

GENERALIZED EQUATION OF DEPENDENCE OF VISCOSITY COEFFICIENT OF BINARY MIXTURE OF N-BUTYL ALCOHOL + N-BUTYRALDEHYDE ON TEMPERATURE, PRESSURE AND CONCENTRATION

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Abstract- Using a Capillary viscometer with an external capillary, experimental study was conducted to determine the dynamic viscosity coefficients of these individual substances and their mixtures, for which thermal and caloric property data are also available. Viscosity measurements were carried in a wide range of parameters state. An equation for approximating the experimental viscosity data was formulated in a form analogous to the equation of state. The coefficients of this equation for the studied compounds and their mixtures (n-butyl alcohol, n-butylaldehyde, and their mixtures) were determined directly from the experimental data using the least squares method via computer processing. The individual equations describe the experimental data with deviations not exceeding the estimated measurement error of the viscosity. A generalized equation was proposed to describe the viscosity of all studied systems, providing satisfactory approximation accuracy and recommended for use in engineering calculations. The error assessment of viscosity measurements of the studied liquids is given, showing high reliability of the conducted studies, which are also confirmed by the results of control measurements of viscosity of liquids for which there are reliable data of other authors. Comparison of the author's experimental data with published results of viscosity measurements for individual alcohols and aldehydes. Also confirms the reliability of these data. Also, an equation for the operation of experimental data on viscosity in the form analogous to the equation of state is compiled. The coefficients of the equation for limited compounds and their mixtures are determined directly from the experimental data by the least squares method on computer technology.

Keywords: Dynamic Viscosity, N-Butyl Alcohol, N-Butylaldehyde.

1. INTRODUCTION

The study of dynamic viscosity is of critical importance in the fields of physical chemistry, chemical engineering, and fluid mechanics, as it governs the internal resistance of fluids to flow and influences a wide range of

industrial and natural processes. Over the past decades, numerous researchers have dedicated considerable effort to investigating the dynamic viscosity coefficients of both pure substances and their mixtures under varying thermodynamic conditions [1-3]. Understanding the behavior of viscosity across different pressures and temperatures is particularly significant for applications in petrochemical processing, lubrication technology, the design of heat exchange systems, and the development of predictive models for fluid dynamics in complex environments.

In this context, an extensive analysis of experimental data on the dynamic viscosity coefficients of individual substances and their binary or multicomponent mixtures has been conducted by various authors. These investigations, performed across different cross-sections of the pressure-temperature surface, have revealed a remarkably simple and consistent pattern in the behavior of these coefficients. Specifically, it has been observed that the lines representing constant pressure on viscosity diagrams tend to exhibit a near-linear configuration. This characteristic linearity is notable not only for its simplicity but also for its persistence across a diverse array of substances with differing molecular structures, compositions, and thermophysical properties.

Moreover, this pattern has been consistently observed over a wide and practically significant range of pressures and temperatures, as reflected in the comprehensive experimental data presented in Tables 1-3. The identification of such a linear relationship offers valuable insights into the fundamental behavior of fluid systems and provides a practical basis for simplifying the modeling and prediction of viscosity in various industrial processes.

Despite the significance of these findings, a comprehensive and systematic interpretation of the causes and implications of this linear configuration in lines of constant pressure remains relatively underexplored in the literature. In particular, there is a need to examine whether this pattern can be universally applied to other classes of substances and whether deviations from this behavior might indicate specific intermolecular interactions or phase transitions.

The aim of this paper is to further investigate and elucidate the observed linearity of constant-pressure lines in dynamic viscosity diagrams. By analyzing experimental data across a wide range of substances and thermodynamic conditions, the study seeks to determine the underlying principles governing this behavior and to assess its potential applications in predictive modeling and process optimization. In doing so, the research contributes to a deeper understanding of the thermophysical properties of fluids and supports the development of more efficient and reliable methods for estimating viscosity in practical engineering systems.

