

Experimental Liquid Viscosities of Decane and Octane + Decane from 298.15 K to 373.15 K and Up to 25 MPa

Alejandro Estrada-Baltazar, Juan F. J. Alvarado, and Gustavo A. Iglesias-Silva*

Departamento de Ingeniería Química, Instituto Tecnológico de Celaya, Celaya, Guanajuato, CP 38010, México

María A. Barrufet

Petroleum Engineering Department, Texas A&M University, College Station, Texas 77843

Experimental liquid viscosities of decane and of a binary mixture of octane + decane have been measured using a rolling ball viscometer at temperatures from 298.15 K to 373.15 K and at pressures up to 25 MPa. The mixture measurements agree with literature values within an average value of 1.2%. Deviations of the results from existing correlations are within 2.5%.

Introduction

Experimental liquid viscosities of pure hydrocarbons and their mixtures are needed for the design of chemical processes where heat and mass transfer and fluid mechanics are important. Prediction of the liquid behavior of hydrocarbon mixture viscosities is not yet possible within the experimental uncertainty. Therefore, experimental measurements are needed to understand the fundamental behavior of this property and then to develop new models.

Experimental measurements of liquid viscosities of *n*-alkanes have been published in the literature. Stephen and Lucas (1979) review the viscosity values of butane, pentane, hexane, and octane and give recommended values of these pure substances. Experimental measurements of decane have been published by Mumford and Phillips (1950), Lee and Ellington (1965b), Carmichael et al. (1969), Moore and Wellek (1974), Dymond and Young (1981), Atrops et al. (1982), Ducoulombier et al. (1986), Knapstad et al. (1989), and Assael et al. (1992). They report an accuracy of approximately 0.5%. Viscosities of octane have been measured by Dymond and Young (1980), Knapstad et al. (1989), Kiran and Sen (1992), and Tanaka et al. (1992).

Unfortunately, experimental values for hydrocarbon mixtures are scarce. Assael et al. (1992b) give a summary of the binary *n*-alkane viscosity data and a correlation to predict the transport properties of *n*-alkane mixtures. The agreement between the correlation and the experimental viscosity data is generally within 5%.

Chevalier et al. (1990) measured the kinematic viscosity at 298.15 K and 0.101 325 MPa for the mixture octane + decane. They claimed an accuracy of $\pm 0.1\%$ for the kinematic viscosity. Also, Copper and Asfour (1991) measured the kinematic viscosity of the mixture at atmospheric pressure and 293.15 K.

In this work, we measure the viscosity of decane and octane + decane using a rolling ball viscometer at temperatures from 298.15 K to 373.15 K and pressures up to 25 MPa. This work presents new measurements at high pressure for this binary mixture over the entire composition range and is a continuation of our earlier work (Barrufet et al., 1996).

Experimental Apparatus

A high-pressure Ruska viscometer (Ruska Instrument Co., 10311 Westpark Dr., Houston, TX 77042), model 160, is used to measure the viscosity of hydrocarbons (see Figure 1). The operation of the apparatus is based on a rolling-ball principle where the roll time of a 0.6-cm diameter sphere is used to determine the fluid viscosities. The viscometer requires 70 cm³ of a measuring fluid for complete filling.

The method consists of rolling a stainless steel sphere through a fluid of unknown viscosity at known conditions of temperature and pressure through a precise distance. The viscosity is a function of the roll time, the density difference between the sphere and fluid, and a constant. The viscosity can be expressed as

$$\eta = Kt(\rho_s - \rho_f) \quad (1)$$

where η is the absolute viscosity, t is the sphere roll time, ρ_s is the density of the sphere, ρ_f is the density of the fluid, and K is a constant obtained by calibrating the viscometer at a given angle with a substance of known viscosity and density.

The measuring system consists of a mechanical test assembly and a control unit with a digital watch. The mechanical assembly is a stainless steel high-pressure housing fixed to a base allowing circular movements. The housing can be fixed at 23, 45, and 70° to obtain a measurement. Inside the housing, there is a cylindrical barrel in which a stainless steel sphere rolls on a perfectly polished surface. A plug containing the barrel seal and a solenoid closes the lower end. When the barrel seal is closed, both ends of the barrel are sealed so the sphere falls through the fluid inside the barrel; if it is open, both ends are open and the sphere can be used as an stirring device.

The solenoid holds the steel sphere in the upper part of the barrel, and the sphere will not fall until the solenoid current is interrupted in the control unit. The human error in timing the sphere roll time is eliminated, since the watch is activated electronically when the current is interrupted and is stopped when the sphere reaches the end of its travel. Repeatability of the roll time measurements is $\pm 0.1\%$.

