

RESEARCH TITLE

Measurement and predication of density and viscosity for binary mixtures n-hexane + n-octane by using PVT system

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HNSJ, 2021, 2(12); <https://doi.org/10.53796/hnsj21234>

Published at 01/12/2021

Accepted at 23/11/2021

Abstract

In this e work presented the viscosity and liquid density for binary mixtures of hydrocarbon system are measured at different temperatures from 40 °C up to 120 °C and 100 psig to 4000 psig pressure (n-hexane + n-octane). The measured results are used to predict the fluid properties, density & viscosity.

Equipment:

In this work used PVT Model 3000 GL Where used for measurement of Viscosity and Density at different pressures and Temperatures above bubble point pressure to hens the liquid phase reign

PVT Model 3000 GL:

A Precision, Multi-Tasking Instrument For Understanding The Behavior Of Complex Mixtures. The study of thermo-physical properties of fluids such as phase behavior, density, viscosity, etc. under varying conditions of pressure, temperature and volume is commonly known as

PVT studies. The Model 3000 PVT System is a precision instrument used

to perform PVT studies on a variety of fluids with a special emphasis on those fluids typically encountered in petroleum reservoirs.

Model 3000 GL is supply with electrical viscometer and densometer at high pressure and temperature measurement; Where used for measurement of Viscosity and Density at different pressures and Temperatures above bubble point pressure to hens the liquid phase reign.

The mPDS 2000V3 is a powerful processor and display unit, designed for the continuous density and concentration measurement in industrial processes. The mPDS 2000V3 can be connected to an Anton Paar DPR(n), SPR(n), Carbo, DSRn transducer or a DMA-HPM high pressure cell. The measured values from these transducers are transmitted via a twin core shielded-cable to the evaluation unit mPDS 2000V3. The evaluation unit determines the concentration for external display or output and control purposes.

The viscometer is made up of a sensor and the operating electronics. The following sections will cover the basic operation of each.

Sensor Overview

The SPL440 sensor is the perfect choice for measuring samples under pressure at temperatures from -40C to +190C. The sensor contains two magnetic coils and an internal temperature detector mounted to the base of the Inconel-718^R measurement chamber. It is designed for continuous operation at 20,000 PSI. With the optional thermal jacket, the sensor temperature can be precisely maintained for accurate viscosity measurements.

High temperature, high pressure (HTHP) volume translated - (VT) EOS.

To predict density used Peneloux [10] introduced a simple method based on the volume translation principles in order to improve the estimation of the liquid molar volume by cubic EOSs.

$$v = \tilde{v} - c \quad (1)$$

The high temperature, high pressure volume translated forms of the PR EOS, referred as HTHP VT -PREOS, are presented here.

HTHP VT-PR EOS:

$$c(T) = V_{PR} - V_{exp} = A + BT_r \quad (2)$$

HTHP VT-PR EOS:

$$P = \frac{RT}{v+c-b} - \frac{a_c \alpha}{(v+c)(v+c+b)+b(v+c-b)} \quad (3)$$

Where $C = A + BT_r$ Eq(2)

$$A, B = f(M, \omega) = k_0 + k_1 \exp\left(\frac{-1}{k_2 M \omega}\right) + k_3 \exp\left(\frac{-1}{k_4 M \omega}\right) + k_5 \exp\left(\frac{-1}{k_6 M \omega}\right) \quad (4)$$

3.3 Extension to mixtures

The HTHP VT-SRK EOS and HTHP VT-PR EOS can be extended to mixtures using the following mixing rule proposed in other volume-translated cubic EOS models [15]:

For an n compound mixture the c parameter is obtained using a linear mixing rule

$$c_m = \sum_{i=1}^n x_i c_i \quad (5)$$

The friction theory (f-theory) viscosity modeling

The theory for viscosity modeling called the friction theory (f-theory) has been introduced [1]. According to the f-theory, the total viscosity η of dense fluids can be separated into a dilute gas term η_0 and a friction term η_f

$$\eta = \eta_0 + \eta_f \quad (6)$$

By analogy with the Amontons–Coulomb friction law, the viscosity friction term has been linked to the van der Waals repulsive pressure term p_r and the attractive pressure term p_a by means of three temperature dependent friction coefficients as follows:

$$\eta_f = \kappa_r P_r + \kappa_{rr} P_r^2 + \kappa_a P_a \quad (7)$$

Predicting the dilute gas viscosity of several polar and non-polar fluids within an uncertainty of 1.5%.