2. PROBLEM STATEMENT

In such cases, the viscosity data can be approximated by an equation of the form:

$$\eta = L(T) + K(T) \times P \tag{1}$$

where, $L(T)$ and $K(T)$ are functions of temperature. As can be seen from the graph, the dependence of L in Ton normal butyl alcohol varies exponentially. This change is true for both normal n-butyl aldehyde and the mixtures studied. It can also be seen from this graph that at certain values of temperature and pressure, n-butyl alcohol and n-butylaldehyde have the same dependence on L in T as their binary counterparts. At higher temperatures, this dependence changes sharply.

The analysis of $L(T)$ and $K(T)$ shows that for different compositions of the chosen system, these functions have a similar form. To illustrate this, Figures 1 and 2 show the dependencies of L and K on T for the system of n-butyl alcohol + n-butylaldehyde with varying compositions. These curves are described by us with equations of the following form:

$$L(T) = \exp\left(\sum_{i=0}^4 \frac{n_i}{T^i}\right) \tag{2}$$

and

$$K(T) = \exp\left(\sum_{i=0}^4 \frac{m_i}{T^i}\right) \tag{3}$$

The values of the coefficients n_i and m_i , found using the least squares method, are given in Table 1 for n-butyl alcohol + n-butylaldehyde.

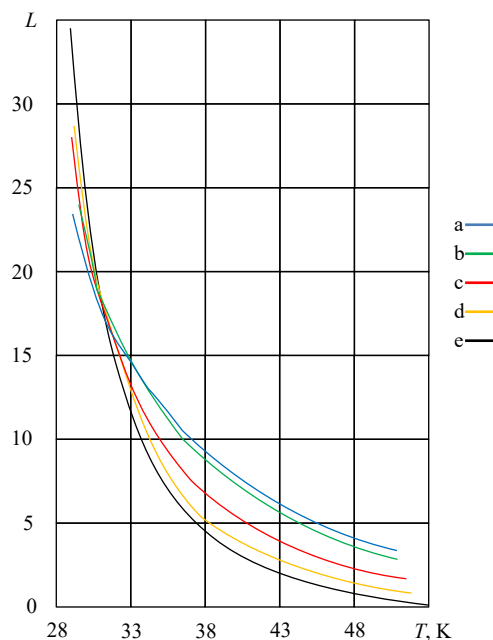


Figure 1. Dependence of L on T for the system of n-butyl alcohol + n-butylaldehyde

- a) n-butyl alcohol, b) n-butylaldehyde
- c) 90% n-butyl alcohol + 10% n-butylaldehyde
- d) 60% n-butyl alcohol + 40% n-butylaldehyde
- e) 10% n-butyl alcohol + 90% n-butylaldehyde

Table 1. Polynomial coefficients for the viscosity functions and their binary mixtures

Coefficients	Substance				
	n-butyl alcohol	n-butylaldehyde	90% n-butyl alcohol + 10% n-butylaldehyde	60% n-butyl alcohol + 40% n-butylaldehyde	10% n-butyl alcohol + 90% n-butylaldehyde
n_0	-2.0114×10^1	-3.5668×10^0	-1.81492×10^7	-1.13222×10^1	-4.65587×10^0
n_1	3.03184×10^4	6.18956×10^3	2.72745×10^4	-1.74463×10^4	7.74503×10^3
n_2	-1.5716×10^7	-1.6605×10^6	-1.39742×10^7	-8.22788×10^6	-2.54057×10^6
n_3	3.83937×10^9	1.82287×10^8	3.37745×10^9	1.86721×10^9	3.98197×10^8
n_4	-3.4583×10^{11}	---	-3.0035×10^{11}	-1.5475×10^{11}	-1.86170×10^{10}
m_0	-4.7743×10^1	1.66790×10^0	-4.38731×10^0	-3.23339×10^1	-2.84506×10^0
m_1	7.65932×10^4	-1.6836×10^3	7.08436×10^4	5.21280×10^4	5.41779×10^3
m_2	-4.7300×10^7	3.63561×10^5	-4.37463×10^7	-3.13007×10^7	-3.38418×10^6
m_3	1.2793×10^{10}	1.40795×10^7	1.17397×10^{10}	8.432200×10^9	1.10024×10^9
m_4	-1.254×10^{12}	---	-1.1500×10^{12}	-8.0608×10^{11}	-1.02198×10^{11}

The values of the coefficients n_i and m_i of Equation (1) for the system of n-butyl alcohol + n-butylaldehyde. The mean deviation, calculated using Equation (1) with the coefficients provided in the table, lies within the range of

0.3-0.6%. We attempted to formulate a generalized equation for describing the dynamic viscosity of the studied substances using a method analogous to that applied when formulating a generalized equation of state [4-5].