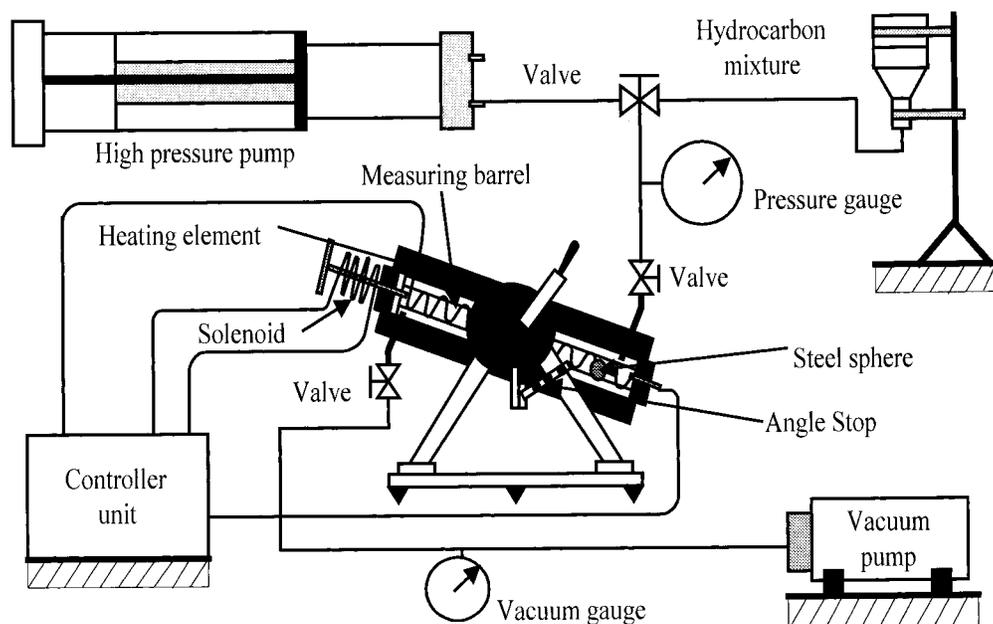


Figure 1. Schematic diagram of the apparatus.

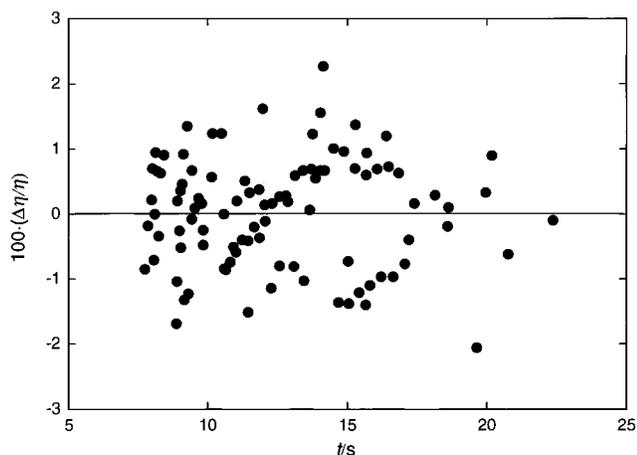


Figure 2. Relative deviation of the viscosity from eq 2.

It is possible to modify the measuring range of the viscosity by using a sphere of different diameter and/or by changing the angle at which the sphere is rolling. For high viscosities, the angle should be increased and/or a sphere of lower diameter should be selected. At lower viscosities, the reverse applies.

The viscometer is heated with electric jackets and the temperature can be controlled within ± 0.2 K. The measuring fluid is injected into the system using a Ruska high-pressure pump with a maximum capacity of 68 MPa. The pressure can be read with an accuracy of ± 0.001 MPa. The estimated accuracy in the preparation of the mixture was better than ± 0.01 mass %.

Calibration

We calibrate the viscometer using a Cannon certified viscosity standard, pentane, and octane. For pentane, experimental densities and viscosities are taken from Lee and Ellinton (1965a) and Kiran and Sen (1992). For octane, experimental values are from Kashiwagi and Makita (1982) and Kiran and Sen (1992). The calibration procedure is similar to the one used by Kiran and Sen (1992) where they consider the constant K of eq 1 as a function of temperature, pressure, and time. First, we

measured several times the roll time of the sphere in pentane, octane, and the Cannon standard at 0.101 MPa and 298.15 K. The viscosity of the substance is related to the density difference by

$$\eta = \kappa(\rho_s - \rho_f) \quad (2)$$

where κ can be considered a function of time and can be obtained when the viscosity, the densities, and the average time are known. Under laminar flow conditions κ can be considered only a linear function of t as in eq 1. The functionality of this constant at 0.101 MPa and 298.15 K is

$$\kappa = k(t) = -0.06929 + 0.01153(t/s) - 1.3 \times 10^{-4}(t/s)^2 \quad (3)$$

