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Measurement and Modeling of the Excess Properties of Binary and Ternary Mixtures of n-heptane, n-decane and n-nonane at Different Temperatures

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Abstract

This paper is concerned with the prediction and calculation of thermodynamic properties for binary and ternary mixtures of n-alkanes. An experimental database was established for this purpose, the database consists of density and dynamic viscosity for n-alkanes. Densities and dynamic viscosities measured were used to calculate the excess molar volumes, deviation in viscosities and excess free energies for the binary and ternary systems of (n-decane + n-heptane, n-decane + n-nonane, n-nonane + n-heptane and n-decane + n-nonane + n-heptane) over the entire range of volume fraction at temperatures from 293.15 K up to 343.15 K and atmospheric pressure. For all of the binary and ternary mixtures the computed excess molar volumes were correlated by applying the Redlich–Kister equation. and Prigogine–Flory–Patterson (PFP) theory. Many works carried out to predict the excess thermodynamic properties, but the mixtures of this work have not been studied so far at such conditions. It is hoped that the present work will help in the availability of experimental data for some unknown mixtures to understand their behavior in the chemical process, petrochemical industries and design processes. Excess molar volume and excess free energy are found to be positive for all binary and ternary mixtures at various temperatures, while the deviation in viscosities is negative. The obtained results are found to be in good agreement in their behavior as those given in the literatures.

Keywords: Correlations, Excess properties, Density, Viscosity, n-heptane, n-nonane, n-decane, Binary and Ternary mixtures.

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قياس ونمذجة الخواص الزائدة للمخاليط الثنائية والثلاثية من الهبتان والنونان والديكان العادي عند درجات حرارة مختلفة

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الملخص

تتناول هذه الورقة البحثية التنبؤ بالخواص الديناميكية الحرارية وحسابها للمخاليط الثنائية والثلاثية من الألكانات. تم إنشاء قاعدة بيانات تجريبية لهذا الغرض، تتكون من قياسات الكثافة واللزوجة الديناميكية للألكانات. تم استخدام نتائج قياس الكثافة واللزوجة لحساب الأحجام المولية الزائدة، وانحراف اللزوجة والطاقة الحرة الزائدة للأنظمة الثنائية والثلاثية (n-decane + n-heptane، n-decane + n-nonane، n-nonane + n-heptane، و(n-decane + n-nonane + n-heptane على كامل نطاق الكسر الحجمي عند درجات حرارة تتراوح من 293.15 كلفن إلى 343.15 كلفن تحت ضغط جوي واحد. بالنسبة لجميع المخاليط الثنائية والثلاثية، تم ربط الأحجام المولية الزائدة المحسوبة من خلال تطبيق معادلة ريدلش–كيستر Redlich–Kister ونظرية بريغوجين–فلوري–باترسون Prigogine–Flory–Patterson (PFP). تم إجراء العديد من الأعمال للتنبؤ بالخواص الديناميكية الحرارية الزائدة، ولكن لم تتم دراسة مخاليط هذا العمل حتى الآن في مثل هذه الظروف. ومن المؤمل أن يساعد هذا العمل في توفير البيانات التجريبية لبعض المخاليط غير المعروفة لفهم سلوكها في العمليات الكيميائية، والصناعات البتروكيماوية، وعمليات التصميم. وقد وُجد أن الحجم المولي الزائد والطاقة الحرة الزائدة موجبان لجميع المخاليط الثنائية والثلاثية عند درجات حرارة مختلفة، بينما كان الانحراف في اللزوجة سالبًا. وقد وجد أن النتائج التي تم الحصول عليها تتفق جيدًا في سلوكها مع تلك المذكورة في المراجع العلمية.

الكلمات المفتاحية: الخصائص الزائدة، الكثافة، اللزوجة، هبتان، نونان، ديكان، مخاليط ثنائية وثلاثية.

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1. Introduction

Viscosity and liquid density are key properties in the design of oil extraction and processing. Knowledge of the viscosity of pure liquids and mixtures is important for practical and theoretical purposes. The viscosity of liquid mixtures is an invaluable data for the chemical engineer in the design and optimization of industrial processes. Extensive studies have been carried out on the thermodynamic properties of binary and ternary mixture systems to understand their thermodynamic behavior. The excess thermodynamic property (M^E) is defined as the disparity between the actual properties (M) and the properties in the ideal case $\left(M^{id}\right)$ of a solution at identical temperature, pressure and composition [1]. Providing data that help in the design of oil extraction and handling processes, such as: separation, extraction, waste water treatment, ground water treatment, solvent recovery and liquid - liquid equilibria. Researches on these thermodynamic properties not only provide reliable data and empirical rules for science and technology, but also enhance the understanding of the behavior of liquid mixtures.