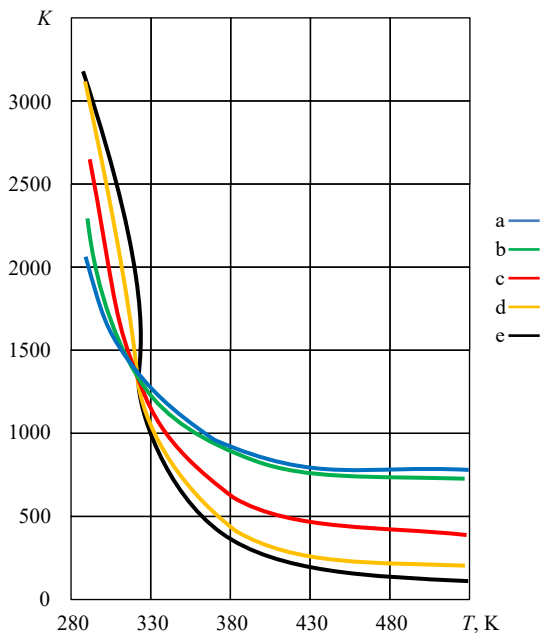


Figure 2. Dependence of KKK on TTT for the system of n-butyl alcohol + n-butyraldehyde; n-butyl alcohol; n-butyraldehyde; 90% n-butyl alcohol + 10% n-butyraldehyde; X – 60% n-butyl alcohol + 40% n-butyraldehyde; – 10% n-butyl alcohol + 90% n-butyraldehyde

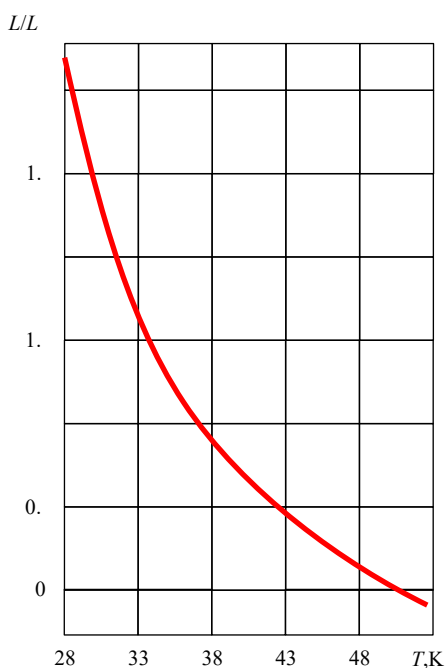


Figure 3. Dependence of L/L_H on T/T_H for the system of n-butyl alcohol + n-butyraldehyde; n-butyl alcohol; n-butyraldehyde; 90% n-butyl alcohol + 10% n-butyraldehyde; 60% n-butyl alcohol + 40% n-butyraldehyde; 10% n-butyl alcohol + 90% n-butyraldehyde

For this purpose, the temperature functions $L(T)$ and $K(T)$ were made dimensionless by dividing the corresponding quantities by the normal boiling temperature T_H . The results of this processing are shown in Figures 3 and 4.

For the system of n-butyl alcohol + isobutyl alcohol, all values of L and K in relative coordinates are well approximated by a single curve. The equation of the generalized curves for the studied systems is as follows.

