2012

Study of the Viscometric and Volumetric Properties of Multicomponent Regular Liquid Systems at Different Temperature Levels

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Recommended Citation

Hussein, Nidal, "Study of the Viscometric and Volumetric Properties of Multicomponent Regular Liquid Systems at Different Temperature Levels" (2012). *Electronic Theses and Dissertations*. 8028.
https://scholar.uwindsor.ca/etd/8028

Study of the Viscometric and Volumetric Properties of Multicomponent Regular Liquid Systems at Different Temperature Levels

By

Nidal Hussein

A Dissertation
Submitted to the Faculty of Graduate Studies
through the Environmental Engineering Program
in Partial Fulfillment of the Requirements for
the Degree of Doctor of Philosophy at the
University of Windsor

Windsor, Ontario, Canada

2012

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395, rue Wellington
Ottawa ON K1A 0N4
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Your file Votre référence
ISBN: 978-0-494-82885-4
Our file Notre référence
ISBN: 978-0-494-82885-4

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ABSTRACT

The densities and viscosities of the following quinary system: Chlorobenzene, p-xylene, octane, ethylbenzene, and 1-hexanol and all its quaternary, ternary and binary subsystems were experimentally measured over the entire composition range at 293.15, 298.15, 308.15, and 313.15 K.

The sets of data obtained were employed, along with other data reported in the literature, to test the predictive capabilities of some of the most widely accepted and used models available from the literature.

The predictive capabilities of the following models were tested: the generalized McAllister three-body interaction model, the pseudo-binary McAllister model, the GC-UNIMOD model, the generalized corresponding states principle (GCSP) model, the Artificial Neural Network (ANN), and the Allan and Teja correlation.

The models testing results show that the generalized McAllister three-body interaction model gave the best predictive capability for the regular mixtures under investigation.

DEDICATION

This work is dedicated to my wife Amira, my sons, and to my parents for their endless love, encouragement and support throughout the years.

ACKNOWLEDGEMENTS

First and foremost, I thank Allah for endowing me health and knowledge to complete this work.

I would like to express my sincere gratitude to my advisor, Professor Abdul-Fattah A. Asfour, and co-advisor, Dr. Ahmed Tawfik for their encouragement, guidance and for sharing their expertise and enthusiasm with me right from the beginning of this work. I will forever be indebted to them.

I would also like to take this chance to express my deep thanks to my wife, Amira. Without her encouragement, support, and understanding this work would have been much harder to achieve if not impossible. I would like also to thank my two beautiful sons, Mohamad and Ahmad for making my life happier during the last few years.

Completing this work and obtaining this degree have been the dream of parents, making their dream come true was always a motivation to complete this work, I just hope that this will make them happy. My deepest appreciation and thanks also go to my sister and brothers for their unlimited support and belief in my abilities. Also, I would like to thank all my great friends, and classmates from school, Jordan University of Science and Technology, University of Twente, and the University of Windsor.

Last but not least, I would like to thank all the good people in the Chemical Control Centre and in the Environmental Engineering program; specially Dr. Noori Cata for making the time spent at the lab more enjoyable. Special thanks are due to Bill Middleton for all the technical help he offered to me during this work.

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CHAPTER 1

INTRODUCTION

1.1 General

Different fluids have different physical and chemical properties that determine the proper ways to handle, store, use, process, and transport them. One of the important and common processes encountered in real life and industrial applications is fluid transport. For these applications it is important to know the fluid's ability to flow or in other words the fluid's resistance to flow. Fluids in general are qualitatively described as either thin or thick fluids. Thin fluids are those less resistant to flow and thick fluids are more resistant to flow.

A fluid in laminar flow can be viewed as if it is moving in layers. If an external shear stress is applied to one layer of a confined fluid it will move at a certain velocity. As a result, the adjacent layer will move at a lower velocity. This results in the development of a velocity gradient (sometimes referred to as the rate of shear) within the fluid that is related to the shear stress. With the help of a simple relation, Newton's law of viscosity, defines a fluid's viscosity as the proportionality constant that relates shear stress (τ_{xy}) to the developed velocity gradient (dv_x/dy). The following equation is the mathematical representation of Newton's law of viscosity:

$$\tau_{xy} = -\mu \frac{dv_x}{dy} \tag{1.1}$$

where μ is a proportionality constant, which is called the absolute viscosity.

Fluids that obey Newton's law are designated as Newtonian fluids. Fluids for which the shear stress is related to the velocity gradient by a more complicated relationship than Newton's law of viscosity are known as non-Newtonian fluids and are classified on the basis of the relationship between the shear stress and the velocity gradient. Figure 1.1 shows the different behaviours of Newtonian and non-Newtonian fluids in terms of the relation between the shear rate (velocity gradient) and the shear stress.

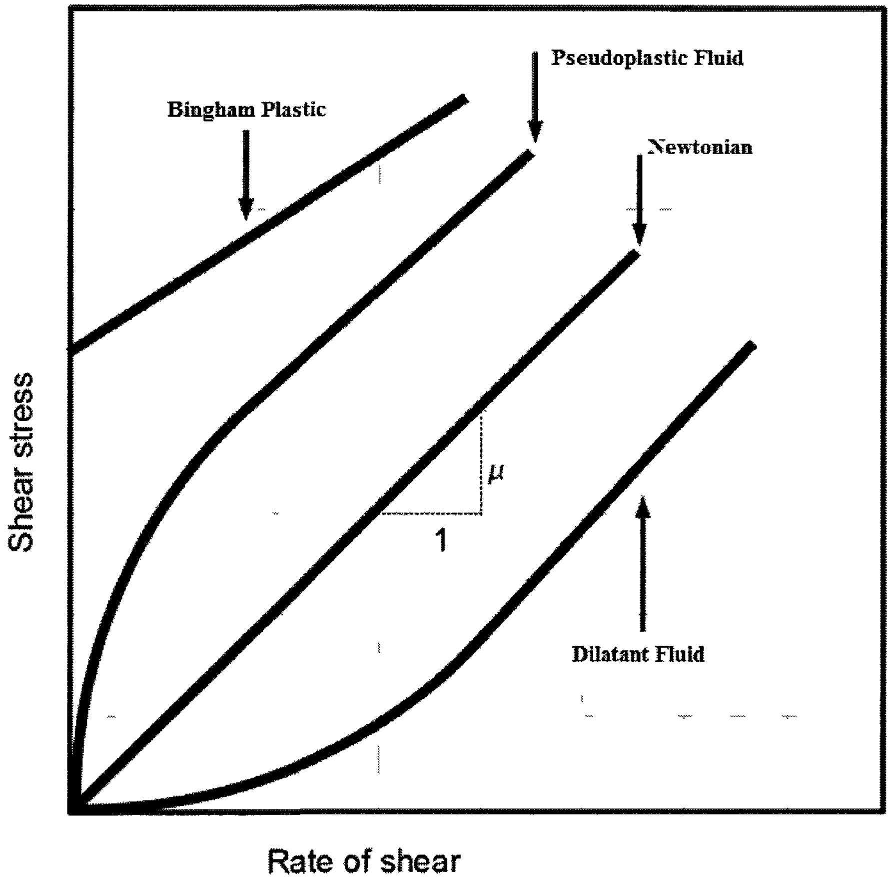

Figure 1.1: Newtonian and non-Newtonian Fluids (Adopted from Wikipedia-Viscosity)

Scientists and engineers use the value of the physical property of viscosity to precisely describe a fluid's internal resistance to flow under shear stress. It is important to know a fluid's viscosity in order to estimate the energy needed to overcome such a resistance in a flow system. Flow systems are extensively employed in engineering applications, especially in heat exchangers as well as in mass transfer processes.

A fluid's viscosity is a function of temperature. In the case of liquids, the viscosity decreases as the temperature increases, whereas in the case of gases, at low density, the viscosity increases with temperature. The difference in the temperature effect on viscosity between gases and liquids was explained by Bird *et al.* 1960 as follows: "*in gases (in which the molecules travel long distances between collisions) the momentum is transported primarily by the molecules in free flight, whereas in liquids (in which the molecules travel only very short distances between collisions) the principal mechanism for momentum transfer is the actual colliding of the molecules.*"

For the case of liquid mixtures, composition is another parameter that significantly affects the molecular interaction within the liquid, thus, changing the fluid's resistance to flow.

In light of the above, it is clear that the impact of the previously mentioned parameters on liquid mixtures' viscosity comes from its impact on the intra molecular forces within the fluid. Thus its impact on the liquid structure. As a result, it is assumed that the knowledge of the dependence of viscosity on temperature, composition, and other parameters may provide a better understanding of the liquid's structure and ultimately leads to a viable molecular theory of liquids. A molecular theory will provide a valuable tool to scientists and engineers that enables them to accurately predict the physical properties of different liquid mixtures' combinations at different conditions without the need to perform costly and time consuming experiments. This has motivated many researchers to investigate the dependence of viscosity of liquid mixtures on composition. Those efforts have resulted in developing different models which can be classified into two categories; *viz.*, correlative and predictive models.

The correlative models contain adjustable parameters that can be determined using experimentally measured values of viscosity. Predictive models can predict the dependence of viscosity on composition and would require the knowledge of some molecular parameters and/or properties of the pure components constituting the mixture being investigated.

Amongst the viscosity models available in the literature, five widely used and accepted viscosity models have been considered in the present study. The predictive capabilities of those models will be tested. The models selected are: the generalized McAllister three-body interaction model, the pseudo-binary McAllister, the GC-UNIMOD model, the generalized corresponding states principle (GCSP) model, and the Allan and Teja correlation. The first four models are predictive whereas the Allan Teja model is correlative. In addition, a model based on the Artificial Neural Network (ANN) has been developed and is tested in the present study in terms of its ability to predict the viscosity of liquid mixtures of different compositions using the viscosity values of pure components used in constituting the mixture.

The previously mentioned models predict either the absolute viscosity or the kinematic viscosity. The kinematic viscosity is related to the absolute viscosity by the following equation:

$$\nu = \frac{\mu}{\rho} \tag{1.2}$$

where ν = kinematic viscosity, μ = absolute viscosity, and ρ = density. Therefore, in order to investigate the predictive capabilities of the above-mentioned models, the kinematic viscosity-density or absolute viscosity-density data must be available.

1.2 Objectives

Contrary to popular belief, reliable data on viscosities and densities of multi-component liquid mixtures are not readily available in the literature. Although sets of data on binary systems have been published, ternary, quaternary, and quinary systems' data are scarcely available. The present study is part of an ongoing research program that aims at measuring and reporting data of multi-component liquid systems at different temperature levels. The objectives of the present study can be summarized as follows:

To measure the densities and kinematic viscosities over the entire composition range and at 293.15, 298.15, 308.15, and 313.15 K of the quinary system: chlorobenzene, p-xylene, octane, ethylbenzene, and 1-hexanol and all its quaternary, ternary and binary sub-systems. The investigated systems in the present study are reported in Table 1.1.

Table 1.1: Systems Investigated in the Present Study

System No.	(i) Binary Systems
1	Chlorobenzene – p-Xylene
2	Chlorobenzene – Octane
3	Chlorobenzene – Ethylbenzene
4	Chlorobenzene – 1-Hexanol
5	p-Xylene – Octane
6	p-Xylene – Ethylbenzene
7	p-Xylene – 1-Hexanol
8	Octane – Ethylbenzene
9	Octane – 1-Hexanol
10	Ethylbenzene – 1-Hexanol
	(ii) Ternary Systems
11	Chlorobenzene – p-Xylene – Octane
12	Chlorobenzene – Octane – Ethylbenzene
13	Chlorobenzene – p-Xylene – Ethylbenzene
14	Chlorobenzene – Octane – 1-Hexanol
15	Chlorobenzene – Ethylbenzene – 1-Hexanol
16	Chlorobenzene – p-Xylene – 1-Hexanol
17	p-Xylene – Octane – Ethylbenzene
18	p-Xylene – Ethylbenzene – 1-Hexanol
19	p-Xylene – Octane – 1-Hexanol
20	Octane – Ethylbenzene – 1-Hexanol

Table 1.2 (Cont'd.): Systems Investigated in the Present Study

System No.	
	(iii) Quaternary Systems
21	Chlorobenzene – p-Xylene – Octane – Ethylbenzene
22	p-Xylene – Octane – Ethylbenzene – 1-Hexanol
23	Chlorobenzene – Octane – Ethylbenzene – 1-Hexanol
24	Chlorobenzene – p-Xylene – Ethylbenzene – 1-Hexanol
25	Chlorobenzene – p-Xylene – Octane – 1-Hexanol
	(iv) Quinary Systems
26	Chlorobenzene – p-Xylene – Octane – Ethylbenzene – 1-Hexanol

2. To test the predictive capability of the various viscosity models reported in the literature using the data reported in this study.
3. To develop an Artificial Neural Network(s) to predict the kinematic viscosities of the different types of multi-components liquid mixtures.
4. To test the predictive capability of the developed Artificial Neural Network(s) using the data reported in this study and data obtained from the literature.

1.3 Contributions and Significance

The present study makes a significant contribution to the literature by providing researchers, scientists, and design engineers with reliable experimental values of the densities and viscosities of pure compounds as well as density and viscosity composition data, over the entire composition range, at different temperatures for the quinary system investigated and all its quaternary, ternary, and binary sub-systems. Such data are needed for many engineering applications that include flow systems and design of equipment.

In addition, the development of Artificial Neural Network(s) to predict the kinematic viscosities of different types of multi-component liquid mixtures and testing their predictive capabilities in order to provide scientists and engineers with powerful tools that enable them to predict the dependence of viscosity on composition in multi-component liquid systems. Furthermore, the predictive capabilities of the already existing viscosity models in the literature were critically tested and discussed. This would enable scientists and engineers to select the best model for their applications.

CHAPTER 2

REVIEW OF THE PERTINENT LITERATURE

2.1 General

Modeling of materials' physical properties is of great importance to scientists and engineers. It eliminates the need to perform time consuming and costly experimental measurements to estimate their values when needed. Predicting flow properties of pure liquids and liquid mixtures has been a research focus for engineers from different areas.

These flow properties are needed in a host of applications that require transportation of liquids from their place of existence to the place of need or utilization. These types of applications include, but are not limited to, the design of heat exchange systems, mass transfer and separation processes, and transportation of raw materials and products from one place to another. Important applications also include mass diffusivity and thermal conductivity estimation of liquids where flow properties are used as independent parameters. Additionally, a better understanding of fluids' flow properties is likely to provide a better insight into the structure of liquids.

In order to overcome fluids resistance to flow, a pressure difference is typically induced to allow the fluids to flow. Consequently, the design of pumping systems is required to induce the pressure difference. The flow resistance is quantatively expressed in terms of viscosity. It is important for design engineers to have a tool that enables them to accurately estimate viscosities, when experimental values are not readily available, for the proper sizing of pumps that provide sufficient energy to move the fluids in flow systems.

For pure liquids, viscosity is temperature sensitive, whereas in liquid mixtures, in addition to temperature dependence, mixture's composition affects the mixture's viscosity. Those independent variables influence the inter-molecular interaction forces and as a result causes changes to liquid's structure that consequently leads to changes in a mixture's viscosity.

Several researchers have examined the relationship between viscosity and the aforementioned independent variables. Their efforts have resulted in several models that quantify such a relationship. The general formula for those viscosity models for liquid mixtures with n components has the following form:

$$\mu_m = f(T, x_1, x_2, \ldots, x_{n-1}, \mu_1, \mu_2, \ldots, \mu_n, C_1, C_2, \ldots) \qquad (2.1)$$

where μ_m: mixture's viscosity,

x_i: the mole fraction of component i,

μ_i: the viscosity of pure component i, (i = 1, 2, …., n).

C_1, C_2, …,etc. are model constants that depend on the type of investigated system.

As per the classification of Monnery *et al.* (1995) liquid mixtures' viscosity models are divided into two groups. They are either empirical models or semi-theoretical models. A model is classified as empirical if it requires fitting of experimental data to estimate the values of some constants (C1, C2 … etc in equation 2.1) without a theoretical framework. Whereas for semi-theoretical models, the relations are based on the principles of popular liquid theories but the models' constants are adjustable and evaluated using experimental data.

The latter type of models is also divided into two subgroups *viz.*, correlative and predictive according to the basis on which the values of the model's constants were estimated. The model is classified as predictive if the physical properties and/or molecular parameters of the pure components constituting the mixture are used to evaluate the model constants. Otherwise, the model is classified as correlative if it only uses experimental data to evaluate the model constants.

Unlike gases where theoretical models are reliably based on the kinetic theory of gases, theoretical description of liquids (and dense gases) is much more complicated. This is due to the nature of the intermolecular forces, which consist of the short range (repulsion and hydrogen bonding), wide range (electrostatic), and long range (attraction) effects [Mehrotra *et al.* 1996]. However, there have been several attempts to develop theoretical models for pure liquids' and mixtures' viscosity. The main theoretical frameworks used in developing such models are either the reaction rate theory, group contribution concept, or the corresponding states principle.

The present work is a continuation of an experimental research program at our laboratory that aims at providing reliable experimental values of viscosity-composition and density-composition data of pure liquids and mixtures of different types of liquids. Additionally, the measured values are used to test the predictive capabilities of different selected empirical and semi-theoretical viscosity models.

The experimental viscosity data collected in the present study have been employed in testing the predictive capabilities of the following models:

1. The generalized McAllister three-body interaction model (Nhaesi and Asfour 2000a).
2. The *pseudo*-binary McAllister model based on the reaction rate theory (Nhasei and Asfour 2000b).
3. The GC-UNIMOD model, based on group contribution theory (Cao *et al.* 1993b).
4. The generalized corresponding states model (GCSP) model, based on corresponding states principle (Teja and Rice 1981).
5. The Allan and Teja correlation (Allan and Teja 1991).

In addition to these models, the present study investigates the use of the artificial neural network (ANN), which has attracted the attention of several researchers, in predicting the mixture viscosity. The main difference between the work reported herein and the earlier work reported by other investigators is that in the present work, the network was trained by using some of the data on binary systems, then the trained network was employed to predict the viscosities of the multi-component systems.

Other investigators employed some of their data to train the network then used the train network to predict the viscosities of the same type of system; i.e., part of the binary system data were used to train the network and the rest of the binary data were used in testing the network for binary systems.

The first four models and the model based on the artificial neural network are predictive semi-theoretical models, whereas the Allan Teja model is classified as a correlative model. A detailed description of the foregoing models, their respective theoretical framework, and their development are now in order.

2.2 The Generalized McAllister Three-Body Interaction Model

McAllister (1960) reported a model based on the reaction rate theory. McAllister's model started as a correlative model for binary mixtures. Asfour *et al.* (1991) could successfully transform the model from a *correlative* equation to a *predictive* model for the case of binary *n*-alkanes liquid systems. Nhaesi and Asfour (2000a) developed and reported a generalized form of the McAllister model which could be used for multi-component regular and *n*-alkane liquid solutions. The following section reviews the theoretical basis of the original McAllister model and the development of the generalized predictive version of the model.

2.2.1 Reaction rate theory and Eyring's equation of viscosity

The reaction rate theory is applied to liquids as suggested by Eyring (1936) and Ewell and Eyring (1937) to describe the viscous flow of liquids. It visualizes the liquid as a group of adjacent molecules in equilibrium positions with "dissolved" holes or vacant sites between them. Each molecule is bonded to other molecules by different types of bonds. The total energy of bonding is the resultant of the different bonding forces between the molecule and other neighbouring molecules. Molecules that are able to break the bonds can jump into the dissolved hole leaving another hole behind.

Figure 2.1a shows a schematic representation of the fluid layers as visualized by Eyring and coworkers. It is assumed that the fluid layers are separated by a distance λ_1 and that the average area available per molecule is $\lambda_2\lambda_3$.

When applied to liquids, the reaction rate theory deals with viscous flow in the same fashion as a chemical reaction. In their analogy, Eyring assumed that under shear stress, the movement of a single molecule in one layer of the liquid requires the availability of a vacant site. The molecule must also have sufficient energy to cross a potential energy barrier Δ^*G_0 (Figure 2.1b) and complete the "jump" from one equilibrium position to another neighbouring vacant site, "dissolved hole". This move is analogous to an elementary step in chemical reactions.

Molecular motion can occur in both directions, forward and backward. For static liquids without any external force acting on the liquid, molecular movement (or jumping) is caused by thermal activation at the same rate in opposite directions and does not result in a net flow. Consider a liquid where a shear force, f, is applied to the liquid in the forward direction, the mechanical work done by the force is used to provide the molecules with sufficient energy to rise above the energy barrier. This mechanical work is equal to $f\lambda_2\lambda_3$ $(\lambda/2)$ and is used to bring the molecule to the top of the peak. Then, the gained energy is given off as heat by the traveling molecule as it moves from top of the peak to the bottom.

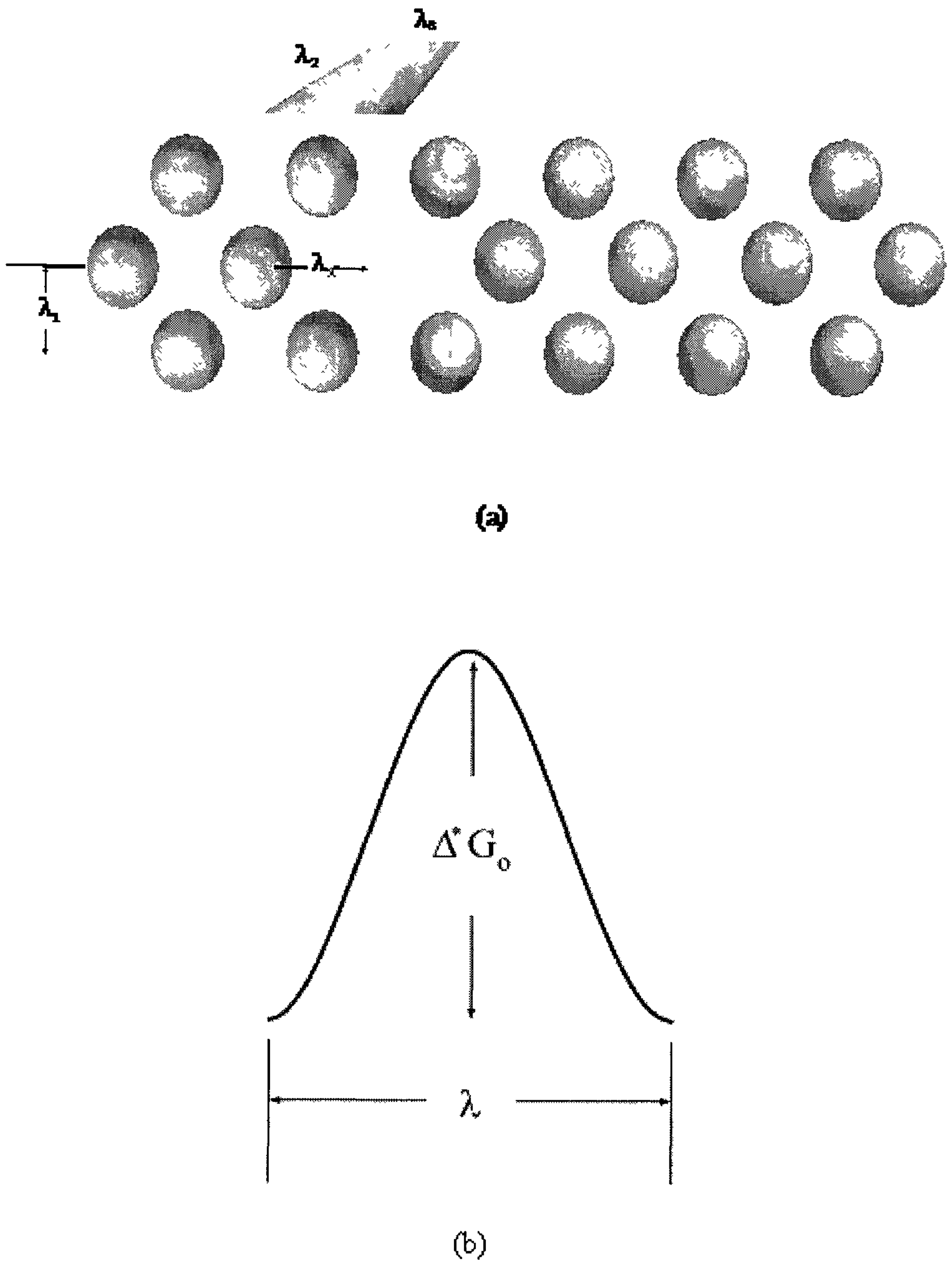

Figure 2.1: The Eyring's Model of Liquid Viscosity

As a result of the work done by the shear force, the energy barrier decreases for the forward jumping by the value of the performed work. On the contrary, it increases by the same magnitude for the backward jumping. Consequently, a net flow in the forward direction occurs.

The final form of the viscosity equation suggested by Eyring is:

$$\mu = \frac{h\lambda_1}{\lambda_2\lambda_3\lambda^2}\exp(\frac{\Delta^* G_0}{kT}) \qquad (2.2)$$

where k is Boltzman constant and h is Plank's constant.