The model is given by

$$\eta_0 = 40.785 \frac{\sqrt{M_w T}}{v_c^{2/3} \Omega^*} F_c \quad (8)$$

n -Alkane mixtures:

$$\eta_{mx} = \eta_{0,mx} + \eta_{f,mx} \quad (9)$$

where the subscript m,x indicates the corresponding mixture property. Here, the mixture dilute gas limit is calculated by:

$$\eta_{0,mx} = \exp \left[\sum_{i=1}^n x_i \ln(\eta_{0,i}) \right] \quad (10)$$

the subscript i refers to the corresponding pure component of an n components mixture. The mixture friction contribution term is given by

$$\eta_{f,mx} = \kappa_{r,mx} P_r + \kappa_{rr,mx} P_r^2 + \kappa_{a,mx} P_a \quad (11)$$

where $\kappa_{r,mx}, \kappa_{rr,mx}, \kappa_{a,mx}$ are the viscous friction coefficients for the mixture[3]

Results and Discussion

The experimental viscosities and densities of binary mixtures n-hexane + n-octane have been measured at different temperatures and different pressure range between 40 C up to 120 C & 100psig up to 4000 psig. The comparisons of some results with literature data for pure n-hexane and nitrogen are presented in Table 1. Generally, agreement between experimental and literature data is good.

Calibration of data for the Dens meter

The dens meter has been calibrated with n-hexane, nitrogen, purity $\geq 99\%$, since table 1 shown data have been reported in the literature for this alkane [13, 14]

Table (1) Comparison of measured Densities (gm/cm³) for pure component n-Hexane with literature

T (C)	40		60	
	EXP.	Meas. Lit(14)	EXP.	Meas. lit(14)
n-Hexane				
P (psig)				
4000	0.684802	0.670665	0.667409	0.653357
3500	0.681300	0.667528	0.664523	0.649784
3000	0.678280	0.664081	0.660996	0.64576
2500	0.675274	0.660607	0.657530	0.641713
2000	0.671783	0.657108	0.653991	0.638235
1500	0.669205	0.653405	0.650296	0.635295
Nitrogen		lit(13)		lit(13)
4000	0.26559	0.27325	0.248361	0.25484
3500	0.239008	0.24433	0.223126	0.22755
3000	0.210093	0.21364	0.19589	0.19876
2500	0.178848	0.1812	0.166662	0.16848
2000	0.146058	0.14708	0.136094	0.13677
1500	0.111457	0.11147	0.103942	0.10376

Table (2) Densities (gm/cm³) for binary mixtures of 80% n- Hexane (1) +20% n-Octane (2)

T°C	40	60	100	120
P PSIG				
4000	0.6882	0.6730	0.6401	0.6257
3500	0.6853	0.6697	0.6353	0.6200
3000	0.6823	0.6664	0.6304	0.6144
2500	0.6794	0.6631	0.6256	0.6087
2000	0.6764	0.6598	0.6207	0.6031
1500	0.6735	0.6565	0.6159	0.5974
1000	0.6705	0.6532	0.6110	0.5918
500	0.6676	0.6499	0.6062	0.5861
250	0.6661	0.6483	0.6038	0.5833
100	0.6652	0.6473	0.6023	0.5816

Table (3) Densities (gm/cm³) for binary mixtures of 20% n- Hexane (1) +80% n-Octane (2)