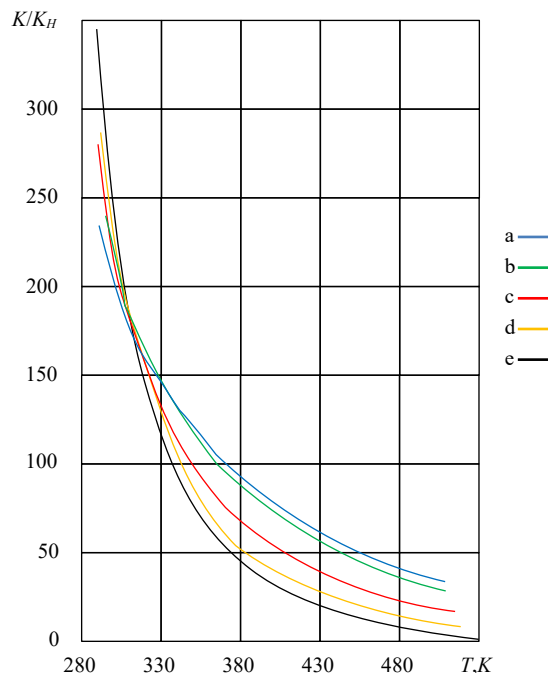


Figure 4. Dependence of K/K_H on T/T_H for the system of n-butyl alcohol + n-butyraldehyde; n-butyl alcohol; n-butyraldehyde; 90% n-butyl alcohol + 10% n-butyraldehyde; 60% n-butyl alcohol + 40% n-butyraldehyde; 10% n-butyl alcohol + 90% n-butyraldehyde

$$\frac{L}{L_H} \left(\frac{T}{T_H} \right) = \exp \left[\sum_{i=0}^5 \varphi_{1i} \left(\frac{T}{T_H} \right)^i \right] \tag{4}$$

$$\frac{K}{K_H} \left(\frac{T}{T_H} \right) = \exp \left[\sum_{i=0}^5 \varphi_{2i} \left(\frac{T}{T_H} \right)^i \right] \tag{5}$$

For all three studied two-component systems, the values of the coefficients φ_{1i} and φ_{2i} are presented in Table 2. The values of the coefficients φ_{1i} and φ_{2i} of Equations (4) and (5).

Table 2. Dimensionless viscosity function coefficients for normalized temperature relations of n-butyl alcohol, n-butyraldehyde, and their binary mixtures

Coefficients	Systems
	n-butyl alcohol, n-butyraldehyde
φ_{10}	1.215276×10^2
φ_{11}	-6.137209×10^2
φ_{12}	1.192799×10^3
φ_{13}	-1.130138×10^3
φ_{14}	5.250166×10^2
φ_{15}	-9.547195×10^1
φ_{20}	1.960413×10^1
φ_{21}	-1.785171×10^1
φ_{22}	1.117271×10^2
φ_{23}	-7.187587×10^1
φ_{24}	-1.811457×10^1
φ_{25}	---

Further analysis of the dependencies $L_H(T_H)$ and $K_H(T_H)$ on T_H showed that they are linear, if the mixture is assumed to $T_H = T_{1H}(1 - \chi) + T_{2H}\chi$.

As we did [5-6] when generalizing P, v, T is data. Here it is accepted that χ is the percentage content of the 2nd component; T_{1H} and T_{2H} are respectively the normal boiling temperatures of the 1st and 2nd components of the mixture. The dependences of $L_H(T_H)$ and $K_H(T_H)$ on T_H for the n-butyl alcohol + n-butyraldehyde system are approximated by linear equations:

$$L_H(T_H) = \psi_{10} + \psi_{11} \times T_H \tag{6}$$

$$K_H(T_H) = \psi_{20} + \psi_{21} \times T_H \tag{7}$$

The values of the coefficients of these equations are given in Table 3. Our analysis showed that the dependence of the viscosity of the studied binary mixtures on the concentration by isotherms is linear for all the studied pressures. This is clearly illustrated in Figure 5. Taking into account the above relationships, the generalized equation for the dynamic viscosity coefficient has the form:

$$\eta = (\psi_{10} + \psi_{11} \times T_H) \times \exp \left[\sum_{i=0}^5 \varphi_{1i} \left(\frac{T}{T_H} \right)^i \right] + (\psi_{20} + \psi_{21} \times T_H) \times \exp \left[\sum_{i=0}^5 \varphi_{2i} \left(\frac{T}{T_H} \right)^i \right] \times P \tag{8}$$

3. METHOD FOR SOLUTION

The maximum deviation of the viscosity values of the studied systems calculated by Equation (8) from our experimental data is 2-3%.

