Viscosity and Density of Methane + Methylcyclohexane from (323 to 423) K and Pressures to 140 MPa

Bahman Tohidi,* Rhoderick W. Burgass, Ali Danesh, and Adrian C. Todd

Department of Petroleum Engineering, Heriot-Watt University, Edinburgh EH14 4AS, U.K.

A new apparatus is described for measuring phase behavior and flow properties of water and/or hydrocarbon systems from ambient conditions to pressures of 140 MPa and temperatures to 474 K. Viscosity and density measurements have been made on pentane and decane and compared to the literature data. The measurements on pentane and decane have been made to 140 MPa and 423 K. Viscosity and density are reported for methane + methylcyclohexane at 25, 50, and 75 mass % methane, and at three temperatures, (323, 373, and 423) K, from saturation pressure to 140 MPa.

Introduction

A number of process operations take place at elevated pressures and temperatures. An example is upstream oil and gas processing. Exploration for hydrocarbons in deeper formations has found hydrocarbon accumulations at high-pressure and -temperature conditions. Exploration and development of these hydrocarbon reservoirs is extremely costly, particularly for offshore conditions. The cost of an offshore well can be several times higher than that of an onshore well, and hence accurate data on the flow performance of the fluids are required to optimize the number of wells. Viscosity and density of reservoir fluids are key properties for such calculations, and at these extreme conditions, there is a paucity of experimental data. Therefore, there is limited data available to test the reliability of the existing viscosity and density prediction models at these extreme conditions.

Methane + methylcyclohexane was chosen as a system containing a cyclic saturated hydrocarbon. Few researchers have studied the viscosity and density of methylcyclohexane with liquid hydrocarbons.[1,2] Ashcroft and Ben Isa[3] have examined the effect of dissolved methane on the density of liquid methylcyclohexane at 298.15 K and a total pressure of 101.06 kPa. However, there is a lack of density and viscosity data on methane + methylcyclohexane at elevated temperature and pressure conditions.

This paper describes the apparatus and reports viscosity and density values for methane + methylcyclohexane to temperatures of 423 K and pressures of 140 MPa.

Apparatus

A capillary viscometer was incorporated into a *PVT* facility designed to examine phase properties of fluids at pressures and temperatures associated with deep hydrocarbon reservoirs. The experimental apparatus can be used in studying the *PVT* phase behavior and properties of pure, multicomponent synthetic and real reservoir fluid systems with and without water. The current capabilities include measurements of the dew point, bubble point, phase volumes, interfacial tension, density, and viscosity. The *PVT* facility is able to conduct measurement from ambient conditions to a maximum pressure of 133 MPa at 524 K or 200 MPa at 474 K.

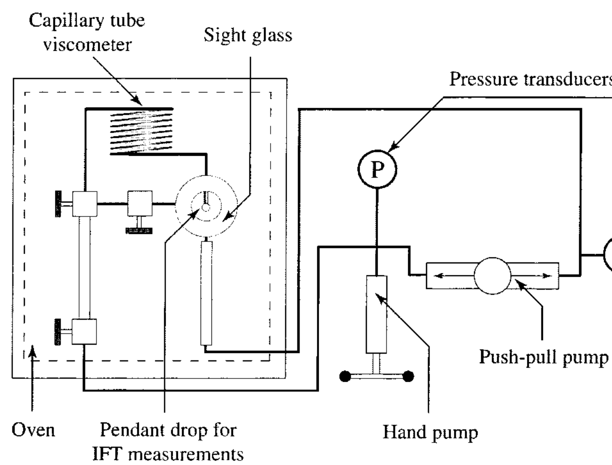

Figure 1. Schematic diagram of the experimental facility.

The capillary tube used in the viscosity measurements was 1480.3 cm long, coiled around a ±20 cm diameter cylinder, and had an internal average diameter of 0.029 94 cm. It was connected between two small-volume (15 cm^3) cells, which were mounted within a temperature-controlled oven. A schematic of the experimental setup is presented in Figure 1. The base of each cell is connected to either side of a motor-driven opposed piston pump. A high-pressure sight-glass is mounted at the top of one of the cells, in conjunction with a macroscope and video camera, for visual observation, measurement, and recording. Two Quartzdyne pressure (207 MPa, uncertainty ±0.02MPa) transducers are used to monitor the system pressure as well as the differential pressure across the tube. The pressure transducers are monitored and logged via a PC with LabVIEW software installed. Mercury is used as the confining medium. A hand pump is used to adjust the volume of the sample. The pipe work, cells, pumps, and sight-glass are all rated to 207 MPa. The oven has a maximum temperature of 524 K, and the temperature stability is ±0.5 K.

