ISSN: 0067-2904

Effect of Concentration on the Viscosity of Some Carboxylic Acids in Diluted Aqueous Solutions

Husam S. Khalaf *, Zainab Abbas AL-Dulaimy , Wedad J. Fendi
Department of Chemistry, College of Education for Pure Science-Ibn-Al-Haitham, University of Baghdad, Baghdad, Iraq

Received: 21/3/2023 Accepted: 8/7/2023 Published: 30/8/2024

Abstract

In the current study, the effect of concentration on the viscosity of formic acid, acetic acid, and propanoic acid in an aqueous solution is investigated. The apparent molar volume (ϕv) was specified from density measurements at 298.15 K. A restrictive apparent molar volume ϕv° under unlimited dilutions of these carboxylic acids has been determined based on Masson's equation. The B and A coefficients for viscosity have been determined using viscosity data for the Jones-Dole equation for all studies, and a positive value of the B-coefficient indicates strong solute-solvent interaction. The modified Jone-Dole equation was projected using a ratio of mole fractions of solute and solvent.

Keywords: Apparent molar volume, Carboxylic acids, Jone-Dole equation, Viscosity and B-coefficient.

تأثير التركيز على لزوجة بعض الاحماض الكاربوكسيلية في المحاليل المائية المخففة

حسام سليم خلف ، زينب عباس حسن، وداد جاسم فندي
قسم علوم الكيمياء، كلية التربيه للعلوم الصرفه (ابن الهيثم)، جامعة بغداد، بغداد، العراق

الخلاصة

في الدراسة الحالية، تم دراسة تأثير التركيز على لزوجة كل من الحوامض (الفورميك، الخليك، و البروبانويك) في المحلول المائي,استخدمت النتائج لحساب الحجم المولاري الظاهري (ϕv) من قياس الكثافة عند 298.15 كلفن. قيس الحجم المولاري الظاهري المحدد ϕv° للمحاليل المخففة للحوامض الكاربوكسيلية بناءا على معادلة ماسون، استخدمت قياسات اللزوجة لحساب معاملي جونز–دول B و A لجميع الدراسات، وتشير القيمة الموجبة لمعامل B إلى تداخل مذاب–مذيب قوي. تم عرض معادلة جونز دول المعدلة باستخدام نسب الكسور المولية للمذاب و المذيب.

1. Introduction

Important physicochemical properties of organic compound solutions are the hydrophobic and hydrophilic interactions between these solutes and water, as well as their effects on the structure of water. For theoretical and practical applications, in particular, the viscometric characteristics of aqueous carboxylic acid solutions are significant. Their study offers imperative information about the nature and influence of interactions between nonpolar and

*Email: husam.s.k@ihcoedu.uobaghdad.edu.iq

polar water groups on water structure [1-2], and the physical-chemical properties are useful to know the properties of liquid solutions [3-7]. Carboxylic acids have a distinctive solubility characteristic in both aqueous and non-aqueous solutions. These molecules display hydrophobic interactions [8-10] that have already been published. Carboxylic acids are used as inhibitors for corrosion and as surfactants and metal finishing compounds in the manufacture of polyesters, polyols, and polyamides in the synthesis of pharmaceutical products [11-16]. A perspective on the dynamic architectures of water molecules in varied environments is also required in such aqueous systems. Water itself is closely connected with solute molecules and has a high propensity to mix. The carboxylic acid group (the name derived from the relation between carbonyl and hydroxyl) is the organic compound. They are capable of forming water-like hydrogen bonds. The interactions between water and carboxylic acids are quite complicated; both acids and water are self-associated fluids by the H-bonding mechanism. Hydrophilic COOH and hydrophobic stand for the groups of carboxylic acids; they are entirely different in their modes of contact with water. The hydrophilic COOH acid group is formed by hydrophilic interactions to form an H-bond of water and disrupt the usual water structure, whereas the alkyl group promotes hydrophobic molecular structures around this group. In the field of solution chemistry, a deeper understanding of the relationship between water and acids is critical because it can provide valuable knowledge about hydrophilic and hydrophobic interactions [17-23]. The viscosity, B-coefficient, and Jone-Dole equation of formic, acetic, and propanoic acids in water are described in the current study as functions of composition at 298.15 K.

2. Experimental

The carboxylic acids (99% purity) were supplied by Fluka Company and employed in this study. The viscosity was measured using a calibrated Ubbelohde suspended viscometer to change the bath temperature to ± 0.01 K at 298.15 K to provide the finished values with a viscosity level. The empiricists completed the experiment at least three times, and the results were accurate. The reported viscosity values were also observed in this variation.

3. Results and discussion

For the estimation of B magnitude from the $\eta/\eta_{\circ}$ (η = viscosity of solutions, $\eta_{\circ}$ = viscosity of solvent) plot vs. C, experimental data for three carboxylic acids should be used, with linear values corresponding to the B-coefficient. The applicability of Equation 1 was taken into account in the case of non-electrolytes. The diagram obtained from η/η to C magnitudes (Figure 1) shows that the intercept value is almost one. Table 1 and Figure 1 depict the details for carboxylic acids. From the plots, it has become understandable that our study's experimental findings validate the lessened equation 2 applicability of Jone-Dole [24,25].