Two assumptions are made. The first one is that $\lambda \approx \lambda_1$ and the second one is that the term $\lambda_1\ \lambda_2\ \lambda_3$ represents the average volume per molecule, or the effective volume of the molecule, V_0, which is given by the following equation:

$$V_0 = V_m / N \qquad (2.3)$$

where V_m is the molar volume and N is Avogadro's number.

Therefore, combining the last two assumptions with the previous equation gives the following formula:

$$\mu = \frac{hN}{V_m}\exp(\frac{\Delta^* G}{RT}) \qquad (2.4)$$

where Δ*G is the activation energy of viscous flow per mole, and R is the universal gas constant.

Equation (2.4) is known as Eyring's equation of viscosity. There is another form of the same equation that is written in terms of the kinematic viscosity. That form is written as

$$\nu = \frac{hN}{M}\exp(\frac{\Delta^{*}G}{RT}) \tag{2.5}$$

where M is the molecular weight.

2.2.2 The McAllister model

McAllister (1960) developed a model for the calculation of the dependence of viscosity on composition of liquid binary mixtures. The model is based on Eyring's reaction rate theory. McAllister (1960) used Eyring's viscosity equation (equation 2.5) to develop a new viscosity model for binary liquid mixtures of two components *viz.,* type 1 and type 2. For such a mixture, if a molecule of type 1 jumps to a neighbouring vacant site by crossing an energy barrier, it may interact with molecules of type 1 or 2 or both depending on the local concentrations of neighbouring components' type.

According to McAllister, this interaction is assumed to be a three-body interaction. McAllister stated that this assumption is valid for the cases where the difference in the molecular sizes of the two types of molecules is relatively small. He suggested that the molecular diameter ratio must be less than 1.5 for this assumption to be valid. For molecules with a higher diameter ratio, a more complicated version of the model based on a four-body interaction needs to be employed.

For the three-body interaction assumption, there are six possible types of interactions. These types are: 1-1-1, 2-2-2, 1-2-1, 2-1-2, 1-1-2, and 1-2-2. Figure 2.2 depicts the different types of interaction.

McAllister made the following major assumptions when developing his model for binary mixtures:

The activation free energies of viscous flow are assumed to be additive quantities.

The probability of occurrence of different types of interactions is only proportional to the mole fractions of the mixture's components.

Therefore, the activation free energy of the mixture, Δ*G, is given by;

$$\Delta * G = \sum_{i=1}^{2} \sum_{j=1}^{2} \sum_{k=1}^{2} x_i x_j x_k \Delta * G_{ijk} \tag{2.6}$$

where x_i, x_j, x_k are the mole fractions of the components constituting the mixture.

In addition, the following assumptions were made to simplify the relationship and reduce the number of unknowns in equation (2.6):

$$\Delta * G_{121} = \Delta * G_{112} = \Delta * G_{12} \tag{2.7}$$

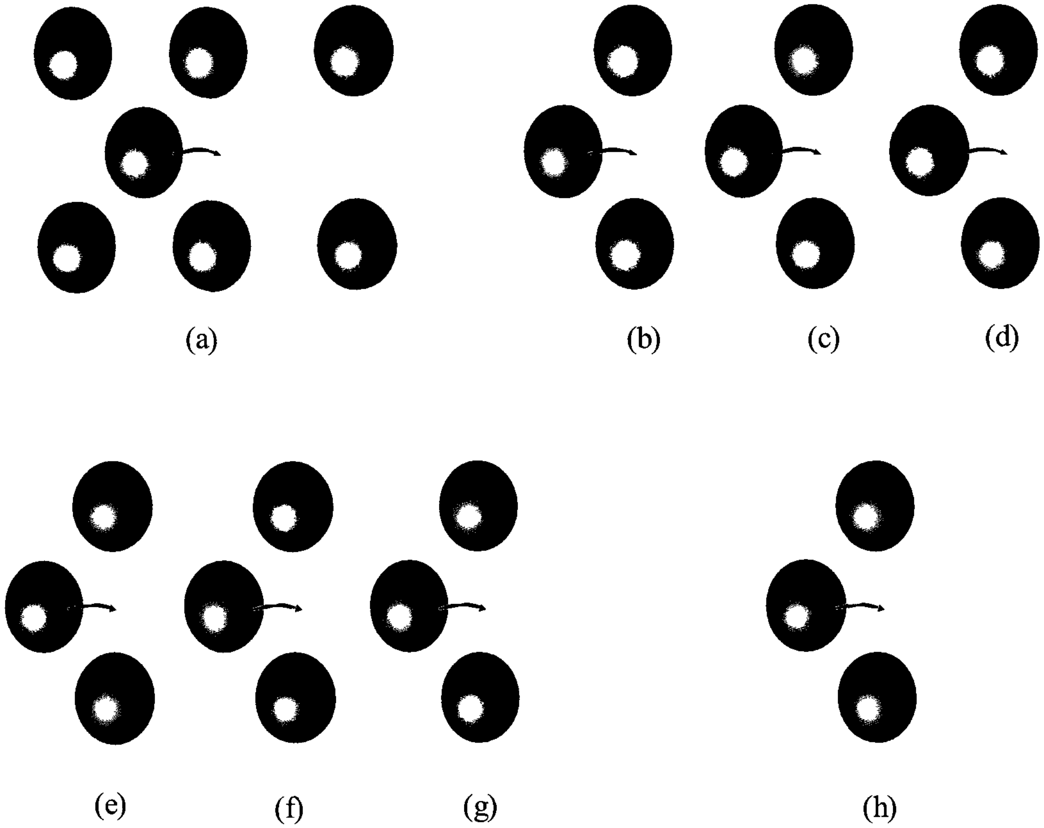

Figure 2.2: Possible types of interactions among the molecules of a binary system.

$$\Delta * G_{212} = \Delta * G_{122} = \Delta * G_{21} \tag{2.8}$$

Substituting equations (2.7) and (2.8) into the expanded form of equation (2.6) yields,

$$\Delta * G = x_1^3 \Delta * G_1 + 3x_1^2 x_2 \Delta * G_{12} + 3x_1 x_2^2 \Delta * G_{21} + x_2^3 \Delta * G_2 \tag{2.9}$$

For a binary mixture, equation (2.4) is written in terms of kinematic viscosity, ν, as follows:

$$\nu = \frac{hN}{M_m} \exp(\frac{\Delta^* G}{RT}) \tag{2.10}$$

where M_m is the molecular weight of the mixture. For a binary mixture M_m is assumed to be equal to $(x_1M_1+x_2M_2)$.

Substituting for Δ*G from equation (2.9) into equation (2.10); one gets

$$\nu = \frac{hN}{M_m} \exp(\frac{x_1^3 \Delta * G_1 + 3x_1^2 x_2 \Delta * G_{12} + 3x_1 x_2^2 \Delta * G_{21} + x_2^3 \Delta * G_2}{RT}) \tag{2.11}$$

For pure components of type 1

$$\nu_1 = \frac{hN}{M_1}\exp(\frac{\Delta^* G_1}{RT}) \tag{2.12}$$

and for pure components of type 2

$$\nu_2 = \frac{hN}{M_1}\exp(\frac{\Delta^* G_2}{RT}) \tag{2.13}$$

For interaction of type 1-2

$$\nu_{12} = \frac{hN}{M_{12}}\exp(\frac{\Delta^* G_{12}}{RT}) \tag{2.14}$$

where M_{12} is given by

$$M_{12} = \frac{2M_1 + M_2}{3} \tag{2.15}$$

whereas, for interaction of type 21

$$\nu_{21} = \frac{hN}{M_{21}}\exp(\frac{\Delta^* G_{21}}{RT}) \tag{2.16}$$

the expression for M_{21} is given by

$$M_{21} = \frac{2M_2 + M_1}{3} \tag{2.17}$$

Taking the natural logarithms of equations (2.10) through (2.16) and rearranging, one obtains equation (2.18) which represents the final and common form of the McAllister three-body interaction model.

$$\begin{aligned}\ell n v = {} & x_1^3 \ell n v_1 + 3x_1^2 x_2 \ell n v_{12} + 3x_1 x_2^2 \ell n v_{21} + x_2^3 \ell n v_2 \\ & - \ell n(x_1 + x_2 M_2 / M_1) + 3x_1^2 x_2 \ell n(\frac{2 + M_2 / M_1}{3}) \\ & + 3x_1 x_2^2 \ell n(\frac{1 + 2M_2 / M_1}{3}) + x_2^3 \ell n(M_2 / M_1)\end{aligned} \tag{2.18}$$

where v_{12} and v_{21} are adjustable parameters which can be determined using experimental kinematic viscosity-composition data.

This model is considered one of the best correlative techniques for the viscosity of binary liquid mixtures (Reid *et al.* 1987).

2.2.3 Extended McAllister's model for ternary liquid mixtures

As stated earlier, McAllister's three-body model is applicable for binary liquid mixtures. Three years after the work of McAllister was published, Chandramouli and Laddha (1963) developed and reported a new version of McAllister's three-body model that can be used for ternary liquid mixtures.

In addition to the binary interaction parameters, ternary interaction parameters were introduced. The final form of the extended McAllister's three-body model is given by the following equation:

$$\begin{aligned}\ell n\nu = {} & x_1^3\ell n\nu_1 + x_2^3\ell n\nu_2 + x_3^3\ell n\nu_3 + 3x_1^2x_2\ell n\nu_{12} + 3x_1^2x_3\ell n\nu_{13} \\ & + 3x_2^2x_1\ell n\nu_{21} + 3x_2^2x_3\ell n\nu_{23} + 3x_3^2x_1\ell n\nu_{31} + 3x_3^2x_2\ell n\nu_{32} \\ & + 6x_1x_2x_3\ell n\nu_{123} - \ell n(x_1M_1 + x_2M_2 + x_3M_3) + x_1^3\ell nM_1 \\ & + x_2^3\ell nM_2 + x_3^3\ell nM_3 + 3x_1^2x_2\ell n(\frac{2M_1+M_2}{3}) \\ & + 3x_1^2x_3\ell n(\frac{2M_1+M_3}{3}) + 3x_2^2x_1\ell n(\frac{2M_2+M_1}{3}) \\ & + 3x_2^2x_3\ell n(\frac{2M_2+M_3}{3}) + 3x_3^2x_1\ell n(\frac{2M_3+M_1}{3}) \\ & + 3x_3^2x_2\ell n(\frac{2M_3+M_2}{3}) + 6x_1x_2x_3\ell n(\frac{M_1+M_2+M_3}{3})\end{aligned} \qquad (2.19)$$

where: ν_{12}, ν_{21}, ν_{13}, ν_{31}, ν_{23}, and ν_{32} are binary interaction parameters, and ν_{123} is the ternary interaction parameter.

The values of the binary and ternary interaction parameters are determined by fitting experimental kinematic viscosity-composition data to equation (2.19).

2.2.4 The Asfour *et al.* (1991) parameter- prediction method

As indicated earlier herein, Reid *et al.* (1987) considered the McAllister model to be one of the best correlative techniques for the viscosity of binary liquid mixtures. But being correlative is a significant disadvantage of this model. Its correlative nature calls for the need to carry out both time consuming and costly experiments in order to estimate the values of the adjustable parameters.

This major drawback was overcome by Asfour and co-workers. They were able to develop a technique that converts the McAllister model from a correlative model into a predictive model. Asfour *et al.* (1991) introduced a modification to the McAllister model that uses the molecular parameters and the viscosities of pure components to predict the values of the interaction parameters in McAllister's model for binary *n-alkane* liquid mixtures.

For the *n-alkane* liquid mixtures, Asfour *et al.* (1991) started with the assumption that the binary interaction parameters in the McAllister model, ν_{12} and ν_{21}, are related to the mixture's pure components kinematic viscosities as follows:

$$\nu_{12} \propto (\nu_1^2 \nu_2)^{1/3} \tag{2.20}$$

$$\nu_{21} \propto (\nu_2^2 \nu_1)^{1/3} \tag{2.21}$$

Dividing equation (2.20) by equation (2.21) results in the following relationship between the two adjustable parameters:

$$\nu_{21} = \nu_{12}\left(\frac{\nu_2}{\nu_1}\right)^{1/3} \qquad (2.22)$$

In addition to that, Asfour *et al.* (1991) plotted the lumped term $\nu_{12}(\nu_1^2 \nu_2)^{-1/3}$ versus the inverse of the absolute temperature using data of several *n-alkane* binary mixtures. Those mixtures are: hexane – heptane, hexane – octane, heptane – octane, heptane – decane, tetradecane – hexadecane, and octane – decane. The experimental data were taken from Cooper (1988). They were selected to satisfy the condition of having the differences in number of carbon numbers to be less than or equal to 3. They assumed that this condition justify the use of McAllister three-body interaction model.

The resulting plot showed a straight line with a slope of zero as shown in Figure 2.3. This has led them to draw the conclusion that the lumped term $\nu_{12}(\nu_1^2 \nu_2)^{-1/3}$ is not a function of temperature.

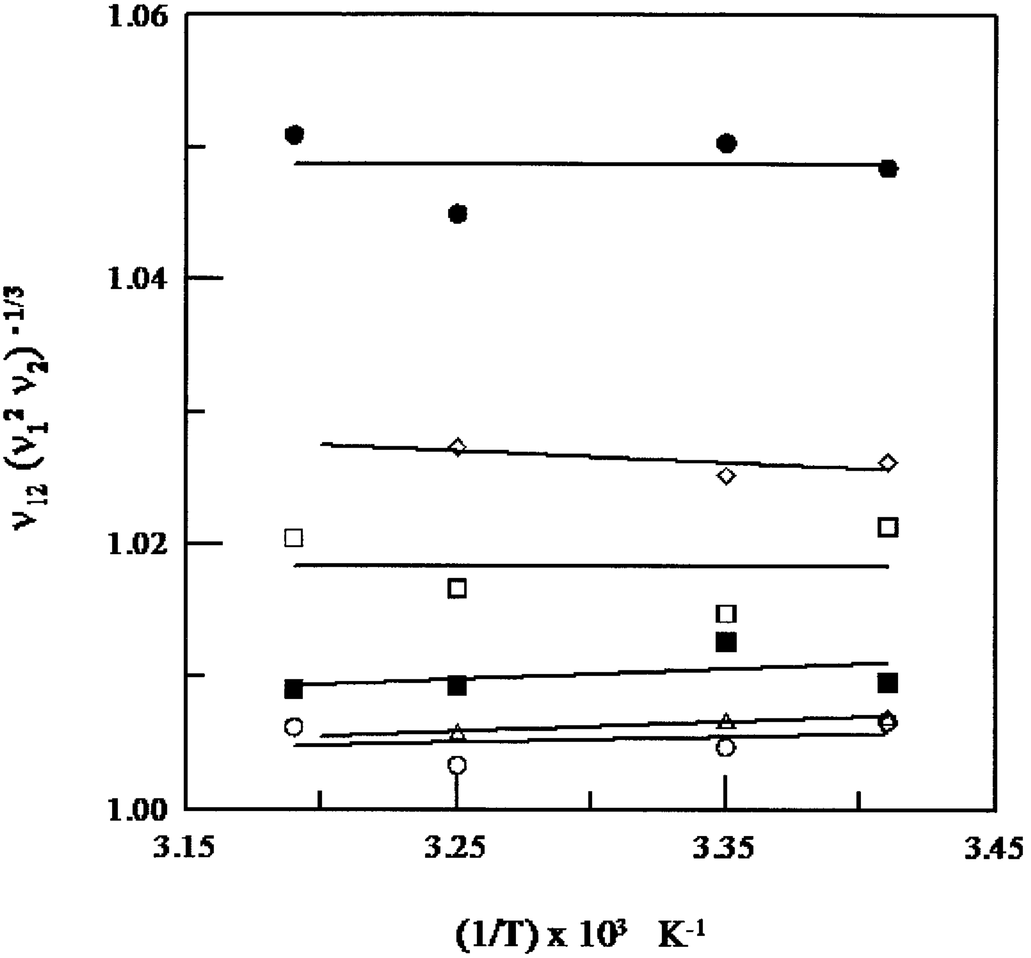

Figure 2.3: Variation of the Lumped Term $v_{12}(v_{12}\, v_1)^{-1/3}$ Versus the Absolute Temperature Inverse [Asfour *et al.* (1991)].

Δ Hexane (A) - Heptane (B)	◊ Hexane (A) - Octane (B)
○ Heptane (A) - Octane (B)	● Heptane (A) - Decane (B)
■ Tetradecane (A) - Hexadecane (B)	□ Octane (A) - Decane (B)

Moreover, Asfour *et al.* (1991) plotted the lumped term $\nu_{12} (\nu_1^2 \nu_1)^{-1/3}$ that was proven to be temperature independent verses another lumped term $[(N_2-N_1)^2/(N_1^2N_2)^{1/3}]$, where the N_1 and N_2 are the number of carbon atoms per molecule of components 1 and 2, respectively. Components 1 and 2 constitute the liquid mixture. They used experimental data of the same *n-alkane* binary mixtures they previously used to make the plot shown in Figure 2.3.

The plot as shown in Figure 2.4 resulted in a straight line with a slope that suggests a linear relationship between the two lumped terms. Using the least-squares technique, Asfour *et al.* (1991) obtained the following equation:

$$\frac{\nu_{12}}{(\nu_1^2\nu_2)^{1/3}} = 1 + 0.044\frac{(N_2 - N_1)^2}{(N_1^2N_2)^{1/3}} \tag{2.23}$$

Therefore, with the help of equation (2.22) and (2.23) the values of the adjustable parameters ν_{12}, and ν_{21} in the McAllister model could be estimated using only the physical properties of the pure components constituting the liquid mixture. The significance of this work is in transforming the McAllister three-body interaction model from a correlative to a predictive model and consequently extending its usefulness and practicality.

As stated earlier, the Asfour *et al.* (1991) work was based on McAllister three-body interaction model that is assumed to be applicable where the differences in carbon numbers of the components composing the mixture are less than or equal 3. For other *n-alkane* binary liquid mixtures where the difference in carbon numbers is greater than 3, Asfour *et al.* (1991)

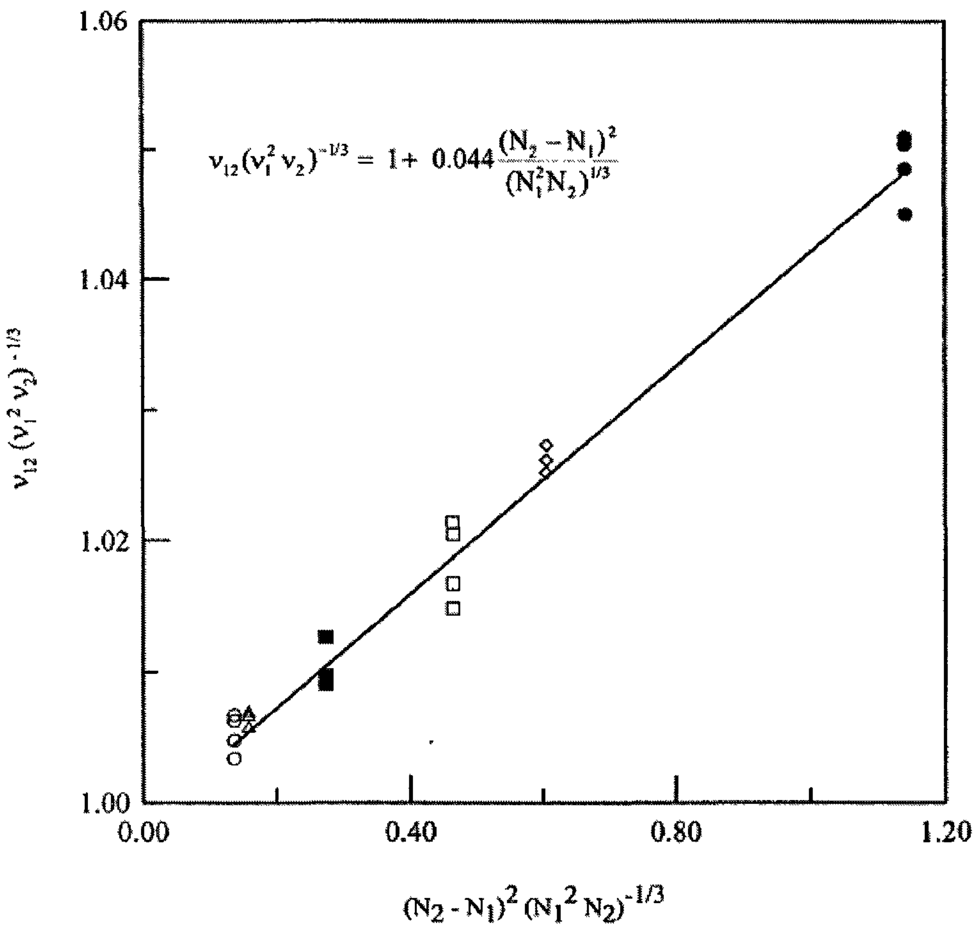

Figure 2.4: Variation of the Lumped Term $v_{12}(v_1^2 v_1)^{-1/3}$ Versus the Term $[(N_2-N_1)^2(N_1^2N_2)^{-1/3}]$. Asfour *et al.* (1991).

Δ Hexane (A) - Heptane (B)

○ Heptane (A) - Octane (B)

■ Tetradecane (A) - Hexadecane (B)

◊ Hexane (A) - Octane (B)

● Heptane (A) - Decane (B)

□ Octane (A) - Decane (B)

developed another equation that is based on the McAllister four-body interaction model. They suggested the following equation for calculating the quaternary interaction adjustable parameter, ν_{1122}:

$$\frac{\nu_{1122}}{(\nu_1^2\nu_2^2)^{1/4}} = 1 + 0.03\frac{(N_2 - N_1)^2}{(N_1^2 N_2^2)^{1/4}} \tag{2.24}$$

Furthermore, Asfour *et al.* (1991) suggested two equations to calculate the other quaternary interaction adjustable parameters, ν_{1112} and ν_{1222}, in terms of the first parameter, ν_{1122}, estimated from equation (2.24). The two equations are as follow:

$$\nu_{1112} = \nu_{1122}\left(\frac{\nu_2}{\nu_1}\right)^{1/4} \tag{2.25}$$

$$\nu_{2221} = \nu_{1122}\left(\frac{\nu_2}{\nu_1}\right)^{1/4} \tag{2.26}$$

In spite of the good improvement that Asfour *et al.* (1991) have brought to the McAllister model, their technique was only applicable to binary liquid *n-alkane*s mixtures. In subsequent work, Nhaesi and Asfour (1998) used a similar approach to extend the technique to binary regular liquid mixtures. They introduced a different definition than that introduced earlier by Allan and Teja (1991) for the effective carbon number, which made it much easier and much less cumbersome to calculate and apply. This enabled Nahesi and Asfour (1998) to estimate the effective carbon number (ECN) for regular liquid components from the value of the kinematic viscosity of the component at 308.15 K. They suggested the following relationship:

$$\ell n(\nu_{@308.15K}) = A + B(ECN) \tag{2.27}$$

where A= - 1.943 and B = 0.193, and $\nu_{@308.15K}$ is the kinematic viscosity, in cSt, of the pure regular component at 308.15 K.

The value of the kinematic viscosity at 308.15 K is substituted into equation (2.27) in order to obtain the ECN of the compound of interest.

2.2.5 Nhaesi and Asfour (1998) extended method

Nhaesi and Asfour (1998) introduced an equation analogous to that developed for *n-alkane*s for predicting the binary interaction parameters for regular mixtures using the ECN instead of the number of carbon atoms in the case of *n-alkane*s. The new equation is given by,

$$\frac{\nu_{12}}{(\nu_1^2\nu_2)^{1/3}} = 0.8735 + 0.0715\frac{(\mathrm{ECN}_2 - \mathrm{ECN}_1)^2}{(\mathrm{ECN}_1^2\mathrm{ECN}_2)^{1/3}} \tag{2.28}$$

Equation (2.22) is used to predict the value of ν_{21}.

2.2.6 The generalized McAllister three-body model

The next major improvement to the McAllister three-body interaction model was introduced by Nhaesi and Asfour (2000a). They developed a new generalized technique to predict the kinematic viscosity for *n-alkane*s and regular liquid mixtures of any number of components.

In developing their model they started with the assumption that the free activation energies for viscous flow are additive. Therefore, the free activation energy of the mixture, ΔG_m, is given by

$$\Delta G_m = \sum_{i=1}^{n} x_i^3 \Delta G_i + 3\sum_{i=1}^{n}\sum_{j=1}^{n} x_i^2 x_j \Delta G_{ij} + 6\sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{k=1}^{n} x_i x_j x_k \Delta G_{ijk} \qquad (2.29)$$

where n is the number of components constituting the mixture.

