and transport (viscosity, thermal conductivity) properties [1-5]. Unfortunately, reliable viscosity data on multicomponent liquid mixtures are very scarce in the literature. Several experimental, predictive and correlative calculation methods for n-alkanes are proposed in the literature [6-18]. Generally, these correlations were used to light hydrocarbon and mixtures. However, these methods may lead to significant errors when they were applied to the heavier compounds. Recently, new empirical correlations about chemical (M) and thermophysical (η,ρ) properties of n-alkanes (C_6-C_{44}) were evaluated by the use of literature data and gas chromatography results. The results obtained with these correlations were compared with API and Yaws experimental data [19-21]. Molecular weight, density and dynamic viscosity predictions were evaluated as average absolute deviations of 0.68, 0.21 and 2.4%, respectively [6].

In this study, we aimed to highly satisfactory measurements of viscosity and density for n-alkanes and their mixtures. N-alkanes were measured as pure in liquid phase at ambient temperature (<C20) but the heavier ones were measured as binary and multicomponent mixtures [18]. The quantitative D2887 calibration mixture containing 17 components in the C_6-C_{44} range was used for gas chromatography calibration in previous work [6].

In the result of our study, we would investigate the changes in thermophysical and chemical properties of n- alkanes and their mixtures.

2. Experimental

2.1 Source of the chemicals

The pure hydrocarbons, qualitative and quantitative mixtures were obtained from various sources. The sources and purities of the materials were as follows: toluene(J.T. Baker; 99.5 wt.%), n-nonane(Merck; 99 wt.%), n-decane(Merck; 99 wt.%), n-undecane(Merck; 99 wt.%), n-dodecane(Fluka; 99.6 wt.%), n-tridecane(Fluka; 99.5 wt.%), n-tetradecane(Merck; 99 wt.%), n-pentadecane(Fluka; 99.8 wt.%), n-octadecane (Merck; 99 wt.%), n-eicosane(Acros; 99 wt.%), n-tetracosane(Merck; 99 wt.%), n-octacosane(Fluka; 99 wt.%), n-dotriacontane(Alfa; 97 wt.%), n-hexatriacontane(Alfa; 97 wt.%), n-tetracontane(Acros; 98 wt.%), n-tetratetracontane(Acros; 98 wt.%), qualitative polywax 1000(Restek), quantitative ASTM D 2887 C_6-C_{44} (Restek), adjustment standard set and certified viscosity standard(Anton Paar ; SH L, M, C, H, D). Three different petroleum wax fractions were obtained from Izmir-Tupras refineries.

2.2 Sample preparations

Heavier n-alkanes(>C_{20}) and their mixtures are include micro and macro crystals. Therefore, heavy n-alkanes were dissoluted in lighter n-alkane. Then the temperature of the wax and solvent mixtures were slowly increased and dissoluted near the dissolution temperature. Analysis temperature was started at this temperature. The concentration of n-alkanes is showed in tables. The purity and concentration of quantitative C_6-C_{44} mixture were given in table 1.

2.3 Viscosity and density measurements

Anton Paar SVM 3000 Stabinger Viscometer operating on the measuring cells are consist of a pair of rotating concentric cylinders and oscillating U-tube according to ASTM D7042-04[22]. The dynamic viscosity is determined from the equilibrium rotational speed of the inner cylinder under the influence of the shear stress of the test specimen and an eddy current brake in conjunction with adjustment data. The density is determined by oscillation frequency of the U-tube in conjunction with adjustment data. The kinematic viscosity is calculated by dividing the dynamic viscosity by the density. Adjustment standard set and certified viscosity standard (Anton Paar; SH L, M, C, H, D) were used to measure the calibration of Anton Paar Stabinger Viscometer SVM 3000. The temperatures were varied in steps of 5/10/20 K in the range between 293 and 373 K. Viscosity and density measuring values' reproducibilities were 0.28% and 0.02%, respectively. Table 2 and 3 show the calibration results for viscosity and density at different temperatures.

3. Results and discussion

Figure 1 illustrates the scatter of n-dodecane for the changes of viscosity and density measurements versus temperature. Figure 2 shows the change in the viscosities of n-alkane mixtures according to density and temperature. It can be observed from the measuring data presented in table 4-5. These data were compared with API 42, 44 and Yaws' experimental data over a wide range of temperatures (293-373 K). Experimental viscosity and density results are as accurate as in following tables.

3. Conclusions

In this paper, viscosity (dynamic (η), (kinematic (ν)), rheological properties (shear rate, shear stress) and density (ρ) were measured by the use of Anton Paar SVM 3000 Stabinger Viscometer of n-alkanes and their binary and multicomponent liquid mixtures. In conclusion, when compared with the other recommended experimental data by API and Yaws, this new measuring data were highly satisfactory.