Table 1: $\eta/\eta_{\circ}$ alteration based on the concentration of formic acid, acetic acid, and propanoic acid at 298.15 K

Formic acid			Acetic acid			Propanoic acid		
s. no.	**Concentration ($mol.dm^{-3}$)**	**$\eta/\eta_{\circ}$**	**s. no.**	**Concentration ($mol.dm^{-3}$)**	**$\eta/\eta_{\circ}$**	**s. no.**	**Concentration ($mol.dm^{-3}$)**	**$\eta/\eta_{\circ}$**
1	0.03951	1.00805	1	0.02665	1.01733	1	0.04113	1.04714
2	0.05836	1.01555	2	0.04604	1.03232	2	0.06225	1.06393
3	0.07081	1.02632	3	0.05963	1.04222	3	0.08188	1.08598
4	0.08516	1.03522	4	0.07911	1.05172	4	0.10112	1.10311
5	0.09841	1.04517	5	0.09789	1.06283	5	0.12115	1.14409
6	0.11602	1.06639	6	0.11787	1.08472	6	0.14049	1.15476
7	0.13034	1.07449	7	0.13744	1.09099	7	0.16224	1.17523
8	0.15022	1.08661	8	0.15076	1.10453	8	0.18183	1.19824
9	0.17022	1.11095	9	0.17073	1.11443	9	0.20172	1.22399
10	0.19033	1.12329	10	0.18532	1.12133	10	0.22066	1.24423
11	0.21031	1.13721	11	0.21118	1.14963	11	0.23398	1.26708

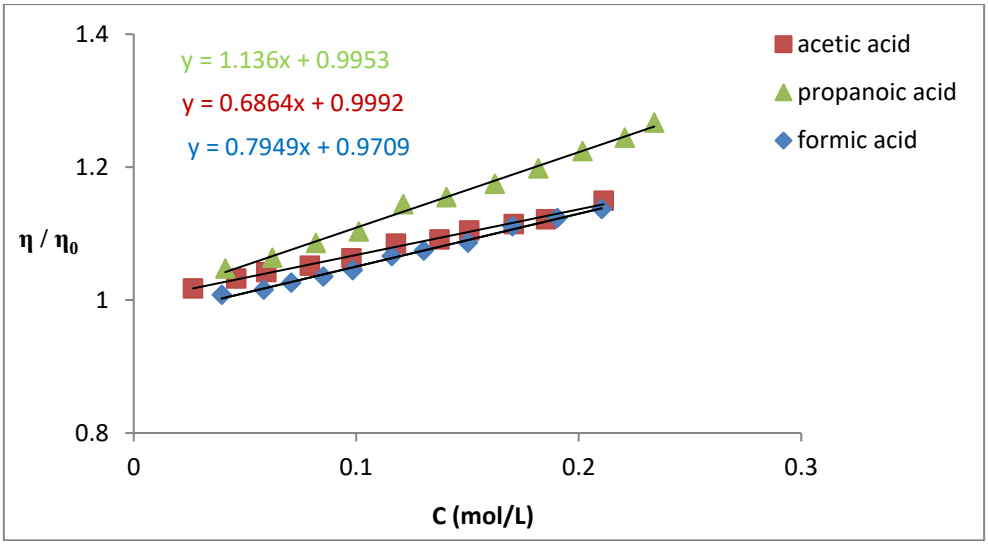

Figure 1 : Plot ($\eta/\eta_\circ$) vs. (C) for carboxylic acids at 298.15 K

$$\eta/\eta_\circ = BC+1 \quad \text{..... (1)}$$

For determining intermolecular interaction in aqueous solution, the magnitudes of $\eta/\eta_\circ$ obtained at various concentrations were used. With the aid of a Jone-Dole equation [26-28], the parameter of interactions was achieved.

$$(\eta/\eta_\circ - 1)/\sqrt{C} = A+B\sqrt{C} \quad \text{..... (2)}$$

Here, ($\eta/\eta_\circ$) stands for the relative viscosity, A and B characterize constants regarding the ion-ion and ion-solvent interaction separately, and C stands for a molar concentration. The magnitudes of A and B have been acquired based on an intercept and the slopes of the linear plots of $(\eta/\eta_\circ-1)/\sqrt{C}$ versus $\sqrt{C}$. The magnitudes are specified in Table 2 and Figure 2.

Table 2: A and B amounts regarding aqueous formic acid, acetic acid, and propanoic acid at 298.15 K for the Jone-Dole equation

Formic acid			Acetic acid			Propanoic acid		
s. no.	$\sqrt{C}$	$(\eta/\eta_\circ-1)/\sqrt{C}$	s. no.	$\sqrt{C}$	$(\eta/\eta_\circ-1)/\sqrt{C}$	s. no.	$\sqrt{C}$	$(\eta/\eta_\circ-1)/\sqrt{C}$
1	0.19877	0.04051	1	016325	0.10616	1	0.20281	0.23245
2	0.24158	0.06437	2	0.21457	0.15063	2	0.24950	0.25627
3	0.26611	0.09891	3	0.24419	0.17291	3	0.28615	0.30047
4	0.29182	0.12069	4	0.28126	0.18389	4	0.31796	0.32429
5	0.31370	0.14399	5	0.31288	0.20082	5	0.34807	0.36849
6	0.34062	0.19491	6	0.34335	0.24611	6	0.37482	0.41291
7	0.36103	0.20633	7	0.37073	0.24675	7	0.40279	0.43503
8	0.38758	0.22346	8	0.38828	0.26923	8	0.42642	0.46492
9	0.41258	0.26892	9	0.41319	0.27694	9	0.44913	0.49873
10	0.43627	0.28261	10	0.43049	0.28184	10	0.46974	0.51994
11	0.45861	0.29917	11	0.45954	0.32561	11	0.48371	0.55215