In addition, they assumed that the activation energies depend only on the type of components involved not their order. They proposed the following equations:

$$\Delta G_{iji} = \Delta G_{iij} = \Delta G_{ij}$$

$$\Delta G_{jij} = \Delta G_{ijj} = \Delta G_{ji}$$

The starting point of the model is McAllister's viscosity equation that is written for a liquid mixture as,

$$\nu_i = \frac{hN}{M_i}\exp(\frac{\Delta^* G_i}{RT}) \qquad (2.30)$$

$$\nu_m = \frac{hN}{M_m}\exp(\frac{\Delta^* G_m}{RT}) \qquad (2.31)$$

where k is Boltzman constant, h is Plank's constant, R is the universal gas constant, and N is Avogadro's number.

The subscript m in equation (2.31) refers to the mixture and the subscript i refers to pure component i. ν_m is the kinematic viscosity of the mixture, M is the molecular weight. The average molecular weight of the mixture, M_m, is calculated using the following mixing rule:

$$M_m = \sum_{i=1}^{n} x_i M_i \tag{2.32}$$

where M_i is the molecular weight of pure component i.

For a binary interaction of type ij

$$\nu_{ij} = \frac{hN}{M_{ij}} \exp\left(\frac{\Delta^* G_{ij}}{RT}\right) \tag{2.33}$$

where M_{ij} is

$$M_{ij} = \frac{2M_i + M_j}{3} \tag{2.34}$$

Similarly, ternary interaction of the type ijk is expressed as:

$$\nu_{ijk} = \frac{hN}{M_{ijk}} \exp\left(\frac{\Delta^{*}G_{ijk}}{RT}\right) \tag{2.35}$$

where M_{ijk} is

$$M_{ijk} = \frac{M_i + M_j + M_k}{3} \tag{2.36}$$

By incorporating equations (2.30) through (2.35) into equation (2.29) one obtains,

$$\begin{aligned} \ell n\nu_m = {} & \sum_{i=1}^{n} x_i^3 \ell n(\nu_i M_i) + 3 \sum_{i=1}^{n} \sum_{\substack{j=1 \\ i \neq j}}^{n} x_i^2 x_j \ell n(\nu_{ij} M_{ij}) \\ & + 6 \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{\substack{k=1 \\ i \neq j \neq k}}^{n} x_i x_j x_k \ell n(\nu_{ijk} M_{ijk}) - \ell n M_m \end{aligned} \tag{2.37}$$

The number of binary interaction parameters, N_2, and ternary interaction parameters, N_3 in equation (2.37) are calculated using the following two equations:

$$N_2 = \frac{n!}{2!(n-2)!} \tag{2.38}$$

$$N_3 = \frac{n!}{3!(n-3)!} \tag{2.39}$$

The concept of effective carbon number (ECN) is employed for the pure regular liquid components. Nhaesi and Asfour (1998) suggested the use of equation (2.27) to determine the numerical value of the effective carbon number of regular liquid components and equation (2.28) for predicting the values of the adjustable parameters of type ij. The values of the other binary adjustable parameters of type ji are calculated with the help of equation (2.22). For the ternary interaction parameters, Nhaesi and Asfour (2000a) developed the following equation to predict the ternary interaction parameters for *n-alkanes*:

$$\frac{\nu_{ijk}}{(\nu_i \nu_j \nu_k)^{1/3}} = 0.9941 + 0.03167\frac{(N_k - N_i)^2}{N_j} \tag{2.40}$$

2.3 The *Pseudo*-Binary McAllister Model

The second model that will be tested in this study is the *pseudo-binary* McAllister model. This modification utilizes the *pseudo-binary* concept that was introduced by Wu and Asfour (1992) with the generalized McAllister model reported by Nhaesi and Asfour (2000).

In the "*pseudo-binary*" model, a multi-component liquid mixture of n components is treated as a binary mixture of component 1 and a "*pseudo-component*" that represents the remaining components of the mixture (2, 3, 4,.., n). The reduction of the number of components in multi-component liquid mixture to two components significantly reduces the complexity of calculations and leads to dramatic reduction in calculation time by requiring fewer calculation steps.

Wu and Asfour (1992) introduced the *pseudo-binary* concept and utilized it in modifying the generalized corresponding states principle (GCSP), which will be discussed later in this chapter. Nhaesi and Asfour (2000b) incorporated the *pseudo-binary* model into the generalized McAllister three-body interaction model which led to the development of the *pseudo-binary* McAllister model for predicting the viscosities of *n-alkane* liquid mixtures.

In addition, they used the effective carbon number, ECN, concept explained earlier to extend the applicability of the *pseudo-binary* McAllister for predicting the viscosities of multi-component regular liquid mixtures. For the regular pure components, the ECN is calculated using equation (2.27). For the "*pseudo-component*", Nhaesi and Asfour (2000a) suggested the use of the following mixing rule to determine its ECN in terms of the those for the pure components constituting the "*pseudo-component*":

$$(ECN)_{2'} = \sum_{i=2}^{n} X_i (ECN)_i \tag{2.41}$$

The kinematic viscosity of the "*pseudo-component*" is calculated with the help of the following equation:

$$\ell n \nu_{2'} = \sum_{i=2}^{n} X_i (\ell n \nu_i) \tag{2.42}$$

The molecular weight of the "*pseudo-component*" is calculated using the following equation:

$$\ell n M_{2'} = \sum_{i=2}^{n} X_i (\ell n M_i) \tag{2.43}$$

The term X_i in equations (2.41) through (2.43) represents the normalized mole-fraction of component i in the "*pseudo-component*". This quantity is calculated using the following equation:

$$X_i = \frac{x_i}{\sum_{i=2}^{n} x_i} \tag{2.44}$$

For regular mixtures, the numerical values of $(ECN)_{2'}$, $M_{2'}$, and $v_{2'}$ for the "*pseudo-component*" obtained from equations (2.41) through (2.43) are substituted into equations (2.28) and (2.22) for regular mixtures in order to predict the McAllister's binary interaction parameters, $v_{12'}$ and $v_{2'1}$. The same procedure is followed when using this technique for *n-alkane*s but the components' carbon numbers are used instead of the ECN in the calculations.

2.4 The Generalized Corresponding States Principle (GCSP) Model

The third model that will be tested in this study is the Generalized Corresponding States Principle (GCSP) viscosity model. The original corresponding states principle (CSP) is based on the reduction of variables by using critical properties; e.g., critical pressure, volume and temperature to calculate a new dimensionless reduced parameters. The reduced parameters represent the ratios of the independent variable to the corresponding critical condition.

The corresponding states principle is based on the assumption that different fluids at the same reduced conditions of temperature, pressure, and/or volume have the same reduced physical properties.

Taja and Rice (1981) utilized the corresponding states principle and used it to develop a new generalized model for predicting the viscosity of pure liquids. Their model is known as the generalized corresponding states principle (GCSP). Their model was based on the liquid's critical volume.

In 1986, Taja and Thurner suggested another form of the Taja and Rice model in that it is based on the critical pressure to avoid the effect of the relatively high experimental uncertainties commonly associated with the measurement of critical volumes and suggested the use of the following equation for viscosity prediction:

$$\ell n(\mu\xi) = \ell n(\mu\xi)^{r1} + \frac{\omega - \omega^{r1}}{\omega^{r2} - \omega^{r1}}\left[\ell n(\mu\xi)^{r2} - \ell n(\mu\xi)^{r1}\right] \tag{2.45}$$

where r1 and r2 refer to two non-spherical fluids, μ is the absolute viscosity, ω is the acentric factor of the non-spherical fluid, and ξ is an adjustable parameter obtained from the critical properties of the fluid and is given by the following equation:

$$\xi = P_c^{-2/3} T_c^{1/6} M^{-1/2} \tag{2.46}$$

where P_c, T_c , and M in equation (2.46) are the critical pressure, temperature, and molecular weight, respectively.

In order to apply equation (2.45) to liquid mixtures, Taja and Thurner (1986) recommended the use of a group of mixing rules that were suggested earlier by Wong *et al.* (1984) to determine the *pseudo-critical* properties and parameters of the liquid mixture. Wong *et al.* (1984) mixing rules are expressed by the following equations:

$$T_{cm}/P_{cm} = \underset{i \neq j}{\sum_{i} \sum_{j}} (x_i x_j T_{cij}/P_{cij}) \tag{2.47}$$

$$T^2_{cm}/P_{cm} = \underset{i \neq j}{\sum_{i} \sum_{j}} (x_i x_j T^2_{cij}/P_{cij}) \tag{2.48}$$

$$\omega_m (T_{cm} P_{cm})^{2/3} = \sum_{i} x_i x_j (T_{ij} P_{ij})^{2/3} \frac{1}{2} (\omega_{ii} + \omega_{jj}) \tag{2.49}$$

$$M_m = \sum_{i} x_i M_i \tag{2.50}$$

$$(T_{cij}/P_{cij}) = \frac{1}{8} \left[(T_{ci}/P_{ci})^{1/3} + (T_{cj}/P_{cj})^{1/3} \right]^3 \tag{2.51}$$

$$T_{cij} = \xi_{ij} (T_{ci} T_{cj})^{1/2} \tag{2.52}$$

For binary liquid mixtures, the two reference fluids; *viz.*, r1 and r2, are the two pure components composing the mixture. The situation becomes more complicated for multi-component liquid mixtures, where there are several combinations of pairs of reference fluids. Each selection of reference fluids, results in significant differences in the predicted mixture's viscosity values. The lack of a reliable criterion to select the best combination of reference fluids that leads to the best predicted values of viscosity represents the major drawback of using this method for multi-component liquid mixtures.

2.5 The Group Contribution (GC) -UNIMOD Model

The fourth semi-theoretical viscosity model that will be tested in the present study is based on the group contribution theoretical framework. This technique has been used in predicting a variety of properties based on the molecular structure. In this technique, a molecule is composed of different types of building blocks. Those blocks are referred to as functional groups (or groups for simplicity) that are composed of atoms and bonds. Figure 2.5 shows the breakdown of the groups that compose the pure component 2-methyl-1propanol.

According to this principle, each functional group has the same contribution to a component's physical properties regardless of the type of other groups in that component. The groups' contributions are additive and when combined result in the component's properties. This concept was coupled with other statistical thermodynamics models to develop a new viscosity prediction model known as the Group Contribution (GC) -UNIMOD model. The different steps that led to the development of this model are described in the following subsection.

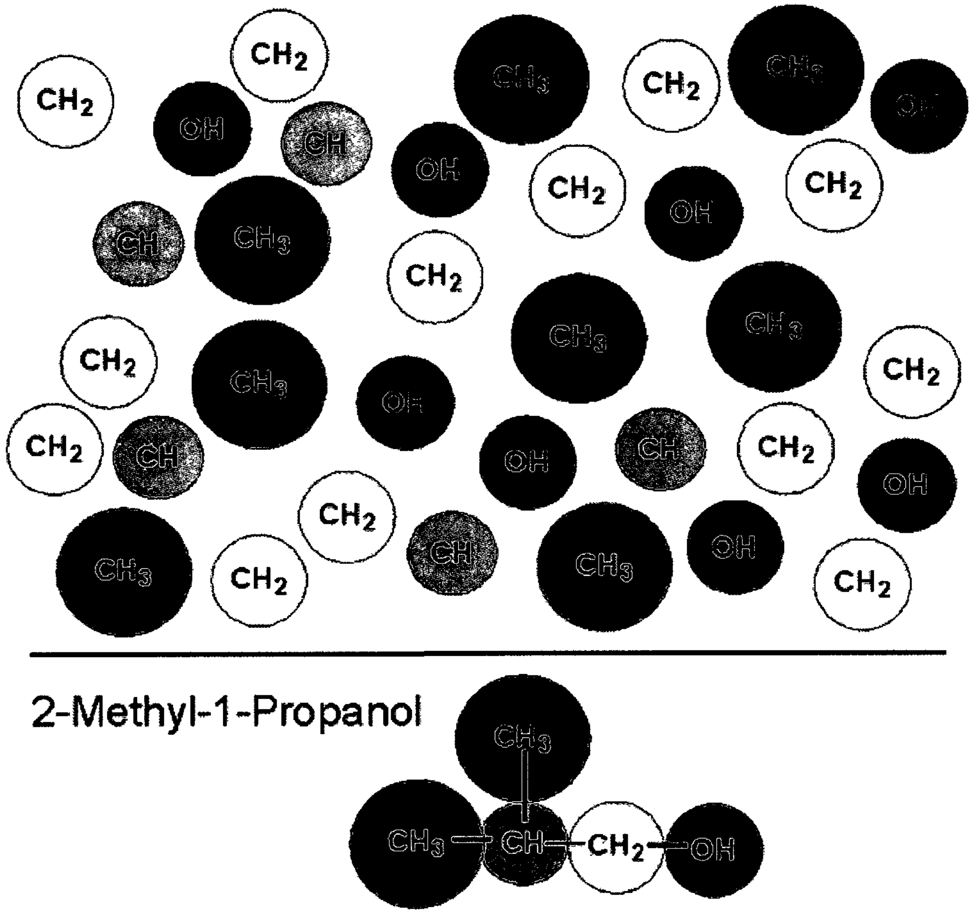

Figure 2.5: The Representation of 2-methyl-1propanol Based on the Group Contribution Principle.

2.5.1 Cao *et al.* (1992) viscosity model

Cao *et al.* (1992) proposed a new viscosity model for pure liquids and liquid mixtures at different temperature levels and compositions. They based their model on principles of statistical thermodynamics, local compositions, and Eyring's absolute rate theory. Cao *et al.* (1992) proposed the following equation for kinematic viscosity prediction:

$$\ell n(\nu M) = \sum_{i=1}^{n} x_i \ell n(\nu_i M_i) - \sum_{i=1}^{n} q_i n_i x_i \sum_{j=1}^{n} \theta_{ij} \ell n(\tau_{ij}) \tag{2.53}$$

where ν is the kinematic viscosity for the mixture, M is the molecular weight of the mixture that is calculated using the simple mixing rule given by equation (2.50), x is the mole-fraction of component i in the liquid mixture, i refers to the pure component i in the mixture, q_i is the external area parameter of molecule i, θ_{ij} is the local composition, τ_{ij} is interaction parameter, n is the number of components constituting the liquid mixture, and n_i is a pure component parameter that is a function in temperature which is calculated using the following formula:

$$\ell n(n_i) = \sum_{j=0} A_i T^j \tag{2.54}$$

where the value of the adjustable parameters A_i's for each pure component were obtained by correlating the experimental viscosities of 314 pure fluid.

Cao *et al.* (1992) evaluated the values of the interaction parameters τ_{ij}'s by correlating the experimental results obtained for binary mixtures and the viscosities of the pure components. The values obtained for τ_{ij}'s were used to predict the viscosities of multi-component mixtures other than binary mixtures which makes the model correlative for binary mixtures and predictive for other multi-component mixtures.

2.5.2 "Viscosity-Thermodynamics" Model (UNIMOD)

Cao *et al.* (1993a) modified the previous model by incorporating a molecular size parameter into the model. In addition to predicting the viscosity of pure liquids and mixtures of liquids, the model is used to predict the activity coefficients and is called the "viscosity-thermodynamics" model (UNIMOD). The viscosity in the UNIMOD model is predicted using the following equation:

$$\ell n(\nu M)=\sum_{i=1}^{n}\varphi_i \ell n(\nu_i M_i)-\sum_{i=1}^{n}\varphi_i \ell n(\frac{x_i}{\phi_i})-\sum_{i=1}^{n}\frac{q_i n_i \varphi_i}{r_i}\sum_{j=1}^{n}\theta_{ji}\ell n(\tau_{ji}) \tag{2.55}$$

where

$$\theta_{ji}=\frac{\theta_j \tau_{ji}}{\sum_{i=1}^{n}\theta_i \tau_{ji}} \tag{2.56}$$

$$\theta_i=\frac{x_i q_i}{\sum_{j=1}^{n}x_j q_j} \tag{2.57}$$

$$\phi_i=\frac{x_i r_i}{\sum_{j=1}^{n}x_j r_j} \tag{2.58}$$

$$x_i=\frac{N_i}{\sum_{j=1}^{n}N_j} \tag{2.59}$$

where ϕ_i is the average segment fraction of component i, r is number of segments in a molecule i, other notations are the same as those in the previous model expressed in equation (2.53).

2.5.3 The Group-contribution (GC) -UNIMOD model

In a subsequent publication, Cao *et al.* (1993b) coupled the group contribution approach with the UNIMOD model which resulted in a new viscosity model, which they called the "group contribution (GC) - UNIMOD model". In the new model, the kinematic viscosity equation is divided into two parts as shown by the following equation:

$$\ell n(\nu) = \sum_{i=1}^{n} \left[\zeta_i^{C} + \zeta_i^{R} \right] \tag{2.60}$$

where ζ_i^C is the combinatorial part of the equation that contains the properties of pure component i and represents its contribution to the viscosity of the mixture as an ideal component. The value of the combinatorial part, ζ_i^C, is calculated using the following equation:

$$\zeta_i^{C} = \phi_i \ell n\left(\nu_i \frac{M_i}{M} \right) + 2\phi_i \ell n\left(\frac{x_i}{\phi_i} \right) \tag{2.61}$$

ζ_i^R is the residual part that contains the interaction parameter between different components and represents the residual contribution of component i to the viscosity of the mixture interaction-differences. The following equation is used to determine the value of this part of the viscosity equation.

$$\xi_i^{R} = \sum_{\mathit{all}\ \text{group k}} \nu_k^{(i)} \left[\Xi_{ki} - \Xi_{ki}^{(i)} \right] \tag{2.62}$$

Substituting equations (2.61) and (2.62) into equations (2.60) yields

$$\ell n(\nu) = \sum_{i=1}^{n}\left[\phi_i \ell n\left(\nu_i \frac{M_i}{M}\right) + 2\phi_i \ell n\left(\frac{x_i}{\phi_i}\right) + \sum_{all\ \text{group k}} \nu_k^{(i)}\left[\Xi_{ki} - \Xi_{ki}^{(i)}\right]\right] \tag{2.63}$$

and

$$\Xi_{mi} = -\frac{Q_m}{R_m} N_{mi}^{vis} \phi_i \sum_{all\ \text{group k}} \theta_{\text{km}} \ell n(\Psi_{km}) \tag{2.64}$$

where Ξ_{ki} : is the group residual viscosity of group k for component i in the mixture

$\Xi_{ki}^{(i)}$: is the group residual viscosity of group k for component i in the solution of group of pure liquid i.

$\nu_k^{(i)}$ is the number of groups k per molecule of component i.

Q_k is the surface area parameter of group k.

R_k is volume parameter of group k.

Ψ_{km} is the group interaction parameter between groups k and m, and

N_{mi}^{vis} is a group viscosity parameter for group k in component i that is given by

$$N_{mi}^{vis} = Q_k\left(\frac{q_i - r_i}{2} - \frac{1 - r_i}{z}\right) \tag{2.65}$$

where: z is the co-ordination number (equal to 10).

q_i are the area parameter of molecule i, and

r_i the number of segments of molecule i.

The following equations are used to estimate the numerical values of the last two terms:

$$q_i = \sum_{\text{all groups k}} \nu_k^{(i)} Q_k \tag{2.66}$$

$$r_i = \sum_{\text{all groups k}} \nu_k^{(i)} R_k \qquad (2.67)$$

The local composition of groups, θ_{mn}, is given by

$$\theta_{mn} = \frac{\theta_m \psi_{mn}}{\sum_{\text{all groups k}} \theta_k \psi_{kn}} \qquad (2.68)$$

where

$$\theta_m = \frac{x_m Q_m}{\sum_{\text{all groups k}} x_k Q_k} \qquad (2.69)$$

$$\Psi_i = \exp\left(-\frac{a_{mn}}{T}\right) \qquad (2.70)$$

where a_{mn} is the interaction energy parameter between group m and n. The value of this adjustable parameters is determined from experimental data.

2.5.4 The Nhaesi *et al.* (2005) parameter- prediction method

The group contribution method was used by Nhaesi *et al.* (2005) to predict the interaction parameters in the generalized version of McAllister model developed by Nhaesi and Asfour (2000b). This technique was developed for n-alkane solutions that are composed of two functional groups: CH_3 and CH_2. They assumed each group has an additive contribution to the value of the interaction parameters in the generalized McAllister three body interaction model.

2.6 The Allan and Teja Correlation

Allan and Teja (1991) developed a correlative method for viscosity prediction of hydrocarbon liquids based on the number of carbon atoms for *n-alkane*s and the effective carbon number for regular solutions.

Allan and Teja (1991) proposed a correlative Antoine-type equation to determine the absolute viscosity, μ, in centipoise, of both defined and undefined (crude oil) hydrocarbon mixtures. They suggested the use the following equation for this purpose:

$$\ell n\,\mu = A\left[-\frac{1}{B}+\frac{1}{T+C}\right] \tag{2.71}$$

where A, B, and C are constants that are correlated to the carbon numbers in the hydrocarbons composing the mixture. They suggested the use of the following polynomial equations to determine the numerical values of the constant A, B, and C:

$$A = 145.73 + 99.01N + 0.83N^2 - 0.125N^3 \tag{2.72}$$

$$B = 30.48 + 34.04N - 1.23N^2 + 0.017N^3 \tag{2.73}$$

$$C = -3.07 - 1.99N \tag{2.74}$$

where N is the carbon number per molecule of the component of interest.

Allan and Teja (1991) extended their technique to predict viscosity of non *n-alkane* hydrocarbons using the effective carbon number concept. The effective carbon number can be estimated using only one experimentally measured viscosity data point at certain temperature for that component. This data point is substituted in equation (2.71-74) resulting in a cubic equation. The real solution to that equation is the effective carbon number of the component. The value of the ECN is used to predict the viscosity of the component of interest at other temperatures.

For mixtures, a simple mixing rule based on the mole fractions, which was suggested by Allan and Teja (1991) is used to calculate N for *n-alkane*s mixture. The rule takes the following form:

$$N_m = \sum_{i=1}^{n} x_i N_i \tag{2.75}$$

where N_m is the carbon number of the mixture and N_i is the carbon number of component i in the mixture.

A similar mixing rule was proposed to estimate the effective carbon number for liquid non n-alkanes mixtures:

$$ECN_m = \sum_{i=1}^{n} x_i (ECN)_i \tag{2.76}$$

where ECN_m is the carbon number of the mixture and ECN_i is the carbon number of component i in the mixture.

The Allan and Teja correlation was tested by Gregory (1992). The study showed that the correlation does not give accurate results for carbon numbers greater than 22.

2.7 Artificial Neural Network (ANN)

The rapidly improving computational capabilities of computers contributed to the development of systems that can partially simulate the behaviour of human brain. An example of that is the area of Artificial Neural Network (ANN).

An Artificial Neural Network is a mathematical representation of a certain problem that has the ability to recognize patterns and learn relationships (experience) and generalize them to different cases of new set of data or information that has not seen before through a structure inspired by the structure of human's neural system as shown in figure 2-6. Simon Haykin (1998) defines an ANN as a massively parallel distributed processor made up of simple processing units, which has a natural propensity for storing experimental knowledge and making it available for use, it resembles the brain in two respects:

1. Knowledge is acquired by the network from the environment through a learning process.
2. Interneuron connection strengths, known as synaptic weights, are used to store the acquired knowledge.

The operation of ANNs requires a powerful computational performance that became available as computer technologies advanced in recent decades. ANNs are commonly used in modeling highly nonlinear relationships.

ANN techniques have received a growing acceptance form researchers from different areas and disciplines to replace other correlative and statistical modeling methods. This is due to the distinguished capabilities of these techniques when compared to other correlative methods. Haykin (1998) summarizes the properties and capabilities the ANNs that enabled them to outperform other correlative techniques. The following is a short list of the major points he mentioned:

1. Nonlinearity. An artificial neuron made up of an interconnection of nonlinear neurons that make the network nonlinear.
2. Adaptivity. Neural networks have a built-in capability to adapt their synaptic weights to changes in the surrounding environment.
3. Very-Large-Scale-Integrated (VLSI) Implementability. The massively parallel nature of a neural network makes it potentially fast for the computation of certain tasks.

2.7.1 History of ANN

The development of the ANN technique has gone through three major and distinguished stages: The first one was in the 1940s with the McCulloch and Pitts (1943) development of their model of a single neuron.

The second major development was through the work of Rosenblatt's (1958) who developed a simple form of a modeled single layer neural network known as perceptron model that was criticized by Minsky and Papert's (1969) who explained the limitations of the Rosenblatt's perceptron model.