Test Procedures

Viscosity Measurements. For viscosity measurements, the fluid is injected into one of the cells, and by operation

* To whom correspondence should be addressed. Tel: +44 (0) 131 451 3672. Fax: +44 (0) 131 451 3127. E-mail: bahman.tohidi@pet.hw.ac.uk.

10.1021/je000191l CCC: $20.00
Published on Web 02/10/2001

Table 1. Test Fluids Used in Viscosity and Density Measurements

fluid	purity	supplier
pentane	99+% pure	Aldrich
decane	99+% pure	Aldrich
methane	instrument grade 99.995% pure	Air Products
methylcyclohexane	anhydrous, 99+% pure	Aldrich

of the opposed piston pump, it can be pushed through the capillary tube into the other cell. After all of the sample has been passed through, then mercury passes through the capillary tube and falls through the sample, giving a good means of mixing the fluids and establishing equilibrium. The speed of the opposed piston pump can be adjusted to provide a maximum flow rate of 5 cm^3/s. The flow rate can be set with an uncertainty of ±0.0005 cm^3/s.

Once the set temperature and pressure were reached, the sample was passed through the capillary tube at a number of different flow rates. At each rate the opposed piston pump was started, the differential pressure was monitored until a stable reading was achieved, and then it was stopped. The difference between the static differential pressure and that when flowing was taken as the differential pressure across the tube for that flow rate. The contribution of the rest of the system, that was other than the capillary tube, was measured by replacing the capillary tube with a short connection (i.e., blank runs). The measured differential pressure was negligible compared to the pressure drop across the capillary tube at all tested flow rates.

A number of repetitions at each flow rate were carried out until three consecutive readings gave less than 1% variation in viscosity. Measurements are only made at flow rates where laminar flow is established. The laminar flow conditions was checked by calculating the Reynolds number and also ensuring that the ratio of the differential pressure to the flow rate remains constant for all flow rates. Measurements are typically conducted with a Reynolds number below 100.

The viscosity is calculated using the modified Poiseuille equation for the flow of compressible fluids through a tube. During the viscosity measurements, the differential pressure across the capillary tube varied from about (0.007 to 0.2) MPa. Hence, the fluid compressibility factor can be assumed to be constant along the tube, resulting in the following equations for isothermal compressible fluid flow.

$$q_1 = \frac{\pi D^4}{256 \eta L P_1}(P_1^{\,2} - P_2^{\,2}) \qquad (1)$$

$$\eta = \frac{\pi D^4}{256 q_1 L P_1}(P_1^{\,2} - P_2^{\,2}) \qquad (2)$$

where L is the length of the tube, D is the tube diameter, P_1 is the inlet pressure, and P_2 is the outlet pressure, η is the viscosity, and q_1 is the fluid volumetric flow rate at the inlet pressure conditions. The impact of end-effect and kinetic-energy correction factors[4] was negligible, because of use of a long (1480.3 cm) capillary tube and low flow rates. The effect of radial acceleration was also calculated to be less than 0.2% by calculating the Dean number[4] at maximum Reynolds number for each system.

The average radius of the tube was calculated from the measured volume and length of the tube. The effect of pressure and temperature on the capillary tube was calculated by neglecting the effect of temperature on the Young's modulus and on the Poisson's ratio. Considering the accuracy of measured parameters, the error in the reported viscosity was estimated at about ±1% for viscosities in the range of those measured in this work. The error is mainly due to the contribution of the measured differential pressure.

Table 2. Viscosity, η, of Pentane

T = (323 ± 0.5) K		T = (373 ± 0.5) K		T = (423 ± 0.5) K	
P/MPa[a]	η/μPa·s[b]	P/MPa[a]	η/μPa·s[b]	P/MPa[a]	η/μPa·s[b]
4.10	194.4	5.43	131.3	3.92	83.9
7.66	202.3	8.78	139.8	7.40	94.4
13.94	215.5	14.17	150.9	14.53	110.4
28.31	248.3	27.36	177.8	27.93	133.0
50.00	293.4	50.46	218.0	50.10	169.7
79.66	355.7	79.34	264.8	80.37	211.7
104.52	411.9	107.03	309.2	105.81	244.5
133.48	482.8	138.79	360.7	136.56	285.0
		Second Measurements			
13.95	218.1	13.91	148.0	13.88	106.9
34.49	260.5	34.52	188.7	34.45	144.9
51.77	296.7	51.77	218.2	51.78	170.1
69.04	332.4	68.96	248.5	69.18	194.4
86.15	371.8	86.23	272.7	86.55	218.5
103.41	407.4	103.72	304.5	103.55	240
120.71	446.9	120.59	329.8	120.69	264.1
137.91	484.5	137.93	358.7	137.87	285.7

[a] Uncertainty ±0.02 MPa. [b] Uncertainty ±1%.