Accordingly, A = -0.1825 ($dm^{3/2}$ $mole^{-1/2}$), A = -0.003 ($dm^{3/2}$ $mole^{-1/2}$), A = -0.0283 ($dm^{3/2}$ $mole^{-1/2}$), B = 1.0656 (dm^3. mol^{-1}), B = 0.6884 (dm^3 mol^{-1}), and B = 1.166 (dm^3. mol^{-1}). Linearity = 0.9815; Linearity = 0.9896; Linearity = 0.988.

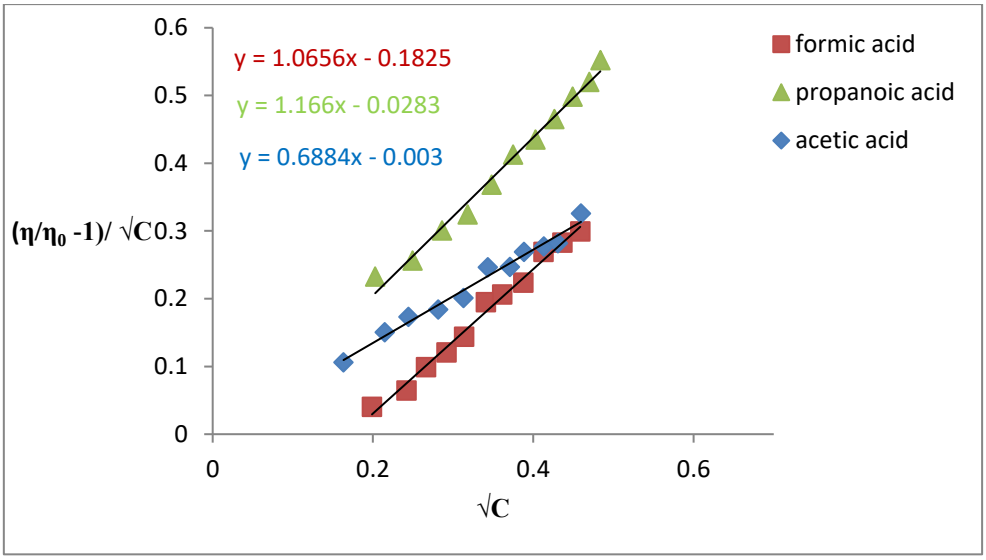

Figure 2: Jone-Dole plot $(\eta/\eta_{\circ}-1)/\sqrt{C}$ versus $\sqrt{C}$ for carboxylic acids at 298.15 K

The B-coefficient for three carboxylic acids, measured based on the Jone-Dole equation, was positive. Namely, they represent 'structure makers' in a highly diluted aqueous solution. The magnitude of the A Coefficient has been small, implying that the probability of solute-solute interaction has been small compared with the intermolecular attraction between solute and solvent. It proposes the formation of an internal hydrogen bond due to the presence of the hydroxyl group and the subsequent contraction that occurs as a result of the strong polar-polar interaction among carboxylic clusters hydrated with water [29]. In this paper, by using a ratio of mole fractions of solute and solvent (ns/nw) instead of the concentration of solute, the Jone-Dole equation has been modified in place of the concentration of solutes that are also accountable for solute-solute and solute-solvent interactions. A suggested relation has been correlated with the original equation, and the equation with the modifications is more accurate as a result of the greater measurements of slopes. For three carboxylic acids, the salts utilizing concentration values, n_s and n_w, have been considered, and the obtained data are explained in Table 3. Based on the linear plots of $(\eta/\eta_{\circ}-1)/\sqrt{n_s/n_w}$, vs. $\sqrt{n_s/n_w}$ Ax and Bx are the coefficients of the modified Jone-Dole equation magnitudes for carboxylic acids, which have been calculated from the intercept and slope, respectively (Figure 3), for testing the validity of the reformed equation. Accordingly, the modified Jone-Dole equation is specified by Equation 3.

$$\frac{(\eta/\eta_{\circ})-1)}{\sqrt{n_s/n_w}} = Ax + Bx\sqrt{\frac{n_s}{n_w}} \quad \ldots\ldots\ldots (3)$$

Here, n_s stand for a mole fraction of solute, and n_w stands for a mole fraction of solvent water. The adopted concentration range in this paper has been optimal for the soundness of Staudinger, the Jone-Dole equation, and the modified Jone-Dole equation that behaves as a structure maker [30-32].