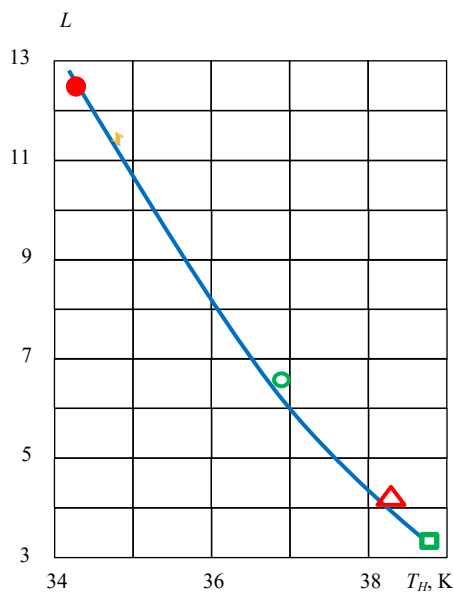


Figure 5. Dependence of L_H on T_H for the system n-butyl alcohol + n-butyraldehyde: - n-butyl alcohol; - 90% n-butyl alcohol + 10% n-butyraldehyde; - 60% n-butyl alcohol + 40% n-butyraldehyde; X - 10% n-butyl alcohol + 90% n-butyraldehyde; - n-butyraldehyde

The concentration dependence of n-butyl alcohol + n-butyraldehyde system viscosity at different temperatures and pressures is illustrated in Figure 7. Values of the coefficients Ψ_{1i} and Ψ_{2i} of Equations (6) and (7).

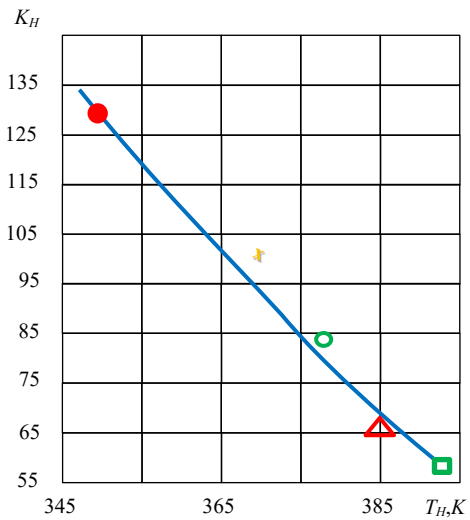


Figure 6. Dependence of K_H on T_H for the system n-butyl alcohol + n-butyraldehyde: - n-butyl alcohol; - 90% n-butyl alcohol + 10% n-butyraldehyde; - 60% n-butyl alcohol + 40% n-butyraldehyde; X - 10% n-butyl alcohol + 90% n-butyraldehyde; - n-butyraldehyde

Table 3. Coefficients for generalized viscosity equation based on binary composition of n-butyl alcohol and n-butyraldehyde

Coefficients	Systems
	n-butyl alcohol + n-butyraldehyde
ψ_{10}	7.12189×10^2
ψ_{11}	6.89694×10^{-1}
ψ_{20}	6.35212×10^0
ψ_{21}	1.52043×10^{-3}