Second, κ is corrected by expressing it as a function of pressure, temperature, and time, so

$$\kappa = k(t)/X(T, P, t) \quad (4)$$

where $k(t)$ is the function given by eq 3. The function X is calculated using the roll times of pentane and octane at temperatures from 298.15 K to 373.15 K and at pressures up to 28 MPa. The best functionality was selected from a data bank of 120 polynomial terms using a stepwise procedure of a statistical package (SAS, 1981). The best polynomial form selected by the program is

$$\begin{aligned} X(T, P, t) = & 0.75218 + 9.207 \times 10^{-5}(TK)(P/MPa) - \\ & 9.352 \times 10^{-6}(TK)^{1.5} + 722.511(t/s)^{-3.5} - \\ & 7793.08(t/s)^{-4.5} + 0.81681(TK)^{-0.5} + \\ & 0.83608(TK)^{-1.5}(P/MPa) + 0.02604[(t/s)(P/MPa)]^{-4.5} \end{aligned} \quad (5)$$

Figure 2 shows deviations for the above measurements from the calibrating equation.

As suggested by Hubbard and Brown (1943), to obtain a good correlation of the viscosity with time, we maintain the fluid in the laminar regime during the experiment. Hubbard and Brown (1943) proposed that if the ratio of the resistance factor at the conditions of the measurement

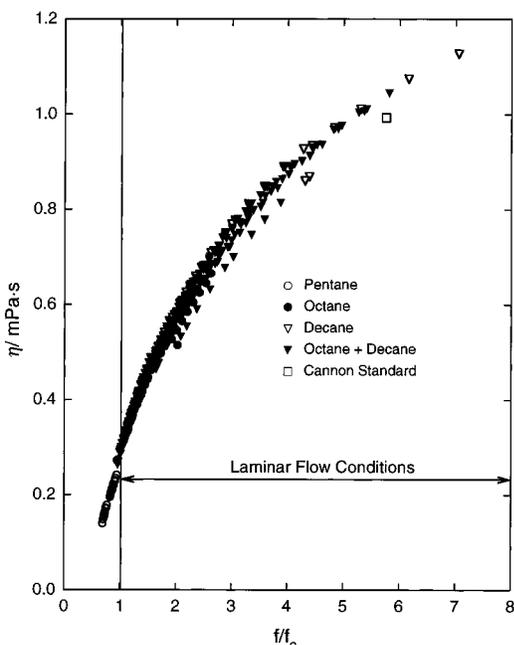


Figure 3. Variation of the viscosity with the resistance factor ratio.

Table 1. Experimental Viscosities for Decane

<i>T</i> /K	<i>P</i> /MPa	η /mPa·s	<i>T</i> /K	<i>P</i> /MPa	η /mPa·s
297.95	0.101	0.8703	343.15	0.101	0.4985
297.95	4.995	0.9351	343.15	4.995	0.5347
297.95	9.913	0.9731	343.15	9.913	0.5741
297.95	14.815	1.0128	343.15	14.815	0.6036
297.95	21.696	1.0733	343.15	21.696	0.6260
297.95	24.626	1.1282	343.15	24.626	0.6608
313.05	0.101	0.7126	358.25	0.101	0.4199
313.05	4.995	0.7701	358.25	4.995	0.4553
313.05	9.913	0.8129	358.25	9.913	0.4850
313.05	14.815	0.8502	358.25	14.815	0.5131
313.05	21.696	0.8890	358.25	21.696	0.5427
313.05	24.626	0.9290	358.25	24.626	0.5669
328.05	0.101	0.5939	373.35	0.101	0.3931
328.05	4.995	0.6402	373.35	4.995	0.4059
328.05	9.913	0.6801	373.35	9.913	0.4139
328.05	14.815	0.7109	373.35	14.815	0.4371
328.05	21.696	0.7510	373.35	21.696	0.4656
328.05	24.626	0.7787	373.35	24.626	0.4891

and the resistance factor at the critical velocity is less than unity, the flow of the fluid is turbulent. Resistance factors were calculated using the diameter ratio between the sphere diameter and the tube diameter, the velocity of the sphere, and the resisting force of the fluid in a procedure given by Hubbard and Brown (1943). Figure 3 shows that our experiments have been done mostly under laminar conditions. It also shows that some measurements are in a transition region in the vicinity of the laminar region.