T°C	40	60	100	120
P PSIG				
4000	0.7141	0.7004	0.6700	0.6525
3500	0.7114	0.6979	0.6661	0.6483
3000	0.7086	0.6953	0.6621	0.6440
2500	0.7059	0.6927	0.6582	0.6398
2000	0.7033	0.6902	0.6542	0.6355
1500	0.7006	0.6876	0.6503	0.6312
1000	0.6979	0.6850	0.6463	0.6270
500	0.6953	0.6825	0.6424	0.6227
250	0.6939	0.6812	0.6404	0.6206
100	0.6931	0.6804	0.6392	0.6193

Table (4) Densities(gm/cm³) for binary mixtures of 60% n- Hexane (1) +40% n-Octane (2)

T°C \ P PSIG	40	60	100	120
4000	0.6985	0.6817	0.6514	0.6377
3500	0.6954	0.6786	0.6467	0.6322
3000	0.6925	0.6755	0.6419	0.6268
2500	0.6893	0.6724	0.6372	0.6213
2000	0.6862	0.6693	0.6324	0.6159
1500	0.6854	0.6662	0.6277	0.6104
1000	0.6806	0.6631	0.6229	0.6050
500	0.6773	0.6600	0.6182	0.5995
250	0.6760	0.6585	0.6158	0.5968
100	0.6751	0.6576	0.6144	0.5952

Table (5) Densities(gm/cm³) for binary mixtures of 40% n- Hexane (1) +60% n-Octane (2)

T°C \ P PSIG	40	60	100	120
4000	0.7054	0.6926	0.6609	0.6461
3500	0.7027	0.6893	0.6567	0.6415
3000	0.6999	0.6860	0.6525	0.6368
2500	0.6972	0.6827	0.6483	0.6322
2000	0.6944	0.6794	0.6441	0.6275
1500	0.6917	0.6761	0.6399	0.6229
1000	0.6889	0.6728	0.6357	0.6182
500	0.6862	0.6695	0.6315	0.6136
250	0.6848	0.6678	0.6294	0.6113
100	0.6840	0.6668	0.6282	0.6099

Table (6) viscosities (Cp) for binary mixtures of 80% n- Hexane (1)+ 20% n-Octane (2)

T°C \ P PSIG	40	60	100	120
4000	0.3942	0.3271	0.2268	0.2106
3500	0.3814	0.3170	0.2193	0.2037
3000	0.3687	0.3069	0.2119	0.1968
2500	0.3559	0.2968	0.2044	0.1899
2000	0.3432	0.2867	0.1970	0.1830
1500	0.3304	0.2766	0.1895	0.1761
1000	0.3177	0.2665	0.1821	0.1692
500	0.3049	0.2564	0.1746	0.1623
250	0.2986	0.2513	0.1709	0.1589
100	0.2947	0.2483	0.1687	0.1568

Table (7) viscosities (Cp) for binary mixtures of 60% n- Hexane (1)+ 40% n-Octane (2)

T°C \ P PSIG	40	60	100	120
4000	0.4279	0.3590	0.2635	0.2359
3500	0.4156	0.3479	0.2551	0.2286
3000	0.4033	0.3368	0.2467	0.2213
2500	0.3911	0.3257	0.2383	0.2140
2000	0.3788	0.3146	0.2299	0.2067
1500	0.3665	0.3035	0.2215	0.1994
1000	0.3542	0.2924	0.2131	0.1921
500	0.3419	0.2813	0.2047	0.1848
250	0.3358	0.2758	0.2005	0.1812
100	0.3321	0.2724	0.1980	0.1790

Table (8) viscosities (Cp) for binary mixtures of 40% n- Hexane (1)+ 60% n-Octane (2)