Table 3: Ax and Bx coefficients regarding aqueous formic acid, acetic acid, and propanoic acid at 298.15 K for the modified Jone-Dole equation

Formic acid			Acetic acid			Propanoic acid		
s. no.	$\sqrt{n_s/n_w}$	$(\eta/\eta_\circ\text{-}1)/\sqrt{n_s/n_w}$	s. no.	$\sqrt{n_s/n_w}$	$(\eta/\eta_\circ\text{-}1)/\sqrt{n_s/n_w}$	s. no.	$\sqrt{n_s/n_w}$	$(\eta/\eta_\circ\text{-}1)/\sqrt{n_s/n_w}$
1	0.02145	0.37529	1	0.02825	0.61124	1	0.04076	1.15648
2	0.03126	0.49744	2	0.04351	0.74282	2	0.05223	1.22406
3	0.03956	0.66532	3	0.05162	0.81791	3	0.06753	1.27322
4	0.04844	0.72709	4	0.06152	0.84072	4	0.07837	1.31573
5	0.05879	0.76833	5	0.07264	0.86495	5	0.09413	1.53076
6	0.06799	0.97647	6	0.08509	0.99556	6	0.09767	1.58419
7	0.07399	1.00676	7	0.08987	1.01248	7	0.10778	1.62581
8	0.07949	1.08957	8	0.09854	1.06079	8	0.11759	1.68586
9	0.09543	1.16956	9	0.10672	1.07229	9	0.12439	1.80085
10	0.09932	1.24134	10	0.11211	1.08223	10	0.13214	1.84827
11	0.10589	1.29557	11	0.12731	1.17532	11	0.13879	1.92435

Notes: Ax, Bx for formic acid = 0.1913, 10.539; Ax, Bx for acetic acid = 0.5007, 5.4364, Ax, Bx for propanoic acid = 0.7673, 8.1473; Linearity (0.9814, 0.9743, and 0.9763) for formic acid, acetic acid, and propanoic acid, respectively.

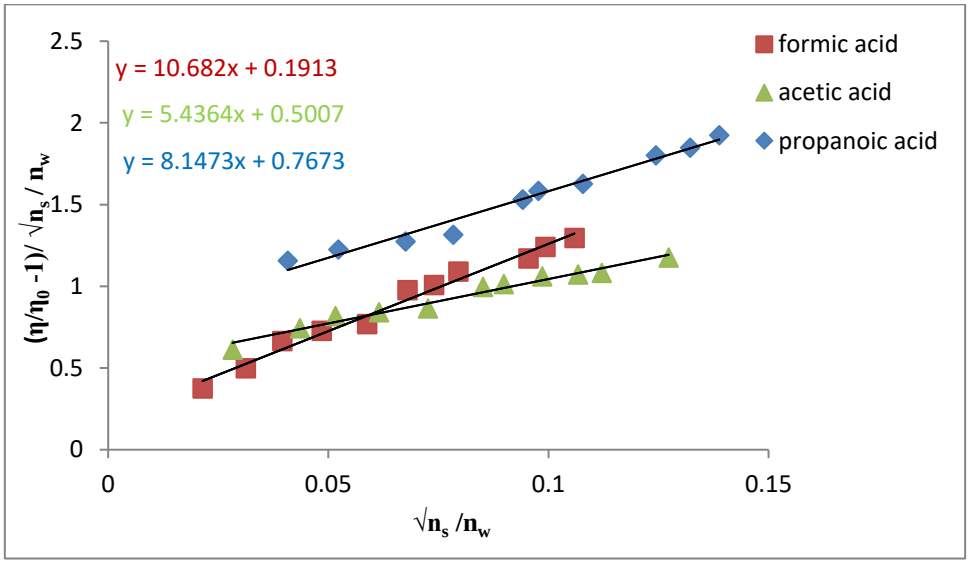

Figure 3: Modified Jone-Dole plot $(\eta/\eta_\circ\text{-}1)/\sqrt{n_s/n_w}$ versus $\sqrt{n_s/n_w}$ for carboxylic acids at 298.15 K

4. Volumetric studies

It can be safely concluded that the densities of the solution of the carboxylic acid have been employed for calculating the apparent molar volume (ϕ_v) of the solute based on equation 4 [33,34]

$$\phi_v = \frac{M}{d_o} + \frac{10^3(d_o - d)}{d_o C} \quad \text{..... (4)}$$

Here, M stands for a molar solute mass, d and d_o stand for densities ($gm.cm^{-3}$) of solution and pure solvent, respectively, and C stands for solute molarity (mol/L). Regarding three carboxylic acids, (ϕ_v) magnitudes have been determined at diverse concentrations; the values

obtained are given in Tables and plotted in Figure 4. The magnitudes of intercept and slope were estimated using Masson's relation given by Equation 5 [35-38].

$$\phi_v = \phi_v^\circ + S_v\sqrt{C} \quad \ldots\ldots\ldots (5)$$

ϕ_v° = Limiting apparent molar volume.
S_v = Volumetric pairwise interaction coefficient.
For three carboxylic acids, ϕ_v° magnitudes are positive, suggesting a strong positive interaction of solute and solvent molecules. There is good solute-solute interaction present in aqueous solutions [39-42].