In the result of our study, we have investigated the changes in thermophysical and chemical properties of n- alkanes and their mixtures in liquid phase.

List of nomenclature, abbreviation and symbols

API	American Petroleum Institute
ASTM	American Society for Testing and Materials
C	Carbon
D	Shear rate (1/s)
T	Temperature (K)

Greek letters

η	Dynamic viscosity (mPa.s)
ν	Kinematic viscosity (mm^2/s)
ρ	Density (kg/m^3)
τ	Shear stress (Pa)

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References:

[1] M. Arıkol, and H. Gürbüz, The Can. J. Chem. Eng., 70(1992)1157-1163.

[2] H. G. Yücel and S. Ozdogan, The Can. J. Chem. Eng., 76(1998)148-155.

[3] S. Ozdogan and H. G. Yücel., Fuel, 79(2000)1209-1214.

[4] S. Ozdogan and H. G. Yücel., Fuel, 80(2001)447-449.

[5] H. G. Yücel, in press Analytica Chimica Acta, 2005.

[6] R. C. Reid, J. M. Prausnitz, and T. K. Sherwood, Mc Graw-Hill, New York, 1987.

[7] W. D. Monnery, W. Y. Svrcek, and A. K. Mehrotra, Can. J. Chem. Eng. 73 (1995) 3.

[8] A.K. Mehrotra, W. D. Monnery, and W. Y. Svrcek, Fluid Phase Equilib. 117 (1996) 344-355.

[9] M.J. Assael, E. Charitidou, J. H. Dymond, and M. Papadaki, Int. J. Thermophys. 13 (1992) 237-249.

[10] J. Wu, Z. Shan, Abdul-Fattah A. Asfour, Fluid Phase Equilib.143 (1998) 263-274.

[11] H. N. Abdulghanni, and Abdul-Fattah A. Asfour, The Can. J. Chem. Eng., 78 (2000) 355.

[12] A. M. Elsharkawy, T. A. Al-Sahhaf, M. A. Fahim, Fuel, 79 (2000) 1047-1055.

[13] E. Retzekas, E. Voutsas, K. Magoulas, and D. Tassios, Ind. Eng. Chem. Res., 41 (2002) 1695-1702.

[14] E. Aesen, E. Rytter, and H. A. Oye, Ind. Eng. Chem. Res., 29 (1990) 1635-1640.

[15] D. R. Caudwell, J.P. M. Trusler, V. Vesovic, and W. A. Wakeham, Int. J. Thermophys, 25 (2004) 1339-1352.

[16] K. S. Pedersen and H. P. Ronningsen, Energy Fuels, 14 (1999) 43-51.

[17] M. R. Daubert, Charecterization and Properties of Petroleum Fractions, ASTM Stock Number; MNL50, Philadelphia, 2005.

[18] D. W. Jennings and K. Weispfennig, Fluid Phase Equilib. 227 (2005) 27-35.

[19] API Research Project 42, The Pennsylvania State University, College of Science, Pensilvania, USA, 1966.

[20] API Research Project 44, Texas A&M University, College Station, Texas 77843, USA,1973.

[21] C. L. Yaws, Chemical Properties Handbook, McGraw-Hill,1999.

[22] ASTM D7042- Standard Test Method for Dynamic Viscosity and Density of Liquids by Stabinger Viscometer, July 2004

Tables

Table 1: Chemical properties of quantitative ASTM D 2887 C_6-C_{44}

No	Compounds	Formula	Percent Purity (%)	Concentration (w/w %)
1	n-Hexane	C_6H_{14}	99	6
2	n-Heptane	C_7H_{16}	99	6
3	n-Octane	C_8H_{18}	99	8
4	n-Nonane	C_9H_{20}	99	8
5	n-Decane	$C_{10}H_{22}$	99	12
6	n-Undecane	$C_{11}H_{24}$	99	12
7	n-Dodecane	$C_{12}H_{26}$	99	12
8	n-Tetradecane	$C_{14}H_{30}$	99	12
9	n-Hexadecane	$C_{16}H_{34}$	99	10
10	n-Octadecane	$C_{18}H_{38}$	99	5
11	n-Eicosane	$C_{20}H_{42}$	99	2
12	n-Tetracosane	$C_{24}H_{50}$	99	2
13	n-Octacosane	$C_{28}H_{58}$	99	1
14	n-Dotriacontane	$C_{32}H_{66}$	99	1
15	n-Hexatriacontane	$C_{36}H_{74}$	99	1
16	n-Tetracontane	$C_{40}H_{82}$	98	1
17	n-Tetratetracontane	$C_{44}H_{90}$	99	1