T°C \ P PSIG	40	60	100	120
4000	0.4943	0.4031	0.2761	0.2505
3500	0.4793	0.3928	0.2665	0.2420
3000	0.4644	0.3825	0.2569	0.2335
2500	0.4494	0.3722	0.2473	0.2250
2000	0.4345	0.3619	0.2377	0.2165
1500	0.4195	0.3516	0.2281	0.2080
1000	0.4046	0.3413	0.2185	0.1995
500	0.3896	0.3310	0.2089	0.1910
250	0.3821	0.3259	0.2041	0.1868
100	0.3776	0.3228	0.2012	0.1842

Table (9) viscosities (Cp) for binary mixtures of 20% n- Hexane (1)+ 80% n-Octane (2)

T°C \ P PSIG	40	60	100	120
4000	0.5229	0.4225	0.3154	0.2707
3500	0.5078	0.4117	0.3062	0.2611
3000	0.4927	0.4008	0.2971	0.2514
2500	0.4777	0.3899	0.2879	0.2417
2000	0.4626	0.3790	0.2788	0.2320
1500	0.4475	0.3681	0.2696	0.2224
1000	0.4325	0.3572	0.2605	0.2127
500	0.4174	0.3463	0.2513	0.2030
250	0.4098	0.3408	0.2468	0.1982
100	0.4053	0.3376	0.2440	0.1953

The new volume translated equations of state, the HTHP VT -PR EOS, is used in this work to predict the density of binary mixtures n-hexane + n-octane in the range of temperatures from ~ 40 to 120 C and pressures from ~ 100 to 4000 PSIG.

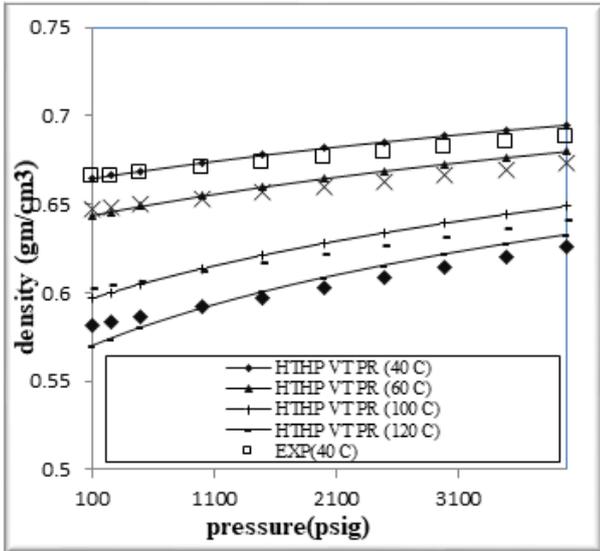


Figure (1) Comparison of density Experimental with HPHT VT PR EOS for binary mixtures of 20% n-Octane (1) + 80% n-Hexane (2)

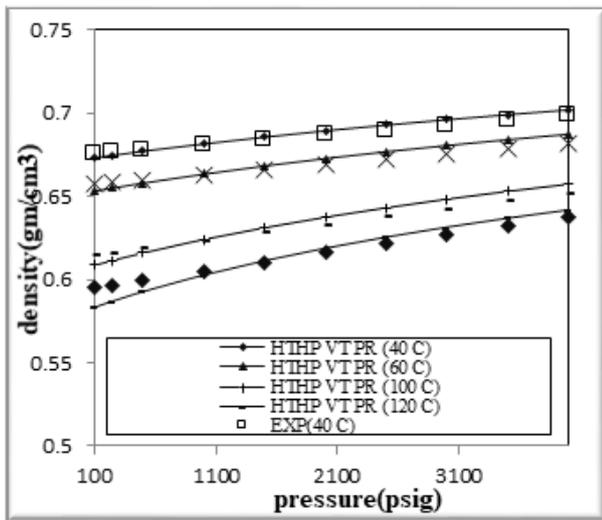


Figure (2) Comparison of density Experimental with HPHT VT PR EOS for binary mixtures of 40% n-Octane (1) + 60% n-Hexane (2)