Table 4: The mutation of densities with a concentration of formic acid, acetic acid, and propanoic acid at temperature of 298.15 K

Formic acid			Acetic acid			Propanoic acid		
s. no.	Concentration (mol/L)	Density (gm/cm^3)	s. no.	Concentration (mol/L)	Density (gm/cm^3)	s. no.	Concentration (mol/L)	Density (gm/cm^3)
1	0.0000	0.99705	1	0.0000	0.99705	1	0.0000	0.99705
2	0.03951	0.99768	2	0.02665	0.99771	2	0.04113	0.99835
3	0.05836	0.99789	3	0.04604	0.99812	3	0.06225	0.99892
4	0.07081	0.99798	4	0.05963	0.99839	4	0.08188	0.99941
5	0.08516	0.99815	5	0.07911	0.99874	5	0.10112	0.99979
6	0.09841	0.99822	6	0.09789	0.99908	6	0.12115	1.00023
7	0.11602	0.99832	7	0.11787	0.99938	7	0.14049	1.00059
8	0.13034	0.99839	8	0.13744	0.99955	8	0.16224	1.00098
9	0.15022	0.99845	9	0.15076	0.99972	9	0.18183	1.00128
10	0.17022	0.99852	10	0.17073	0.99991	10	0.20172	1.00159
11	0.19033	0.99858	11	0.18532	1.00002	11	0.22066	1.00162
12	0.21031	0.99862	12	0.21118	1.00018	12	0.23398	1.00169

Table 5: Accounts ϕ_v of the Masson equation for aqueous formic acid, acetic acid, and to propanoic acid at 298.15 K

Formic acid			Acetic acid			Propanoic acid		
s. no.	$\sqrt{C}$	ϕ_v (cm^3.mol^{-1})	s. no.	$\sqrt{C}$	ϕ_v (cm^3.mol^{-1})	s. no.	$\sqrt{C}$	ϕ_v (cm^3.mol^{-1})
1	0.19877	30.10729	1	016325	35.29401	1	0.20281	42.44938
2	0.24158	31.66076	2	0.21457	36.81174	2	0.24950	43.99846
3	0.26611	32.92388	3	0.24419	37.57407	3	0.28615	45.19871
4	0.29182	33.13619	4	0.28126	38.67482	4	0.31796	46.91314
5	0.31370	34.16659	5	0.31288	39.28921	5	0.34807	47.74289
6	0.34062	35.11018	6	0.34335	40.99954	6	0.37482	48.77911
7	0.36103	35.77636	7	0.37073	41.82722	7	0.40279	49.73614
8	0.38758	36.73968	8	0.38828	42.30116	8	0.42642	50.68277
9	0.41258	37.42394	9	0.41319	43.25472	9	0.44913	51.42523
10	0.43627	38.02151	10	0.43049	43.97736	10	0.46974	53.22191
11	0.45861	38.54789	11	0.45954	45.17846	11	0.48371	54.09914

Notes: ϕ_v°= 23.846, ϕ_v°= 29.502, ϕ_v°= 33.983, S_v= 32.71, S_v=33.315, S_v= 39.972. C= molar concentration (mol/L)

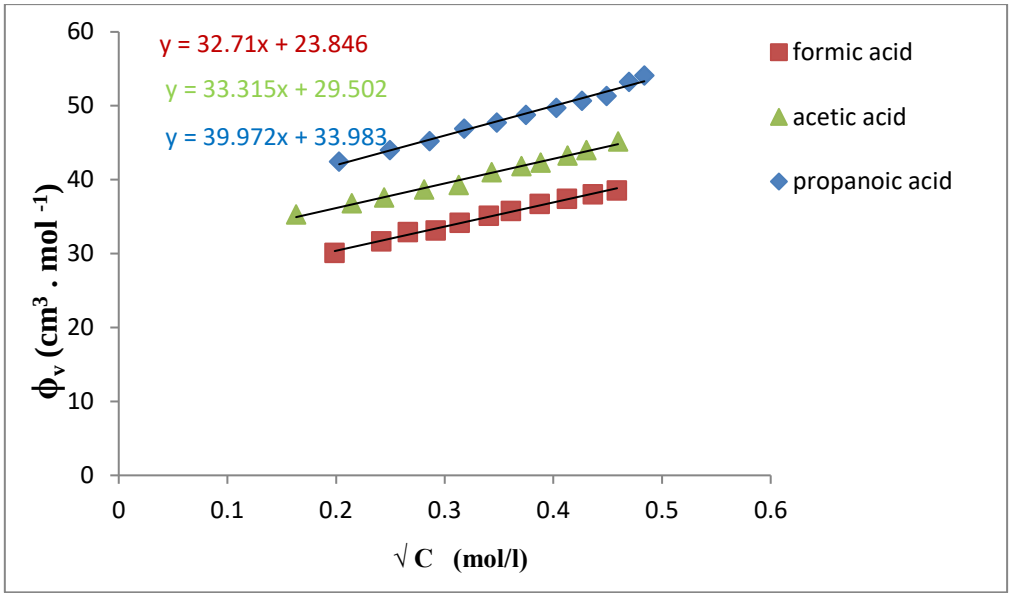

Figure 4: Masson plot molal volumes (ϕ_v) versus ($\sqrt{C}$) for carboxylic acids at 298.15 K.