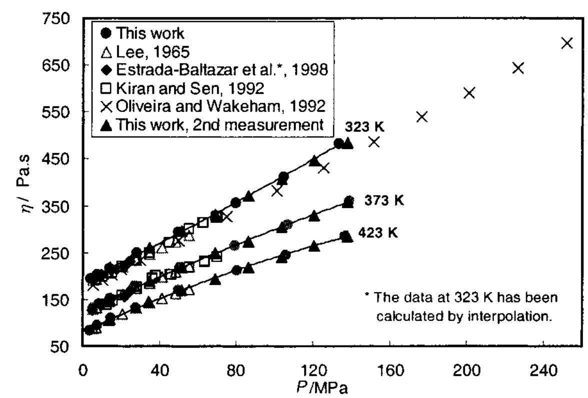

Figure 2. Comparison of viscosity measurements made on pentane with literature data.

Density Measurements. The density was calculated from the mass and volume of the sample. The apparatus is comprised of one of the small-volume (15.6 cm^3) cells blanked at one end and a valve at the other. This is mounted in the oven and connected to the hand pump with one pressure transducer in line.

The procedure is that the volume of the cell is measured accurately by filling it with mercury and weighing on an accurate balance. The cell is disconnected, and the components of the test fluid are added by mass, after application of a vacuum to the cell. The cell is replaced in the oven, and mercury is injected to the desired starting pressure. Once the temperature and pressure have stabilized, the valve is shut and the cell removed and reweighed. The volume of the fluid in the cell can then be calculated from the volume of mercury injected, known from the mass and density of the mercury.

The cell is then replaced, and once the system temperature and pressure has stabilized, mercury is injected incrementally into the cell. The amount of mercury injected is measured by a linear transducer mounted on the hand pump and is corrected for the compressibility of the whole system, which was measured previously. This provides the volume and hence the density of the fluid at various

Table 3. Viscosity, η, of Decane

T = (323 ± 0.5)K		T = (373 ± 0.5) K		T = (423 ± 0.5) K	
P/MPa[a]	η/μPa·s[b]	P/MPa[a]	η/μPa·s[b]	P/MPa[a]	η/μPa·s[b]
2.25	662	7.17	421	6.03	277
7.27	698	14.60	459	14.44	311
14.77	752	51.03	640	27.39	357
27.21	852	79.00	796	50.81	440
50.52	1060	106.29	959	79.21	540
78.93	1332	137.05	1146	103.98	637
105.66	1617			137.98	781
137.58	2013				

[a] Uncertainty ±0.02 MPa. [b] Uncertainty ±1%.

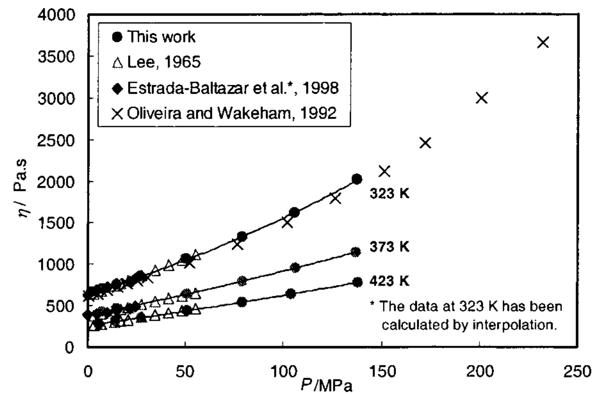

Figure 3. Comparison of viscosity measurements made on decane with literature data.

Table 4. Density, ρ, of Pentane at 323 K

P/MPa[a]	ρ/kg·m^{-3} [b]	P/MPa[a]	ρ/kg·m^{-3} [b]	P/MPa[a]	ρ/kg·m^{-3} [b]
6.95	604	44.63	643	100.79	678
13.77	613	58.89	653	118.84	687
26.86	627	75.80	664	139.71	697

[a] Uncertainty ±0.02 MPa. [b] Uncertainty ±0.5%.

Table 5. Density, ρ, of Decane at 323 K

P/MPa[a]	ρ/kg·m^{-3} [b]	P/MPa[a]	ρ/kg·m^{-3} [b]	P/MPa[a]	ρ/kg·m^{-3} [b]
4.69	716	43.41	745	93.85	770
12.62	724	59.20	754	118.85	780
27.18	735	73.57	761	139.82	788

[a] Uncertainty ±0.02 MPa. [b] Uncertainty ±0.5%.

pressures (as the mass of the test fluid is constant). At the highest pressure, the cell is again isolated and removed from the oven for weighing. The final mass is used to calculate the final volume and gives a check on the measured values by the linear transducer.