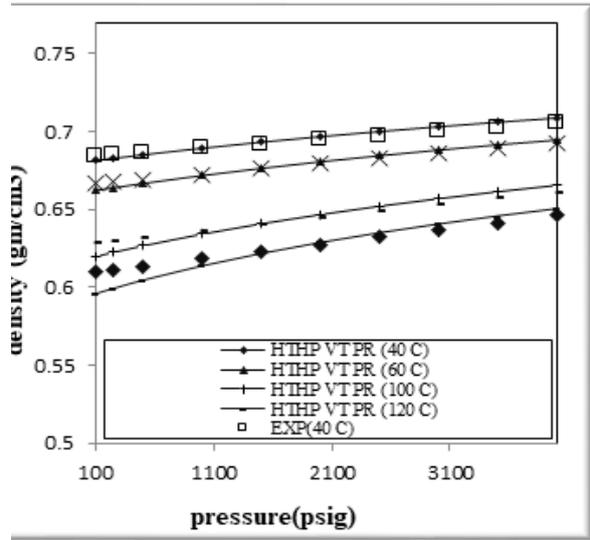


Figure (3) Comparison of density Experimental with HPHT VT PR EOS for binary mixtures of 60% n-Octane (1) + 40% n-Hexane (2)

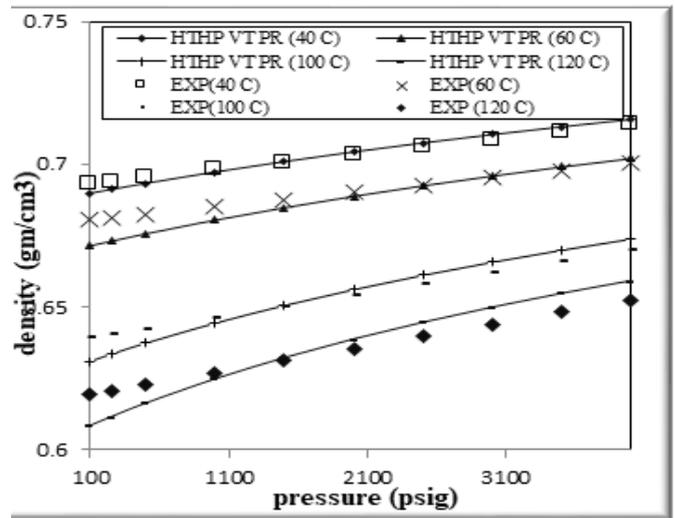


Figure (4) Comparison of density Experimental with HPHT VT PR EOS for binary mixtures of 80% n-Octane (1) + 20% n-Hexane (2)

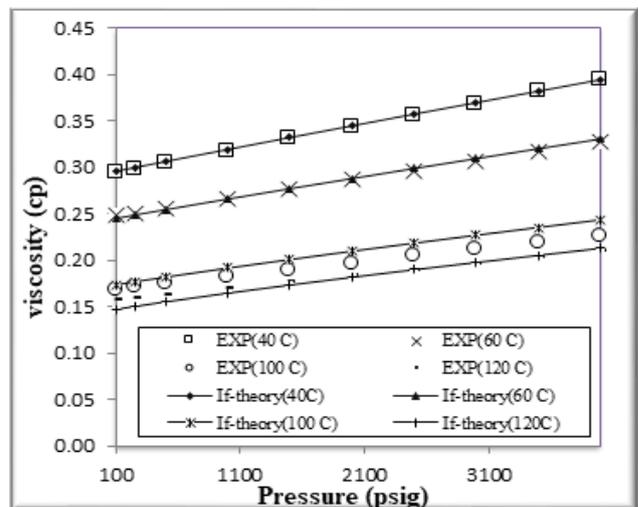


Figure (5) Comparison of viscosity Experimental with if theory for binary mixtures of 20% n-Octane (1) + 80% n-Hexane (2)