However, many empirical or semi-empirical equations can be correlated with the density and viscosity data of binary mixtures using several adjustable parameters. The literature on correlations of flow properties for binary and ternary multicomponent liquid mixtures is rather limited. Recently, the empirical and semi-empirical equations for binary mixtures were extended to ternary mixtures by introducing a ternary parameter; also, new models have been developed for the prediction of excess molar volumes, viscosity deviation, excess activation energy, and refractive index of mixtures.

In previous works [Derdar,2015 and Amer 2016], densities, kinematic viscosities, excess volume, excess viscosities and excess activation energies of viscous flow were reported for binary and ternary mixtures of toluene + n-hexane + n-decane + n-dodecane + hexadecane at temperatures 293.15, 308.15, 323.15 K and over the whole mole fraction range to understand the effect of carbon atom number and temperature increasing in the systems. In this paper, we extend our studies to the binary and ternary mixtures of n-alkanes (n-heptane, n-decane and n-nonane) at 293.15, 303.15, 313.15, 323.15, 333.15 and 343.15 K [2,3].

In another previous work, [Derdar and Amer 2024], Densities, dynamic viscosities, refractive index, excess molar volumes,

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viscosity deviation and excess activation energies of viscous flow were reported for binary and ternary mixtures of cyclohexane, n-butanol and 1-octanol at temperatures of 20,30,40,50 and 60 ^{o}C [4]. The refractive indices and densities of acetone + methanol with (water, 1-butanol) and of binary mixtures acetone + (water, 1-butanol) and methanol + (water, 1-butanol) experimentally over the entire range of composition were determined at the temperature 298.15 K and atmospheric pressure. Methods for predicting ternary excess properties from the values of the corresponding three binary mixtures involved are tested and compared. An estimation of excess volumes is also evaluated using a modified Heller equation which depends on the refractive indices of the mixture [5].

Torres et al, measured the densities for binary mixtures of acetonitrile with dichloromethane, trichloromethane and tetra chloromethane at 298.15 K and atmospheric pressure by using a vibrating-tube densimeter. Excess molar volumes V_m^E were determined. The experimental V_m^E results studied here have been used to test the extended real associated solution (ERAS)-Model [6]. Torres et al, the densities of $\{(1-x)CH_3(CH_2)_{n-1}OH + xCH_3CN\}$ for $n = 1,2,3$ or 4 as a function of composition were determined at different temperatures and atmospheric pressure using a vibrating-tube densimeter. Excess molar volumes were calculated. The Extended Real Associated Solution Model (ERAS-Model) used to correlate experimental data. The model is able to reproduce the asymmetrical V_m^E behavior of the studied systems [7].

Tu Chein-Hsiun et al, measured the densities, viscosities and refractive indices of the ternary system ethanol+2-methylpropan-2-ol + 2,2,4-trimethylpentane at T = 298.15 K and the binary systems ethanol + 2-methylpropan-2-ol, ethanol + 2,2,4-trimethylpentane and 2-methylpropan-2-ol + 2,2,4-trimethylpentane at different temperatures and atmospheric pressure over the whole composition range. Densities were determined using a vibrating-tube densimeter. Viscosities were measured with an automatic microviscometer based on the rolling ball principle. Excess molar volumes (V^E), deviations in the viscosity ($\Delta\eta$) from the mole fraction average were derived from experimental data [8].

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This study aims to provide additional insights into the development of mixed species and their impact on the excess properties of the mixtures. Furthermore, this study will serve as a validation test for various empirical equations designed to correlate property data of binary mixtures comprising both polar and nonpolar components.

2. Methodology section

2.1. Materials

In this study, three of n-alkanes are selected and some of another materials (n-heptane, n-nonane, n-decane, cyclohexane, carbon tetrachloride, toluene and acetone). The purity of all the liquids was stated by the manufacturer to be 99%.

Reagents: Toluene and acetone were used to clean and dry the cell of Anton Paar SVM 3000.

2.2. Equipment

Anton Paar SVM 3000 was used to measures the density and viscosity of binary and ternary of n-alkanes at different temperatures from 293.15 K up to 343.15 K.