The uncertainty of the measured mass is ±0.01 g based upon the accuracy of the balance used to weigh the sample. The uncertainty of the initial volume measurement is estimated at ±0.0007 cm^3. The amount of mercury injected (by movement of the piston on the hand pump) is readable to ±0.0008 cm^3. The largest uncertainty is associated with the compressibility of the system and it is estimated that the uncertainty of the volumetric measurement is better than ±0.01 cm^3. This gives an estimated accuracy of ±0.5% for the density values reported in this work.

Test Fluids. The fluids used in the viscosity and density measurements are listed in Table 1, together with their purity and supplier.

Results and Discussion

Pentane and Decane. Pentane and decane have been widely studied by a number of researchers. To examine the reliability of the experimental methods used in this work, the viscosity and density of pentane and decane were measured and compared with those reported in the literature. Viscosity measurements were made at three temperatures, (323, 373, and 423) K, and at pressures up to 140 MPa. Density measurements were conducted at 323 K and at various pressures up to 140 MPa.

The pentane results are presented in Table 2 and compared with literature data[5−7] in Figure 2. The one significant difference is the deviation with the Oliveira and Wakeham[8] data for pentane at 323 K. The authors used a vibrating-wire viscometer, which was calibrated with re-

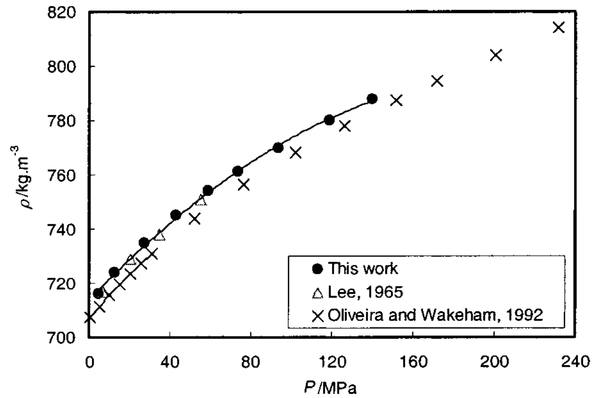

Figure 4. Comparison of density measurements made on pentane at 323 K with literature data.

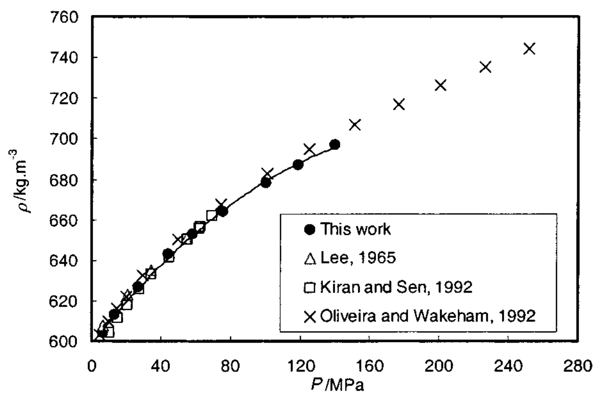

Figure 5. Comparison of density measurements made on decane at 323 K with literature data.

Table 6. Viscosity, η, of Methane (25.0 mass %) + Methylcyclohexane (Saturation Pressures: 25.99 MPa at 323 K, 27.23 MPa at 373 K, and 27.58 MPa at 423 K, All ±0.2 MPa)

T = (323 ± 0.5) K		T = (373 ± 0.5) K		T = (423 ± 0.5) K	
P/MPa[a]	η/μPa·s[b]	P/MPa[a]	η/μPa·s[b]	P/MPa[a]	η/μPa·s[b]
29.79	104.0[c]	28.03	72.7[c]	28.34	54.7[d]
34.12	110.1[c]	29.52	75.3[c]	31.00	57.7[d]
41.92	119.3[c]	42.28	91.0[c]	48.81	77.4[d]
49.19	133.5[c]	50.70	101.4[c]	71.60	99.2[d]
90.53	187.7[c]	69.96	121.1[c]	93.56	119.1[d]
56.51	145.2[d]	84.27	135.5[c]	113.25	135.3[d]
69.66	162.3[d]	125.54	176.5[c]	138.34	154.6[d]
91.70	190.3[d]	42.32	90.5[d]		
138.18	242.6[d]	73.11	124.9[d]		
139.01	253.2	90.14	142.3[d]		
		111.67	163.0[d]		
		125.40	175.9[d]		
		138.65	190.9[d]		

[a] Uncertainty ±0.02 MPa. [b] Uncertainty ±1%. [c] 25.0 mass % methane (uncertainty ±0.4). [d] 24.6 mass % methane (uncertainty ±0.4).