By comparison, the results such as ϕ_v, S_v, and A and B coefficients in the present work with the other articles obtained and illustrated in Table 6. Solutions' viscosities rise with increasing solution concentrations. Propanoic acid was ultimately discovered to be the best acid due to the incredibly complicated interactions that exist between water and carboxylic acids. Through H-bonding, acids and water are both self-associated liquids. Except for formic acid, carboxylic acids have both a hydrophilic COOH group and a hydrophobic group [43].

Table 6: comparison the results such as ϕ_v, S_v, and A, B coefficients in the present work with the other article

Acid	Parameters	The present work	Reference 44	Reference 45	Reference 46	Reference 47
Acetic acid	ϕ_v° ($cm^3.mol^{-1}$)	29.502	51.884	-	51.737	-
	S_v	33.315	0.616	-	1.305	-
	A	-0.003	-	-	-	0.0030
	B	0.6884	-	-	-	0.295
Formic acid	ϕ_v° ($cm^3.mol^{-1}$)	23.846	-	35.035	36.134	-
	S_v	32.71	-	0.535	0.637	-
	A	-0.1825	-	-	-	0.0025
	B	1.0656	-	-	-	0.137
Propanoic acid	ϕ_v° ($cm^3.mol^{-1}$)	33.983	-	-	67.225	-
	S_v	39.972	-	-	1.686	-
	A	-0.0283	-	-	-	0.0032
	B	1.166	-	-	-	0.394

5. Conclusion

An analysis of the results suggests that the B-coefficient has been positive and reasonably high for carboxylic acids in the examined concentration range. This demonstrates the presence of strong ion-solvent interactions in dilute aqueous solutions. Additionally, the negative A-value for three carboxylic acids means that ion-ion or solute-solvent interactions have been very poor. For the dilute carboxylic acid due to hydrogen bond formation, the association

between viscosity data and solute concentration of polymolecular compounds suggested by Staudinger's was observed. The viscosity data matches the predictions for the Jone-Dole and reformed Jone-Dole equations.

Acknowledgement
The authors would like to thank the University of Baghdad for its help in this research.

References

[1] P. Patyar, G. Kaur, and T. Kaur, "Volumetric investigations on molecular interactions of glycine / l‑alanine in aqueous citric acid solutions at different temperatures", *Journal of Solution Chemistry*, vol. 47, no. 12, pp. 2039-2067, 2018.

[2] K. Amirchand and V. Singh, "Density, speed of sound, and surface tension of binary aqueous solutions containing ammonium based protic ionic liquids", *Journal of Molecular Liquids*, vol. 354, pp. 3-5, 2022.

[3] J. Aher, "Molecular interaction study of n-phenyl maleanilic acid and n-phenyl maleimide in aqueous dimethyl sulphoxide at 298.15 and 303.15 k", *Scholarly Research Journal for Interdisciplinary Studies*, vol. 4/31, pp. 5160–5165, 2017.

[4] S. Pattnaik, B. Nanda, B. Dalai, and B. Nanda, "Effect of the temperature and solvents on the solvolysis of barium bromide in aqueous-organic solutions: volumetric and viscometric study", *Biointerface Research in Applied Chemistry*, vol. 12, no. 1, pp. 339-350, 2021.

[5] L. Hnedkovsky, L. Rasanen, P. Koukkari, and G. Hefter, "Densities and apparent molar volumes of aqueous solutions of zinc sulfate at temperatures from 293 to 373 k and 0.1 mpa pressure", *Journal of Chemical and Engineering Data*, vol. 66, no. 1, pp. 38-44, 2021.

[6] A. Thakur, K. Juglan, and H. Kumar, "Acoustic and viscometric studies of ternary liquid mixtures of aqueous sodium methyl p-hydroxybenzoate with polyethylene glycols at 250 ℃", *Journal of Physics: Conference Series*, vol. 1531, no. 1, pp. 1–11, 2020.

[7] M. Khandelwal, S. Ampily, B. Rai1 and G. Sarasan,"Thermodynamic study of micellization of sdbs in aqueous and in binary solvent systems of ethylene glycol", *International Journal of Engineering Research and Technology*, vol. 9, no. 6, pp. 581-586, 2020.

[8] J. Skjoldli, "Religious interaction: what gaming can teach us about religion", *World Youth Day*, pp. 51-86, 2021.

[9] U. Herath, P. Tavadze, X. He, E. Bousquet, S. Singh, F. Mu˜noz, and A. Romero, "PyProcar: A Python library for electronic structure pre/post-processing", *Computer Physics Communications*, vol. 251, pp. 1-33, 2020.

[10] N. Hyttinen, R. Heshmatnezhad, J. Elm, T. Kurtén, and N. Prisle, "Technical note: estimating aqueous solubilities and activity coefficients of mono- and α,ω-dicarboxylic acids using cosmo therm", *Atmospheric Chemistry and Physics*, vol. 20, pp. 13131-13143, 2020.

[11] S. Deosarkar, A. Arsule, R. Sawale, and V. Pingle, "Volumetric and viscometric studies of molecular interactions in systems containing tartaric acid in water/aqueous-L-arginine solutions at 303.15 K", *Journal of Molecular Liquids*, vol. 323, pp. 4-8, 2021.