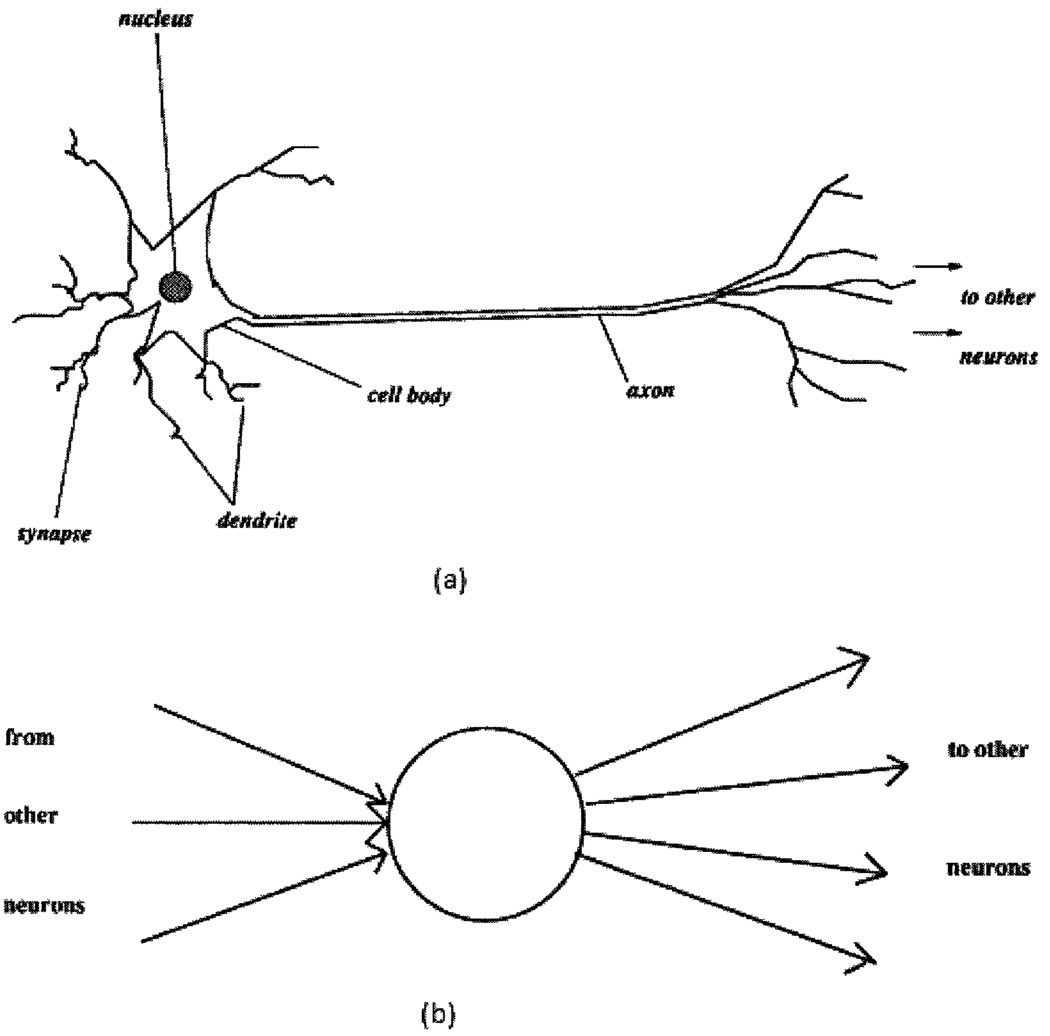

Figure 2.6: (a) Schematic diagram of real neuron (b) Schematic diagram of artificial neuron (Reproduced and modified from Cheng and Titterington (1994)).

The third major development in the field of ANN was the introduction of the back propagation learning algorithm by Rumelhart *et al.* (1986) that can be used to train a multilayer preceptron and overcome the limitation of the Rosenblatt's single layer perceptron.

2.7.2 Network structure

The processing units in an ANN are usually referred to as artificial nodes, or neurons for simplicity, and are organized in layers. The neurons are interconnected with each other by a set of synapses or links in different layers to form a network. A common form of networks consists of three layers; namely, input, processing (hidden), and output layers. The synapses or links are characterized by their weights. Each neuron calculates the weighted sum of its signals and the output of each neuron is determined by the output of its activation function. As shown in Figure 2.7 that gives a simple representation of an artificial neuron. The ANNs are characterized by the number of neurons, number of layers of neurons, the complexity of interconnectivity, type of activation function as well as the direction of signal flow. Three main architectures of ANNs are mostly used; *viz.*,

1. Single layer feed forward network: The simplest type of neural network and was the first type introduced by McCulloch-Pitts (1943). In this type, information flow occurs in one direction from an input layer to an output layer.

2. Multilayer feed forward network: In this type of networks, there is at least one hidden layer of neurons between the input and output layers to perform additional processing of the information received from the input layer. But the flow of data is in one direction

from the input to the hidden to the output layers. This type is a good choice for application that includes prediction.

3. Recurrent networks: Feedback loops distinguish this type from the second type. At least one feedback loop from neurons in one layer to neurons in pervious layer is required to classify the network as a recurrent network.

2.7.3 Types of activation functions

The activation function transforms the weighted sum of inputs in a neuron into an output or response. Several types of activation function can be used in building an ANN. The most commonly used activation function are the threshold (or step function) and the sigmoid function.

The first type is used for applications that involve the need to classify input signal into two groups. For more complicated clustering or classification; a combination of multiple units with threshold functions is necessary. The latter type uses a continuous and differentiable function that is by far the most popular type of activation function. This is due to the need for a differentiable function in some learning algorithms that are based on finding the minimum value of error that requires the computation of the function gradient. This can only be satisfied by a differentiable function. The sigmoid function is typically used to represent nonlinear relations for application that involves forecasting.

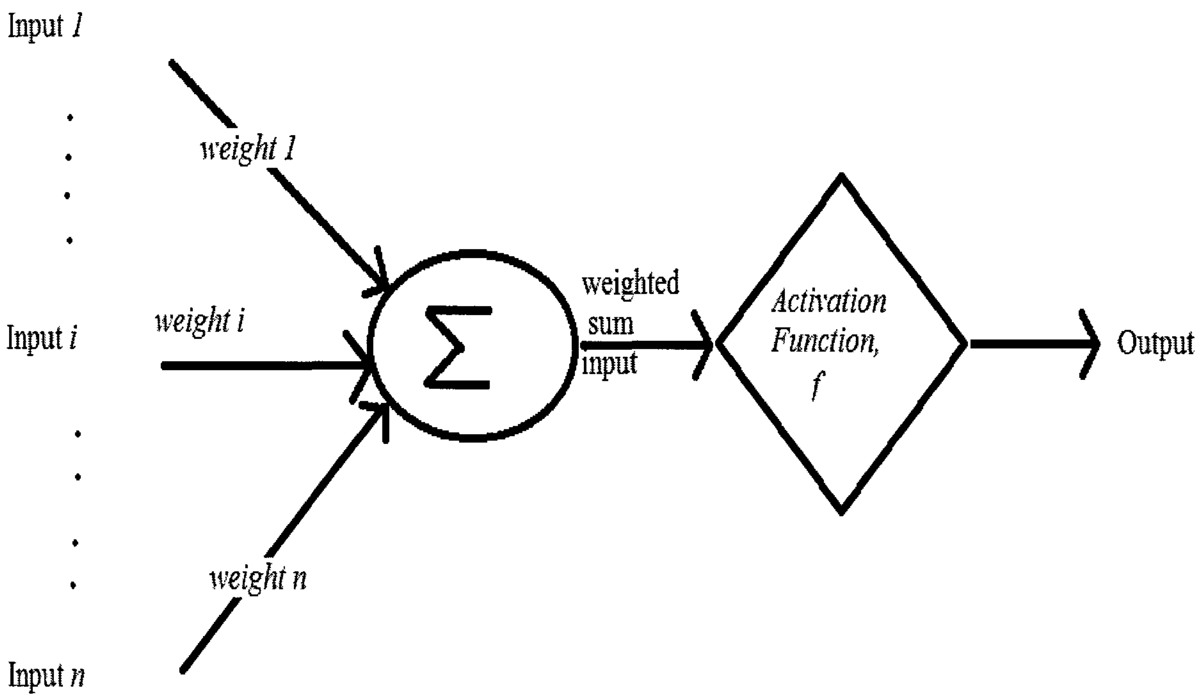

Figure 2.7: A Schematic representation of an Artificial Neuron.

Two more types of differentiable activation functions are also used in ANNs *viz.*, piecewise linear and gaussian functions. The different types of activation functions are shown below in figure 2.8.

2.7.4 Design and Operation of an ANN

Designing an ANN involves several selection of the network architecture or structure. This includes the selection of the number of input points, number of layers and the type of learning algorithm.

Once the selection has been made, the procedure followed in operating a neural network consists of three major steps and is as follows:

1. Training: the first step in operating a neural network is recognizing the relationships between the different inputs into the network that ultimately produce the desired output. Supervised learning, from examples, is the most commonly used type of learning in ANNs where a set of inputs and corresponding outputs are introduced to enable the network to learn and recognizes the relation between the independent and dependent variables.

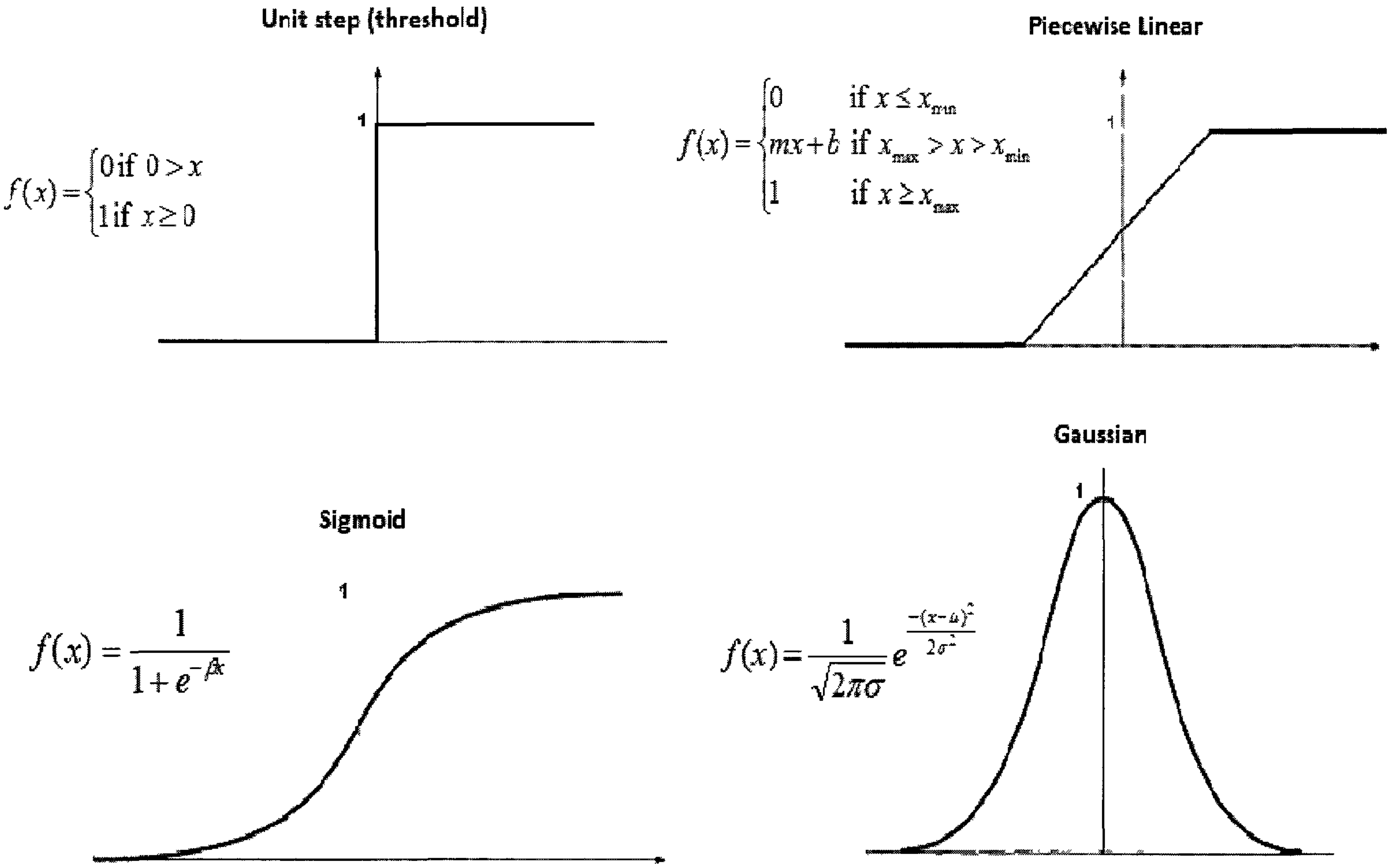

Figure 2.8: The Different Types of Activation Functions (Reproduced and Modified from: Data Mining in Engineering, Business, and Medicine)

2. Testing: once the network has learned the relationship, the second step of testing its understanding is performed. In this step, the other portion of the data used in the first step is introduced to network. Only inputs (of known outputs) are fed to the network. The network is run and the predicted outputs are compared with the measured values. This step is necessary to ensure that the network has actually learned the relation not just memorized the examples.

3. Generalization: the final step of preparing the network is to ensure that the network is able to use the acquired knowledge in predicting outputs for inputs the network has not seen before during the previous steps. For example, for networks built to predict physical properties, one may use certain compounds in training and testing. Other compounds are used to check the network ability to generalize its knowledge to them.

2.7.5 Applications

Artificial neural networks are used in a wide range of applications that are mainly related to pattern recognition, clustering, and function approximation for prediction and forecasting. In a review paper, Cheng and Titterington (1994) gave the following list of application domains where artificial neural networks are used:

1. Speech recognition and speech generation.
2. Prediction of financial indices such as currency exchange rates.
3. Location of radar point sources.
4. Optimization of chemical processes.

5. Target recognition and mine detection.
6. Identification of cancerous cells.
7. Recognition of chromosomal abnormalities.
8. Prediction of re-entry trajectories of spacecraft.
9. Automatic recognition of handwritten characters.
10. Sexing of faces.
11. Recognition of coins of different denominations.
12. Solution of optimal routing problems such as the Traveling Salesman Problem.
13. Discrimination of chaos from noise in the prediction of time series.

The ANN ability to represent nonlinear relationships that are commonly encountered in engineering applications has attracted engineers and researchers to utilize this technique in solving many engineering problems. David M. Himmelblau (2000), Krasnopolsky and Schiller (2003), Meireles *et al.* (2003), and Ahmad *et al.* (2009) among several other researchers gave a review of broad range of engineering applications where the ANN technique has been successfully used.

Processes control and modeling, optimization, and physical properties' prediction are two other areas that engineers have successfully applied this technique.

2.7.6 Application in predicting viscosity and other physical properties

The previously mentioned benefits of using the ANN technique as well as the availability of computers with appropriate computational power have attracted the attention of many researchers to employ this technique in predicting materials' physical properties. Researchers started employing the ANN technique as early as the 1990s.

This section covers some examples where researchers have used the ANN technique in predicting the physical properties of pure materials as well as liquid mixtures with focus on viscosity prediction.

One of the early examples is the work of Lee and Chen (1993), where they incorporated the group contribution model into the artificial neural networks technique in order to predict the normal boiling point, critical properties, and acentric factor. They used two vectors one for group-numbers and the second for boiling point, critical properties, and acentric factor of 421 data sets obtained from Reid *et al.* (1987) to train the ANN. Then they used the network to predict the properties of 29 pure chemicals (unseen during the training) with an average AAD ranging from 6.6% to 13.6% for the different properties.

The same authors worked with Hwang (1994) and used the same technique to predict the density and viscosity of binary and ternary mixtures (mostly aqueous mixtures). They were successful in predicting the density within about 1%. Viscosity was predicted with %AAD values ranging from 1.13 to 13.71%.

Mehlman *et al.* (1998) used a network trained by a binary mixture data to calculate the density, viscosity and refractive index of a number of ternary and quaternary mixtures. The absolute average deviation of prediction by the ANNs was generally a maximum of 1.71 % for density, and 0.27 % for refractive index, and 14.26 % for the viscosity excluding one system with a value of about 21%.

Nashawi and Elgibaly (1999), Suzuki *et al.* (2001), and Sozen *et al.* (2009) are other examples where researchers have applied the ANN techniques in predicting the viscosity of a variety of pure chemicals of different types of liquids along with other thermodynamic properties. Whereas the work of Rai *et al.* (2005), Baskaran and Kubendran (2008), Obanijesu and Omidiora (2009), Balabin *et al.* (2011), Torabi *et al.* (2011), and Sencan *et al.* (2011) represent excellent examples where the ANN technique was employed to successfully predict the viscometric properties of different types multi-components liquid mixtures.

CHAPTER 3

EXPERIMENTAL EQUIPMENT AND PROCEDURES

3.1 General

The materials employed in the present study and their purity verification are reported in the present Chapter. Moreover, detailed explanation of the procedures followed in preparing the solution mixtures as well as a description of the experimental setups that were used in measuring the densities and viscosities and their operation are given. The experimental procedures followed in calibrating the density meter and viscometers are also presented.

3.2 Chemicals and Purity Verification

Different chemicals were used at different stages in the present study. The first group of chemicals used in this study includes: Nitrobenzene, 1-octanol, m-xylene, benzene, cyclohexane, cyclooctane, heptane, and decane were used for the density meter calibration. Cannon viscosity standard fluids (N0.8, N1.0, N2.0, and N4.0) were used in viscometer calibration. The third group of chemicals includes: Chlorobenzene, p-xylene, octane, eythlbenzene, and 1-hexanol that were used in preparing samples of the different systems investigated in the present study.

Table 3.1: Purity Verification of Pure Chemicals Used in Present Study Using Gas Chromatography.

Compound	Supplier	Stated Purity mol %	GC Analysis, mass%
Chlorobenzene	Sigma-Aldrich	99.8%	99.98
p-Xylene	Sigma-Aldrich	99+%	99.99
Octane	Sigma-Aldrich	99+%	99.78
Eythlbenzene	Sigma-Aldrich	99.8+%	99.99
1-Hexanol	Fluka	99+%	99.61
Nitrobenzene	Sigma-Aldrich	99.5+%	99.98
1-Octanol	Sigma-Aldrich	99+%	99.77
m-Xylene	Sigma-Aldrich	99+%	99.82
Benzene	Sigma-Aldrich	99.5+%	99.71
Cyclohexane	Sigma-Aldrich	99+%	99.67
Cyclooctane	Sigma-Aldrich	99+%	99.75
Heptane	Sigma-Aldrich	99+%	99.69
Decane	Sigma-Aldrich	99+%	99.84

The first and third groups of chemicals used in the present study were purchased from Sigma-Aldrich and from Fluka, respectively, whereas the viscosity standards, represented by the second group, were purchased from Cannon Instrument Company.

The stated purities of the chemicals used in mixture composing and density meter calibration were 99.0+%. These purity values were verified using with the help of Hewlett-Packard 5890A Gas Chromatograph with a flam ionization detector (FID) and a cross-linked methyl silicone gum HP 1 column. The column is 30m (long) x 0.53 mm (diameter) and 2.65 μm in film thickness. A comparison between the supplier's stated purities and the GC analysis results of those chemicals is given in Table 3.1.

3.3 Preparation of Solutions

Each sample investigated in the present study was prepared according to the procedure described earlier in details by Asfour (1980). The samples were gravimetrically prepared using a Mettler HK 160 electronic balance with a precision of ± 0.1 mg. The balance was turned on and left for at least thirty minutes to reach equilibrium before use..

Each sample was placed in a .03 L glass vials sealed with Tuf-Bond discs and aluminum seals to prevent evaporation. The pure components were injected into glass vials using glass syringes. The sizes of the syringes employed in the present study were 0.01, 0.02, and 0.03 L fitted with G18, G20, or G22 stainless steel needles. The empty vial was first weighed, and then it was weighed after each component is injected. This injection was repeated depending on the number of components constituting the mixture.

The differences in weight readings represent the weight of the injected pure component. These values were converted into molar values and used to calculate the composition of the sample. The vials containing the liquid samples were kept at low temperature inside a refrigerator until used.

3.4 Experimental Measurements

The densities and kinematic viscosities of the systems under investigation were measured over the entire composition range at 293.15, 298.15, 308.15, and 313.15 K. This section describes the experimental setup used to carry out these measurements and its principle of operation. A detailed description of the operational procedures and precautions are also given in the following subsections. The relevant density meter and viscometer equations employed are also given.

3.5 Density Measurement

3.5.1 Equipment and principle of operation

The densities of the systems under investigation were measured using an Anton-Paar density meter. The Anton-Paar density meter consists of a DMA 60 processing unit and a DMA 602 measuring cell. The DMA 602 measuring cell contains a U-shaped borosilicate glass sample tube (oscillator) where the sample is injected. The U-shaped sample tube is electronically excited into oscillation. The variation of the natural frequency of vibration (period of oscillation) of the U-shaped tube when filled with different liquid sample is measured.

The oscillation period or the frequency of the oscillator depends only on the mass of that part of the liquid between two points on the U-shaped glass oscillator that has a fixed volume and is therefore, only related directly to the density of the injected liquid sample. The oscillation period is displayed by the DMA 60 processing unit to the eighth decimal place as a density meter reading. The density of the fluid injected into the tube is calculated using the density meter equation.

The DMA 60 processing unit and the DMA 602 measuring cell are both kept inside a wooden box to minimize the effect of the ambient temperature fluctuations. This wooden box is equipped with fans to circulate the air inside. There is also a 200W light bulb inside the chamber that works alternatively with a refrigeration unit to precisely control the chamber's internal temperature. This is an extra measure suggested by Asfour (1980) to prevent any instability of the density meter reading due to the changes in laboratory temperature. The temperature inside the chamber is kept within ±0.5 K of the desired temperature. The internal temperature of the wooden box is monitored using a mercury-in-glass thermometer.

The temperature of the injected liquid sample is controlled at the desired level with the help of Haake N4 circulator. The circulator is connected to a Lauda RMT-20 refrigerating unit that can work at temperatures as low as -15 ^{o}C to enable operation below the laboratory temperature. The Haake N4 circulator passes a constant-temperature water through a double wall glass cylinder where the U-shaped oscillator is fused. The circulator water temperature is monitored by an Omega electronic thermometer fitted with a calibrated platinum temperature sensor (ITS 90) with a precision of ± 0.005 K. Figure 3.1 shows a pictorial view of the density measurement setup.

3.5.2 Procedures

The density meter was turned on and the water bath temperature was set to the desired level. The oscillator tube was washed, first using ethanol (solvent) that was passed through the u-shaped tube after every use. The solvent is used to dissolve and remove any remaining traces of any chemicals from previous runs. After washing, an air pump that is installed within the measuring cell unit is used to dry the U-shaped tube by passing dry air through it. This cleaning and drying procedure was repeated three times before making a new injection.

After reaching the desired temperature, the liquid sample is injected slowly into the opening of the U-tube of the measuring cell using a 0.002 L glass syringe. It is important at this stage that one makes sure that the tube is filled with liquid and there are no air bubbles inside the tube that affects the measuring cell reading. The other ends of the U-tube were sealed using Teflon stoppers. The system is then left for at least 20-30 minutes to make sure that thermal equilibrium is reached.

The oscillation period readings were taken ten times. The average value of the oscillation period is used in the density meter equation to calculate the density of the sample at that temperature.

3.5.3 Density meter calibration

The densitymeter manufacturer suggested the following equation to be used to convert the oscillation period reading into a density value

$$\rho = \frac{AT^2}{1 - BT^2} - C \tag{3.1}$$

where ρ is the density of the sample in kg/L and T is the oscillation period in seconds.

The values of the calibration constants A, B, and C are determined using the densities of some compounds with accurately known density values. The oscillation periods of those compounds were determined at each temperature level. The densities of those compounds and their corresponding periods of oscillation were fitted using the least-squares technique to find the values of the calibration constants.

3.6 Viscosity Measurement

3.6.1 Equipment and principle of operation

Cannon-Ubbelohde glass viscometers were used in the present study to carry out the kinematic viscosity measurements. This type of the U-shaped glass viscometer (shown in Figure 3.2) is suspended level viscometers which uses a capillary based technique to measure kinematic viscosities. It consists of two tubes, the liquid is introduced into one tube which has a reservoir at the bottom and sucked through the other tube which has a measuring bulb. The fluid is allowed to flow through the measuring bulb. The time required for the test fluid to travel between two etched marks above and below the measuring bulb is known as the efflux time that is related to the kinematic viscosity of the fluid.

Figure 3.1: Pictorial View of the Anton-Paar Density Meter and the Temperature Controlled Chamber.

The Cannon-Ubbelohde glass viscometers come in different sizes depending on the type of fluid and its viscosity that needs to be measured. The kinematic viscosity values of the compounds investigated in the present study range between 0.58 and 6.53 x 10^{-6} m^2/s. Therefore, four different sizes were selected to conduct the measurements. Theses sizes are: 25, 50, 75, and 100. These sizes are used to measure the kinematic viscosities that ranges between 0.5- 2 x 10^{-6} m^2/s (size 25), 0.8- 4 x 10^{-6} m^2/s (size 50), and 1.6- 8 x 10^{-6} m^2/s (size 75).

A Cannon CT-1000 constant temperature water bath was used to control the temperature of the viscometers. The system temperature is monitored by the same Omega electronic thermometer described in the previous section. The system temperature is controlled using a combination of a refrigeration unit and a built in heating system installed in the Cannon water bath.