Table 2: Dynamic viscosity calibration results (Standard: SH C112 2004 07 07)

t(°C)	$\eta_{\text{Reference}}$ (mPa.s)	$\eta_{\text{Measuring}}$ (mPa.s)	Deviations%
20	99.09	99.25	+0.16
40	38.55	38.54	-0.02
60	18.29	18.27	-0.09
80	10.06	10.05	-0.09
100	6.190	6.172	-0.28

$$\text{Deviation (\%)} = \left| \frac{\eta_{i,\text{measuring}} - \eta_{i,\text{Reference}}}{\eta_{i,\text{Reference}}} \right|$$

Table 3: Density calibration results (Standard: SH C112 2004 07 07)

t(°C)	$\rho_{\text{Reference}}$(g/cm^3)	$\rho_{\text{Measuring}}$ (g/cm^3)	Deviation%
20	0.8290	0.8292	+0.02
40	0.8166	0.8168	+0.02
60	0.8043	0.8044	+0.01
80	0.7920	0.7919	-0.01
100	0.7797	0.7796	-0.02

Table 4: The changes of the viscosity and density measurements with temperature of pure hydrocarbons

T(K)	η(mPa,s)	ρ(kg/m^3)	ν (mm^2/s)	τ(Pa)	D(1/s)	η(mPa,s) API44	Deviation %
dodecane(C_{12})							
293.15	1.494	748.5	1.996	1.518	1016	1.503	-0.619
303.15	1.253	741.4	1.690	1.294	1033	1.261	-0.674
313.15	1.068	734.1	1.455	1.118	1047	1.078	-0.900
323.15	0.924	726.9	1.272	0.978	1058	0.929	-0.543
333.15	0.809	719.7	1.124	0.863	1067	0.812	-0.415
343.15	0.715	711.9	1.004	0.767	1074	0.717	-0.280
353.15	0.635	704.4	0.902	0.686	1080	0.638	-0.406
363.15	0.567	697.0	0.814	0.616	1086	0.573	-0.922
373.15	0.507	689.6	0.735	0.553	1091	0.517	-1.887
tridecane(C_{13})							
293.15	1.887	756.1	2.495	1.852	981.8	1.880	0.356
303.15	1.568	749.0	2.093	1.572	1003	1.555	0.804
313.15	1.304	741.9	1.758	1.333	1022	1.310	-0.443
323.15	1.116	734.7	1.519	1.157	1036	1.120	-0.330
333.15	0.968	727.5	1.330	1.014	1048	0.970	-0.173
343.15	0.848	720.3	1.177	0.897	1057	0.849	-0.087
353.15	0.749	713.0	1.051	0.798	1065	0.751	-0.189
363.15	0.665	705.7	0.943	0.713	1072	0.669	-0.549
373.15	0.593	698.5	0.849	0.639	1078	0.600	-1.214
pentadecane(C_{15})							
293.15	2.859	768.5	3.721	2.588	905.2	2.863	-0.129
303.15	2.293	761.6	3.011	2.155	939.5	2.303	-0.426
313.15	1.885	754.5	2.498	1.821	966.6	1.894	-0.502
323.15	1.580	747.4	2.113	1.561	988.1	1.586	-0.404
333.15	1.346	740.4	1.818	1.353	1006	1.349	-0.252
343.15	1.162	733.3	1.584	1.185	1020	1.163	-0.129
353.15	1.013	726.2	1.396	1.046	1032	1.014	-0.059
363.15	0.892	719.1	1.240	0.929	1042	0.900	-0.889
373.15	0.790	712.1	1.110	0.830	1050	0.793	-0.303
toluene							
293.15	0.579	866.5	0.668	0.641	1107	0.585	-0.952
298.15	0.546	862.0	0.634	0.606	1109	0.550	-0.669
303.15	0.516	857.3	0.602	0.574	1111	0.519	-0.467
308.15	0.489	852.5	0.574	0.544	1113	0.490	-0.171
313.15	0.464	847.8	0.547	0.518	1115	0.464	0.106
318.15	0.441	843.1	0.523	0.492	1117	0.440	0.282
323.15	0.420	838.3	0.501	0.469	1118	0.418	0.522
328.15	0.401	833.6	0.481	0.449	1119	0.398	0.729
333.15	0.382	828.8	0.461	0.428	1121	0.379	0.755
338.15	0.362	824.0	0.439	0.406	1122	0.361	0.296
343.15	0.343	819.1	0.419	0.386	1123	0.345	-0.542
348.15	0.328	814.2	0.403	0.369	1124	0.330	-0.642

Table 5: The changes of the viscosity and density with temperature of n-alkanes mixtures