For all the measurements, we use a sphere of 0.6-cm diameter and an angle of 23°. At these conditions, laminar flow is obtained during the measurements at different pressures and temperatures. Fluid densities are calculated using the correlation of Assael et al. (1994) who reported an average deviation of their correlation with respect to the experimental values of pentane and octane of 0.1%. For hydrocarbons binary mixtures, the average deviation of the correlation from the experimental data is 0.1% with a maximum deviation of 0.4%.

Samples

The pentane, octane, and decane samples were purchased from Lancaster Synthesis Inc. with a minimum

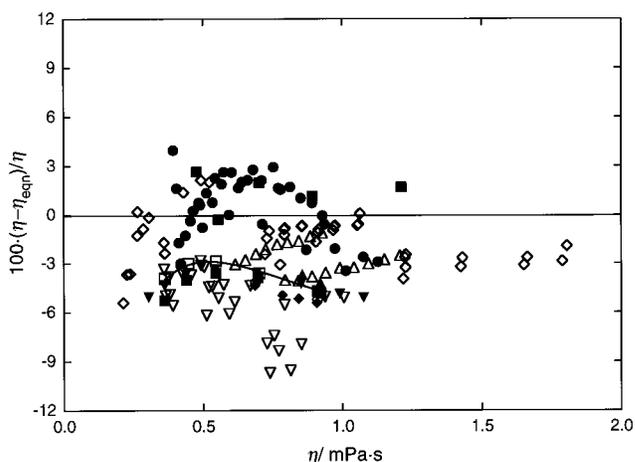


Figure 4. Relative deviation of measured decane viscosities from the equation of Assael et al. (1992a): (□) Knapstad et al. (1989); (Δ) Assael et al. (1992); (◇) Carmichael et al. (1969); (○) Atrops et al. (1982); (▽) Lee and Ellington (1965b); (■) Ducoulombier et al. (1986); (▲) Mumford and Phillips (1950); (◆) Moore and Welke (1974); (▼) Dymond and Young (1981); (—) Dymond and Øye (1994); (●) this work.

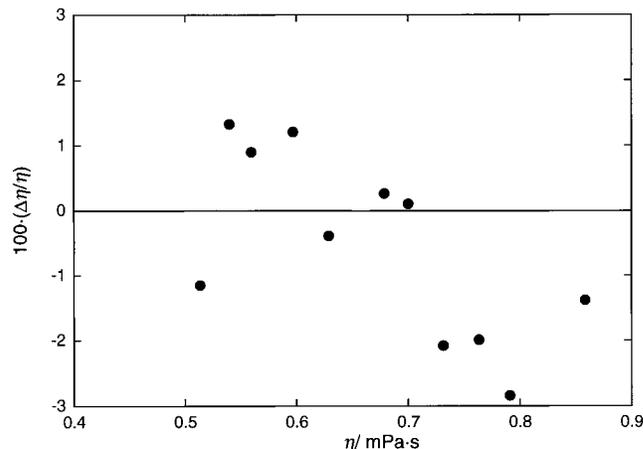


Figure 5. Relative deviation of measured octane + decane viscosities at 0.1 MPa from the viscosities measured by Chevalier et al. (1990).

stated purity of 99+%. The hydrocarbon binary mixture was prepared gravimetrically using a Mettler PM4600 balance with an accuracy of ± 0.01 g.

Results and Discussion

For each viscosity value, an average value of 10 measurements of the roll time was used. The viscometer was rotated during 10 min to obtain a uniform temperature and mixing in the barrel. Thermal and mechanical equilibrium was reached in the viscometer before the time was recorded. Table 1 and Table 2 show the experimental values of decane and octane + decane, respectively, at different pressures, temperatures, and compositions.

We have compared our experimental viscosities of decane with the correlation of Assael et al. (1992a). Our values are within 3% of the values predicted by this correlation. Figure 4 shows the percentage deviation of the new measurements of decane with Assael's correlation. The straight line corresponds to the recommended correlation for decane given by Dymond and Øye (1994).

For the binary mixture of octane + decane, we can compare our measurements only at 0.1 MPa with the values published by Chevalier et al. (1990) since experi-

Table 2. Experimental Viscosities for Octane (1) + Decane (2)