3.6.2 Procedure

The first step of conducting viscosity measurements is cleaning the viscometer before any use to remove any traces of organic liquids from previous runs. The viscometer is first washed using diluted special detergent solution that is passed through the viscometer. Then, it is rinsed with deionised water followed by acetone. The viscometer was then placed in an oven at 120 °C for 10-15 min to dry all remaining traces of the acetone. The viscometer was then allowed to cool down to room temperature. At this stage the viscometer is ready for use.

All pieces of equipment were turned on at the beginning of each round of measurements. The viscometer was then placed into a special plastic holder provided by Cannon Instrument Company. The viscometer holders fit any of the seven holes of 51 mm in diameter located on the top cover of the Cannon CT-1000 water bath. Up to seven viscometers can be placed in the bath simultaneously. The holder ensures that the viscometer remains in a perfect vertical position in the water bath. The viscometer was charged with the test fluid by pouring enough volume of it through arm L shown in Figure 3.2 to fill the lower reservoir until the liquid level (liquid meniscus) is between the marked fill lines on the lower reservoir.

The water bath temperature was set to the desired value by rotating a switch on the front panel of the bath. A fine tuning control allows temperature adjustment reach the target temperature. An Omega electronic thermometer is used to monitor the system temperature. After reaching the desired temperature, the viscometer and the sample were left in the water bath for approximately 20 minutes to reach thermal equilibrium.

The procedure suggested by the manufacturer was followed in operating the viscometer where the branching vent tube M was sealed using a finger and suction is applied to tube N until the liquid reached the center of bulb D. At this point, the suction and the seal from tube N and vent tube M were removed. The efflux time is the time taken by the liquid meniscus to travel between the etched marks E and F.

The efflux time measurement was repeated three times for every sample and the average value was used for calculating the viscosity. The average efflux time value of the tested fluid is substituted into an equation that converts this reading into a kinematic viscosity value. This equation is called the viscometer equation and is given by equation (3.2) in the following section.

3.6.3 Viscometer calibration

The kinematic viscosity value is calculated with the help of equation (3.2).. The following equation was suggested by the manufacturer of the Cannon-Ubbelohde viscometer and is given by:

$$v = Ct - \frac{E}{t^2} \tag{3.2}$$

where v is the kinematic viscosity of the sample in m^2/s and t is the efflux time in seconds. In order to calculate the viscosities of the test samples, the efflux time was measured three times and the average value was substituted into the viscometer equation. The difference in the three different efflux time for the same sample must not exceed 1 second, otherwise the measurements were repeated.

In equation (3.2), C, and E are the calibration constants. The values of the calibration constants were determined using calibration fluids of known viscosities supplied by Cannon Instrument Company. The viscosities of the calibration fluids and their corresponding efflux times were fitted using the least-squares technique to equation (3.2) and the values of the constants C and E for each viscometer at each temperature level were determined.

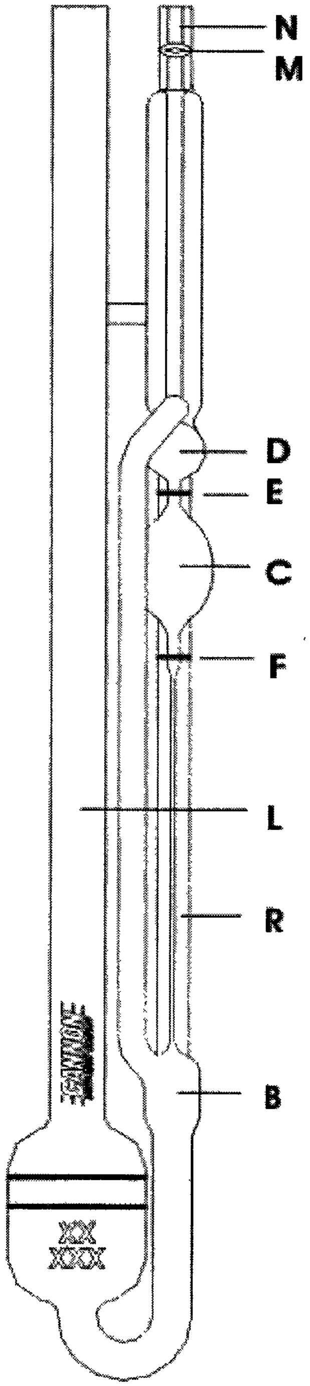

Figure 3.2: The Cannon-Ubbelohde viscometer

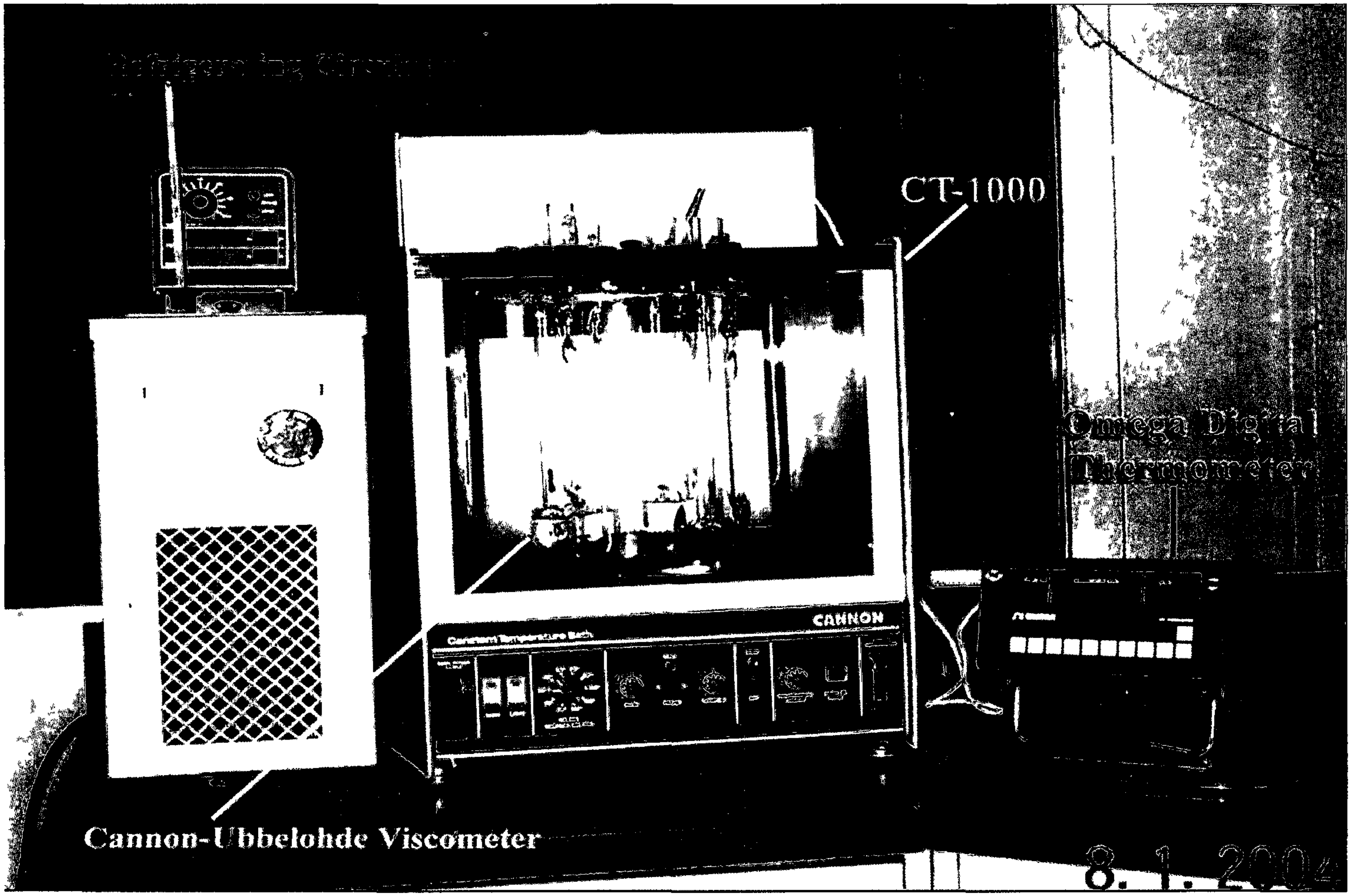

Figure 3.3: The experimental set up used for viscosity measurements

CHAPTER 4

EXPERIMENTAL RESULTS

In the present chapter, the experimental values of the kinematic viscosities and densities are reported for the quinary system: Chlorobenzene, p-xylene, octane, ethylbenzene, and 1-hexanol and its quaternary, ternary, and binary subsystems at 293.15, 298.15, 308.15, and 313.15 K are reported in the present chapter. In addition, the experimental values of kinematic viscosities and densities of the pure components used to constitute the mixtures are also reported. Each system contains between five to nine mixture samples that cover the entire composition range of system under investigation. The experimental results related to the kinematic viscosities and density measurements including the density meter and viscometers calibration are also reported. The systems investigated in the present study are summarized in Table 1.1. The raw data of the efflux times and oscillation periods are reported in Appendix A.

4.1 Density Meter Calibration Results

The density meter was calibrated using the density values of selected compounds with known densities at the desired temperatures. The compounds used in calibrating the density meter were: Nitrobenzene, 1-Octanol, m-xylene, benzene, cyclohexane, cyclooctane, heptane, and decane. The calibration data of the density meter employed in the present study are given in Tables 4.1. This set of data was fitted using the least-square method to equation (3.1) that contains the three densitymeter's constants.

Table 4.1: Calibration Data for the Density Meter

T (K)	Compound	Reference	Density, kg/L	Density meter reading, s
293.15	Nitrobenzene	Timmermans (1950)	1.2033	0.792394
	1-Octanol	TRC Tables (1991)	0.8261	0.725730
	m-Xylene	Timmermans (1965)	0.86417	0.732851
	Benzene	TRC Tables (1988)	0.879	0.735529
	Cyclohexane	Timmermans (1950)	0.7787	0.717048
	Cyclooctane	Tranzado *et al.* (2002)	0.8359	0.727621
	Heptane	TRC Tables (1988)	0.68375	0.699198
	Decane	TRC Tables (1988)	0.73012	0.707909
298.15	Nitrobenzene	Timmermans (1950)	1.1985	0.791292
	1-Octanol	TRC Tables (1991)	0.8222	0.724850
	m-Xylene	Timmermans (1965)	0.8599	0.731825
	Benzene	TRC Tables (1988)	0.8737	0.734314
	Cyclohexane	TRC Tables (1998)	0.7712	0.715931
	Cyclooctane	Tranzado *et al.* (2002)	0.8318	0.726624
	Heptane	TRC Tables (1988)	0.6796	0.698151
	Decane	TRC Tables (1988)	0.72635	0.706956

Table 4.1 (Cont'd.): Calibration Data for the Density Meter.

T (K)	Compound	Reference	Density, kg/L	Density meter reading, s
308.15	Nitrobenzene	Timmermans (1950)	1.1894	0.789108
	1-Octanol	Rauf *et al.* (1983)	0.8142	0.723095
	m-Xylene	George and Sastry (2003)	0.85157	0.729768
	Benzene	Timmermans (1950)	0.8629	0.731885
	Cyclohexane	TRC Tables (1998)	0.7597	0.713686
	Cyclooctane	Ewing *et al.* (1970)	0.8238	0.724648
	Heptane	Nayak *et al.* (2001)	0.6705	0.696058
	Decane	TRC Tables (1988)	0.71915	0.705060
313.15	Nitrobenzene	Timmermans (1950)	1.1837	0.788017
	1-Octanol	TRC Tables (1991)	0.8117	0.722211
	m-Xylene	Song *et al.* (2008)	0.8469	0.728737
	Benzene	TRC Tables (1988)	0.8577	0.730669
	Cyclohexane	TRC Tables (1998)	0.7562	0.712564
	Cyclooctane	Tranzado *et al.* (2002)	0.8195	0.723664
	Heptane	TRC Tables (1988)	0.6665	0.695004
	Decane	TRC Tables (1988)	0.715	0.704112

The values of the density meter's constants are given in Tables 4.2. The constants were evaluated at 293.15, 298.15, 308.15, and 313.15 K.

4.2 Viscometer Calibration

As indicated earlier in Chapter 3, a total of nine viscometers of four different sizes were employed in measuring the kinematic viscosities of pure components and the liquid mixtures. These sizes were: 25, 50, 75, and 100. The viscometers were as follows: 25 [B-349], 25 [B-350], 25 [B-366], 50 [B-830], 50 [B-831], 50 [B-158], 75 [K-95], 75 [K-96], and 100 [C-334]. The viscometers were calibrated at: 293.15, 298.15, 308.15, and 3 13.15K by using N0.8, N1, N2, and N4 calibration standards purchased from Cannon Instrument Company.

The calibration standard fluids have known viscosities and densities at the temperatures indicated above. The viscometers were selected to cover the viscosity ranges of the systems under investigation. The two calibration constants that appear in equation (3.2), *viz.* C and E, are temperature sensitive and were evaluated for each viscometer at every investigated temperature level. The average values of the measured efflux times and the corresponding kinematic viscosities values of the calibration fluids were fitted using the least-squares technique to equation (3.2). Table 4.3 summarizes the data sets used in the calibration of the viscometers as well as the values of the viscometers constants at different temperature levels.

Table 4.2: Calculated Values of Density Meter's Constants.

	Fitting Parameters			Standard Deviation kg/L
Temperature (K)	A	B	C	
293.15	3.858834	-2.926511×10^{-2}	1.175923	2.4×10^{-4}
298.15	3.806655	-1.513783×10^{-2}	1.162570	9.1×10^{-4}
308.15	3.775402	-4.074335×10^{-3}	1.155455	1.6×10^{-4}
313.15	3.850799	-2.346480×10^{-2}	1.173117	1.1×10^{-4}

Table 4.3: Calibration Data for the Viscometer.

Viscometer No.	Temperature (K)	STD Fluid	Kin. Visc. x $10^6 m^2/s$	Efflux. time (s)	C x 10^8	E x 10^4
25 [B349]	293.15	N 0.8	0.7561	429.61	0.1759	-1.0923
		N 1	1.27	722.05		
	298.15	N 0.8	0.7145	406.19	0.1760	0.3787
		N 1	1.184	672.93		
	308.15	N 0.8	0.6421	365.62	0.1763	3.1050
		N 1	1.04	590.56		
	313.15	N 0.8	0.6113	347.39	0.1761	0.4596
		N 1	0.9776	555.29		
25 [B350]	293.15	N 0.8	0.7561	432.34	0.1742	-5.6670
		N 1	1.27	728.50		
	298.15	N 0.8	0.7145	408.78	0.1741	-5.0060
		N 1	1.184	679.62		
	308.15	N 0.8	0.6421	368.02	0.1740	-2.2682
		N 1	1.04	597.27		
	313.15	N 0.8	0.6113	349.85	0.1736	-4.6904
		N 1	0.9776	562.16		

Table 4.3 (Cont'd.): Calibration Data for the Viscometer.

Viscometer No.	Temperature (K)	STD Fluid	Kin. Visc. x $10^6 m^2/s$	Efflux. time (s)	C x 10^8	E x 10^4
25 [B366]	293.15	N 0.8	0.7561	400.01	0.1892	1.2470
		N 1	1.27	671.34		
	298.15	N 0.8	0.7145	377.59	0.1896	2.1253
		N 1	1.184	624.69		
	308.15	N 0.8	0.6421	339.74	0.1897	2.6594
		N 1	1.04	548.77		
	313.15	N 0.8	0.6113	323.16	0.1894	0.7900
		N 1	0.9776	516.32		
50 [B830]	293.15	N 1	1.27	300.18	0.4242	2.9145
		N 2	2.906	685.27		
	298.15	N 1	1.184	279.72	0.4208	0.6670
		N 2	2.63	620.25		
	308.15	N 1	1.04	245.52	0.4237	0.2017
		N 2	2.19	516.86		
	313.15	N 1	0.9776	230.96	0.4239	0.7210
		N 2	2.014	475.23		

Table 4.3 (Cont'd.): Calibration Data for the Viscometer.

Viscometer No.	Temperature (K)	STD Fluid	Kin. Visc. x $10^6 m^2/s$	Efflux. time (s)	C x 10^8	E x 10^4
50 [B831]	293.15	N 1	1.27	310.75	0.4089	0.6491
		N 2	2.906	710.71		
	298.15	N 1	1.184	289.72	0.4085	-0.4750
		N 2	2.63	643.83		
	308.15	N 1	1.04	254.29	0.4086	-0.5956
		N 2	2.19	535.90		
	313.15	N 1	0.9776	239.27	0.4088	0.3611
		N 2	2.014	492.65		
50 [B158]	293.15	N 1	1.27	295.70	0.4297	0.6406
		N 2	2.906	676.26		
	298.15	N 1	1.184	275.59	0.4298	0.4101
		N 2	2.63	611.91		
	308.15	N 1	1.04	241.76	0.4295	-0.9333
		N 2	2.19	509.79		
	313.15	N 1	0.9776	227.85	0.4296	0.6904
		N 2	2.014	468.84		

Table 4.3 (Cont'd.): Calibration Data for the Viscometer.

Viscometer No.	Temperature (K)	STD Fluid	Kin. Visc. x $10^6 m^2/s$	Eff. time (s)	C x 10^8	E x 10^4
75 [K95]	293.15	N 2	2.906	315.11	0.9119	-32.2289
		N 4	6.7	734.06		
	298.15	N 2	2.63	286.39	0.9139	2.9878
		N 4	5.818	637.63		
	308.15	N2	2.19	238.44	0.9112	-9.8847
		N 4	4.507	494.19		
	313.15	N 2	2.014	219.30	0.9096	-9.2340
		N 4	4.014	440.76		
75 [K96]	293.15	N 2	2.906	323.62	0.8884	-32.5889
		N 4	6.7	753.56		
	298.15	N 2	2.63	293.85	0.8932	9.8323
		N 4	5.818	654.15		
	308.15	N2	2.19	245.07	0.8879	-8.4702
		N 4	4.507	507.25		
	313.15	N 2	2.014	225.47	0.8880	-6.0245
		N 4	4.014	451.70		

Table 4.3 (Cont'd.): Calibration Data for the Viscometer.

Viscometer No.	Temperature (K)	STD Fluid	Kin. Visc. x $10^6 m^2/s$	Eff. time (s)	C x 10^8	E x 10^4
100 [C334]	293.15	N 2	2.906	175.43	1.6565	-0.0073
		N 4	6.7	404.47		
	298.15	N 2	2.63	158.77	1.6566	0.0537
		N 4	5.818	351.20		
	308.15	N2	2.19	132.34	1.6563	0.3416
		N 4	4.507	272.14		
	313.15	N 2	2.014	121.70	1.6572	0.4146
		N 4	4.014	242.26		

4.3 The Densities and Viscosities of the Pure Components

The densities and viscosities of the pure components that were used to constitute the liquid mixtures were measured at 293.15, 298.15, 308.15, and 313.15 K. Those components are: Chlorobenzene, p-xylene, octane, ethylbenzene, and 1-hexanol. Table 4.4 summarizes the measured experimental density and kinematic viscosity values the temperatures indicated. A comparison between the measured density and kinematic viscosity values and corresponding values reported in the literature is also included in Table 4.4. The experimental efflux times and oscillation periods are reported in Appendix A.

4.4 Binary System Results

The density and kinematic viscosity experimental data pertaining to ten binary sub-systems of the quinary system: Chlorobenzene, p-xylene, octane, ethylbenzene, and 1-hexanol are reported in Tables 4.5 through 4.14. Every binary system consists of nine samples that cover the entire composition range at the four temperature levels of interest. The absolute viscosity values were calculated from the density values and the corresponding kinematic viscosity values and reported in the aforementioned tables whereas the raw data of the efflux times and oscillation periods for the binary systems investigated are reported in Apendix A.

Table 4.4: Pure Components Properties and their Comparison with their Corresponding Literature Values at Different Temperatures.

Compound	Density (kg/L)		μ, mPa.s	Kinematic Viscosity m^2/s x10^6	
	Experimental Values	Literature Values	Calculated Values	Experimental Values	Literature Values
T= 293.15 K					
Chlorobenzene	1.1067	1.1064 (1)	0.8035	0.7260	0.7304 (2)
p-Xylene	0.8613	0.860917 (3)	0.6560	0.7616	0.755 (3)
Octane	0.7025	0.70267 (4)	0.5416	0.7709	0.7758 (5)
Ethylbenzene	0.8674	0.867 (6)	0.6689	0.7712	0.7800 (5)
1-Hexanol	0.8184	0.8196 (7)	5.344	6.530	6.548 (8)
T= 298.15 K					
Chlorobenzene	1.1013	1.1011 (1)	0.7709	0.7000	0.702 (9)
p-Xylene	0.8565	0.85662 (3)	0.6139	0.7167	0.7132 (3)
Octane	0.6980	0.69862 (4)	0.5099	0.7305	0.7352 (5)
Ethylbenzene	0.8625	0.825 (6)	0.6306	0.7311	0.7367 (5)
1-Hexanol	0.8144	0.8159 (7)	4.5641	5.604	5.625 (10)

Table 4.4 (Cont'd.): Pure Components Properties and their Comparison with their Corresponding Literature Values at Different Temperatures.

Compound	Density (kg/L)		μ, mPa.s	Kinematic Viscosity m^2/s	
	Experimental Values	Literature Values	Calculated Values	Experimental Values $x10^6$	Literature Values
T= 308.15 K					
Chlorobenzene	1.0910	1.0904 (1)	0.6817	0.6249	0.627 (9)
p-Xylene	0.8476	0.84799 (11)	0.5398	0.6368	0.6363 (11)
Octane	0.6893	0.6906 (12)	0.4534	0.6677	0.6649 (5)
Ethylbenzene	0.8534	0.85348 (13)	0.5596	0.6558	0.6614 (5)
1-Hexanol	0.8073	0.80777 (14)	3.3887	4.197	4.15 (14)
T= 313.15 K					
Chlorobenzene	1.0852	1.085 (1)	0.6371	0.5871	0.585 (9)
p-Xylene	0.8434	0.8439 (15)	0.5116	0.6066	0.6067 (15)
Octane	0.6855	0.6863 (4)	0.4302	0.6376	0.6343 (5)
Ethylbenzene	0.8492	0.8495 (6)	0.5303	0.6244	0.6286 (6)
1-Hexanol	0.8040	0.8046 (7)	2.9507	3.670	3.620 (10)

(1) TRC (1990)
(2) Yang *et al.* (2004)
(3) Al-Kandary (2006)
(4) TRC (1973)
(5) TRC (1955)
(6) TRC (1953)
(7) TRC (1966)
(8) Al-Jimaz (2004)
(9) Aralaguppi *et al.* (2003)
(10) Singh (1985)
(11) Bhatia (2011)
(12) Aminabhavi (1996)
(13) Wankhede (2008)
(14) Domanska (2010)
(15) Habibullah (2010)

Table 4.5: Densities and Viscosities of the Binary System: Chlorobenzene (1) + p-Xylene (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6 (m^2/s)$	Absolute Viscosity (mPa.s)
		293.15 K	
0.0000	0.8613	0.7260	0.6254
0.1085	0.8838	0.7405	0.6545
0.2083	0.9054	0.7398	0.6698
0.3097	0.9281	0.7275	0.6752
0.3882	0.9463	0.7299	0.6907
0.5098	0.9753	0.7304	0.7123
0.6180	1.0022	0.7269	0.7285
0.7055	1.0225	0.7259	0.7422
0.7907	1.0475	0.7270	0.7615
0.8829	1.0730	0.7264	0.7794
1.0000	1.1067	0.7616	0.8429

Table 4.5 (Cont'd.): Densities and Viscosities of the Binary System: Chlorobenzene (1) + p-Xylene (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6$ (m^2/s)	Absolute Viscosity (mPa.s)
		298.15 K	
0.0000	0.8565	0.7167	0.6139
0.1085	0.8790	0.7063	0.6209
0.2083	0.9005	0.7115	0.6407
0.3097	0.9231	0.7008	0.6469
0.3882	0.9412	0.7046	0.6632
0.5098	0.9701	0.7047	0.6837
0.6180	0.9971	0.6936	0.6916
0.7055	1.0172	0.7021	0.7142
0.7907	1.0422	0.6973	0.7267
0.8829	1.0676	0.6911	0.7379
1.0000	1.1013	0.7000	0.7709

Table 4.5 (Cont'd.): Densities and Viscosities of the Binary System: Chlorobenzene (1) + p-Xylene (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6 (m^2/s)$	Absolute Viscosity (mPa.s)
		308.15 K	
0.0000	0.8476	0.6368	0.5398
0.1085	0.8698	0.6258	0.5443
0.2083	0.8912	0.6288	0.5604
0.3097	0.9137	0.6336	0.5790
0.3882	0.9328	0.6233	0.5814
0.5098	0.9604	0.6231	0.5985
0.6180	0.9872	0.6282	0.6201
0.7055	1.0073	0.6218	0.6263
0.7907	1.0321	0.6178	0.6376
0.8829	1.0574	0.6123	0.6475
1.0000	1.0910	0.6249	0.6817