Table 7. Viscosity, η, of Methane (50.0 mass %) + Methylcyclohexane (Saturation Pressures: 28.47 MPa at 323 K, 26.44 MPa at 373 K, and 19.72 MPa at 423 K, All ±0.2 MPa)

T = (323 ± 0.5) K		T = (373 ± 0.5) K		T = (423 ± 0.5) K	
P/MPa[a]	η/μPa·s[b]	P/MPa[a]	η/μPa·s[b]	P/MPa[a]	η/μPa·s[b]
34.67	50.3[c]	33.29	38.0[c]	34.72	33.9[c]
41.89	57.1[c]	41.71	44.0[c]	41.99	38.0[c]
48.61	62.5[c]	55.81	53.4[c]	48.98	42.4[c]
55.83	67.6[c]	70.13	62.2[c]	70.83	52.8[c]
70.21	76.2[c]	85.28	70.1[c]	86.60	60.5[c]
84.52	85.6[c]	104.13	80.6[c]	105.31	68.3[c]
99.53	95.8[c]	121.21	89.6[c]	122.11	77.3[c]
112.11	104.0[c]	138.17	99.2[c]	34.22	33.5[d]
125.38	111.2[c]			57.35	46.1[d]
138.18	119.5[c]			77.10	55.0[d]
				106.01	70.0[d]
				138.44	83.0[d]

[a] Uncertainty ±0.02 MPa. [b] Uncertainty ±1%. [c] 49.9 mass % methane (uncertainty ±0.2). [d] 49.4 mass % methane (uncertainty ±0.2).

Table 8. Viscosity, η, of Methane (75.0 mass %) + Methylcyclohexane (Saturation Pressure: (23.58 ± 0.2) MPa at 323 K, Not Measured at 373 K or 423 K)

T = (323 ± 0.5) K		T = (373 ± 0.5) K		T = (423 ± 0.5) K	
P/MPa[a]	η/μPa·s[b]	P/MPa[a]	η/μPa·s[b]	P/MPa[a]	η/μPa·s[b]
21.36	23.50[c]	20.69	21.23[c]	20.87	21.10[c]
22.13	24.47[c]	27.37	24.98[c]	27.41	23.76[c]
22.84	24.62[c]	34.25	28.78[c]	34.31	26.37[c]
23.48	24.98[c]	40.61	31.24[c]	41.01	28.27[c]
24.21	25.49[c]	47.47	34.73[c]	47.67	31.46[c]
27.59	28.54[c]	55.91	38.04[c]	55.80	34.92[c]
31.09	30.47[c]	69.96	45.01[c]	70.53	38.48[c]
38.33	35.51[c]	84.27	49.45[c]	83.48	44.43[c]
55.84	44.85[c]	99.16	54.59[c]	98.37	48.57[c]
70.73	51.18[c]	112.36	60.78[c]	111.83	51.84[c]
84.00	57.37[c]	126.38	64.07[c]	127.42	56.98[c]
98.47	63.39[c]	138.86	69.43[c]	139.32	59.46[c]
112.47	69.75[c]				
128.07	74.29[c]				
138.58	79.35[c]				
39.22	35.15[d]				
72.09	51.55[d]				

[a] Uncertainty ±0.02 MPa. [b] Uncertainty ±1%. [c] 75.5 mass % methane (uncertainty ±0.1). [d] 75.3 mass % methane (uncertainty ±0.1).

spect to the viscosity data of toluene, *n*-hexane, *n*-heptane, *n*-octane, and *n*-decane.[8] As shown in Figure 2, the other three sources of data[5−7] are in good agreement with the data generated in this work, though the highest reported pressure is 70 MPa. Various methods, such as rolling ball and falling cylinder viscometers, have been used for the data reported in the literature. In all cases, the viscometers have been calibrated with the fluids of known viscosity. Estrada-Baltazar and Iglesias-Silva[6,9] used a rolling ball viscometer, whereas Kiran and Sen[7] used a falling cylinder viscometer. However, it was decided to repeat the experiments. A second series of viscosity measurements were conducted at (323, 373, and 423) K. As presented in Figure 2, the second set of data are in excellent agreement with the original set, demonstrating the repeatability of the procedures used in this work.

