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Viscosity and Density Data of Two North Sea Gas Condensate Samples at Temperatures to 423 K and Pressures to 140 MPa

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A high-pressure−high-temperature experimental facility, equipped with a capillary tube viscometer, has been employed to measure the viscosity and density of two gas condensate samples at (323, 373, and 423) K and pressures up to 140 MPa. The stabilized condensate has been fractionated to single carbon number (SCN) cuts by true-boiling-point (TBP) distillation, and the molecular weight and density of the fractions are reported.

Introduction

Development of high-pressure−high-temperature (HPHT) fields is a major challenge for various sectors involved in the oil industry. There is little experience with this type of reservoirs where the pressure and temperature of formation can reach up to 110 MPa and 473 K.[1,2] A knowledge of fluid phase and flow properties, density and viscosity in particular, can have a major contribution in field development. Viscosity and density data at HPHT may be found for well-defined binary systems,[3] whereas there is little information on real reservoir fluids at these conditions in the open literature. Ungerer et al.[4] studied the phase behavior of four synthetic gas condensates at (298 to 426) K and pressures up to 60 MPa. They investigated the sensitivity of the dew point pressure of the mixtures with concentration of heavy hydrocarbons.

In this paper, experimental data on the density and viscosity of two North Sea-based gas condensates at HPHT conditions (up to 423 K and 140 MPa) are presented. A North Sea-stabilized condensate, topped-up with intermediate fractions (C_{6s}, C_{7s}, and C_{8s}), was used to prepare in-situ reservoir fluids in the laboratory by recombining it with separator gas. Two different separator gas samples, prepared by gravimetrically mixing pure components to match the separator gas composition, were used in fluid recombination. The stabilized condensate was characterized as single carbon number (SCN) cuts by true-boiling-point (TBP) distillation, and the molecular weight and density of the fractions were measured.

Apparatus and Test Procedures

A capillary tube viscometer, incorporated into a high-pressure−high-temperature (HPHT) experimental facility, is used to make the viscosity measurements. The HPHT facility has a maximum working pressure of 140 MPa at 473 K. The density measurements are made by determining the mass of a known volume of the fluid. The HPHT experimental facility along with the test procedures is fully described in ref 3.

The only modification is in the high-pressure−high-temperature (HPHT) density measurements. In this work we have used a more accurate balance, called a mass comparator Mettler Toledo PR5003, to weigh the sample, with an accuracy of ±0.001 g, resulting in an uncertainty of ±0.2%, in the reported density.

Table 1. Density of Pentane

T = 323 K[a]		T = 373 K[a]		T = 423 K[a]	
P^b/MPa	ρ^c/kg·m^{-3}	P^b/MPa	ρ^c/kg·m^{-3}	P^b/MPa	ρ^c/kg·m^{-3}
7.05	604.1	6.97	553.1	6.92	491.6
13.89	612.4	13.83	567.6	13.80	517.1
34.49	633.4	34.50	598.6	34.51	561.1
51.79	647.9	51.77	616.8	51.79	584.6
68.97	660.4	69.10	632.0	69.02	603.5
86.18	671.7	86.21	644.9	86.21	618.9
103.47	680.4	103.49	655.5	103.52	631.8
120.68	689.3	120.71	665.7	121.01	643.1
137.94	697.5	138.10	675.1	137.93	653.9

[a] Uncertainty ±0.5 K. [b] Uncertainty ±0.02 MPa. [c] Uncertainty ±0.2%.

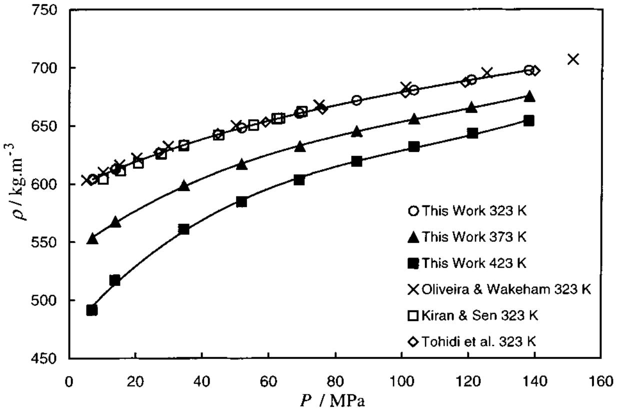

Figure 1. Density, ρ, of pentane at 323, 373, and 423 K.