Table 4.5 (Cont'd.): Densities and Viscosities of the Binary System: Chlorobenzene (1) + p-Xylene (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6$ (m^2/s)	Absolute Viscosity (mPa.s)
		313.15 K	
0.0000	0.8434	0.6066	0.5116
0.1085	0.8656	0.6023	0.5214
0.2083	0.8868	0.6071	0.5384
0.3097	0.9092	0.6031	0.5483
0.3882	0.9270	0.6000	0.5562
0.5098	0.9557	0.6003	0.5736
0.6180	0.9822	0.5968	0.5862
0.7055	1.0022	0.5955	0.5968
0.7907	1.0268	0.5943	0.6102
0.8829	1.0518	0.5900	0.6206
1.0000	1.0852	0.5871	0.6371

Table 4.6: Densities and Viscosities of the Binary System: Chlorobenzene (1) + Octane (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6 (m^2/s)$	Absolute Viscosity (mPa.s)
		293.15 K	
0.0000	0.7025	0.7709	0.5416
0.1467	0.7419	0.7448	0.5526
0.2763	0.7810	0.7295	0.5697
0.3416	0.8017	0.7185	0.5760
0.4192	0.8294	0.7101	0.5889
0.5096	0.8627	0.7051	0.6083
0.6071	0.9022	0.7001	0.6316
0.7067	0.9466	0.7002	0.6628
0.7983	0.9914	0.7054	0.6994
0.8932	1.0428	0.7084	0.7387
1.0000	1.1067	0.7260	0.8035

Table 4.6 (Cont'd.): Densities and Viscosities of the Binary System: Chlorobenzene (1) + Octane (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6$ (m^2/s)	Absolute Viscosity (mPa.s)
		298.15 K	
0.0000	0.6980	0.7305	0.5099
0.1467	0.7372	0.7050	0.5197
0.2763	0.7763	0.6906	0.5361
0.3416	0.7968	0.6817	0.5432
0.4192	0.8244	0.6726	0.5545
0.5096	0.8576	0.6679	0.5728
0.6071	0.8971	0.6637	0.5954
0.7067	0.9413	0.6625	0.6237
0.7983	0.9861	0.6672	0.6579
0.8932	1.0374	0.6722	0.6974
1.0000	1.1013	0.7000	0.7709

Table 4.6 (Cont'd.): Densities and Viscosities of the Binary System: Chlorobenzene (1) + Octane (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6 (m^2/s)$	Absolute Viscosity (mPa.s)
		308.15 K	
0.0000	0.6893	0.6577	0.4534
0.1467	0.7283	0.6353	0.4626
0.2763	0.7669	0.6227	0.4775
0.3416	0.7875	0.6155	0.4847
0.4192	0.8150	0.6069	0.4946
0.5096	0.8480	0.6029	0.5113
0.6071	0.8873	0.5988	0.5313
0.7067	0.9314	0.5977	0.5567
0.7983	0.9759	0.6007	0.5862
0.8932	1.0271	0.6037	0.6201
1.0000	1.0910	0.6249	0.6817

Table 4.6 (Cont'd.): Densities and Viscosities of the Binary System: Chlorobenzene (1) + Octane (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6 (m^2/s)$	Absolute Viscosity (mPa.s)
		313.15 K	
0.0000	0.6855	0.6276	0.4302
0.1467	0.7243	0.6010	0.4353
0.2763	0.7628	0.5878	0.4484
0.3416	0.7833	0.5798	0.4542
0.4192	0.8107	0.5729	0.4644
0.5096	0.8436	0.5694	0.4803
0.6071	0.8827	0.5643	0.4981
0.7067	0.9265	0.5644	0.5229
0.7983	0.9709	0.5666	0.5501
0.8932	1.0217	0.5680	0.5803
1.0000	1.0852	0.5871	0.6371

Table 4.7: Densities and Viscosities of the Binary System: Chlorobenzene (1) + Ethylbenzene (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6 (m^2/s)$	Absolute Viscosity (mPa.s)
		293.15 K	
0.0000	0.8674	0.7712	0.6689
0.1114	0.8903	0.7558	0.6729
0.2250	0.9146	0.7568	0.6921
0.2984	0.9307	0.7479	0.6961
0.4194	0.9583	0.7500	0.7187
0.4982	0.9767	0.7492	0.7318
0.5984	1.0010	0.7444	0.7451
0.6891	1.0236	0.7373	0.7547
0.7894	1.0495	0.7359	0.7723
0.8840	1.0746	0.7267	0.7809
1.0000	1.1067	0.7260	0.8035

Table 4.7 (Cont'd.): Densities and Viscosities of the Binary System: Chlorobenzene (1) + Ethylbenzene (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6 (m^2/s)$	Absolute Viscosity (mPa.s)
		298.15 K	
0.0000	0.8625	0.7311	0.6306
0.1114	0.8850	0.7209	0.6380
0.2250	0.9096	0.7194	0.6543
0.2984	0.9257	0.7178	0.6644
0.4194	0.9532	0.7149	0.6814
0.4982	0.9716	0.7127	0.6924
0.5984	0.9958	0.7089	0.7059
0.6891	1.0184	0.7024	0.7152
0.7894	1.0441	0.6983	0.7292
0.8840	1.0693	0.6917	0.7396
1.0000	1.1013	0.7000	0.7709

Table 4.7 (Cont'd.): Densities and Viscosities of the Binary System: Chlorobenzene (1) + Ethylbenzene (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6 (m^2/s)$	Absolute Viscosity (mPa.s)
		308.15 K	
0.0000	0.8534	0.6558	0.5596
0.1114	0.8761	0.6545	0.5734
0.2250	0.9001	0.6546	0.5892
0.2984	0.9162	0.6521	0.5974
0.4194	0.9435	0.6484	0.6118
0.4982	0.9618	0.6478	0.6231
0.5984	0.9859	0.6415	0.6325
0.6891	1.0083	0.6350	0.6403
0.7894	1.0340	0.6307	0.6521
0.8840	1.0590	0.6233	0.6600
1.0000	1.0910	0.6249	0.6817

Table 4.7 (Cont'd.): Densities and Viscosities of the Binary System: Chlorobenzene (1) + Ethylbenzene (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6$ (m^2/s)	Absolute Viscosity (mPa.s)
		313.15 K	
0.0000	0.8492	0.6244	0.5303
0.1114	0.8718	0.6238	0.5438
0.2250	0.8956	0.6233	0.5583
0.2984	0.9116	0.6201	0.5653
0.4194	0.9387	0.6150	0.5773
0.4982	0.9570	0.6152	0.5887
0.5984	0.9808	0.6089	0.5972
0.6891	1.0031	0.6044	0.6064
0.7894	1.0286	0.6009	0.6181
0.8840	1.0534	0.5931	0.6248
1.0000	1.0852	0.5871	0.6371

Table 4.8: Densities and Viscosities of the Binary Systems Chlorobenzene (1) + 1-Hexanol (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6$ (m^2/s)	Absolute Viscosity (mPa.s)
		293.15 K	
0.0000	0.8184	6.5298	5.3443
0.1271	0.8502	4.8235	4.1011
0.2264	0.8754	3.7423	3.2759
0.3205	0.8999	2.9899	2.6905
0.4111	0.9243	2.4014	2.2196
0.5110	0.9521	1.8787	1.7888
0.6021	0.9784	1.5673	1.5334
0.7022	1.0085	1.2376	1.2481
0.7953	1.0376	1.0370	1.0760
0.8874	1.0678	0.8296	0.8858
1.0000	1.1067	0.7260	0.8035

Table 4.8 (Cont'd.): Densities and Viscosities of the Binary Systems Chlorobenzene (1) + 1-Hexanol (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6 (m^2/s)$	Absolute Viscosity (mPa.s)
		298.15 K	
0.0000	0.8144	5.6040	4.5641
0.1271	0.8460	4.1649	3.5234
0.2264	0.8709	3.2559	2.8357
0.3205	0.8953	2.5436	2.2772
0.4111	0.9196	2.1511	1.9781
0.5110	0.9472	1.7236	1.6326
0.6021	0.9734	1.4322	1.3941
0.7022	1.0033	1.1926	1.1966
0.7953	1.0324	0.9646	0.9958
0.8874	1.0624	0.8461	0.8989
1.0000	1.1013	0.7000	0.7709

Table 4.8 (Cont'd.): Densities and Viscosities of the Binary Systems Chlorobenzene (1) + 1-Hexanol (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6 (m^2/s)$	Absolute Viscosity (mPa.s)
		308.15 K	
0.0000	0.8073	4.1974	3.3887
0.1271	0.8380	3.1680	2.6547
0.2264	0.8626	2.5242	2.1773
0.3205	0.8866	2.0242	1.7948
0.4111	0.9107	1.6615	1.5131
0.5110	0.9380	1.3356	1.2529
0.6021	0.9639	1.1124	1.0722
0.7022	0.9935	0.9158	0.9098
0.7953	1.0224	0.7871	0.8047
0.8874	1.0522	0.6871	0.7229
1.0000	1.0910	0.6249	0.6817

Table 4.8 (Cont'd.): Densities and Viscosities of the Binary Systems Chlorobenzene (1) + 1-Hexanol (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6 (m^2/s)$	Absolute Viscosity (mPa.s)
		313.15 K	
0.0000	0.8040	3.6701	2.9507
0.1271	0.8343	2.7888	2.3267
0.2264	0.8587	2.2410	1.9243
0.3205	0.8826	1.8149	1.6018
0.4111	0.9063	1.5000	1.3595
0.5110	0.9335	1.2286	1.1469
0.6021	0.9591	1.0354	0.9931
0.7022	0.9885	0.8527	0.8429
0.7953	1.0171	0.7380	0.7506
0.8874	1.0466	0.6476	0.6778
1.0000	1.0852	0.5871	0.6371

Table 4.9: Densities and Viscosities of the Binary System: p-Xylene (1) + Octane (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6 (m^2/s)$	Absolute Viscosity (mPa.s)
		293.15 K	
0.0000	0.7025	0.7709	0.5416
0.1335	0.7190	0.7469	0.5371
0.2243	0.7312	0.7387	0.5401
0.3336	0.7462	0.7214	0.5383
0.3985	0.7556	0.7176	0.5422
0.4986	0.7707	0.7131	0.5496
0.5856	0.7846	0.7080	0.5555
0.6830	0.8010	0.7086	0.5676
0.7750	0.8174	0.7150	0.5844
0.8707	0.8353	0.7211	0.6023
1.0000	0.8613	0.7616	0.6560

Table 4.9 (Cont'd.): Densities and Viscosities of the Binary System: p-Xylene (1) + Octane (2).

x_1	Density kg/L	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity (mPa.s)
		298.15 K	
0.0000	0.6980	0.7305	0.5099
0.1335	0.7145	0.7070	0.5052
0.2243	0.7266	0.7000	0.5087
0.3336	0.7416	0.6845	0.5076
0.3985	0.7509	0.6794	0.5102
0.4986	0.7661	0.6759	0.5178
0.5856	0.7799	0.6715	0.5237
0.6830	0.7963	0.6712	0.5345
0.7750	0.8126	0.6765	0.5498
0.8707	0.8305	0.6829	0.5671
1.0000	0.8565	0.7167	0.6139

Table 4.9 (Cont'd.): Densities and Viscosities of the Binary System: p-Xylene (1) + Octane (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6 (m^2/s)$	Absolute Viscosity (mPa.s)
		308.15 K	
0.0000	0.6893	0.6577	0.4534
0.1335	0.7057	0.6373	0.4498
0.2243	0.7178	0.6297	0.4520
0.3336	0.7327	0.6187	0.4533
0.3985	0.7421	0.6135	0.4553
0.4986	0.7571	0.6099	0.4618
0.5856	0.7710	0.6071	0.4681
0.6830	0.7873	0.6052	0.4765
0.7750	0.8036	0.6095	0.4898
0.8707	0.8215	0.6145	0.5048
1.0000	0.8476	0.6368	0.5398

Table 4.9 (Cont'd.): Densities and Viscosities of the Binary System: p-Xylene (1) + Octane (2).

x_1	Density kg/L	Kinematic Viscosity $\times 10^6$ (m^2/s)	Absolute Viscosity (mPa.s)
		313.15 K	
0.0000	0.6855	0.6276	0.4302
0.1335	0.7019	0.6085	0.4272
0.2243	0.7140	0.6035	0.4309
0.3336	0.7288	0.5906	0.4305
0.3985	0.7382	0.5869	0.4332
0.4986	0.7532	0.5834	0.4394
0.5856	0.7670	0.5793	0.4443
0.6830	0.7833	0.5782	0.4529
0.7750	0.7996	0.5821	0.4654
0.8707	0.8175	0.5859	0.4789
1.0000	0.8434	0.6066	0.5116

Table 4.10: Densities and Viscosities of the Binary System: p-Xylene (1) + Ethylbenzene (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6 (m^2/s)$	Absolute Viscosity (mPa.s)
		293.15 K	
0.0000	0.8674	0.7712	0.6689
0.1235	0.8666	0.7679	0.6654
0.2082	0.8661	0.7669	0.6642
0.3060	0.8655	0.7638	0.6611
0.4007	0.8649	0.7636	0.6604
0.5051	0.8643	0.7636	0.6600
0.5963	0.8639	0.7583	0.6551
0.6805	0.8633	0.7562	0.6528
0.7752	0.8627	0.7568	0.6529
0.8513	0.8622	0.7505	0.6471
1.0000	0.8613	0.7616	0.6560

Table 4.10 (Cont'd.): Densities and Viscosities of the Binary System: p-Xylene (1) + Ethylbenzene (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6 (m^2/s)$	Absolute Viscosity (mPa.s)
		298.15 K	
0.0000	0.8625	0.7311	0.6306
0.1235	0.8617	0.7268	0.6263
0.2082	0.8612	0.7276	0.6267
0.3060	0.8607	0.7239	0.6230
0.4007	0.8601	0.7224	0.6213
0.5051	0.8595	0.7210	0.6197
0.5963	0.8591	0.7172	0.6161
0.6805	0.8585	0.7147	0.6136
0.7752	0.8579	0.7151	0.6135
0.8513	0.8574	0.7108	0.6095
1.0000	0.8565	0.7167	0.6139

Table 4.10 (Cont'd.): Densities and Viscosities of the Binary System: p-Xylene (1) + Ethylbenzene (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6 (m^2/s)$	Absolute Viscosity (mPa.s)
		308.15 K	
0.0000	0.8534	0.6558	0.5596
0.1235	0.8526	0.6542	0.5578
0.2082	0.8521	0.6529	0.5563
0.3060	0.8516	0.6495	0.5531
0.4007	0.8510	0.6472	0.5508
0.5051	0.8504	0.6464	0.5497
0.5963	0.8500	0.6434	0.5469
0.6805	0.8494	0.6404	0.5439
0.7752	0.8488	0.6398	0.5431
0.8513	0.8484	0.6372	0.5406
1.0000	0.8476	0.6368	0.5398

Table 4.10 (Cont'd.): Densities and Viscosities of the Binary System: p-Xylene (1) + Ethylbenzene (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6 (m^2/s)$	Absolute Viscosity (mPa.s)
		313.15 K	
0.0000	0.8492	0.6244	0.5303
0.1235	0.8484	0.6216	0.5273
0.2082	0.8479	0.6216	0.5271
0.3060	0.8474	0.6182	0.5239
0.4007	0.8468	0.6165	0.5221
0.5051	0.8462	0.6151	0.5205
0.5963	0.8458	0.6128	0.5183
0.6805	0.8453	0.6098	0.5154
0.7752	0.8447	0.6090	0.5144
0.8513	0.8442	0.6054	0.5111
1.0000	0.8434	0.6066	0.5116

Table 4.11: Densities and Viscosities of the Binary System: p-Xylene (1) + 1-Hexanol (2).

x_1	Density kg/L	Kinematic Viscosity x10^6 (m^2/s)	Absolute Viscosity (mPa.s)
		293.15 K	
0.0000	0.8184	6.5298	5.3443
0.1273	0.8242	4.7911	3.9487
0.2049	0.8275	3.7744	3.1232
0.3086	0.8318	3.0104	2.5041
0.4047	0.8357	2.4380	2.0375
0.5064	0.8399	1.9005	1.5962
0.5913	0.8433	1.6069	1.3552
0.6856	0.8472	1.3260	1.1234
0.7803	0.8512	1.0714	0.9120
0.8733	0.8552	0.8926	0.7633
1.0000	0.8613	0.7616	0.6560

Table 4.11 (Cont'd.): Densities and Viscosities of the Binary System: p-Xylene (1) + 1-Hexanol (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6$ (m^2/s)	Absolute Viscosity (mPa.s)
		298.15 K	
0.0000	0.8144	5.6040	4.5641
0.1273	0.8205	3.9443	3.2361
0.2049	0.8237	3.3389	2.7502
0.3086	0.8279	2.6531	2.1965
0.4047	0.8317	2.1339	1.7748
0.5064	0.8358	1.7349	1.4500
0.5913	0.8391	1.4253	1.1960
0.6856	0.8402	1.1543	0.9698
0.7803	0.8468	1.0054	0.8514
0.8733	0.8506	0.8657	0.7364
1.0000	0.8565	0.7167	0.6139

Table 4.11 (Cont'd.): Densities and Viscosities of the Binary System: p-Xylene (1) + 1-Hexanol (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6$ (m^2/s)	Absolute Viscosity (mPa.s)
		308.15 K	
0.0000	0.8073	4.1974	3.3887
0.1273	0.8135	3.0190	2.4559
0.2049	0.8165	2.4924	2.0351
0.3086	0.8205	2.0748	1.7024
0.4047	0.8242	1.7035	1.4040
0.5064	0.8281	1.4169	1.1733
0.5913	0.8313	1.1847	0.9848
0.6856	0.8350	1.0123	0.8452
0.7803	0.8388	0.8696	0.7294
0.8733	0.8425	0.7335	0.6180
1.0000	0.8476	0.6368	0.5398

Table 4.11 (Cont'd.): Densities and Viscosities of the Binary System: p-Xylene (1) + 1-Hexanol (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6 (m^2/s)$	Absolute Viscosity (mPa.s)
		313.15 K	
0.0000	0.8040	3.6701	2.9507
0.1273	0.8097	2.6613	2.1548
0.2049	0.8126	2.2277	1.8103
0.3086	0.8165	1.8176	1.4841
0.4047	0.8201	1.6458	1.3497
0.5064	0.8239	1.2323	1.0153
0.5913	0.8270	1.1105	0.9185
0.6856	0.8306	0.9136	0.7589
0.7803	0.8343	0.8093	0.6752
0.8733	0.8381	0.7014	0.5878
1.0000	0.8434	0.6066	0.5116

Table 4.12: Densities and Viscosities of the Binary System: Octane (1) + Ethylbenzene (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6 (m^2/s)$	Absolute Viscosity (mPa.s)
		293.15 K	
0.0000	0.8674	0.7712	0.6689
0.1124	0.8430	0.7505	0.6327
0.2141	0.8227	0.7389	0.6079
0.3059	0.8055	0.7287	0.5870
0.4028	0.7884	0.7243	0.5711
0.4942	0.7733	0.7290	0.5637
0.5890	0.7584	0.7269	0.5513
0.6796	0.7449	0.7333	0.5462
0.7456	0.7355	0.7410	0.5450
0.8581	0.7204	0.7509	0.5409
1.0000	0.7025	0.7709	0.5416

Table 4.12 (Cont'd.): Densities and Viscosities of the Binary System: Octane (1) + Ethylbenzene (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6$ (m^2/s)	Absolute Viscosity (mPa.s)
		298.15 K	
0.0000	0.8625	0.7311	0.6306
0.1124	0.8382	0.7096	0.5948
0.2141	0.8180	0.6999	0.5725
0.3059	0.8007	0.6917	0.5539
0.4028	0.7837	0.6865	0.5380
0.4942	0.7686	0.6916	0.5316
0.5890	0.7537	0.6896	0.5197
0.6796	0.7403	0.6963	0.5155
0.7456	0.7310	0.7027	0.5136
0.8581	0.7158	0.7117	0.5094
1.0000	0.6980	0.7305	0.5099

Table 4.12 (Cont'd.): Densities and Viscosities of the Binary System: Octane (1) + Ethylbenzene (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6 (m^2/s)$	Absolute Viscosity (mPa.s)
		308.15 K	
0.0000	0.8534	0.6558	0.5596
0.1124	0.8291	0.6390	0.5298
0.2141	0.8089	0.6310	0.5105
0.3059	0.7918	0.6246	0.4946
0.4028	0.7748	0.6202	0.4805
0.4942	0.7597	0.6228	0.4732
0.5890	0.7448	0.6227	0.4638
0.6796	0.7314	0.6289	0.4600
0.7456	0.7222	0.6397	0.4620
0.8581	0.7070	0.6422	0.4540
1.0000	0.6893	0.6577	0.4534

Table 4.12 (Cont'd.): Densities and Viscosities of the Binary System: Octane (1) + Ethylbenzene (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6$ (m^2/s)	Absolute Viscosity (mPa.s)
		313.15 K	
0.0000	0.8492	0.6244	0.5303
0.1124	0.8250	0.6110	0.5040
0.2141	0.8048	0.6025	0.4849
0.3059	0.7878	0.5963	0.4697
0.4028	0.7708	0.5927	0.4569
0.4942	0.7557	0.5951	0.4498
0.5890	0.7409	0.5957	0.4414
0.6796	0.7276	0.6008	0.4371
0.7456	0.7183	0.6061	0.4354
0.8581	0.7032	0.6124	0.4306
1.0000	0.6855	0.6276	0.4302

Table 4.13: Densities and Viscosities of the Binary System: Octane (1) + 1-Hexanol (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6 (m^2/s)$	Absolute Viscosity (mPa.s)
		293.15 K	
0.0000	0.8184	6.5298	5.3443
0.1104	0.8030	4.7272	3.7960
0.2173	0.7883	3.8530	3.0374
0.3144	0.7756	3.0075	2.3325
0.4188	0.7625	2.2474	1.7137
0.5031	0.7524	1.9131	1.4394
0.5951	0.7421	1.4840	1.1013
0.6975	0.7311	1.3757	1.0058
0.7890	0.7219	1.0505	0.7583
0.8764	0.7135	0.9268	0.6613
1.0000	0.7025	0.7709	0.5416

Table 4.13 (Cont'd.): Densities and Viscosities of the Binary System: Octane (1) + 1-Hexanol (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6 (m^2/s)$	Absolute Viscosity (mPa.s)
		298.15 K	
0.0000	0.8144	5.6040	4.5641
0.1104	0.7989	4.1092	3.2828
0.2173	0.7841	3.2886	2.5786
0.3144	0.7713	2.5822	1.9915
0.4188	0.7581	2.0367	1.5441
0.5031	0.7480	1.7389	1.3007
0.5951	0.7377	1.4161	1.0446
0.6975	0.7267	1.2080	0.8778
0.7890	0.7174	0.9835	0.7056
0.8764	0.7090	0.8541	0.6055
1.0000	0.6980	0.7305	0.5099

Table 4.13 (Cont'd.): Densities and Viscosities of the Binary System: Octane (1) + 1-Hexanol (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6$ (m^2/s)	Absolute Viscosity (mPa.s)
		308.15 K	
0.0000	0.8073	4.1974	3.3887
0.1104	0.7911	3.1361	2.4808
0.2173	0.7761	2.3970	1.8602
0.3144	0.7631	2.1169	1.6153
0.4188	0.7498	1.6722	1.2538
0.5031	0.7396	1.4258	1.0545
0.5951	0.7291	1.2305	0.8972
0.6975	0.7180	1.0066	0.7228
0.7890	0.7087	0.8623	0.6111
0.8764	0.7002	0.7881	0.5518
1.0000	0.6893	0.6577	0.4534

Table 4.13 (Cont'd.): Densities and Viscosities of the Binary System: Octane (1) + 1-Hexanol (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6 (m^2/s)$	Absolute Viscosity (mPa.s)
		313.15 K	
0.0000	0.8040	3.6701	2.9507
0.1104	0.7876	2.7694	2.1812
0.2173	0.7725	2.1391	1.6525
0.3144	0.7595	1.9687	1.4951
0.4188	0.7461	1.5252	1.1380
0.5031	0.7359	1.3248	0.9749
0.5951	0.7254	1.0973	0.7960
0.6975	0.7143	0.9789	0.6992
0.7890	0.7048	0.8203	0.5782
0.8764	0.6963	0.7146	0.4976
1.0000	0.6855	0.6276	0.4302

Table 4.14: Densities and Viscosities of the Binary System: Ethylbenzene (1) + 1-Hexanol (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6$ (m^2/s)	Absolute Viscosity (mPa.s)
		293.15 K	
0.0000	0.8184	6.5298	5.3443
0.1257	0.8249	4.6057	3.7993
0.2131	0.8290	3.6202	3.0011
0.2997	0.8330	3.0949	2.5779
0.4063	0.8378	2.4482	2.0510
0.5064	0.8425	1.9426	1.6366
0.5960	0.8467	1.6365	1.3856
0.6853	0.8510	1.2790	1.0884
0.7906	0.8561	1.0910	0.9341
0.8956	0.8615	0.8978	0.7735
1.0000	0.8674	0.7712	0.6689

Table 4.14 (Cont'd.): Densities and Viscosities of the Binary System: Ethylbenzene (1) + 1-Hexanol (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6$ (m^2/s)	Absolute Viscosity (mPa.s)
		298.15 K	
0.0000	0.8144	5.6040	4.5641
0.1257	0.8207	4.3533	3.5730
0.2131	0.8248	3.5153	2.8994
0.2997	0.8286	2.8841	2.3898
0.4063	0.8333	2.2650	1.8875
0.5064	0.8380	1.8076	1.5147
0.5960	0.8421	1.6189	1.3632
0.6853	0.8469	1.2455	1.0548
0.7906	0.8514	1.0713	0.9121
0.8956	0.8567	0.8897	0.7622
1.0000	0.8625	0.7311	0.6306

Table 4.14 (Cont'd.): Densities and Viscosities of the Binary System: Ethylbenzene (1) + 1-Hexanol (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6$ (m^2/s)	Absolute Viscosity (mPa.s)
		308.15 K	
0.0000	0.8073	4.1974	3.3887
0.1257	0.8129	3.0556	2.4839
0.2131	0.8167	2.6847	2.1926
0.2997	0.8204	2.2500	1.8458
0.4063	0.8250	1.7400	1.4355
0.5064	0.8294	1.4939	1.2391
0.5960	0.8334	1.2553	1.0461
0.6853	0.8375	1.0461	0.8761
0.7906	0.8424	0.8756	0.7377
0.8956	0.8476	0.7506	0.6362
1.0000	0.8534	0.6558	0.5596

Table 4.14 (Cont'd.): Densities and Viscosities of the Binary System: Ethylbenzene (1) + 1-Hexanol (2).

x_1	Density kg/L	Kinematic Viscosity $x10^6 (m^2/s)$	Absolute Viscosity (mPa.s)
		313.15 K	
0.0000	0.8040	3.6701	2.9507
0.1257	0.8091	2.6956	2.1809
0.2131	0.8131	2.3700	1.9270
0.2997	0.8167	1.8802	1.5355
0.4063	0.8212	1.5722	1.2911
0.5064	0.8255	1.2635	1.0430
0.5960	0.8294	1.1349	0.9413
0.6853	0.8335	0.9680	0.8068
0.7906	0.8383	0.7959	0.6672
0.8956	0.8434	0.6965	0.5874
1.0000	0.8492	0.6244	0.5303

4.5 Ternary Systems Results

The kinematic viscosities and densities of ten ternary sub-systems of the quinary system: Chlorobenzene, p-xylene, octane, ethylbenzene, and 1-hexanol are reported in Tables 4.15 through 4.24. Each system consists of seven samples for which the measurements were conducted at 293.15, 298.15, 308.15, and 313 K. The absolute viscosity values were calculated from the density values and the corresponding kinematic viscosity values and reported in the aforementioned tables.