<i>T</i> /K	<i>P</i> /MPa	η /mPa·s	<i>T</i> /K	<i>P</i> /MPa	η /mPa·s	<i>T</i> /K	<i>P</i> /MPa	η /mPa·s
$x_1 = 0.1384$								
297.95	0.101	0.8136	328.05	0.101	0.5653	358.25	0.101	0.4134
297.95	4.995	0.8907	328.05	4.995	0.6096	358.25	4.995	0.4447
297.95	9.913	0.9305	328.05	9.913	0.6482	358.25	9.913	0.4722
297.95	14.815	0.9675	328.05	14.815	0.6822	358.25	14.815	0.5009
297.95	21.696	1.0025	328.05	21.696	0.7125	358.25	21.696	0.5241
297.95	24.626	1.0447	328.05	24.626	0.7491	358.25	24.626	0.5539
313.05	0.101	0.6803	343.15	0.101	0.4839	373.35	0.101	0.3488
313.05	4.995	0.7410	343.15	4.995	0.5177	373.35	4.995	0.3799
313.05	9.913	0.7773	343.15	9.913	0.5486	373.35	9.913	0.4051
313.05	14.815	0.8105	343.15	14.815	0.5788	373.35	14.815	0.4293
313.05	21.696	0.8477	343.15	21.696	0.6056	373.35	21.696	0.4553
313.05	24.626	0.8890	343.15	24.626	0.6438	373.35	24.626	0.4777
$x_1 = 0.2144$								
297.95	0.101	0.7783	328.05	0.101	0.5373	358.25	0.101	0.3919
297.95	4.995	0.8578	328.05	4.995	0.5853	358.25	4.995	0.4271
297.95	9.913	0.8954	328.05	9.913	0.6182	358.25	9.913	0.4524
297.95	14.815	0.9361	328.05	14.815	0.6476	358.25	14.815	0.4754
297.95	21.696	0.9741	328.05	21.696	0.6788	358.25	21.696	0.5000
297.95	24.626	1.0117	328.05	24.626	0.7127	358.25	24.626	0.5266
313.05	0.101	0.6439	343.15	0.101	0.4577	373.35	0.101	0.3366
313.05	4.995	0.7014	343.15	4.995	0.4950	373.35	4.995	0.3687
313.05	9.913	0.7446	343.15	9.913	0.5222	373.35	9.913	0.3907
313.05	14.815	0.7802	343.15	14.815	0.5492	373.35	14.815	0.4156
313.05	21.696	0.8107	343.15	21.696	0.5796	373.35	21.696	0.4396
313.05	24.626	0.8475	343.15	24.626	0.6102	373.35	24.626	0.4629
$x_1 = 0.3015$								
297.95	0.101	0.7465	328.05	0.101	0.5393	358.25	0.101	0.3757
297.95	4.995	0.8479	328.05	4.995	0.5671	358.25	4.995	0.4112
297.95	9.913	0.8865	328.05	9.913	0.5998	358.25	9.913	0.4361
297.95	14.815	0.9267	328.05	14.815	0.6315	358.25	14.815	0.4614
297.95	21.696	0.9673	328.05	21.696	0.6630	358.25	21.696	0.4856
297.95	24.626	1.0072	328.05	24.626	0.6971	358.25	24.626	0.5127
313.05	0.101	0.6261	343.15	0.101	0.4380	373.35	0.101	0.3342
313.05	4.995	0.6837	343.15	4.995	0.4794	373.35	4.995	0.3663
313.05	9.913	0.7236	343.15	9.913	0.5080	373.35	9.913	0.3916
313.05	14.815	0.7615	343.15	14.815	0.5374	373.35	14.815	0.4157
313.05	21.696	0.7936	343.15	21.696	0.5640	373.35	21.696	0.4406
313.05	24.626	0.8298	343.15	24.626	0.5946	373.35	24.626	0.4463
$x_1 = 0.3894$								
297.95	0.101	0.6993	328.05	0.101	0.5063	358.25	0.101	0.3746
297.95	4.995	0.7896	328.05	4.995	0.5520	358.25	4.995	0.4057
297.95	9.913	0.8275	328.05	9.913	0.5831	358.25	9.913	0.4301
297.95	14.815	0.8637	328.05	14.815	0.6140	358.25	14.815	0.4536
297.95	21.696	0.8997	328.05	21.696	0.6434	358.25	21.696	0.4777
297.95	24.626	0.9368	328.05	24.626	0.6754	358.25	24.626	0.5034
313.05	0.101	0.5975	343.15	0.101	0.4324	373.35	0.101	0.3200
313.05	4.995	0.6553	343.15	4.995	0.4700	373.35	4.995	0.3496
313.05	9.913	0.6931	343.15	9.913	0.4964	373.35	9.913	0.3722
313.05	14.815	0.7247	343.15	14.815	0.5232	373.35	14.815	0.3945
313.05	21.696	0.7560	343.15	21.696	0.5512	373.35	21.696	0.4182
313.05	24.626	0.7939	343.15	24.626	0.5801	373.35	24.626	0.4409
$x_1 = 0.4520$								
297.95	0.101	0.6767	328.05	0.101	0.4933	358.25	0.101	0.3627
297.95	4.995	0.7679	328.05	4.995	0.5370	358.25	4.995	0.3961
297.95	9.913	0.7982	328.05	9.913	0.5643	358.25	9.913	0.4184
297.95	14.815	0.8379	328.05	14.815	0.5935	358.25	14.815	0.4403
297.95	21.696	0.8721	328.05	21.696	0.6191	358.25	21.696	0.4636
297.95	24.626	0.9129	328.05	24.626	0.6526	358.25	24.626	0.4873
313.05	0.101	0.5817	343.15	0.101	0.4210	373.35	0.101	0.3110
313.05	4.995	0.6395	343.15	4.995	0.4551	373.35	4.995	0.3425
313.05	9.913	0.6733	343.15	9.913	0.4823	373.35	9.913	0.3649
313.05	14.815	0.7085	343.15	14.815	0.5090	373.35	14.815	0.3867
313.05	21.696	0.7380	343.15	21.696	0.5339	373.35	21.696	0.4095
313.05	24.626	0.7734	343.15	24.626	0.5606	373.35	24.626	0.4318
$x_1 = 0.6010$								
297.95	0.101	0.6312	328.05	0.101	0.4679	358.25	0.101	0.3434
297.95	4.995	0.7093	328.05	4.995	0.5089	358.25	4.995	0.3726
297.95	9.913	0.7470	328.05	9.913	0.5333	358.25	9.913	0.3944
297.95	14.815	0.7813	328.05	14.815	0.5572	358.25	14.815	0.4163
297.95	21.696	0.8122	328.05	21.696	0.5798	358.25	21.696	0.4367
297.95	24.626	0.8451	328.05	24.626	0.6084	358.25	24.626	0.4573
313.05	0.101	0.5417	343.15	0.101	0.3972	373.35	0.101	0.2966
313.05	4.995	0.5902	343.15	4.995	0.4325	373.35	4.995	0.3267
313.05	9.913	0.6221	343.15	9.913	0.4548	373.35	9.913	0.3466
313.05	14.815	0.6508	343.15	14.815	0.477	373.35	14.815	0.3654
313.05	21.696	0.6797	343.15	21.696	0.4998	373.35	21.696	0.3862
313.05	24.626	0.7107	343.15	24.626	0.5234	373.35	24.626	0.4062