2.3. Apparatus and Procedure

The calibration of the setup is necessary to measure the density and viscosity of n-decane ($C_{10}H_{22}$) at different temperatures from 293.15 K up to 373.15 K and the calibration was done to make shore that the results of our work obtained are in line with the pervious results with literature for n-decane were reported in Table (1) [9].

The calibration of the equipment is made using the pure components, such as: carbon tetrachloride, toluene, n-heptane at temperature of 298.15 K and comparison with literature values are obtained at one atmospheric (1atm). Table (2)

Table (1). Comparison of measured densities and viscosities of n-Decane ($C_{10}H_{22}$) with the literature values at atmospheric pressure

Temp.(C^O)	η (mPa.s) exp.	η (mPa.s) meas.	ρ (gm/cm^3) exp.	ρ (gm/cm^3) meas.
20	0.8994	0.8849	0.7288	0.7346
30	0.7665	0.7584	0.7223	0.7276
40	0.6659	0.6585	0.7147	0.7203
50	0.5871	0.5773	0.7070	0.7124
60	0.5224	0.5104	0.6993	0.7048
70	0.4715	0.4544	0.6916	0.6972

Table (2). Pure component experimental density and absolute viscosity and comparison with the corresponding literature values at T = 298.15 K.

Compound	Density (gm/cm^3) Meas.	Density (gm/cm^3) Lit.	Abs. viscosity (mPa.s) Meas.	Abs. viscosity (mPa.s) Lit.
n-Heptane	0.6848	0.6795[10]	0.3951	0.3905[10]
Toluene	0.8666	0.8623[11]	0.5561	0.5516[11]
Carbon tetrachloride	1.5813	1.5840[11]	0.9036	0.9004[11]

3. Results and Discussion

This study was conducted to obtain the excess thermodynamic properties data experimentally for n-decane + n-heptane, n-decane + n-nonane, and n-nonane + n-heptane in the binary system. In addition, n-decane + n-nonane + n-heptane in ternary system. However, the study was undertaken at different temperatures 298.15 K, 303.15 K, 313.15 K, 323.15 K, 333.15 K and 343.15 K for each mixture. The experiment results for the binary system are shown in Tables (3,4 and 7) while, Tables (5, 6, and 8) show the ternary system. The tables displaying the density and viscosity measurements for binary and ternary systems show a clear trend: these properties decrease as the temperature increases.

Table (3). Densities for the Binary System at Different Temperature, g/cm^3

n-decane (1) + n-heptane (2)	**Temperatures, C°**					
x_i	**20**	**30**	**40**	**50**	**60**	**70**
0	0.6894	0.6810	0.6724	0.6637	0.6548	0.6459
0.1	0.6935	0.6855	0.6764	0.6681	0.6598	0.6506
0.2	0.6979	0.6899	0.6813	0.6729	0.6647	0.6558
0.3	0.7025	0.6946	0.6864	0.6780	0.6697	0.6612
0.4	0.7072	0.6996	0.6915	0.6833	0.6749	0.6667
0.5	0.7120	0.7048	0.6965	0.6886	0.6802	0.6721
0.6	0.7168	0.7099	0.7015	0.6939	0.6856	0.6774
0.7	0.7216	0.7148	0.7065	0.6991	0.6908	0.6826
0.8	0.7263	0.7193	0.7115	0.7040	0.6958	0.6876
0.9	0.7307	0.7235	0.7163	0.7085	0.7004	0.6925
1	0.7346	0.7276	0.7203	0.7124	0.7048	0.6972