4.6 Quaternary Systems Results

The kinematic viscosities, densities, and calculated absolute viscosity values of five quaternary sub-systems of the quinary system: Chlorobenzene, p-xylene, octane, ethylbenzene, and 1-hexanol mixtures are reported in Tables 4.25 through 4.29. These data were measured over the entire composition range and at 293.15, 298.15, 308.15, and 313 K.

4.7 Quinary Systems Results

The kinematic viscosities and densities and the calculated absolute viscosity values of the quinary system: Chlorobenzene, p-xylene, octane, ethylbenzene, and 1-hexanol at 293.15, 298.15, 308.15, and 313 K are reported in Table 4.30.

Table 4.15: Densities and Viscosities of the Ternary System: Chlorobenzene (1) + p-Xylene (2) + Octane (3).

T (K)	x_1	x_2	x_3	Density kg/L	Kinematic Viscosity x10^6 (m^2/s)	Absolute Viscosity (mPa.s)
293.15	1.0000	0.0000	0.0000	1.1067	0.7260	0.8035
	0.0000	1.0000	0.0000	0.8613	0.7616	0.6560
	0.0000	0.0000	1.0000	0.7025	0.7709	0.5416
	0.1320	0.1764	0.6916	0.7629	0.7248	0.5529
	0.2162	0.6230	0.1608	0.8718	0.7234	0.6307
	0.3436	0.3172	0.3392	0.8606	0.7078	0.6091
	0.4115	0.1989	0.3896	0.8637	0.7074	0.6110
	0.4979	0.3787	0.1233	0.9410	0.7256	0.6828
	0.5905	0.2443	0.1652	0.9518	0.7184	0.6837
	0.6868	0.1045	0.2087	0.9631	0.7080	0.6819
298.15	1.0000	0.0000	0.0000	1.1013	0.7000	0.7709
	0.0000	1.0000	0.0000	0.8565	0.7167	0.6139
	0.0000	0.0000	1.0000	0.6980	0.7305	0.5099
	0.1320	0.1764	0.6916	0.7582	0.6866	0.5206
	0.2162	0.6230	0.1608	0.8669	0.6870	0.5956
	0.3436	0.3172	0.3392	0.8557	0.6710	0.5742
	0.4115	0.1989	0.3896	0.8587	0.6722	0.5772
	0.4979	0.3787	0.1233	0.9359	0.6852	0.6413
	0.5905	0.2443	0.1652	0.9466	0.6862	0.6496
	0.6868	0.1045	0.2087	0.9579	0.6699	0.6416

Table 4.15 (Cont'd.): Densities and Viscosities of the Ternary System: Chlorobenzene (1) + p-Xylene (2) + Octane (3).

T (K)	x_1	x_2	x_3	Density kg/L	Kinematic Viscosity x10^6 (m^2/s)	Absolute Viscosity (mPa.s)
308.15	1.0000	0.0000	0.0000	1.0910	0.6249	0.6817
	0.0000	1.0000	0.0000	0.8476	0.6368	0.5398
	0.0000	0.0000	1.0000	0.6893	0.6577	0.4534
	0.1320	0.1764	0.6916	0.7492	0.6191	0.4638
	0.2162	0.6230	0.1608	0.8576	0.6175	0.5296
	0.3436	0.3172	0.3392	0.8462	0.6052	0.5122
	0.4115	0.1989	0.3896	0.8492	0.6079	0.5163
	0.4979	0.3787	0.1233	0.9262	0.6155	0.5701
	0.5905	0.2443	0.1652	0.9368	0.6106	0.5720
	0.6868	0.1045	0.2087	0.9479	0.6015	0.5701
313.15	1.0000	0.0000	0.0000	1.0852	0.5871	0.6371
	0.0000	1.0000	0.0000	0.8434	0.6066	0.5116
	0.0000	0.0000	1.0000	0.6855	0.6276	0.4302
	0.1320	0.1764	0.6916	0.7452	0.5916	0.4408
	0.2162	0.6230	0.1608	0.8533	0.5882	0.5019
	0.3436	0.3172	0.3392	0.8419	0.5776	0.4863
	0.4115	0.1989	0.3896	0.8448	0.5830	0.4925
	0.4979	0.3787	0.1233	0.9215	0.5867	0.5406
	0.5905	0.2443	0.1652	0.9320	0.5811	0.5416
	0.6868	0.1045	0.2087	0.9430	0.5820	0.5488

Table 4.16: Densities and Viscosities of the Ternary System: Chlorobenzene (1) + Octane (2) + Ethylbenzene (3).

T (K)	x_1	x_2	x_3	Density kg/L	Kinematic Viscosity x10^6 (m^2/s)	Absolute Viscosity (mPa.s)
293.15	1.0000	0.0000	0.0000	1.1067	0.7260	0.8035
	0.0000	1.0000	0.0000	0.7025	0.7709	0.5416
	0.0000	0.0000	1.0000	0.8674	0.7712	0.6689
	0.1609	0.1551	0.6840	0.8654	0.7434	0.6434
	0.2256	0.6265	0.1479	0.7884	0.7218	0.5690
	0.3318	0.3343	0.3339	0.8609	0.7180	0.6181
	0.3999	0.2162	0.3839	0.9001	0.7305	0.6575
	0.4913	0.4011	0.1076	0.8776	0.7064	0.6199
	0.5621	0.2857	0.1522	0.9175	0.7109	0.6522
	0.6802	0.1191	0.2007	0.9866	0.7276	0.7178
298.15	1.0000	0.0000	0.0000	1.1013	0.7000	0.7709
	0.0000	1.0000	0.0000	0.6980	0.7305	0.5099
	0.0000	0.0000	1.0000	0.8625	0.7311	0.6306
	0.1609	0.1551	0.6840	0.8605	0.7065	0.6080
	0.2256	0.6265	0.1479	0.7836	0.6846	0.5365
	0.3318	0.3343	0.3339	0.8559	0.6400	0.5478
	0.3999	0.2162	0.3839	0.8951	0.6894	0.6170
	0.4913	0.4011	0.1076	0.8725	0.6698	0.5844
	0.5621	0.2857	0.1522	0.9124	0.6722	0.6133
	0.6802	0.1191	0.2007	0.9814	0.6874	0.6746

Table 4.16 (Cont'd.): Densities and Viscosities of the Ternary System: Chlorobenzene (1) + Octane (2) + Ethylbenzene (3).

T (K)	x_1	x_2	x_3	Density kg/L	Kinematic Viscosity x10^6 (m^2/s)	Absolute Viscosity (mPa.s)
308.15	1.0000	0.0000	0.0000	1.0910	0.6249	0.6817
	0.0000	1.0000	0.0000	0.6893	0.6577	0.4534
	0.0000	0.0000	1.0000	0.8534	0.6558	0.5596
	0.1609	0.1551	0.6840	0.8512	0.6351	0.5406
	0.2256	0.6265	0.1479	0.7745	0.6181	0.4787
	0.3318	0.3343	0.3339	0.8465	0.6128	0.5187
	0.3999	0.2162	0.3839	0.8855	0.6199	0.5489
	0.4913	0.4011	0.1076	0.8629	0.6049	0.5219
	0.5621	0.2857	0.1522	0.9026	0.6060	0.5470
	0.6802	0.1191	0.2007	0.9713	0.6177	0.6000
313.15	1.0000	0.0000	0.0000	1.0852	0.5871	0.6371
	0.0000	1.0000	0.0000	0.6855	0.6276	0.4302
	0.0000	0.0000	1.0000	0.8492	0.6244	0.5303
	0.1609	0.1551	0.6840	0.8470	0.6042	0.5118
	0.2256	0.6265	0.1479	0.7704	0.5900	0.4545
	0.3318	0.3343	0.3339	0.8421	0.5856	0.4931
	0.3999	0.2162	0.3839	0.8809	0.5766	0.5080
	0.4913	0.4011	0.1076	0.8584	0.5772	0.4955
	0.5621	0.2857	0.1522	0.8979	0.5789	0.5198
	0.6802	0.1191	0.2007	0.9663	0.5736	0.5543

Table 4.17: Densities and Viscosities of the Ternary System: Chlorobenzene (1) + p-Xylene (2) + Ethylbenzene (3).

T (K)	x_1	x_2	x_3	Density kg/L	Kinematic Viscosity x10^6 (m^2/s)	Absolute Viscosity (mPa.s)
293.15	1.0000	0.0000	0.0000	1.1067	0.7260	0.8035
	0.0000	1.0000	0.0000	0.8613	0.7616	0.6560
	0.0000	0.0000	1.0000	0.8674	0.7712	0.6689
	0.1254	0.1579	0.7167	0.8923	0.7691	0.6863
	0.2246	0.6279	0.1476	0.9101	0.7554	0.6875
	0.3456	0.3375	0.3169	0.9389	0.7375	0.6924
	0.4094	0.1825	0.4082	0.9545	0.7463	0.7124
	0.5094	0.3842	0.1063	0.9762	0.7377	0.7202
	0.5909	0.2528	0.1563	0.9969	0.7355	0.7332
	0.6871	0.1116	0.2013	1.0219	0.7292	0.7452
298.15	1.0000	0.0000	0.0000	1.1013	0.7000	0.7709
	0.0000	1.0000	0.0000	0.8565	0.7167	0.6139
	0.0000	0.0000	1.0000	0.8625	0.7311	0.6306
	0.1254	0.1579	0.7167	0.8874	0.7274	0.6455
	0.2246	0.6279	0.1476	0.9052	0.7138	0.6461
	0.3456	0.3375	0.3169	0.9338	0.7233	0.6754
	0.4094	0.1825	0.4082	0.9494	0.7198	0.6834
	0.5094	0.3842	0.1063	0.9710	0.7070	0.6865
	0.5909	0.2528	0.1563	0.9917	0.7193	0.7133
	0.6871	0.1116	0.2013	1.0167	0.7058	0.7176

Table 4.17 (Cont'd.): Densities and Viscosities of the Ternary System: Chlorobenzene (1) + p-Xylene (2) + Ethylbenzene (3).

T (K)	x_1	x_2	x_3	Density kg/L	Kinematic Viscosity x10^6 (m^2/s)	Absolute Viscosity (mPa.s)
308.15	1.0000	0.0000	0.0000	1.0910	0.6249	0.6817
	0.0000	1.0000	0.0000	0.8476	0.6368	0.5398
	0.0000	0.0000	1.0000	0.8534	0.6558	0.5596
	0.1254	0.1579	0.7167	0.8781	0.6531	0.5735
	0.2246	0.6279	0.1476	0.8958	0.6391	0.5725
	0.3456	0.3375	0.3169	0.9243	0.6490	0.5998
	0.4094	0.1825	0.4082	0.9397	0.6502	0.6111
	0.5094	0.3842	0.1063	0.9613	0.6331	0.6086
	0.5909	0.2528	0.1563	0.9818	0.6467	0.6350
	0.6871	0.1116	0.2013	1.0067	0.6324	0.6367
313.15	1.0000	0.0000	0.0000	1.0852	0.5871	0.6371
	0.0000	1.0000	0.0000	0.8434	0.6066	0.5116
	0.0000	0.0000	1.0000	0.8492	0.6244	0.5303
	0.1254	0.1579	0.7167	0.8738	0.6207	0.5423
	0.2246	0.6279	0.1476	0.8914	0.6084	0.5424
	0.3456	0.3375	0.3169	0.9196	0.6208	0.5709
	0.4094	0.1825	0.4082	0.9350	0.6123	0.5725
	0.5094	0.3842	0.1063	0.9565	0.6022	0.5760
	0.5909	0.2528	0.1563	0.9768	0.6182	0.6039
	0.6871	0.1116	0.2013	1.0015	0.6012	0.6021

Table 4.18: Densities and Viscosities of the Ternary System: Chlorobenzene (1) + Octane (2) + 1-Hexanol (3).

T (K)	x_1	x_2	x_3	Density kg/L	Kinematic Viscosity x10^6 (m^2/s)	Absolute Viscosity (mPa.s)
293.15	1.0000	0.0000	0.0000	1.1067	0.7260	0.8035
	0.0000	1.0000	0.0000	0.7025	0.7709	0.5416
	0.0000	0.0000	1.0000	0.8184	6.5298	5.3443
	0.1275	0.1592	0.7134	0.8252	3.2407	2.6741
	0.2251	0.6159	0.1590	0.7833	0.9315	0.7297
	0.3302	0.3273	0.3426	0.8460	1.4559	1.2317
	0.3863	0.2206	0.3931	0.8784	1.5455	1.3576
	0.4893	0.3979	0.1128	0.8722	0.8521	0.7432
	0.5880	0.2541	0.1579	0.9221	0.9021	0.8318
	0.6732	0.1193	0.2075	0.9727	1.0715	1.0423
298.15	1.0000	0.0000	0.0000	1.1013	0.7000	0.7709
	0.0000	1.0000	0.0000	0.6980	0.7305	0.5099
	0.0000	0.0000	1.0000	0.8144	5.6040	4.5641
	0.1275	0.1592	0.7134	0.8207	2.8184	2.3132
	0.2251	0.6159	0.1590	0.7786	0.8773	0.6831
	0.3302	0.3273	0.3426	0.8412	1.2890	1.0842
	0.3863	0.2206	0.3931	0.8736	1.3899	1.2142
	0.4893	0.3979	0.1128	0.8672	0.7849	0.6806
	0.5880	0.2541	0.1579	0.9170	0.8139	0.7463
	0.6732	0.1193	0.2075	0.9675	0.8960	0.8669

Table 4.18 (Cont'd.): Densities and Viscosities of the Ternary System: Chlorobenzene (1) + Octane (2) + 1-Hexanol (3).

T (K)	x_1	x_2	x_3	Density kg/L	Kinematic Viscosity $x10^6 (m^2/s)$	Absolute Viscosity (mPa.s)
308.15	1.0000	0.0000	0.0000	1.0910	0.6249	0.6817
	0.0000	1.0000	0.0000	0.6893	0.6577	0.4534
	0.0000	0.0000	1.0000	0.8073	4.1974	3.3887
	0.1275	0.1592	0.7134	0.8124	2.1826	1.7732
	0.2251	0.6159	0.1590	0.7695	0.7844	0.6036
	0.3302	0.3273	0.3426	0.8320	1.0872	0.9045
	0.3863	0.2206	0.3931	0.8644	1.1394	0.9849
	0.4893	0.3979	0.1128	0.8575	0.6931	0.5943
	0.5880	0.2541	0.1579	0.9071	0.7738	0.7020
	0.6732	0.1193	0.2075	0.9577	0.7907	0.7572
313.15	1.0000	0.0000	0.0000	1.0852	0.5871	0.6371
	0.0000	1.0000	0.0000	0.6855	0.6276	0.4302
	0.0000	0.0000	1.0000	0.8040	3.6701	2.9507
	0.1275	0.1592	0.7134	0.8087	1.8817	1.5217
	0.2251	0.6159	0.1590	0.7654	0.6939	0.5311
	0.3302	0.3273	0.3426	0.8278	0.8945	0.7405
	0.3863	0.2206	0.3931	0.8601	1.0028	0.8625
	0.4893	0.3979	0.1128	0.8530	0.6417	0.5474
	0.5880	0.2541	0.1579	0.9025	0.6817	0.6152
	0.6732	0.1193	0.2075	0.9527	0.7587	0.7228

Table 4.19: Densities and Viscosities of the Ternary System: Chlorobenzene (1) + Ethylbenzene (2) + 1-Hexanol (3).

T (K)	x_1	x_2	x_3	Density kg/L	Kinematic Viscosity $x10^6$ (m^2/s)	Absolute Viscosity (mPa.s)
293.15	1.0000	0.0000	0.0000	1.1067	0.7260	0.8035
	0.0000	1.0000	0.0000	0.8674	0.7712	0.6689
	0.0000	0.0000	1.0000	0.8184	6.5298	5.3443
	0.1234	0.1548	0.7218	0.8567	3.1706	2.7162
	0.2161	0.6241	0.1598	0.9036	0.9233	0.8343
	0.3395	0.3259	0.3346	0.9214	1.2507	1.1523
	0.3993	0.2028	0.3978	0.9314	1.4332	1.3349
	0.4975	0.3854	0.1171	0.9693	0.8611	0.8347
	0.5856	0.2553	0.1591	0.9879	0.9138	0.9027
	0.6839	0.1117	0.2044	1.0092	0.9795	0.9885
298.15	1.0000	0.0000	0.0000	1.1013	0.7000	0.7709
	0.0000	1.0000	0.0000	0.8625	0.7311	0.6306
	0.0000	0.0000	1.0000	0.8144	5.6040	4.5641
	0.1234	0.1548	0.7218	0.8523	3.0137	2.5686
	0.2161	0.6241	0.1598	0.8987	0.8711	0.7828
	0.3395	0.3259	0.3346	0.9165	1.1861	1.0870
	0.3993	0.2028	0.3978	0.9265	1.3345	1.2365
	0.4975	0.3854	0.1171	0.9642	0.8076	0.7786
	0.5856	0.2553	0.1591	0.9827	0.8539	0.8391
	0.6839	0.1117	0.2044	1.0040	0.9212	0.9249

Table 4.19 (Cont'd.): Densities and Viscosities of the Ternary System: Chlorobenzene (1) + Ethylbenzene (2) + 1-Hexanol (3).

T (K)	x_1	x_2	x_3	Density kg/L	Kinematic Viscosity $x10^6(m^2/s)$	Absolute Viscosity (mPa.s)
308.15	1.0000	0.0000	0.0000	1.0910	0.6249	0.6817
	0.0000	1.0000	0.0000	0.8534	0.6558	0.5596
	0.0000	0.0000	1.0000	0.8073	4.1974	3.3887
	0.1234	0.1548	0.7218	0.8440	2.1815	1.8411
	0.2161	0.6241	0.1598	0.8893	0.7573	0.6735
	0.3395	0.3259	0.3346	0.9072	0.9927	0.9005
	0.3993	0.2028	0.3978	0.9173	1.1081	1.0164
	0.4975	0.3854	0.1171	0.9544	0.7126	0.6801
	0.5856	0.2553	0.1591	0.9728	0.7476	0.7273
	0.6839	0.1117	0.2044	0.9941	0.8023	0.7976
313.15	1.0000	0.0000	0.0000	1.0852	0.5871	0.6371
	0.0000	1.0000	0.0000	0.8492	0.6244	0.5303
	0.0000	0.0000	1.0000	0.8040	3.6701	2.9507
	0.1234	0.1548	0.7218	0.8401	1.9738	1.6582
	0.2161	0.6241	0.1598	0.8849	0.7136	0.6315
	0.3395	0.3259	0.3346	0.9027	0.9181	0.8288
	0.3993	0.2028	0.3978	0.9128	1.0279	0.9383
	0.4975	0.3854	0.1171	0.9495	0.6748	0.6408
	0.5856	0.2553	0.1591	0.9679	0.7041	0.6815
	0.6839	0.1117	0.2044	0.9891	0.7454	0.7372

Table 4.20: Densities and Viscosities of the Ternary System: Chlorobenzene (1) + p-Xylene (2) + 1-Hexanol (3).

T (K)	x_1	x_2	x_3	Density kg/L	Kinematic Viscosity $x10^6 (m^2/s)$	Absolute Viscosity (mPa.s)
293.15	1.0000	0.0000	0.0000	1.1067	0.7260	0.8035
	0.0000	1.0000	0.0000	0.8613	0.7616	0.6560
	0.0000	0.0000	1.0000	0.8184	6.5298	5.3443
	0.1189	0.1549	0.7262	0.8549	3.1554	2.6975
	0.2142	0.6302	0.1556	0.8995	0.8921	0.8024
	0.3346	0.3262	0.3391	0.8192	1.3422	1.0996
	0.4072	0.2051	0.3876	0.9325	1.4633	1.3645
	0.4884	0.3925	0.1192	0.9639	0.8485	0.8180
	0.5880	0.2474	0.1646	0.9861	0.9114	0.8987
	0.6805	0.1135	0.2061	1.0074	0.9780	0.9853
298.15	1.0000	0.0000	0.0000	1.1013	0.7000	0.7709
	0.0000	1.0000	0.0000	0.8565	0.7167	0.6139
	0.0000	0.0000	1.0000	0.8144	5.6040	4.5641
	0.1189	0.1549	0.7262	0.8505	2.7537	2.3419
	0.2142	0.6302	0.1556	0.8946	0.8324	0.7447
	0.3346	0.3262	0.3391	0.9131	1.2381	1.1305
	0.4072	0.2051	0.3876	0.9276	1.3585	1.2602
	0.4884	0.3925	0.1192	0.9588	0.7963	0.7635
	0.5880	0.2474	0.1646	0.9810	0.8493	0.8332
	0.6805	0.1135	0.2061	1.0022	0.9097	0.9117

Table 4.20 (Cont'd.): Densities and Viscosities of the Ternary System: Chlorobenzene (1) + p-Xylene (2) + 1-Hexanol (3).

T (K)	x_1	x_2	x_3	Density kg/L	Kinematic Viscosity $x10^6 (m^2/s)$	Absolute Viscosity (mPa.s)
308.15	1.0000	0.0000	0.0000	1.0910	0.6249	0.6817
	0.0000	1.0000	0.0000	0.8476	0.6368	0.5398
	0.0000	0.0000	1.0000	0.8073	4.1974	3.3887
	0.1189	0.1549	0.7262	0.8421	2.1764	1.8329
	0.2142	0.6302	0.1556	0.8853	0.7338	0.6497
	0.3346	0.3262	0.3391	0.9039	0.9754	0.8817
	0.4072	0.2051	0.3876	0.9183	1.0839	0.9954
	0.4884	0.3925	0.1192	0.9492	0.7013	0.6656
	0.5880	0.2474	0.1646	0.9712	0.7451	0.7237
	0.6805	0.1135	0.2061	0.9924	0.7944	0.7884
313.15	1.0000	0.0000	0.0000	1.0852	0.5871	0.6371
	0.0000	1.0000	0.0000	0.8434	0.6066	0.5116
	0.0000	0.0000	1.0000	0.8040	3.6701	2.9507
	0.1189	0.1549	0.7262	0.8383	1.9629	1.6456
	0.2142	0.6302	0.1556	0.8809	0.6888	0.6067
	0.3346	0.3262	0.3391	0.8995	0.9071	0.8159
	0.4072	0.2051	0.3876	0.9138	0.9995	0.9133
	0.4884	0.3925	0.1192	0.9444	0.6613	0.6245
	0.5880	0.2474	0.1646	0.9663	0.7001	0.6765
	0.6805	0.1135	0.2061	0.9873	0.7415	0.7321

Table 4.21: Densities and Viscosities of the Ternary System: p-Xylene (1) + Octane (2) + Ethylbenzene (3).