Table 2. (continued)

<i>T</i> /K	<i>P</i> /MPa	η /mPa·s	<i>T</i> /K	<i>P</i> /MPa	η /mPa·s	<i>T</i> /K	<i>P</i> /MPa	η /mPa·s
$x_1 = 0.6988$								
297.95	0.101	0.5898	328.05	0.101	0.4384	358.25	0.101	0.3282
297.95	4.995	0.6690	328.05	4.995	0.4749	358.25	4.995	0.3581
297.95	9.913	0.7006	328.05	9.913	0.5017	358.25	9.913	0.3786
297.95	14.815	0.7351	328.05	14.815	0.5292	358.25	14.815	0.3989
297.95	21.696	0.7694	328.05	21.696	0.5513	358.25	21.696	0.4163
297.95	24.626	0.8054	328.05	24.626	0.5756	358.25	24.626	0.4402
313.05	0.101	0.5129	343.15	0.101	0.3791	373.35	0.101	0.2858
313.05	4.995	0.5594	343.15	4.995	0.4122	373.35	4.995	0.3148
313.05	9.913	0.5889	343.15	9.913	0.4330	373.35	9.913	0.3319
313.05	14.815	0.6188	343.15	14.815	0.4564	373.35	14.815	0.3514
313.05	21.696	0.6479	343.15	21.696	0.4786	373.35	21.696	0.3768
313.05	24.626	0.6799	343.15	24.626	0.5022	373.35	24.626	0.3959
$x_1 = 0.8208$								
297.95	0.101	0.5543	328.05	0.101	0.4091	358.25	0.101	0.3114
297.95	4.995	0.6206	328.05	4.995	0.4454	358.25	4.995	0.3389
297.95	9.913	0.6533	328.05	9.913	0.4702	358.25	9.913	0.3565
297.95	14.815	0.6857	328.05	14.815	0.4937	358.25	14.815	0.3770
297.95	21.696	0.7191	328.05	21.696	0.5158	358.25	21.696	0.3942
297.95	24.626	0.7509	328.05	24.626	0.5407	358.25	24.626	0.4136
313.05	0.101	0.4761	343.15	0.101	0.3578	373.35	0.101	0.2697
313.05	4.995	0.5190	343.15	4.995	0.3865	373.35	4.995	0.2995
313.05	9.913	0.5497	343.15	9.913	0.4089	373.35	9.913	0.3182
313.05	14.815	0.5769	343.15	14.815	0.4274	373.35	14.815	0.3345
313.05	21.696	0.6024	343.15	21.696	0.4469	373.35	21.696	0.3540
313.05	24.626	0.6329	343.15	24.626	0.4690	373.35	24.626	0.3714
$x_1 = 0.8858$								
297.95	0.101	0.5327	328.05	0.101	0.4020	358.25	0.101	0.3053
297.95	4.995	0.5988	328.05	4.995	0.4384	358.25	4.995	0.3327
297.95	9.913	0.6290	328.05	9.913	0.4596	358.25	9.913	0.3510
297.95	14.815	0.6630	328.05	14.815	0.4801	358.25	14.815	0.3704
297.95	21.696	0.6883	328.05	21.696	0.5031	358.25	21.696	0.3880
297.95	24.626	0.7219	328.05	24.626	0.5273	358.25	24.626	0.4074
313.05	0.101	0.4643	343.15	0.101	0.3507	373.35	0.101	0.2624
313.05	4.995	0.5104	343.15	4.995	0.3803	373.35	4.995	0.2893
313.05	9.913	0.5369	343.15	9.913	0.4004	373.35	9.913	0.3076
313.05	14.815	0.5622	343.15	14.815	0.4194	373.35	14.815	0.3268
313.05	21.696	0.5853	343.15	21.696	0.4382	373.35	21.696	0.3447
313.05	24.626	0.6119	343.15	24.626	0.4593	373.35	24.626	0.3627