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n-decane (1) + n-nonane (2) Temperatures, C°						
x_i	**20**	**30**	**40**	**50**	**60**	**70**
0	0.7227	0.7151	0.7077	0.6997	0.6920	0.6840
0.1	0.7240	0.7163	0.7089	0.7009	0.6932	0.6853
0.2	0.7252	0.7176	0.7102	0.7022	0.6945	0.6866
0.3	0.7264	0.7188	0.7115	0.7034	0.6958	0.6879
0.4	0.7276	0.7200	0.7127	0.7047	0.6971	0.6892
0.5	0.7288	0.7213	0.7140	0.7060	0.6984	0.6906
0.6	0.7300	0.7226	0.7153	0.7073	0.6997	0.6919
0.7	0.7312	0.7239	0.7165	0.7086	0.7010	0.6932
0.8	0.7323	0.7252	0.7178	0.7099	0.7023	0.6946
0.9	0.7335	0.7264	0.7191	0.7112	0.7036	0.6959
1	0.7346	0.7276	0.7203	0.7124	0.7048	0.6972
n-nonane (1) + n-heptane (2) Temperatures, C°						
x_i	**20**	**30**	**40**	**50**	**60**	**70**
0	0.6894	0.6810	0.6724	0.6637	0.6548	0.6459
0.1	0.6925	0.6841	0.6759	0.6671	0.6584	0.6496
0.2	0.6957	0.6876	0.6794	0.6707	0.6621	0.6533
0.3	0.6991	0.6911	0.6830	0.6744	0.6659	0.6573
0.4	0.7026	0.6947	0.6866	0.6782	0.6698	0.6613
0.5	0.7061	0.6986	0.6902	0.6819	0.6736	0.6651
0.6	0.7095	0.7023	0.6937	0.6856	0.6774	0.6690
0.7	0.7131	0.7059	0.6973	0.6894	0.6813	0.6729
0.8	0.7165	0.7093	0.7009	0.6931	0.6850	0.6766
0.9	0.7197	0.7124	0.7043	0.6965	0.6886	0.6804
1	0.7227	0.7151	0.7077	0.6997	0.6920	0.6840

Table (4). Dynamic Viscosity for the Binary System at Different Temperature, mPa.s

n-decane (1) + n-heptane (2) Temperatures, C°						
x_i	**20**	**30**	**40**	**50**	**60**	**70**
0	0.3627	0.3264	0.2915	0.2602	0.2342	0.2113
0.1	0.3773	0.3313	0.2955	0.2647	0.2359	0.2145
0.2	0.4184	0.3677	0.3255	0.2894	0.2560	0.2325
0.3	0.4660	0.4098	0.3596	0.3172	0.2795	0.2534
0.4	0.5125	0.4485	0.3905	0.3429	0.3018	0.2736
0.5	0.5587	0.4849	0.4203	0.3688	0.3249	0.2945

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0.6	0.6098	0.5258	0.4555	0.4004	0.3536	0.3198
0.7	0.6711	0.5780	0.5023	0.4427	0.3919	0.3526
0.8	0.7439	0.6429	0.5610	0.4950	0.4391	0.3923
0.9	0.8214	0.7115	0.6216	0.5477	0.4857	0.4318
1	0.8849	0.7584	0.6585	0.5773	0.5104	0.4544

n-decane (1) + n-nonane (2) Temperatures, C°

x_i	20	30	40	50	60	70
0	0.67397	0.58515	0.51259	0.45265	0.40244	0.35863
0.1	0.69500	0.60394	0.52922	0.46590	0.41381	0.36643
0.2	0.71509	0.62024	0.54298	0.47830	0.42362	0.37281
0.3	0.73386	0.63521	0.55550	0.48984	0.43215	0.37960
0.4	0.75235	0.65028	0.56823	0.50112	0.44056	0.38788
0.5	0.77213	0.66675	0.58216	0.51293	0.45025	0.39803
0.6	0.79456	0.68544	0.59778	0.52593	0.46229	0.40988
0.7	0.81995	0.70622	0.61483	0.54025	0.47681	0.42270
0.8	0.84682	0.72772	0.63225	0.55518	0.49246	0.43541
0.9	0.87100	0.74685	0.64791	0.56873	0.50573	0.44655
1	0.88494	0.75849	0.65857	0.57736	0.51048	0.45446

n-nonane (1) + n-heptane (2) Temperatures, C°

x_i	20	30	40	50	60	70
0	0.36278	0.3264	0.29159	0.26029	0.23423	0.21135
0.1	0.38220	0.33416	0.29154	0.25736	0.23204	0.21246
0.2	0.40219	0.35095	0.30700	0.27155	0.24195	0.21955
0.3	0.42667	0.37413	0.32988	0.29317	0.25919	0.23204
0.4	0.45628	0.40120	0.35520	0.31653	0.28001	0.24864
0.5	0.48952	0.42997	0.38039	0.33900	0.30165	0.26763
0.6	0.52416	0.45894	0.40479	0.36018	0.32245	0.28730
0.7	0.55836	0.48752	0.42898	0.38100	0.34181	0.30628
0.8	0.59208	0.51637	0.45422	0.40289	0.36027	0.32396
0.9	0.62821	0.54760	0.48182	0.42685	0.37952	0.34076
1	0.67397	0.58515	0.51259	0.45265	0.40244	0.35863