Experimental Results

HPHT Density of Pentane. To evaluate the reliability of the density measurement, the density of pentane is measured at three temperatures [(323, 373, and 423) K] and at the pressures (6.92 to 138.10) MPa. The procedure has been described in ref 3. The measured density data on pentane are presented in Table 1 and compared with those reported in the literature[3,5,6] in Figure 1. The reported

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Table 2. Molecular Weight and Density of SCN Groups of Stabilized Condensate

fraction	mol wt[a]	density[b]/kg·m^{-3}
C_{6s}	88.5	677
C_{7s}	92[c]	732
C_{8s}	103	756
C_{9s}	116	777
C_{10s}	131	789
C_{11s}	147	788
C_{12s}	161	808
C_{13s}	173	821
C_{14s}	186	838
C_{15s}	203	836
C_{16s}	215	842
C_{17s}	229	840
C_{18s}	246	842
C_{19s}	258	853
C_{20+}	384	879

[a] Uncertainty ±1% for C_{6s} to C_{19s} and ±2.5% for the plus fraction (C_{20+}). [b] Uncertainty ±1. [c] C_{7s} measurement corrected for a benzene content of 5.9% by mass.

Table 3. Molar Composition of Gas Condensates A and B

component	fluid A mole %[a]	fluid B mole %[a]
C_1	71.930	69.624
C_2	11.780	13.142
C_3	4.747	9.189
iC_4	0.812	0.674
nC_4	1.712	2.433
iC_5	0.608	0.439
nC_5	0.769	0.565
C_{6s}	0.886	0.560
C_{7s}	1.377	0.595
C_{8s}	1.399	0.630
C_{9s}	0.774	0.418
C_{10s}	0.513	0.277
C_{11s}	0.435	0.235
C_{12s}	0.300	0.162
C_{13s}	0.300	0.162
C_{14s}	0.284	0.153
C_{15s}	0.214	0.116
C_{16s}	0.174	0.094
C_{17s}	0.178	0.096
C_{18s}	0.125	0.067
C_{19s}	0.100	0.054
C_{20+}	0.583	0.315

[a] Uncertainty: ±1% for C_1 to C_{19s} and about ±2% for C_{20+}.

density data by Oliviera and Wakeham[5] at 323 K, with an uncertainty of ±0.2%, are systematically higher than our data at all pressures with a maximum deviation of +0.5%. The reported data by Kiran and Sen[6] are lower than our data at pressures below 50 MPa with a maximum deviation of −0.8%. The uncertainty of the reported density data by Kiran and Sen is ±1.0%.

Fluid Characterization. Two gas condensate samples were prepared by recombining a North Sea-based condensate with separator gases. Prior to addition of separator gas, some intermediate fractions (C_{6s}, C_{7s}, and C_{8s}) were added to the stabilized condensate to compensate those components that had been lost from the condensate liquid in the stabilization process. The added intermediate fractions (C_{6s}, C_{7s}, and C_{8s}) were obtained by distillation of additional stabilized condensate fluid into single carbon number (SCN) cuts.

Table 4. Density of Gas Condensate Fluids at (323 ± 0.5) K

fluid A		fluid B	
P^a/MPa	ρ^b/kg·m^{-3}	P^a/MPa	ρ^b/kg·m^{-3}
40.73	421.2	37.94	382.2
51.33	442.3	42.43	393.8
69.38	468.9	51.79	413.2
86.14	487.3	69.19	440.4
103.73	504.6	86.19	460.6
120.56	513.6	103.51	476.2
137.85	523.0	120.79	489.3
		137.96	500.9

[a] Uncertainty ±0.02 MPa. [b] Uncertainty ±0.2%.