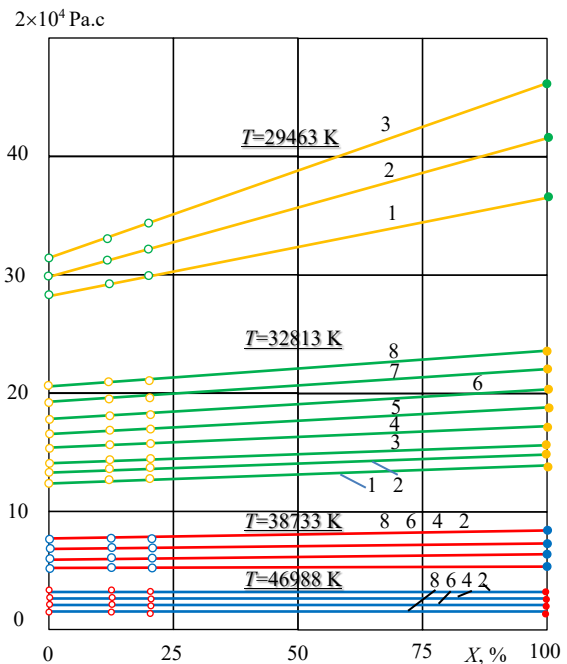


Figure 7. Concentration dependence of the viscosity of the n-butyl alcohol - n-butyraldehyde system at different temperatures and pressures: - n-butyl alcohol; - n-butyraldehyde; 1- 0.1 MPa; 2- 5.0; 3- 9.9; 4- 19.7; 5- 29.5; 6- 39.3; 7- 49.1; 8- 58.9; X: concentration of n-butyraldehyde

4. APPLICATION OF RESULT TO ENGINEERING PROBLEMS

Accurate and reliable data on thermophysical properties such as dynamic viscosity are crucial for the design and optimization of chemical engineering processes and equipment. In particular, binary mixtures involving *n*-butyl alcohol and *n*-butyraldehyde find extensive applications in industries such as petrochemical refining, pharmaceutical production, and solvent extraction processes.

The generalized equation presented in this study facilitates precise prediction of viscosity for these mixtures under varying temperature and pressure conditions. This capability is essential for the accurate modeling of flow dynamics, mass transfer, and heat exchange processes. Reliable viscosity predictions allow engineers to optimize reactor designs, piping systems, pumps, and heat exchangers, significantly enhancing operational efficiency and safety.

Moreover, the generalized viscosity equation supports computational fluid dynamics (CFD) simulations, enabling detailed analysis and forecasting of fluid behavior in complex industrial systems. By reducing uncertainties in viscosity values, engineers can achieve better process control, energy savings, and improved product quality.

Furthermore, this generalized approach can be extended to other similar chemical systems, thus providing a versatile tool for engineering calculations and process simulations across various sectors. Consequently, the findings of this study directly contribute to the advancement of chemical engineering methodologies and practical applications in fluid management systems.

5. CONCLUSIONS

In this study, we conducted a comprehensive experimental investigation of the dynamic viscosity coefficients of *n*-butyl alcohol, *n*-oil aldehyde, and their mixtures in various concentrations over a broad range of temperatures (290-500 K) and pressures (0.1-58.9 MPa). The measurements were performed using the extraction capillary viscometer method, which provided reliable and repeatable results across all tested conditions. To verify the accuracy and reliability of the experimental technique and obtained data, reference liquids with well-established viscosity values -*n*-heptane and *n*-toluene- were used as calibration standards. The viscosity coefficients determined for these reference liquids showed excellent agreement with previously reported data, achieving a measurement accuracy within 0.1%.

Based on the comprehensive set of experimental results obtained in this work, a generalized equation of state was formulated to describe the viscosity behavior of the *n*-butyl alcohol-*n*-oil aldehyde binary mixture. This equation enables the estimation of viscosity coefficients at any arbitrary mixture composition, within the investigated range of temperatures and pressures. Subsequent control experiments confirmed the validity and accuracy of the proposed model, with results consistently falling within the expected range of experimental error.

The findings of this study offer important contributions not only to the understanding of the thermophysical properties of alcohol-aldehyde systems but also to their practical application in various fields. The ability to predict viscosity coefficients across a wide range of conditions is essential for the design and optimization of industrial processes such as petrochemical refining, pharmaceutical formulation, and solvent extraction operations. Furthermore, the data and model generated from this study can be valuable in the development of computational fluid dynamics (CFD) simulations, facilitating more precise and efficient process control in industries dealing with alcohol-based mixtures and organic fluid systems.

Additionally, the methodology and approach employed in this work can be extended to investigate other binary and multicomponent liquid systems, offering potential for further research in the areas of lubricant formulation, polymer solution processing, and heat exchanger design where viscosity plays a crucial role in system performance and energy efficiency. In summary, this study not only provides accurate experimental data and a reliable predictive model for the viscosity of *n*-butyl alcohol-*n*-oil aldehyde mixtures but also highlights their significance in practical industrial applications, laying a foundation for future investigations into related liquid systems.

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