The decane results are presented in Table 3 and compared with literature data[5,8,9] in Figure 3. As presented in Figure 3, the values for the viscosity of decane are in excellent agreement with those reported by Lee[5] and Estrada-Baltazar et al.[9] There is an acceptable agreement between this work and that reported by Oliveira and Wakeham.[8]

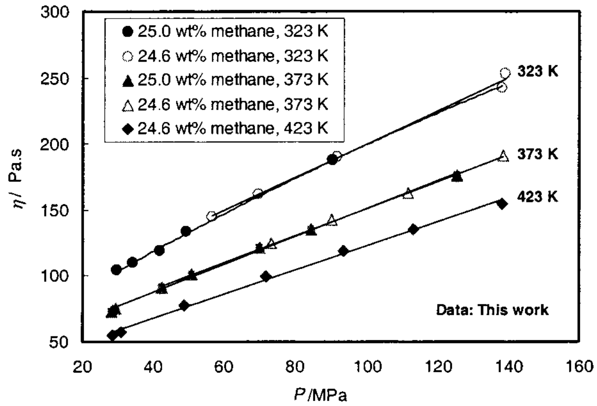

Figure 6. Viscosity measurements for methane + methylcyclohexane, close to 25 mass % methane at different temperatures.

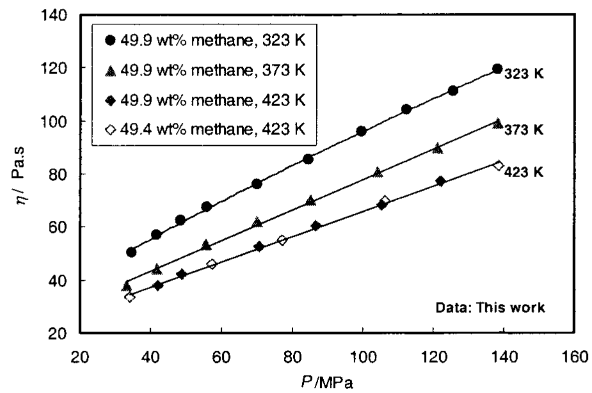

Figure 7. Viscosity measurements for methane + methylcyclohexane, close to 50 mass % methane at different temperatures.

Considering the fact that no calibration has been used in this work, the above comparison demonstrates the reliability of the methods used. As shown in the figures, in almost all cases, there is a close match between the data generated in this work and those reported in the literature.[5−9] Also, the data from this work extend the measured viscosity values for pentane and decane to higher temperatures and/or pressures.

Density measurements were made on pentane and decane at 323 K from 7 to 140 MPa. The results are shown in Tables 4 and 5 and are compared with the literature data[5,7,8] in Figures 4 and 5. As shown in the figures, the results from this work compare well with those reported in the literature,[5,7,8] giving confidence in the experimental methods. The only exception is the data reported by Oliveira and Wakeham[8] on the density of decane, which is systematically lower than other data (at all pressures).

Methane + Methylcyclohexane. A series of viscosity and density measurements were made at three compositions (25, 50, and 75 mass % methane) of methane + methylcyclohexane at three temperatures, (323, 373, and 423) K and pressures up to 140 MPa. The viscosity values for the three compositions at the three temperatures are listed in Tables 6−8.

For each mixture the various compositions were prepared gravimetrically, as reported in Tables 6−8. The saturation pressure for each mixture at the three different temperatures was measured using the visual capability, provided by the sight-glass. The saturation pressure data at three isotherms and different fluid compositions are reported in Tables 6−8 (together with the viscosity data). In most cases, two runs, with slightly different feed compositions, were carried out at different temperatures

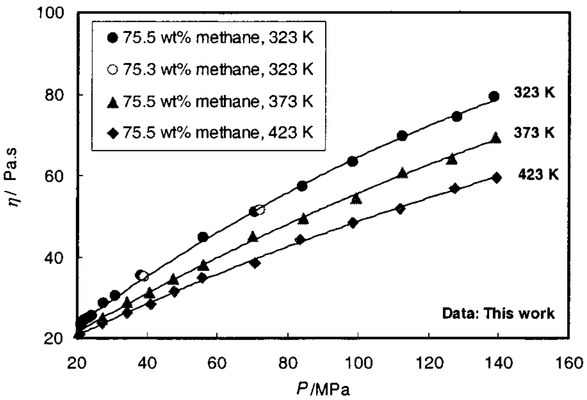

Figure 8. Viscosity measurements for methane + methylcyclohexane, close to 75 mass % methane at different temperatures.