Table 5. Density of Gas Condensate Fluids at (373 ± 0.5) K

fluid A		fluid B	
P^a/MPa	ρ^b/kg·m^{-3}	P^a/MPa	ρ^b/kg·m^{-3}
41.51	371.2	46.82	356.2
52.07	397.2	52.13	368.8
60.19	412.9	69.08	400.6
69.22	427.7	86.48	424.1
86.61	450.4	103.72	442.5
104.70	469.4	120.82	458.0
121.00	483.3	137.98	471.0
138.37	496.6		

[a] Uncertainty ±0.02 MPa. [b] Uncertainty ±0.2%.

Table 6. Density of Gas Condensate Fluids at (423 ± 0.5) K

fluid A		fluid B	
P^a/MPa	ρ^b/kg·m^{-3}	P^a/MPa	ρ^b/kg·m^{-3}
41.07	322.0	61.56	355.9
51.83	354.0	68.75	368.9
69.67	390.5	86.27	396.6
86.62	409.6	103.49	418.6
103.46	435.0	120.74	435.7
120.60	451.6	138.09	450.9
137.94	466.5		

[a] Uncertainty ±0.02 MPa. [b] Uncertainty ±0.2%.

The composition of stabilized condensate was measured by gas chromatography, by on-line injection into a HP-1 column (Hewlett-Packard Ltd.). The column dimensions were 30 m × 0.53 mm (i.d.) × 2.65 μm film. The column was polyimide-coated fused silica, with a methyl siloxane stationary phase. The carrier gas used was helium with a flow rate of 6 mL/min, and the temperature program was from 233 to 573 K at 20 K/min. The uncertainty of the measured composition was believed to be ±1% (It was about ±2% for the plus fraction, C_{20+}).[7]

A true-boiling-point (TBP) distillation was carried out on the stabilized condensate to fractionate the liquid into single carbon number (SCN) cuts, ranging from C_{6s} to C_{20+}. The distillation was performed using a fully calibrated Fischer Still (model HMS 500C), with a 90 theoretical plate efficiency.

Molecular weights (MWs) of single carbon cuts were measured by cryoscopy, using water-saturated benzene as solvent. The cryoscope used was a “Cryette”, Model 5008 (Precision Systems Inc.), which supercools the solution, “seeds” the benzene crystals, and monitors the freezing-point depression with a resolution of ±0.001 K. The uncertainty of measured molecular weights is ±1% with the exception of the plus fraction (C_{20+}) residues, which have an uncertainty of ±2.5%. The measured MWs of the distilled cuts are given in Table 2.

For the measurement of the density of the single carbon number (SCN) fractions, an Anton Paar densitometer, model DMA 602, linked to a DMA 45 digital readout was used. The uncertainty of data measured by this unit was ±1 kg/m^3. The measured density data are also listed in Table 2.

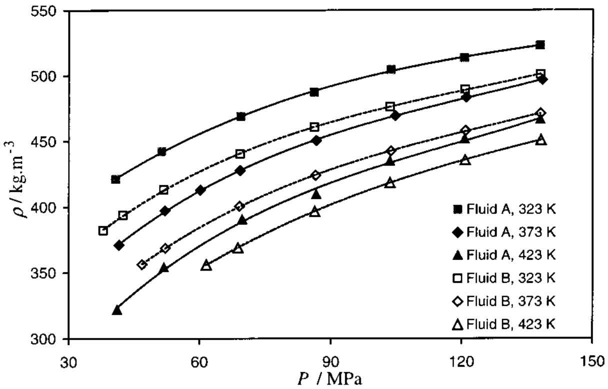

Figure 2. Density, ρ, of gas condensates A and B at 323, 373, and 423 K.