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Table(5). Densities for the Ternary System at Different Temperature, g/cm^3

	n-decane (1) + n-nonane(2) + n-heptane (3) Temperatures, C^o						
x_1	x_2	20	30	40	50	60	70
0	0	0.6894	0.6810	0.6724	0.6637	0.6548	0.6459
0.1	0.3	0.7069	0.6995	0.6911	0.6828	0.6745	0.6661
0.2	0.4	0.7114	0.7041	0.6960	0.6876	0.6794	0.6711
0.3	0.1	0.7123	0.7048	0.6970	0.6885	0.6803	0.6720
0.4	0.2	0.7143	0.7068	0.6991	0.6908	0.6826	0.6744
0.5	0.1	0.7183	0.7109	0.7033	0.6953	0.6872	0.6791
0.6	0.2	0.7234	0.7162	0.7085	0.7008	0.6930	0.6850
0.7	0.15	0.7276	0.7205	0.7127	0.7051	0.6975	0.6896
0.8	0.1	0.7298	0.7227	0.7149	0.7071	0.6995	0.6917
0.9	0.1	0.7307	0.7235	0.7158	0.7077	0.7001	0.6924
1	0	0.7346	0.7276	0.7203	0.7124	0.7048	0.6972

Table (6). Viscosity for the Ternary System at Different Temperature, mPa.s

	n-decane (1) + n-nonane(2) + n-heptane (3) Temperatures, C^o						
x_1	x_2	20	30	40	50	60	70
0	0	0.36278	0.32640	0.29159	0.26029	0.23423	0.21135
0.1	0.3	0.52070	0.46090	0.41050	0.36610	0.32640	0.28780
0.2	0.4	0.55168	0.48202	0.42511	0.37792	0.33627	0.30035
0.3	0.1	0.55600	0.48140	0.42200	0.37320	0.33080	0.29970
0.4	0.2	0.57994	0.50083	0.43939	0.38666	0.34072	0.30941
0.5	0.1	0.63180	0.54670	0.48160	0.42260	0.37080	0.33390
0.6	0.2	0.69714	0.60447	0.53361	0.46805	0.41068	0.36598
0.7	0.15	0.75440	0.65370	0.57500	0.50500	0.44510	0.39460
0.8	0.1	0.79069	0.68217	0.59484	0.52318	0.46444	0.41260
0.9	0.1	0.81720	0.70090	0.60580	0.53290	0.47520	0.42460
1	0	0.88494	0.75849	0.65857	0.57736	0.51048	0.45446

The excess molar volume (V^E), viscosity deviations (μ^E), and the excess activation energy (G^{*E}) of viscous flow were calculated from the following equations respectively

$$V_m^E = \frac{\sum_{i=1}^{n} x_i Mwt}{\rho_m} - \sum_{i=1}^{n} \frac{x_i Mwt}{\rho_i} \tag{1}$$

$$\mu^E = \mu_m - \sum_{i=1}^{n} x_i \mu_i \tag{2}$$

$$G^{*E} = RT(ln\mu_m V_m - \sum_{i=1}^{n} x_i ln(\mu_i V_i)) \qquad (3)$$

Each set of values has been fitted to the Redlich–Kister type equation:

$$M_{ij}^E = x_i x_j \sum_{k=0}^{n_{ij}} a_k \left(x_i - x_j\right)^k \qquad (4)$$

where a_i is the polynomial coefficient and k is the polynomial degree. The values of the coefficients $a_i$are summarized in Table (7) along with standard deviations $Q^E(x)$ represents, V^E, μ^E and G^{*E}

The excess properties for the ternary systems have been correlated to Equation (5), the expression proposed by Cibulka [12]:

$$M_{123}^E = \sum_{i<j} x_i x_j \sum_{k=0}^{n_{ij}} a_k \left(x_i - x_j\right)^k + x_1 x_2 x_3 (A + Bx_1 + Cx_2) \qquad (5)$$

A, B and C are adjustable parameters, while, $M_{123}^E(x)$ denotes (V^E), (μ^E), or (G^{*E}), where M_{ij}^E signifies the three binary contributions assessed by the Redlich–Kister expansion Equation (5). These contributions, represented as M_{ij}^E, are fitted to binary mixture data but computed using ternary mole fractions. This notation is employed to emphasize that $x_i + x_j$ does not equal one.