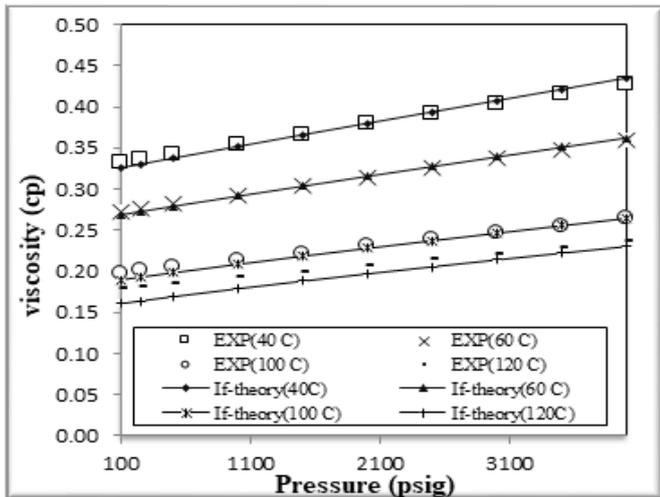


Figure (6) Comparison of viscosity Experimental with if theory for binary mixtures of 40% n-Octane (1) + 60% n- Hexane (2)

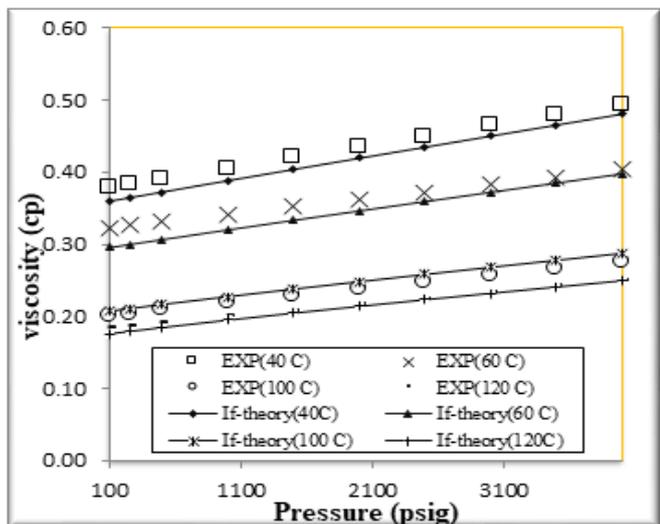


Figure (7) Comparison of viscosity Experimental with if theory for binary mixtures of 60% n-Octane (1) + 40% n- Hexane (2)

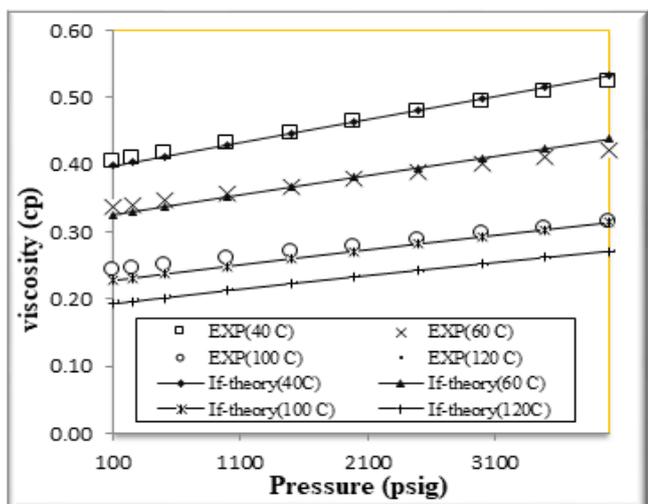


Figure (8) Comparison of viscosity Experimental with if theory for binary mixtures of 80% n-Octane (1) + 20% n- Hexane (2)

The accuracy of the predictions of equation of state is represented by the average absolute deviation in percent (AAD%) for the n data points.

$$AAD(\%) = \frac{100}{n} \sum_n \frac{|y_{clc.} - y_{exp.}|}{y_{exp.}}$$

The figures from (1) to (4) show the comparison results of density over wide range of temperature and pressure where the AAD show in table (10) this method yield very good predications.