Table 9. Density, ρ, of Methane (25.0 mass %) + Methylcyclohexane

T = (323 ± 0.5) K		T = (373 ± 0.5) K		T = (423 ± 0.5) K	
P/MPa[a]	ρ/kg·m^{-3} [b]	P/MPa[a]	ρ/kg·m^{-3} [b]	P/MPa[a]	ρ/kg·m^{-3} [b]
28.83	534[c]	29.62	482[d]	29.03	414[d]
37.30	551[c]	43.64	512[d]	33.75	436[d]
43.70	562[c]	52.59	529[d]	46.96	481[d]
50.16	571[c]	60.56	542[d]	55.99	505[d]
61.81	587[c]	70.73	556[d]	70.89	532[d]
75.58	601[c]	95.08	583[d]	88.90	557[d]
91.71	615[c]	113.07	599[d]	111.36	582[d]
112.30	631[c]	138.23	615[d]	138.55	604[d]
138.61	647[c]				

[a] Uncertainty ±0.02 MPa. [b] Uncertainty ±0.5%. [c] 25.0 mass % methane (uncertainty ±0.4). [d] 24.8 mass % methane (uncertainty ±0.4).

Table 10. Density, ρ, of Methane [(50.3 ± 0.2) mass %] + Methylcyclohexane

T = (323 ± 0.5) K		T = (373 ± 0.5) K		T = (423 ± 0.5) K	
P/MPa[a]	ρ/kg·m^{-3} [b]	P/MPa[a]	ρ/kg·m^{-3} [b]	P/MPa[a]	ρ/kg·m^{-3} [b]
29.51	349	32.96	306	29.05	239
34.09	370	34.63	314	31.86	255
41.67	396	44.73	351	35.62	273
51.01	419	51.23	371	38.85	287
65.13	444	64.07	399	44.39	307
81.15	466	76.37	419	51.30	331
98.96	486	90.95	440	62.18	358
119.19	504	111.31	462	76.13	385
138.37	519	138.52	486	97.82	417
				116.45	438
				139.37	460

[a] Uncertainty ±0.02 MPa. [b] Uncertainty ±0.5%.

Table 11. Density, ρ, of Methane [(75.4 ± 0.1) mass %] + Methylcyclohexane

T = (323 ± 0.5) K		T = (373 ± 0.5) K		T = (423 ± 0.5) K	
P/MPa[a]	ρ/kg·m^{-3} [b]	P/MPa[a]	ρ/kg·m^{-3} [b]	P/MPa[a]	ρ/kg·m^{-3} [b]
22.33	204	23.64	169	23.22	139
29.28	248	30.27	205	29.56	169
36.67	281	41.33	249	38.98	207
43.60	303	55.12	291	48.23	236
56.50	335	69.92	319	68.68	285
73.17	364	90.70	348	83.19	309
92.93	391	113.38	375	96.80	328
117.31	414	138.16	397	115.04	349
138.44	432			138.10	370

[a] Uncertainty ±0.02 MPa. [b] Uncertainty ±0.5%.

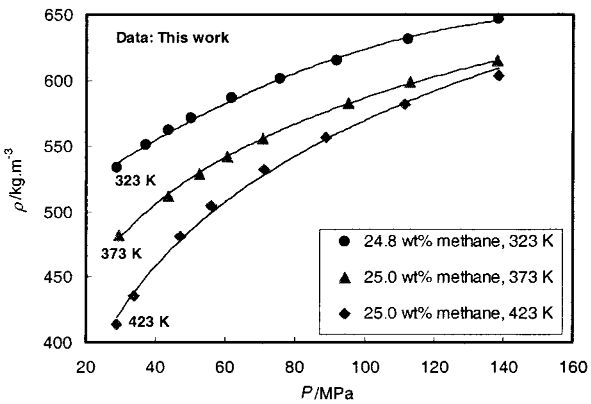

Figure 9. Density measurements for methane + methylcyclohexane, close to 25 mass % methane at different temperatures.

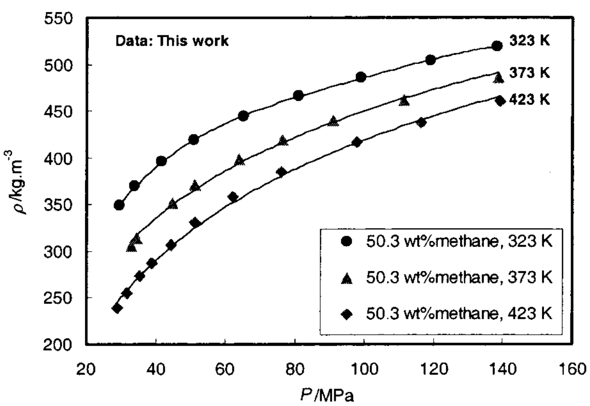

Figure 10. Density measurements for methane (50.3 mass %) + methylcyclohexane at different temperatures.

in order to crosscheck the data. The results are presented in Tables 6−8 and plotted in Figures 6−8. As shown in the above figures and tables, there is good agreement between experimental data, where more than one run was conducted at one temperature.