Table 7. Viscosity of Gas Condensate Fluids at (323 ± 0.5) K

fluid A		fluid B	
P^a/MPa	μ^b/μPa·s	P^a/MPa	μ^b/μPa·s
41.74	76.0	37.99	56.5
52.28	85.1	51.92	67.9
69.00	98.9	68.93	79.3
86.14	110.7	86.20	89.4
103.27	124.8	103.43	102.3
119.79	137.9	120.78	112.0
137.84	153.4	137.93	121.2

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

Table 8. Viscosity of Gas Condensate Fluids at (373 ± 0.5) K

fluid A		fluid B	
P^a/MPa	μ^b/μPa·s	P^a/MPa	μ^b/μPa·s
41.78	58.0	37.92	43.9
51.88	64.6	51.74	53.8
69.14	78.4	68.94	64.2
86.10	88.0	86.14	74.7
104.42	99.8	103.35	83.0
120.65	111.9	120.66	93.0
137.49	120.7	137.85	101.7

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

On completion of the compositional characterization, the required amounts of separator gas and intermediate hydrocarbons (C_{6s}, C_{7s}, and C_{8s}) were added to the stabilized condensate to obtain the in-situ reservoir fluid. The second gas condensate sample (fluid B, Table 3) was prepared by using a different separator gas with a higher gas-to-condensate ratio in the recombination process. It is acknowledged that the relative distribution of components in a real reservoir system may by different from that used in this work. The mixtures were then thoroughly mixed and pressurized at the reservoir temperature to stabilize them as single-phase fluids, with the composition shown in Table 3. The composition was calculated by numerically adding the measured values of the condensate liquid and gravimetrically prepared gas samples.

Volumetric and Viscosity Data of Gas Condensate Samples. Gas condensate A showed a dew point pressure of 37.54 MPa at 373 K with a maximum liquid fraction (liquid volume/total volume) of 12.77% at 24.13 MPa. The measured dew point pressure of gas condensate B was 34.68 MPa at 373 K with a maximum liquid fraction of 4.32% at 18.62 MPa.[8]

Table 9. Viscosity of Gas Condensate Fluids at (423 ± 0.5) K

fluid A		fluid B	
P^a/MPa	μ^b/μPa·s	P^a/MPa	μ^b/μPa·s
41.28	44.9	38.24	36.4
51.72	53.6	51.77	45.5
68.88	63.7	69.14	55.2
85.37	74.5	86.24	63.2
103.48	85.9	103.55	71.5
120.25	95.6	120.64	79.4
138.26	106.6	138.06	86.5

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

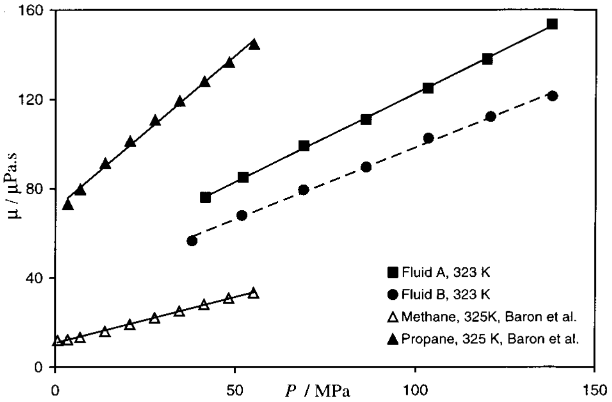

Figure 3. Viscosity, μ, of gas condensates A and B at 323 K, compared to viscosities of methane and propane at 325 K.

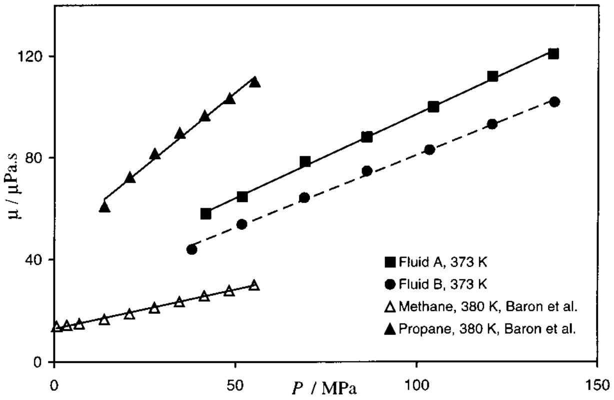

Figure 4. Viscosity, μ, of gas condensates A and B at 373 K, compared to viscosities of methane and propane at 380 K.