[12] O. Kadyseva, V. Bykov, O. Strelova, and A. Grebenyuk, "Study of the effect of the physicochemical properties of chitosan on its haemostatic activity", *Progress on Chemistry and Application of Chitin and its Derivatives*, vol. 26, pp. 112-120, 2021.

[13] Z. Kinart, "Conductance studies of sodium salts of selected dicarboxylic acids in water at temperatures of 283.15 K to 313.15 K", *Journal of Molecular Liquids*, vol. 337, pp. 14-16, 2021.

[14] Y. Blanco, Ö. Topel, É. Bajnóczi, J. Werner, O. Björneholm, and I. Persson, "Chemical equilibria of aqueous ammonium-carboxylate systems in aqueous bulk, close to and at the water-air interface", *Physical Chemistry Chemical Physics*, vol. 21, no. 23, pp. 12434-12445, 2019.

[15] A. Galvão, A. Savoldi, P. Arce, and W. Robazza, "Viscosity of binary aqueous solutions involving malonic, maleic, malic, tartaric, and citric acids in the temperature range between 303 and 363 k: experimental data and modeling", *Journal of Chemical and Engineering Data*, vol. 67, no. 9, pp. 2052-2058, 2022.

[16] Z. Kinart, "Conductometric studies of dissociation constants of selected monocarboxylic acids a wide range of temperatures", *Journal of Molecular Liquids*, vol. 292, pp. 6-9, 2019.

[17] A. Jain, V. Shende, D. Kawadkar, U. Pratap, A. Wankhade, and S. Zodape, "Studies of solute-

solvent interactions of imidazolium-based ionic liquid in water and aqueous L-alanine solution via volumetric and compressibility properties at T = (293.15–313.15) K", *Journal of Chemical Thermodynamics*, vol. 162, pp. 4-7, 2021.

[18] A. Navarkhele, "Molecular interaction studies on thermophysical and excess properties of formamide with n-propanol", *Research Square*, pp. 1-21, 2022.

[19] G. Egorov and D. Makarov, "Densities and thermal expansions of (water + tetrahydrofuran) mixtures within the temperature range from (274.15 to 333.15) k at atmospheric pressure", *Journal of Molecular Liquids*, vol. 310, pp. 6-10, 2020.

[20] S. Ganatra, V. Shaikh, P. Tomar, and K. Patil, "Volumetric studies of solvation of carboxylic acids in aqueous, carbon tetrachloride, methanolic and methanolic-urea binary solutions at 298.15 K", *Journal of Molecular Liquids*, vol. 304, pp. 2-5, 2020.

[21] E. Hasret, Ş. Klrbaşlar, and H. Uslu, "Comparison of extractability of oxalic acid from dilute aqueous solutions using dioctylamine and trioctylphosphine oxide", *Journal of Chemical and Engineering Data*, vol. 64, no. 3, pp. 1275-1280, 2019.

[22] M. Kadhim, "Studies on ion association of some a-amino acids with l-ascorbic acid in aqueous solution at different temperature", *Iraqi Journal of Science*, vol. 60, no. 1. pp. 1-11, 2019.

[23] M. Kadhim, "The effect of sodium chloride on ion association of lysine and arginine ionizable side chains amino acids with dehydro-l-ascorbic acid in aqueous solution at different temperatures", *Iraqi Journal of Science*, vol. 60, no. 7. pp. 1412-1422, 2019.

[24] A. Abdulzahra, M. Saleem, I. Radhi, and Z. Al-Dulaimy, "Molecular interaction in aqueous solution of butanol isomers at 298.15 k", *International Journal of Pharmaceutical Research*, vol. 12, no. 2, pp. 1229-1232, 2020.

[25] S. Sharma and A. Thakur, "Volumetric, acoustic and viscometric studies of solute-solute and solute-solvent interactions of glycyl-glycyl-glycine in aqueous tartaric acid at different temperatures", *Journal of Molecular Liquids*, vol. 322, pp. 17-20, 2021.

[26] L. Almásy, O. Artykulnyi, V. Petrenko, O. Ivankov, L. Bulavin, M. Yan, and V. Haramus, "Structure and intermolecular interactions in aqueous solutions of polyethylene glycol", *Molecules*, vol. 27, no. 8, pp. 1-14, 2022.

[27] T. Salman; and K. Abd, "Thermodynamic properties of nicotinic acid in dilute hcl and in aqueous nacl solutions at (293.15, 298.15, 303.15 and 308.15) k", *Baghdad Science Journal*, vol. 10, no. 2, pp. 432-441, 2013.

[28] S. Merza, "Viscosity and density of chrom alum in aqueous poly (ethylene glycol) solution at different temperature", *Ibn AL-Haitham Journal For Pure and Applied Sciences*, vol. 25, no. 2, pp. 280-292, 2012.

[29] M. Meza, P. López, Y. Vega, D. Sotelo, J. Mendoza, and L. Alcalá, "thermodynamic study of amino acids in an aqueous solution of calcium acetate at T= 283.15-308.15 k and pressure p = 0.1 mpa: a volumetric approach", *Journal of Chemical and Engineering Data*, vol. 66, no. 12, pp. 4740-4750, 2021.