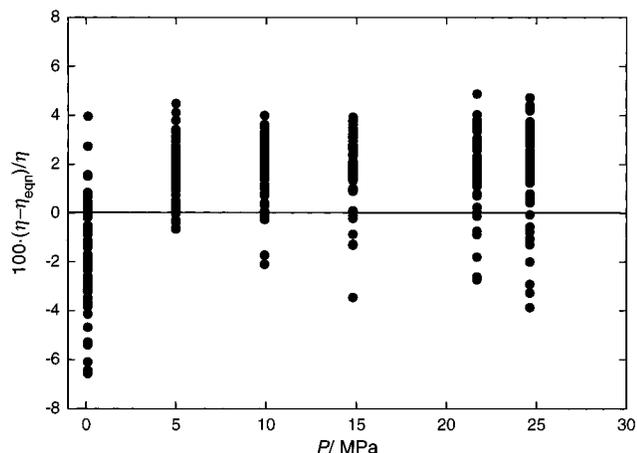


Figure 6. Relative deviation of measured octane + decane viscosities from the equation of Assael et al. (1992b).

mental measurements at higher pressures do not exist. At viscosities less than 0.7 mPa·s the agreement with Chevalier's data is within 1% but at higher viscosities increases up to 3% as shown in Figure 5. At pressures other than atmospheric pressure, we compare our experimental results with the correlation presented by Assael et al. (1992b) for hydrocarbon mixtures. The predictive capability of the correlation is shown in Figure 6.

Conclusions

We have measured the viscosity of decane and the binary mixture of octane + decane. Our experimental values

agree with the published values within an average error of 3%. The correlation developed for Assael et al. (1992a,b) proves to be an adequate equation to predict the viscosity of pure hydrocarbons and their mixtures. The average deviation of the correlation with the experimental measurements is 1% at different pressures and temperatures.

Literature Cited

- Atrops, H.; Kalali, H. E.; Kohler, F. Melting Curves, Densities, Viscosities and Thermodynamic Excess Properties of 1,2,4-Trichlorobenzene + *n*-Decane and + *n*-Tetradecane. *Ber. Bunsen-Ges. Phys. Chem.* **1982**, *86*, 26–31.
- Assael, M. J.; Dymond, J. H.; Papadaki, M. Viscosity Coefficients of Binary *n*-Heptane + *n*-Alkane Mixtures. *Fluid Phase Equilib.* **1992**, *75*, 287–297.
- Assael, M. J.; Dymond, J. H.; Papadaki, M.; Patterson, P. M. Correlation and Prediction of Dense Fluid Transport Coefficients. I. *n*-Alkanes. *Int. J. Thermophys.* **1992a**, *13*, 269–281.
- Assael, M. J.; Dymond, J. H.; Papadaki, M.; Patterson, P. M. Correlation and Prediction of Dense Fluid Transport Coefficients. III. *n*-Alkanes Mixtures. *Int. J. Thermophys.* **1992b**, *13*, 659–669.
- Assael, M. J.; Dymond, J. H.; Exadaktilou, D. An Improved Representation for *n*-Alkane Liquid Densities. *Int. J. Thermophys.* **1994**, *15*, 155–164.
- Barrufet, M. A.; Salem, S. K.; Tantawy, M.; Iglesias-Silva, G. A. Liquid Viscosities of Carbon Dioxide + Hydrocarbons from 310 K to 403 K. *J. Chem. Eng. Data* **1996**, *41*, 436–439.
- Carmichael, L. T.; Berry, V. M.; Sage, B. H. Viscosity of Hydrocarbons. *n*-Decane. *J. Chem. Eng. Data* **1969**, *14*, 27–31.
- Chevalier, J. L. E.; Petrino, P. J.; Gaston-Bonhomme, Y. H. Viscosity and Density of Some Aliphatic, Cyclic, and Aromatic Hydrocarbons Binary Liquid Mixtures. *J. Chem. Eng. Data* **1990**, *35*, 206–212.
- Cooper, E. F.; Asfour, A. A. Densities and Kinematic Viscosities of Some C6–C16 *n*-Alkane Binary Liquid Systems at 293.15. *J. Chem. Eng. Data* **1991**, *36*, 285–288.
- Dong, Q.; Marsh, K. N.; Gammon, B. E.; Dewan, A. K. R. *Transport Properties and Related Thermodynamic Data of Binary Mixtures Part 3*, DIPPR: New York, 1996.