If theory for viscosity modeling is used conjunction with PR EOS The general model if theory presented in this work are based on the viscosity behavior of binary mixtures n-hexane + n-octane. If theory provide good viscosity predictions of hydrocarbons. However, F-theory under -predicts the viscosity .

Table (10): AAD % of measurement results of binary mixtures with experimental values for densities and viscosities

Binary mixtures	AAD%	
	f-Theory	HTHP VT PR EOS
80% n- Hexane(1)+ 20% n-Octane(2)	1.85745	0.82275
60% n- Hexane (1)+ 40% n-Octane (2)	1.83341	0.61737
40% n- Hexane (1)+ 60% n-Octane (2)	2.91209	0.56162
20% n- Hexane (1)+ 80% n-Octane (2)	1.44235	0.56568

The estimation of recommended viscosities have been performed within the experimental temperature and pressure ranges. Because the viscosity modeling with the f-theory does not depend on the accuracy of the density, since the viscosity is linked to the pressure in the f-theory, the f-theory approach is a faster method in order to obtain recommended viscosities.

The uncertainty in the dilute gas viscosity predicted by Eq.(7) will not have any effect on the total predicted viscosity of subcritical liquids, since

the total viscosity of a subcritical liquid is very high compared to the dilute gas viscosity contribution. However, when predicting the viscosity of light gases or dense fluids at high temperatures the estimated dilute gas viscosity term becomes important. This is due to the fact that the dilute gas viscosity increases with increasing temperature. while the viscosity of dense fluids decreases with increasing temperatures.

The very accurate viscosity predictions obtained over wide ranges of temperature and pressure for binary mixtures n-hexane + n-octane by the f-theory models can also clearly be seen in Figures from[5] to [8]

We had good results and AAD% for viscosity of binary mixtures n-hexane + n-octane shown in table [10]

Conclusions

Density and viscosity of binary mixtures n-hexane + n-octane was measured at temperatures from 40 °C up to 120 °C and pressure from 100 to 4000 psig. The measured density data are in good agreement with the literature data.

The high temperature high pressure volume translate PR EOS Model is applied to correlate molar volume to predicted density for binary mixtures n-hexane + n-octane The new proposed HTHP VT-PR equations of state provide very good results with an overall AAD table [10]

The Fraction theory-Model is applied to predicted viscosity binary mixtures n-hexane + n-octane and comparison with the experimental results of binary mixtures n-hexane + n-octane obtained in this work.

F-theory typically gives average absolute deviation in percent (AAD%) from experimental viscosity values shown in table [10]

Nomenclature

MW molecular weight of component

p total pressure

p_a van der Waals attractive pressure term

p_c critical pressure

p_r van der Waals repulsive pressure term

R molar gas constant

T absolute temperature

T_c critical temperature

v_c critical volume

A parameter for the new proposed equations of state

B parameter for the new proposed equations of state

c volume correction

k_0 – k_6 constants of the new proposed equations of state

Greek Letters

ρ density (g cm⁻³)

η dynamic viscosity (cp)

η total viscosity

η_c critical viscosity

η_f friction viscosity

η_0 dilute gas viscosity

κ_a linear attractive viscous friction coefficient

κ_r linear repulsive viscous friction coefficient

κ_{rr} quadratic repulsive viscous friction coefficient

ρ_c critical molar density

ω Pitzer's a centric factor

Acknowledgement

Superscripts

* characteristic value

~ reduced value

Subscripts

i component i

c critical

r reduced

exp experimental

ref reference

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Prediction of hydrocarbon densities at extreme conditions using volume-translated SRK and PR equations of state fit to high temperature, high pressure PVT data
Fluid Phase Equilibria **317** (2012) 65– 76