[30] P. Patyar and G. Kaur, "Volumetric, viscometric and spectroscopic properties of glycylglycine in citrate and acetate buffer solutions at different temperatures", *Journal of Solution Chemistry*, vol. 51, no. 1, pp. 58-83, 2022.

[31] O. Sethi, M. Singh, T. Kang, and A. Sood, "Volumetric and compressibility studies on aqueous mixtures of deep eutectic solvents based on choline chloride and carboxylic acids at different temperatures: experimental, theoretical and computational approach", *Journal of Molecular Liquids*, vol. 340, Article no. 117212, 2021.

[32] M. Páez, D. Pérez, and J. Lafont, "Volumetric, viscosimetric and thermodynamic study of alanine in aqueous solutions of sodium sulphate at different temperatures", *Información Tecnológica*, vol. 30, no. 2, pp. 125-134, 2019.

[33] M. Shakeel and K. Mahmood, "Use of masson's and jones-dole equations to study different types of interactions of three pharmacologically important drugs in ethanol", *Journal of the Chinese Chemical Society*, vol. 67, no. 9, pp. 1552-1562, 2020.

[34] I. Saxena, R. Devi, and V. Kumar, "Verification of masson's equation by the density and apparent molar volume prediction in some ternary electrolyte solutions", *International Journal of Chemical and Physical Sciences*, vol. 7, no. 1, p. 1-12, 2018.

[35] N. Chakraborty, K. Juglan, H. Kumar, and M. Singla, "Measurement of the density and ultrasonic speed of the sound of poly(ethylene glycols) (600 and 6000) in aqueous vitamin b5solutions at

different temperatures", *Journal of Chemical and Engineering Data*, vol. 67, no. 9, pp. 2292-2306, 2022.

[36] M. Budeanu and V. Dumitrescu, "Densities, viscosities and excess properties for dimethyl sulfoxide with diethylene glycol and methyldiethanolamine at different temperatures", *Applied Sciences*, vol. 12, no. 1, Article no. 116, 2022.

[37] A. Thakur, K. Juglan, H. Kumar, and K. Kaur, "Apparent molar properties of glycols in methanol solutions of propyl 4-hydroxybenzoate (propylparaben) at T = (293.15 to 308.15) k: an acoustic and volumetric approach", *Physics and Chemistry of Liquids*, vol. 58, no. 6, pp. 803-819, 2020.

[38] Z. AL-Dulaimy , Z. AL-Amel , R. AL-Khalisy, Z. Hussein "Density and viscosity of amino acid serine in aqueous dimethyl sulfoxide solution at different temperatures", *Ibn AL-Haitham Journal For Pure and Applied Sciences*, vol. 25, no. 1, pp. 292-301, 2012.

[39] H. Attiya, Z. Al-Dulaimy, K. Sadiq, and M. Saleem, "Viscosity and density studies of drugs in aqueous solution and in aqueous threonine solution at 298.15 k", *Oriental Journal of Chemistry*, vol. 35, no. 1, pp. 337-342, 2019.

[40] H. Khalaf, Z. Al-Dulaimy, D. Al-Heetimi and A. Abbas, "Excess molar quantities of binary mixture of dipropyl amine with aliphatic alcohols at 298.15 k", *Oriental Journal of Chemistry*, vol. 34, no. 4, pp. 2074-2082, 2018.

[41] H. Khalaf, A. Abbas, M. Saleem, and Z. Al-Dulaimy, "Estimation of excess properties of binary liquids systems of tetrahydrofurfuryl alcohol with short-chain carboxylic acids at 298.15 k", *Asian Journal of Chemistry*, vol. 31, no. 4, pp. 820-824, 2019.

[42] P. Raundal, A. Sheikh, and S. Kasim "Study the temperature effect on apparent molar volumes and viscosity (jones dole coefficient) of magnesium sulphate, aluminium ammonium sulphate and potassium aluminium sulphate in binary mixture of aqueous dmf and aqueous dmso", *Journal of Advanced Scientific Research*, vol. 12, no. 1, pp. 99-105, 2021.

[43] M. Motin, M. Kabir, and E. Huque, "Densities and excess molar volumes of formic acid, acetic acid and propionic acid in pure water and in water + Surf Excel solutions at different temperatures", *Physics and Chemistry of Liquids*, vol. 43, no. 3, pp. 277-288, 2005.

[44] S. Khobragade, S. Ganatra, and A. Ujjankar, "Volumetric properties and molecular interactions of acetic acid in water at 298.15 K", *Journal of Chemical and Pharmaceutical Research*, vol. 8, no. 5, pp. 783-791, 2016.

[45] N. DattKandpal, "Molecular interactions of aqueous formic acid", *Physical Chemistry*, vol. 2, no. 1, pp. 95–99, 2007.

[46] A. Bald and Z. Kinart, "Volumetric properties of some aliphatic monoand dicarboxylic acids in water at 298.15 K", *Journal of Solution Chemistry*, vol. 40, no. 1, pp. 1-16, 2011.

[47] A. Chmielewska, A. Wypych-Stasiewicz, and A. Bald, "Viscosity of aqueous solutions of monocarboxylic acids", *Journal of Molecular Liquids*, vol. 130, no. 1-3, pp. 42-47, 2007.