The correlating ability of each of the Equations (4 and 5), was tested by calculating the standard deviations SD between the experimental and the calculated excess properties as

$$SD = \left\{\frac{1}{n-m} \sum \left[\frac{\left(M_{exp}^E - M_{cal}^E\right)}{M_{exp}^E}\right]^2\right\}^{0.5} \qquad (6)$$

Both viscosity and liquid density were measured at atmospheric pressure, from 20°C up to 70 °C, in temperature intervals of 10 C^0, Because the boiling point of n-heptane equal 98 C^0, also the phase between (70-98 C^0) are (liquid + vapor) usually.

Viscosity and liquid density were determined with Anton Paar SVM 3000. Results of pure components are in good agreement with those of data of standard solution, for liquid density difference was in 0.6209 % and for dynamic viscosity is 0.6960 % .

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For all temperatures and binary system investigated, a near-linear relationship between density and mole fraction of the chain-alkane was observed, this may be due to the molecular weight. For each of the mixtures studied, the density values increase with increasing the molecular weight.

Excess properties for liquid mixtures primarily on temperature and composition. This properties are often strong functions of temperature, but at normal temperatures are not strongly influenced by pressure. All excess properties become zero as either species approaches purity.

The thermodynamic property information is advantageously provided by residual properties. This property relations already presented would suffice.

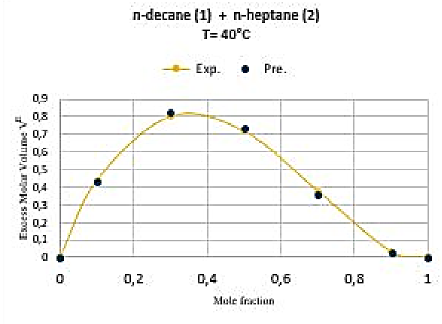

Figure (1). Comparison between experimental data and prediction values for excess molar volume [n-decane(1) +n-heptane(2)] at 40 ºC

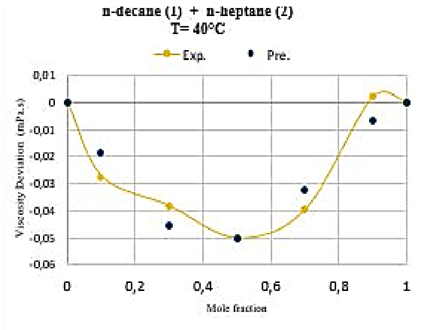

Figure (2). Comparison between experimental data and prediction values for viscosity deviations [n-decane(1)+n-heptane(2)] at 40 ºC

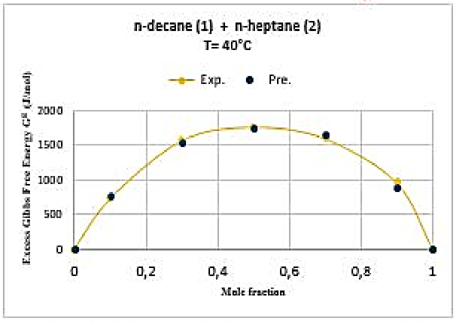

Figure (3). Comparison between experimental data and prediction values for excess gibbs free energy [n-decane(1)+n-heptane(2)] at 40 ºC

In this study, all figures (1,3,4,6) of V^E and G^E show that positive for all binary and ternary mixtures over the whole range of volume fraction and showed the same trend of behavior at other temperatures. Positive values might be related to the predominance of expansion in volume, caused by the difference in size and shape of component molecules and the experimental data and prediction

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values for ternary system are more identical than the binary systems. In a ternary mixture, the presence of an intermediate component (n-nonane) between n-heptane and n-decane helps to smooth out composition-related non-idealities. This leads to nearly ideal mixing behaviour, making both experimental and model-predicted viscosities more similar. In contrast, in the binary mixture of n-heptane + n-decane, the difference in chain length (C7 vs C10) is more pronounced, and there's no intermediate chain-length component to buffer the effect. This leads to slightly greater deviation from ideality, which might not be captured perfectly by predictive models.

In figures(2,5), the viscosity deviation for all binary and ternary systems are negative over the entire composition range. In fact, negative deviations in viscosity are observed which regularly increase as the size or viscosity of the alkane is increased. This reveals that the strength of specific interaction is not the only factor influencing the viscosity deviation of liquid mixtures. The molecular size and shape of the components also play an equally important role.