Tables 4−6 list the measured single-phase densities for the two gas condensate fluids (A and B) at (323, 373, and 423) K, respectively. The results of the density measurements are also represented graphically in Figure 2. As expected, the density decreases with increase in temperature but it increases with increase in pressure. The effect of temperature on density variation is higher at lower pressures. The density of gas condensate A is higher than that of gas condensate B at all tested conditions because gas condensate A is heavier in comparison to fluid B (Figure 2).

The results of viscosity measurements made on the gas condensate fluids (A and B) at three temperatures (323, 373, and 423) K and at pressures up to 138 MPa are given in Tables 7−9. The measured viscosity data are also presented graphically in Figures 3−5, and they are compared with the viscosities of pure methane and propane at similar temperatures.[9] The viscosities of both fluids (A and B) decrease with an increase in temperature over the tested pressure range, as expected for dense gases. The effect of temperature on viscosity reduction is lower at lower pressures. The results show that viscosity isotherms are

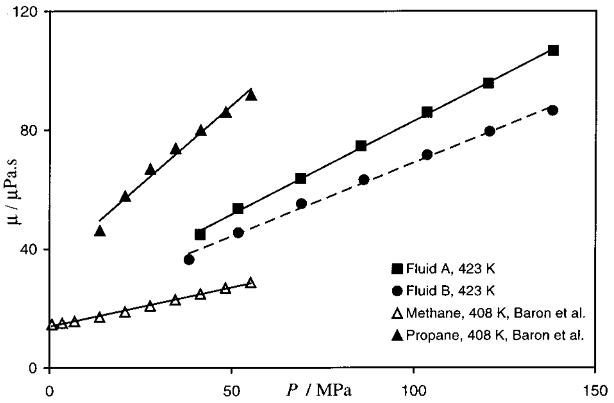

Figure 5. Viscosity, μ, of gas condensates A and B at 423 K, compared to viscosities of methane and propane at 408 K.

almost linear with pressure over the tested range, with the slope being temperature dependent. For gas condensate A, the slope of the viscosity increment with pressure is 0.795 $\times 10^{-12}$ s at 323 K. The slope reduces to 0.629 $\times 10^{-12}$ s at 423 K. This shows that as temperature increases, the viscosity of the gas condensate becomes less sensitive to pressure change. This observation is in-line with the viscosity behavior of pure compounds. The slopes of the viscosity increments with pressure for methane and propane are (0.410 $\times 10^{-12}$ and 1.284 $\times 10^{-12}$) s at 325 K, respectively. These slopes reduce to (0.263 $\times 10^{-12}$ and 0.968 $\times 10^{-12}$) s at 408 K for methane and propane, respectively. The slopes of the viscosity increments with pressure for gas condensate B are (0.646 $\times 10^{-12}$ and 0.496 $\times 10^{-12}$) s at (323 and 423) K, respectively.

The slope of the isothermal viscosity increment with pressure also depends on the molecular weight of the system. The molecular weight of fluid A is higher than that of fluid B but lower than that of propane; therefore, the slope of the viscosity increment with pressure for fluid A is higher than that for fluid B but lower than that for propane at the same temperature.

Conclusions

Experimental data have been generated on the densities and viscosities of two fully characterized North Sea-based gas condensate fluids under high-pressure−high-temperature (HPHT) conditions. The measurements have been conducted at three temperatures (323, 373, and 423 K) and at pressures up to 140 MPa. The viscosity decreased with an increase in temperature with the viscosity isotherms varied almost linearly with pressure. The slope of the viscosity increment with pressure was a function of temperature and molecular weight of the mixture.

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