T(K)	η(mPa,s)	ρ(kg/m^3)	ν(mm^2/s)	τ(Pa)	D(1/s)
C_6-C_{44} (0.25 v/v in dodecane)					
313.15	1.050	733.0	1.434	1.101	1049
323.15	0.908	725.6	1.253	0.962	1059
333.15	0.797	718.2	1.111	0.851	1068
343.15	0.705	710.7	0.993	0.758	1075
353.15	0.625	703.2	0.891	0.676	1082
363.15	0.555	695.5	0.799	0.604	1087
373.15	0.494	688.0	0.719	0.539	1093
wax1 (10% w/w in toluene)					
308.15	0.638	849.9	0.751	0.699	1096
313.15	0.603	845.0	0.713	0.662	1099
318.15	0.570	840.5	0.679	0.628	1101
323.15	0.541	836.0	0.647	0.597	1103
328.15	0.514	831.4	0.618	0.568	1105
333.15	0.489	826.7	0.591	0.541	1107
338.15	0.465	822.0	0.565	0.515	1108
343.15	0.441	817.3	0.540	0.490	1110
348.15	0.417	812.6	0.513	0.463	1112
353.15	0.387	807.8	0.479	0.431	1115
358.15	0.374	802.9	0.466	0.417	1115
363.15	0.335	797.1	0.420	0.375	1119
wax2(10% w/w in toluene)					
313.15	0.636	842.2	0.755	0.696	1095
318.15	0.599	837.8	0.715	0.657	1097
323.15	0.567	833.2	0.680	0.623	1100
328.15	0.536	828.6	0.647	0.591	1102
333.15	0.506	8240	0.614	0.559	1104
338.15	0.480	819.3	0.586	0.531	1106
343.15	0.433	814.6	0.532	0.481	1111
348.15	0.406	809.8	0.501	0.452	1113
353.15	0.374	805.0	0.464	0.417	1117
358.15	0.364	800.2	0.455	0.407	1117
wax3(10% w/w in toluene)					
293.15	0.746	859.8	0.867	0.812	1089
298.15	0.700	855.3	0.818	0.765	1093
303.15	0.658	850.6	0.774	0.721	1095
308.15	0.621	846.1	0.734	0.682	1098
313.15	0.588	841.6	0.698	0.647	1100
318.15	0.556	837.1	0.664	0.613	1103
323.15	0.527	832.6	0.633	0.582	1105
328.15	0.500	828.0	0.604	0.553	1107
333.15	0.474	823.4	0.576	0.526	1108
338.15	0.440	818.7	0.538	0.489	1111
343.15	0.416	814.1	0.511	0.463	1113
348.15	0.386	809.4	0.477	0.431	1116
353.15	0.354	804.7	0.439	0.396	1119
358.15	0.355	799.9	0.444	0.397	1118
363.15	0.330	795.2	0.416	0.370	1120

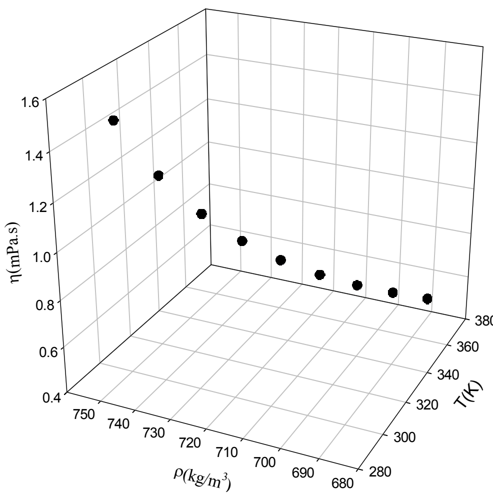

Figure 1. The change in the viscosity of n-dodecane according to density and temperature .

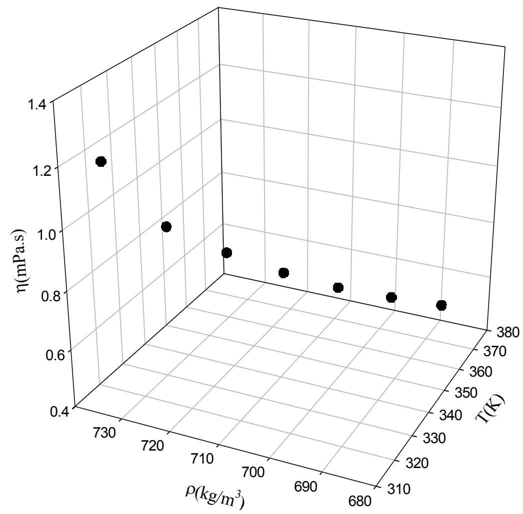

Figure 2. Viscosity and density change with temperature of C_6-C_{44} in dodecane mixture.