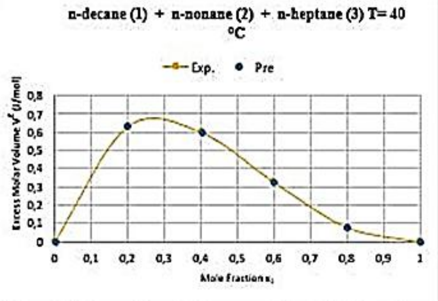

Figure (4). Comparison between experimental data and prediction values for excess molar volume (n-decane+n-nonane+n-heptane) at 40 °C

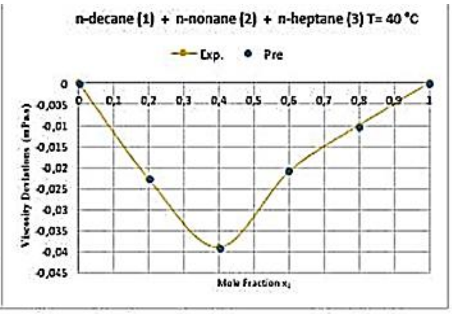

Figure (5). Comparison between experimental data and prediction values for viscosity deviation (n-decane+n-nonane+n-heptane) at 40 °C

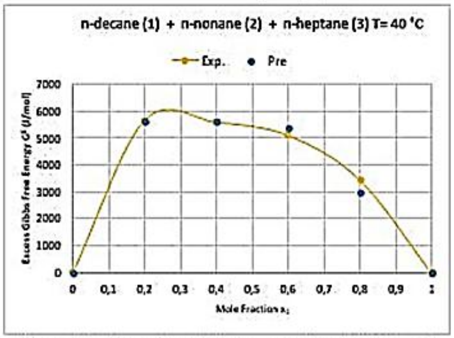

Figure (6). Comparison between experimental data and prediction values for excess gibbs free energy (n-decane+n-nonane+n-heptane) at 40 °C

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Table (7) . Coefficients a_i of Equation (5) and SDs of Equation (7)

	T,C	a_0	a_1	a_2	SD
n-decane (1) + n-heptane (2)					
$V^E, cm^3/mol$	20	3.13096	-1.82426	-0.78792	0.02777
	30	2.54536	-1.62290	0.35437	0.09904
	40	3.32314	-2.40973	-0.60234	0.09479
	50	2.94093	-2.78589	-0.64547	0.03027
	60	3.03842	-1.46716	-0.64033	0.05221
	70	3.16762	-1.66913	0.72448	0.01879
$\Delta\mu, mPa$	20	-0.26039	0.06471	-0.01721	0.00794
	30	-0.23011	0.08530	-0.00497	0.01034
	40	-0.21897	0.08141	0.05608	0.00966
	50	-0.20009	0.08165	0.09462	0.00818
	60	-0.18967	0.09145	0.09658	0.00729
	70	-0.15347	0.07384	0.07128	0.00569
$G^{*E}, J/mol$	20	6711.46	489.356	2641.73	39.1449
	30	6828.99	675.751	2627.81	58.1145
	40	6893.12	728.566	3083.49	59.0369
	50	7014.40	786.032	3512.48	56.2793
	60	7096.12	1014.83	3659.55	58.0199
	70	7426.75	923.782	3749.11	52.2967
n-decane (1) + n-nonane (2)					
$V^E, cm^3/mol$	20	0.10569	0.02466	0.00120	0.02777
	30	0.29925	-0.16402	-0.05601	0.09904
	40	0.28769	-0.08994	-0.00289	0.09479
	50	0.33706	-0.12550	-0.02526	0.03027
	60	0.30307	-0.16486	-0.00542	0.05221
	70	0.36025	-0.13147	-0.02626	0.01879
$\Delta\mu, mPa$	20	-0.02929	0.02708	0.10742	0.00154
	30	-0.02025	0.01823	0.09375	0.00075
	40	-0.01366	0.00881	0.07327	0.00029
	50	-0.00829	0.01082	0.05315	0.00070
	60	-0.02483	0.02111	0.09642	0.00113
	70	-0.03402	0.02654	0.05224	0.00017
$G^{*E}, J/mol$	20	6634.03	168.123	2923.47	22.6530
	30	6796.65	439.061	2584.38	19.1717