- Ducoulombier, D.; Zhou, H.; Boned, C.; Peyrelasse, J.; Saint-Guirons, H.; Xans, P. Pressure (1–1000 bar) and Temperature (20–100 °C) Dependence of the Viscosity of Liquid Hydrocarbons. *J. Phys. Chem.* **1986**, *90*, 1692–1700.
- Dymond, J. H.; Young, K. J. Transport Properties of Nonelectrolyte Liquid Mixture. I. Viscosity Coefficients for *n*-Alkane Mixtures at Saturation Pressure from 283 to 378 K. *Int. J. Thermophys.* **1980**, *1*, 331–344.
- Dymond, J. H.; Young, K. J. Transport Properties of Nonelectrolyte Liquid Mixture. V. Viscosity Coefficients for Binary Mixtures of Benzene Plus Alkanes at Saturation Pressure from 283 to 393 K. *Int. J. Thermophys.* **1981**, *2*, 237–247.
- Dymond, J. H.; Øye, H. A. Viscosity of Selected Liquid *n*-Alkanes. *J. Phys. Chem. Ref. Data* **1994**, *23*, 41–53.
- Hubbard, R. M.; Brown, G. G. The Rolling Ball Viscometer. *Ind. Eng. Chem. Anal.* **1943**, *15*, 212–218.
- Kiran, E.; Sen, Y. L. High-Pressure Viscosity and Density of *n*-Alkanes. *Int. J. Thermophys.* **1992**, *13*, 411–442.
- Kishiwagi, H.; Makita, T. Viscosity of Twelve Hydrocarbon Liquids in the Temperature Range 298–348 K at Pressure up to 110 MPa. *Int. J. Thermophys.* **1982**, *3*, 289–305.
- Knapstad, B.; Skjølsvik, P. A.; Øye, H. A. Viscosity of Pure Hydrocarbons. *J. Chem. Eng. Data* **1989**, *34*, 37–43.
- Lee, A. L.; Ellington, R. T. Viscosity of *n*-Pentane. *J. Chem. Eng. Data* **1965a**, *10*, 101–104.
- Lee, A. L.; Ellington, R. T. Viscosity of *n*-Decane in the Liquid Phase. *J. Chem. Eng. Data* **1965b**, *10*, 346–348.
- Moore, J. W.; Wellek, R. M. Diffusion Coefficients of *n*-Heptane and *n*-Decane in Alkanes and *n*-Alcohols at Several Temperatures. *J. Chem. Eng. Data* **1974**, *19*, 136–141.
- Mumford, S. A.; Phillips, J. W. C. The Physical Properties of Some Aliphatic Compounds. *J. Chem. Soc.* **1950**, *19*, 75–84.
- SAS. *SAS User's Guide*; Institute Statistical Analysis System: Cary, NC, 1981.
- Stephen, K.; Lucas, K. *Viscosity of Dense Fluids*; Plenum Press: New York, 1979.
- Tanaka, Y.; Hosokawa, H.; Kubota, H.; Makita, T. Viscosity and Density of Binary Mixtures of Cyclohexane with *n*-Octane, *n*-Decane, and *n*-Hexadecane Under High Pressures. *Int. J. Thermophys.* **1991**, *12*, 245–264.

Received for review October 3, 1997. Accepted February 18, 1998. Texas A&M University and the Instituto Tecnológico de Celaya have provided financial support for this work.

JE970233E