The results of the density measurements made on methane and methylcyclohexane at different compositions and temperatures are given in Tables 9−11. As with the viscosity data, the composition of the mixture is presented with the density data. The density data for the three compositions at different temperatures are presented in Figures 9−11.

Conclusions

A new high-pressure and high-temperature (133 MPa at 523 K or 200 MPa at 474 K) facility has been developed to measure a range of phase behavior properties, including saturation pressures, interfacial tension (IFT), phase volumes, and viscosity and density of water and/or hydrocarbon systems.

A series of density and viscosity measurements have been conducted on pentane and decane. The data are compared with the available literature data, demonstrating the reliability of the methods used in this laboratory. The results extend the range of available data on pentane and decane to 423 K and/or 140 MPa.

Viscosity and density data for three methane + methylcyclohexane binary mixtures has been measured for a temperature range from 323 K to 423 K and up to 140 MPa. The results should provide valuable information for those assessing and developing viscosity and density prediction methods applicable at these extreme conditions.

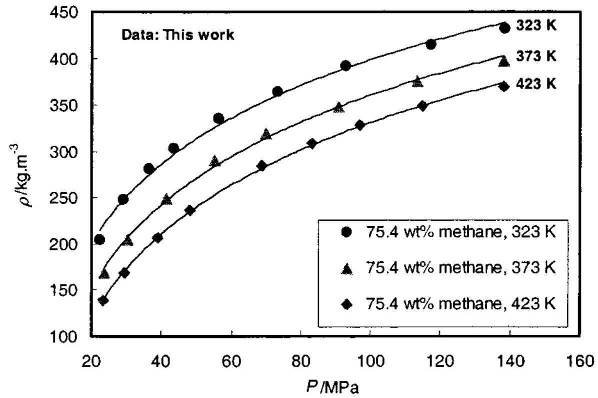

Figure 11. Density measurements for methane (75.4 mass %) + methylcyclohexane at different temperatures.

Acknowledgment

This work was accomplished within the European project EVIDENT under the Joule Program, Contract No. JOF3-CT97-0034, which is gratefully acknowledged.

Literature Cited

(1) Baylaucq, A.; Boned, C.; Dauge, P.; Lagourette, B. Measurements of the viscosity and density of three hydrocarbons and the three associated binary mixtures versus pressure and temperature. *Int. J. Thermophys.* **1997**, *18* (1), 3−23.

(2) Ettahir, A.; Boned, C.; Lagourette, B.; Xans, P. Determination of the viscosity of various hydrocarbons and mixtures of hydrocarbons versus temperature and pressure. *Int. J. Thermophys.* **1995**, *16* (6), 1309−1334.

(3) Ashcroft, S. J.; Ben Isa, M. Effect of dissolved gases on the densities of hydrocarbons. *J. Chem. Eng. Data* **1997**, *42* (6), 1244−1248.

(4) Wakeham, W. A.; Nagashima, A.; Sengers J. V. *Experimental Thermodynamics. Volume III. Measurement of the Transport Properties of Fluids*; Blackwell Scientific Publications: Oxford, U.K., 1991.

(5) Lee, A. L. *Viscosity of Light Hydrocarbons*; Monograph on API Research Project 65; American Petroleum Institute: New York, 1965.

(6) Estrada-Baltazar, A.; Iglesias-Silva, G. A.; Barrufet, M. A. Liquid viscosities of pentane and pentane + decane from 298.15 K to 373.15 K and up to 25 MPa. *J. Chem. Eng. Data* **1998**, *43* (4), 601−604.

(7) Kiran, E.; Sen, Y. L. High-pressure viscosity and density of normal-alkanes. *Int. J. Thermophys.* **1992**, *13* (3), 411−442.

(8) Oliveira, C. M. B. P.; Wakeham, W. A. The viscosity of 5 liquid hydrocarbons at pressures up to 250 MPa. *Int. J. Thermophys.* **1992**, *13* (5), 773−790.

(9) Estrada-Baltazar, A.; Alvarado, J. F. J.; Iglesias-Silva, G. A.; Barrufet, M. A. Experimental liquid viscosities of decane and octane + decane from 298.15 K to 373.15 K and up to 25 MPa. *J. Chem. Eng. Data* **1998**, *43* (3), 441−446.

Received for review June 28, 2000. Accepted December 4, 2000.

JE000191L