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	40	7034.79	710.123	2236.99	22.7088
	50	7301.49	854.041	2062.46	27.2643
	60	7459.20	1034.53	2258.28	21.4981
	70	7555.95	1045.87	3064.45	23.3607
	T, C	a_0	a_1	a_2	**SD**
n-nonane (1) + n-heptane (2)					
$V^E, cm^3/mol$	20	1.49623	-0.93647	-0.09380	0.00045
	30	1.09608	-1.66105	-0.16774	0.00064
	40	1.53458	-0.39183	-0.04177	0.00034
	50	1.47557	-0.98531	-0.10077	0.00061
	60	1.56841	-0.75763	-0.05453	0.00030
	70	1.69628	-0.57966	0.04807	0.00077
$\Delta\mu, mPa$	20	-0.11538	0.01610	-0.04824	0.00244
	30	-0.10321	0.05287	-0.09723	0.00054
	40	-0.08678	0.07635	-0.13183	0.00115
	50	-0.06987	0.08323	-0.14010	0.00168
	60	-0.06672	0.09058	-0.11370	0.00006
	70	-0.06944	0.08342	-0.03688	0.00071
$G^{*E}, J/mol$	20	6634.03	168.123	2923.47	22.6530
	30	6796.65	439.061	2584.38	19.1717
	40	7034.79	710.123	2236.99	22.7088
	50	7301.49	854.041	2062.46	27.2643
	60	7459.20	1034.53	2258.28	21.4981
	70	7555.95	1045.87	3064.45	23.3607

Table (8). Coefficients $A, B, and\ C$ of Equation (5) and SDs of Equation (6)

	T, C	A	B	C	SD
n-decane (1)+ n-nonane(2) + n-heptane (3)					
$V^E, cm^3/mol$	20	43.32247	-54.7014	-66.5113	0.059955
	30	43.58440	-46.9868	-74.8499	0.059945
	40	36.96247	-47.1525	-58.9369	0.029819
	50	44.16864	-53.8779	-68.4410	0.004207
	60	59.38443	-81.5138	-88.3558	0.043619
	70	65.40449	-92.1347	-97.6048	0.069603
$\Delta\mu, mPa$	20	-3.75590	4.147545	6.828676	0.001183
	30	-4.08308	4.463704	7.683984	0.001320
	40	-4.16569	4.830601	7.996063	6.41E-05

	50	-3.62440	3.890557	7.293274	0.000246
	60	-3.07156	2.921727	6.599076	0.000648
	70	-1.85345	1.665930	4.169337	0.000176
$G^{*E}, J/mol$	20	157182.6	-78334.1	-82265.1	289.6514
	30	156503.3	-74226.4	-72955.4	303.9116
	40	157707.7	-71145.5	-66759.4	308.8585
	50	162214.6	-74691.7	-65662.9	321.1961
	60	167299.7	-79835.1	-64708.1	332.7410
	70	180688.6	-91190.2	-83104.3	333.3627

4. Conclusion

The excess properties were determined by measuring the experimental densities, viscosities n-decane + n-nonane + n-heptane at the temperature range of 20^{o} to 70^{o}C over the whole composition range and atmospheric pressure. The densities and viscosities of all mixtures (Binary and Ternary) decrease with increasing temperatures. The excess molar volume, obtained from density, was positive for both the studied binaries and the ternary increased with temperature rising. The positive excess molar volume is ascribed to the weak interactions between unlike molecules. The calculated negative values of viscosity deviation represented no specific interaction between components. The results indicate that for n-alkanes mixtures the Redlich–Kister equation predicts the experimental data well, showing smallest deviations. The fitting of this equation for excess activation energy in producing the experimental gives the largest deviations. All data for binary and ternary mixtures show that the densities and viscosities of all these mixtures decrease with increasing temperatures. The estimated error in densities and dynamic viscosities were 0.6209% and 0.6960% respectively. The excess free energies of binary systems increase with an increasing of temperature. These functions were used to explain the intermolecular interactions between mixture components. Comparison must be evaluated for the calculated excess property and the data obtained from calorimeter. It is possible to predict the excess molar enthalpy of all binary and ternary mixtures from these data in this work using the Flory theory-Model. More data must be collected for excess molar enthalpy using calorimeter and compared with calculated data. Re evaluated the parameter which must be used in theoretical model using the collected data from different literature.

Nomenclature

M^E = Molar excess property
M = Molar property
V = Molar volume
G = Molar Gibbs free energy
V^E = Molar excess volume
μ^E = Excess viscosity
G^{*E} = Molar excess activation energy
x_i = Mole fraction of pure compound i
R = Universal gas constant
μ_m & μ_i = Viscosity of mixture and pure component i respectively
ρ_m & ρ_i = Density of mixture and pure component i respectively
V_i = the volume of pure component i
Mwt = Molecular weight of the pure compound

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