T (K)	x_1	x_2	x_3	Density kg/L	Kinematic Viscosity $x10^6$ (m^2/s)	Absolute Viscosity (mPa.s)
293.15	1.0000	0.0000	0.0000	0.8613	0.7616	0.6560
	0.0000	1.0000	0.0000	0.7025	0.7709	0.5416
	0.0000	0.0000	1.0000	0.8674	0.7712	0.6689
	0.1088	0.1584	0.7328	0.8332	0.7405	0.6169
	0.2021	0.6300	0.1679	0.7518	0.7245	0.5447
	0.3289	0.3274	0.3436	0.8004	0.7222	0.5781
	0.3836	0.2069	0.4095	0.8225	0.7270	0.5980
	0.4854	0.3922	0.1224	0.7887	0.7126	0.5620
	0.5719	0.2618	0.1662	0.8113	0.7193	0.5835
	0.6667	0.1163	0.2170	0.8389	0.7318	0.6139
298.15	1.0000	0.0000	0.0000	0.8565	0.7167	0.6139
	0.0000	1.0000	0.0000	0.6980	0.7305	0.5099
	0.0000	0.0000	1.0000	0.8625	0.7311	0.6306
	0.1088	0.1584	0.7328	0.8284	0.7023	0.5818
	0.2021	0.6300	0.1679	0.7471	0.6865	0.5129
	0.3289	0.3274	0.3436	0.7957	0.6839	0.5442
	0.3836	0.2069	0.4095	0.8177	0.6894	0.5637
	0.4854	0.3922	0.1224	0.7840	0.6749	0.5291
	0.5719	0.2618	0.1662	0.8065	0.6848	0.5523
	0.6667	0.1163	0.2170	0.8342	0.6927	0.5779

Table 4.21 (Cont'd.): Densities and Viscosities of the Ternary System: p-Xylene (1) + Octane (2) + Ethylbenzene (3).

T (K)	x_1	x_2	x_3	Density kg/L	Kinematic Viscosity $x10^6 (m^2/s)$	Absolute Viscosity (mPa.s)
308.15	1.0000	0.0000	0.0000	0.8476	0.6368	0.5398
	0.0000	1.0000	0.0000	0.6893	0.6577	0.4534
	0.0000	0.0000	1.0000	0.8534	0.6558	0.5596
	0.1088	0.1584	0.7328	0.8193	0.6328	0.5185
	0.2021	0.6300	0.1679	0.7383	0.6200	0.4577
	0.3289	0.3274	0.3436	0.7868	0.6173	0.4857
	0.3836	0.2069	0.4095	0.8087	0.6211	0.5023
	0.4854	0.3922	0.1224	0.7750	0.6088	0.4719
	0.5719	0.2618	0.1662	0.7976	0.6136	0.4894
	0.6667	0.1163	0.2170	0.8251	0.6231	0.5141
313.15	1.0000	0.0000	0.0000	0.8434	0.6066	0.5116
	0.0000	1.0000	0.0000	0.6855	0.6276	0.4302
	0.0000	0.0000	1.0000	0.8492	0.6244	0.5303
	0.1088	0.1584	0.7328	0.8152	0.6042	0.4926
	0.2021	0.6300	0.1679	0.7344	0.5927	0.4353
	0.3289	0.3274	0.3436	0.7827	0.5896	0.4615
	0.3836	0.2069	0.4095	0.8046	0.5928	0.4770
	0.4854	0.3922	0.1224	0.7711	0.5826	0.4492
	0.5719	0.2618	0.1662	0.7936	0.5870	0.4658
	0.6667	0.1163	0.2170	0.8210	0.5941	0.4878

**Table 4.22: Densities and Viscosities of the Ternary System:
p-Xylene (1) + Ethylbenzene (2) + 1-Hexanol (3).**

T (K)	x_1	x_2	x_3	Density kg/L	Kinematic Viscosity x10^6 (m^2/s)	Absolute Viscosity (mPa.s)
293.15	1.0000	0.0000	0.0000	0.8613	0.7616	0.6560
	0.0000	1.0000	0.0000	0.8674	0.7712	0.6689
	0.0000	0.0000	1.0000	0.8184	6.5298	5.3443
	0.1113	0.1693	0.7195	0.8316	3.1936	2.6558
	0.2029	0.6321	0.1650	0.8572	0.9514	0.8156
	0.3175	0.3394	0.3431	0.8480	1.3871	1.1763
	0.3896	0.2146	0.3958	0.8452	1.5900	1.3439
	0.4764	0.4000	0.1236	0.8579	0.8577	0.7358
	0.5722	0.2644	0.1634	0.8553	0.9024	0.7719
	0.6561	0.1290	0.2149	0.8524	1.0044	0.8562
298.15	1.0000	0.0000	0.0000	0.8565	0.7167	0.6139
	0.0000	1.0000	0.0000	0.8625	0.7311	0.6306
	0.0000	0.0000	1.0000	0.8144	5.6040	4.5641
	0.1113	0.1693	0.7195	0.8273	2.9082	2.4059
	0.2029	0.6321	0.1650	0.8525	0.8596	0.7328
	0.3175	0.3394	0.3431	0.8434	1.2565	1.0597
	0.3896	0.2146	0.3958	0.8405	1.3988	1.1756
	0.4764	0.4000	0.1236	0.8530	0.8040	0.6859
	0.5722	0.2644	0.1634	0.8506	0.8434	0.7174
	0.6561	0.1290	0.2149	0.8478	0.9402	0.7971

Table 4.22 (Cont'd.): Densities and Viscosities of the Ternary System: p-Xylene (1) + Ethylbenzene (2) + 1-Hexanol (3).

T (K)	x_1	x_2	x_3	Density kg/L	Kinematic Viscosity x10^6 (m^2/s)	Absolute Viscosity (mPa.s)
308.15	1.0000	0.0000	0.0000	0.8476	0.6368	0.5398
	0.0000	1.0000	0.0000	0.8534	0.6558	0.5596
	0.0000	0.0000	1.0000	0.8073	4.1974	3.3887
	0.1113	0.1693	0.7195	0.8191	2.3668	1.9386
	0.2029	0.6321	0.1650	0.8435	0.7473	0.6303
	0.3175	0.3394	0.3431	0.8345	1.0963	0.9149
	0.3896	0.2146	0.3958	0.8319	1.2170	1.0124
	0.4764	0.4000	0.1236	0.8440	0.7112	0.6003
	0.5722	0.2644	0.1634	0.8416	0.7423	0.6248
	0.6561	0.1290	0.2149	0.8388	0.7901	0.6627
313.15	1.0000	0.0000	0.0000	0.8434	0.6066	0.5116
	0.0000	1.0000	0.0000	0.8492	0.6244	0.5303
	0.0000	0.0000	1.0000	0.8040	3.6701	2.9507
	0.1113	0.1693	0.7195	0.8154	1.8854	1.5373
	0.2029	0.6321	0.1650	0.8393	0.7132	0.5986
	0.3175	0.3394	0.3431	0.8306	1.0053	0.8350
	0.3896	0.2146	0.3958	0.8279	1.1047	0.9147
	0.4764	0.4000	0.1236	0.8399	0.6469	0.5433
	0.5722	0.2644	0.1634	0.8375	0.6993	0.5857
	0.6561	0.1290	0.2149	0.8347	0.7612	0.6354

Table 4.23: Densities and Viscosities of the Ternary System: p-Xylene (1) + Octane (2) + 1-Hexanol (3).

T (K)	x_1	x_2	x_3	Density kg/L	Kinematic Viscosity x10^6 (m^2/s)	Absolute Viscosity (mPa.s)
293.15	1.0000	0.0000	0.0000	0.8613	0.7616	0.6560
	0.0000	1.0000	0.0000	0.7025	0.7709	0.5416
	0.0000	0.0000	1.0000	0.8184	6.5298	5.3443
	0.1076	0.1620	0.7305	0.8000	3.2218	2.5776
	0.2190	0.6234	0.1576	0.7465	0.9099	0.6792
	0.3121	0.3365	0.3515	0.7865	1.3652	1.0738
	0.3976	0.2265	0.3758	0.8039	1.4187	1.1405
	0.4918	0.3994	0.1088	0.7827	0.8653	0.6772
	0.5825	0.2564	0.1612	0.8049	0.9457	0.7612
	0.6740	0.1227	0.2032	0.8279	1.0024	0.8298
298.15	1.0000	0.0000	0.0000	0.8565	0.7167	0.6139
	0.0000	1.0000	0.0000	0.6980	0.7305	0.5099
	0.0000	0.0000	1.0000	0.8144	5.6040	4.5641
	0.1076	0.1620	0.7305	0.7957	2.9119	2.3171
	0.2190	0.6234	0.1576	0.7419	0.8582	0.6367
	0.3121	0.3365	0.3515	0.7819	1.2720	0.9947
	0.3976	0.2265	0.3758	0.7993	1.3814	1.1042
	0.4918	0.3994	0.1088	0.7780	0.7985	0.6212
	0.5825	0.2564	0.1612	0.8002	0.8748	0.7001
	0.6740	0.1227	0.2032	0.8232	0.9574	0.7881

Table 4.23 (Cont'd.): Densities and Viscosities of the Ternary System: p-Xylene (1) + Octane (2) + 1-Hexanol (3).

T (K)	x_1	x_2	x_3	Density kg/L	Kinematic Viscosity $x10^6 (m^2/s)$	Absolute Viscosity (mPa.s)
308.15	1.0000	0.0000	0.0000	0.8476	0.6368	0.5398
	0.0000	1.0000	0.0000	0.6893	0.6577	0.4534
	0.0000	0.0000	1.0000	0.8073	4.1974	3.3887
	0.1076	0.1620	0.7305	0.7876	2.3668	1.8640
	0.2190	0.6234	0.1576	0.7330	0.7713	0.5654
	0.3121	0.3365	0.3515	0.7732	1.0477	0.8101
	0.3976	0.2265	0.3758	0.7906	1.0897	0.8615
	0.4918	0.3994	0.1088	0.7690	0.7223	0.5554
	0.5825	0.2564	0.1612	0.7913	0.7577	0.5996
	0.6740	0.1227	0.2032	0.8143	0.7916	0.6446
313.15	1.0000	0.0000	0.0000	0.8434	0.6066	0.5116
	0.0000	1.0000	0.0000	0.6855	0.6276	0.4302
	0.0000	0.0000	1.0000	0.8040	3.6701	2.9507
	0.1076	0.1620	0.7305	0.7840	2.0628	1.6172
	0.2190	0.6234	0.1576	0.7291	0.7239	0.5278
	0.3121	0.3365	0.3515	0.7694	1.0154	0.7812
	0.3976	0.2265	0.3758	0.7867	1.0058	0.7913
	0.4918	0.3994	0.1088	0.7650	0.6596	0.5046
	0.5825	0.2564	0.1612	0.7873	0.7265	0.5720
	0.6740	0.1227	0.2032	0.8103	0.7770	0.6295

**Table 4.24: Densities and Viscosities of the Ternary System:
Octane (1) + Ethylbenzene (2) + 1-Hexanol (3).**

T (K)	x_1	x_2	x_3	Density kg/L	Kinematic Viscosity $x10^6$ (m^2/s)	Absolute Viscosity (mPa.s)
293.15	1.0000	0.0000	0.0000	0.7025	0.7709	0.5416
	0.0000	1.0000	0.0000	0.8674	0.7712	0.6689
	0.0000	0.0000	1.0000	0.8184	6.5298	5.3443
	0.1133	0.1586	0.7281	0.8095	3.3185	2.6865
	0.2104	0.6310	0.1586	0.8158	0.9234	0.7533
	0.3249	0.3297	0.3454	0.7871	1.3591	1.0698
	0.3987	0.2028	0.3985	0.7726	1.5651	1.2093
	0.4949	0.3942	0.1109	0.7683	0.8352	0.6417
	0.5751	0.2621	0.1627	0.7539	0.9557	0.7205
	0.6762	0.1153	0.2085	0.7375	1.0526	0.7763
298.15	1.0000	0.0000	0.0000	0.6980	0.7305	0.5099
	0.0000	1.0000	0.0000	0.8625	0.7311	0.6306
	0.0000	0.0000	1.0000	0.8144	5.6040	4.5641
	0.1133	0.1586	0.7281	0.8052	2.9691	2.3908
	0.2104	0.6310	0.1586	0.8111	0.8844	0.7173
	0.3249	0.3297	0.3454	0.7825	1.2209	0.9554
	0.3987	0.2028	0.3985	0.7681	1.3832	1.0625
	0.4949	0.3942	0.1109	0.7637	0.8118	0.6199
	0.5751	0.2621	0.1627	0.7493	0.8668	0.6495
	0.6762	0.1153	0.2085	0.7330	0.9997	0.7328

Table 4.24 (Cont'd.): Densities and Viscosities of the Ternary System: Octane (1) + Ethylbenzene (2) + 1-Hexanol (3).

T (K)	x_1	x_2	x_3	Density kg/L	Kinematic Viscosity $x10^6 (m^2/s)$	Absolute Viscosity (mPa.s)
308.15	1.0000	0.0000	0.0000	0.6893	0.6577	0.4534
	0.0000	1.0000	0.0000	0.8534	0.6558	0.5596
	0.0000	0.0000	1.0000	0.8073	4.1974	3.3887
	0.1133	0.1586	0.7281	0.7971	2.3108	1.8419
	0.2104	0.6310	0.1586	0.8021	0.8087	0.6487
	0.3249	0.3297	0.3454	0.7739	1.0831	0.8382
	0.3987	0.2028	0.3985	0.7596	1.1736	0.8914
	0.4949	0.3942	0.1109	0.7548	0.6876	0.5190
	0.5751	0.2621	0.1627	0.7405	0.7646	0.5661
	0.6762	0.1153	0.2085	0.7242	0.8758	0.6343
313.15	1.0000	0.0000	0.0000	0.6855	0.6276	0.4302
	0.0000	1.0000	0.0000	0.8492	0.6244	0.5303
	0.0000	0.0000	1.0000	0.8040	3.6701	2.9507
	0.1133	0.1586	0.7281	0.7935	2.0890	1.6575
	0.2104	0.6310	0.1586	0.7981	0.7554	0.6028
	0.3249	0.3297	0.3454	0.7700	1.0212	0.7863
	0.3987	0.2028	0.3985	0.7558	1.0485	0.7924
	0.4949	0.3942	0.1109	0.7508	0.6525	0.4899
	0.5751	0.2621	0.1627	0.7366	0.6987	0.5147
	0.6762	0.1153	0.2085	0.7204	0.8014	0.5774

Table 4.25: Densities and Viscosities of the Quaternary System: Chlorobenzene (1) + p-Xylene (2) + Octane (3) + Ethylbenzene (4).

T (K)	x_1	x_2	x_3	x_4	Density kg/L	Kinematic Viscosity x10^6 (m^2/s)	Absolute Viscosity (mPa.s)
293.15	1.0000	0.0000	0.0000	0.0000	1.1067	0.7260	0.8035
	0.0000	1.0000	0.0000	0.0000	0.8613	0.7616	0.6560
	0.0000	0.0000	1.0000	0.0000	0.7025	0.7709	0.5416
	0.0000	0.0000	0.0000	1.0000	0.8674	0.7712	0.6689
	0.1193	0.1173	0.1153	0.6481	0.8651	0.7536	0.6520
	0.2608	0.2519	0.2428	0.2445	0.8650	0.7247	0.6268
	0.2993	0.2088	0.0678	0.4241	0.9126	0.7485	0.6831
	0.1715	0.2989	0.4284	0.1012	0.8123	0.7114	0.5779
	0.2601	0.2941	0.1113	0.3344	0.8930	0.7405	0.6613
	0.4831	0.1615	0.2913	0.0641	0.8991	0.7084	0.6369
298.15	1.0000	0.0000	0.0000	0.0000	1.1013	0.7000	0.7709
	0.0000	1.0000	0.0000	0.0000	0.8565	0.7167	0.6139
	0.0000	0.0000	1.0000	0.0000	0.6980	0.7305	0.5099
	0.0000	0.0000	0.0000	1.0000	0.8625	0.7311	0.6306
	0.1193	0.1173	0.1153	0.6481	0.8603	0.7061	0.6075
	0.2608	0.2519	0.2428	0.2445	0.8601	0.6852	0.5893
	0.2993	0.2088	0.0678	0.4241	0.9076	0.7088	0.6433
	0.1715	0.2989	0.4284	0.1012	0.8075	0.6745	0.5447
	0.2601	0.2941	0.1113	0.3344	0.8881	0.6995	0.6212
	0.4831	0.1615	0.2913	0.0641	0.8940	0.6721	0.6008

Table 4.25 (Cont'd.): Densities and Viscosities of the Quaternary System: Chlorobenzene (1) + p-Xylene (2) + Octane (3) + Ethylbenzene (4).

T (K)	x_1	x_2	x_3	x_4	Density kg/L	Kinematic Viscosity x10^6 (m^2/s)	Absolute Viscosity (mPa.s)
308.15	1.0000	0.0000	0.0000	0.0000	1.0910	0.6249	0.6817
	0.0000	1.0000	0.0000	0.0000	0.8476	0.6368	0.5398
	0.0000	0.0000	1.0000	0.0000	0.6893	0.6577	0.4534
	0.0000	0.0000	0.0000	1.0000	0.8534	0.6558	0.5596
	0.1193	0.1173	0.1153	0.6481	0.8510	0.6360	0.5412
	0.2608	0.2519	0.2428	0.2445	0.8507	0.6202	0.5276
	0.2993	0.2088	0.0678	0.4241	0.8982	0.6364	0.5716
	0.1715	0.2989	0.4284	0.1012	0.7984	0.6080	0.4854
	0.2601	0.2941	0.1113	0.3344	0.8787	0.6284	0.5522
	0.4831	0.1615	0.2913	0.0641	0.8844	0.6053	0.5353
313.15	1.0000	0.0000	0.0000	0.0000	1.0852	0.5871	0.6371
	0.0000	1.0000	0.0000	0.0000	0.8434	0.6066	0.5116
	0.0000	0.0000	1.0000	0.0000	0.6855	0.6276	0.4302
	0.0000	0.0000	0.0000	1.0000	0.8492	0.6244	0.5303
	0.1193	0.1173	0.1153	0.6481	0.8468	0.6184	0.5237
	0.2608	0.2519	0.2428	0.2445	0.8464	0.5887	0.4982
	0.2993	0.2088	0.0678	0.4241	0.8937	0.6049	0.5406
	0.1715	0.2989	0.4284	0.1012	0.7942	0.5814	0.4618
	0.2601	0.2941	0.1113	0.3344	0.8743	0.5989	0.5236
	0.4831	0.1615	0.2913	0.0641	0.8798	0.5774	0.5080

Table 4.26: Densities and Viscosities of the Quaternary System:
p-Xylene (1) + Octane (2) + Ethylbenzene (3) + 1-Hexanol (4).

T (K)	x_1	x_2	x_3	x_4	Density kg/L	Kinematic Viscosity x10^6 (m^2/s)	Absolute Viscosity (mPa.s)
293.15	1.0000	0.0000	0.0000	0.0000	0.8613	0.7616	0.6560
	0.0000	1.0000	0.0000	0.0000	0.7025	0.7709	0.5416
	0.0000	0.0000	1.0000	0.0000	0.8674	0.7712	0.6689
	0.0000	0.0000	0.0000	1.0000	0.8184	6.5298	5.3443
	0.1108	0.1129	0.1155	0.6609	0.8120	2.8847	2.3423
	0.2421	0.2504	0.2551	0.2524	0.8032	1.1587	0.9307
	0.2899	0.2023	0.0776	0.4302	0.8044	1.6470	1.3248
	0.1558	0.2855	0.4394	0.1193	0.8030	0.9115	0.7319
	0.2445	0.2934	0.1246	0.3375	0.7921	1.4028	1.1112
	0.4743	0.1553	0.3043	0.0662	0.8287	0.7707	0.6387
298.15	1.0000	0.0000	0.0000	0.0000	0.8565	0.7167	0.6139
	0.0000	1.0000	0.0000	0.0000	0.6980	0.7305	0.5099
	0.0000	0.0000	1.0000	0.0000	0.8625	0.7311	0.6306
	0.0000	0.0000	0.0000	1.0000	0.8144	5.6040	4.5641
	0.1108	0.1129	0.1155	0.6609	0.8076	2.4949	2.0149
	0.2421	0.2504	0.2551	0.2524	0.7986	0.9779	0.7809
	0.2899	0.2023	0.0776	0.4302	0.7999	1.4804	1.1841
	0.1558	0.2855	0.4394	0.1193	0.7983	0.8101	0.6467
	0.2445	0.2934	0.1246	0.3375	0.7875	1.2612	0.9933
	0.4743	0.1553	0.3043	0.0662	0.8239	0.7282	0.6000

Table 4.26 (Cont'd.): Densities and Viscosities of the Quaternary System: p-Xylene (1) + Octane (2) + Ethylbenzene (3) + 1-Hexanol (4).

T (K)	x_1	x_2	x_3	x_4	Density kg/L	Kinematic Viscosity x10^6 (m^2/s)	Absolute Viscosity (mPa.s)
308.15	1.0000	0.0000	0.0000	0.0000	0.8476	0.6368	0.5398
	0.0000	1.0000	0.0000	0.0000	0.6893	0.6577	0.4534
	0.0000	0.0000	1.0000	0.0000	0.8534	0.6558	0.5596
	0.0000	0.0000	0.0000	1.0000	0.8073	4.1974	3.3887
	0.1108	0.1129	0.1155	0.6609	0.7993	2.0742	1.6579
	0.2421	0.2504	0.2551	0.2524	0.7898	0.8710	0.6879
	0.2899	0.2023	0.0776	0.4302	0.7912	1.2266	0.9705
	0.1558	0.2855	0.4394	0.1193	0.7893	0.7247	0.5720
	0.2445	0.2934	0.1246	0.3375	0.7788	1.0913	0.8499
	0.4743	0.1553	0.3043	0.0662	0.8148	0.6519	0.5312
313.15	1.0000	0.0000	0.0000	0.0000	0.8434	0.6066	0.5116
	0.0000	1.0000	0.0000	0.0000	0.6855	0.6276	0.4302
	0.0000	0.0000	1.0000	0.0000	0.8492	0.6244	0.5303
	0.0000	0.0000	0.0000	1.0000	0.8040	3.6701	2.9507
	0.1108	0.1129	0.1155	0.6609	0.7957	1.6382	1.3035
	0.2421	0.2504	0.2551	0.2524	0.7858	0.7700	0.6051
	0.2899	0.2023	0.0776	0.4302	0.7874	1.1679	0.9196
	0.1558	0.2855	0.4394	0.1193	0.7853	0.6543	0.5138
	0.2445	0.2934	0.1246	0.3375	0.7749	0.9844	0.7628
	0.4743	0.1553	0.3043	0.0662	0.8108	0.6187	0.5016

Table 4.27: Densities and Viscosities of the Quaternary System: Chlorobenzene (1) + Octane (2) + Ethylbenzene (3) + 1-Hexanol (4).

T (K)	x_1	x_2	x_3	x_4	Density kg/L	Kinematic Viscosity x10^6 (m^2/s)	Absolute Viscosity (mPa.s)
293.15	1.0000	0.0000	0.0000	0.0000	1.1067	0.7260	0.8035
	0.0000	1.0000	0.0000	0.0000	0.7025	0.7709	0.5416
	0.0000	0.0000	1.0000	0.0000	0.8674	0.7712	0.6689
	0.0000	0.0000	0.0000	1.0000	0.8184	6.5298	5.3443
	0.1200	0.1081	0.1241	0.6478	0.8368	2.6676	2.2322
	0.2516	0.2441	0.2574	0.2468	0.8522	1.0424	0.8883
	0.3036	0.1980	0.0701	0.4284	0.8637	1.7151	1.4813
	0.1665	0.2933	0.4343	0.1059	0.8328	0.8697	0.7243
	0.2484	0.2931	0.1153	0.3433	0.8374	1.3286	1.1125
	0.4818	0.1572	0.3023	0.0587	0.9279	0.7684	0.7130
298.15	1.0000	0.0000	0.0000	0.0000	1.1013	0.7000	0.7709
	0.0000	1.0000	0.0000	0.0000	0.6980	0.7305	0.5099
	0.0000	0.0000	1.0000	0.0000	0.8625	0.7311	0.6306
	0.0000	0.0000	0.0000	1.0000	0.8144	5.6040	4.5641
	0.1200	0.1081	0.1241	0.6478	0.8324	2.2207	1.8484
	0.2516	0.2441	0.2574	0.2468	0.8473	1.0190	0.8634
	0.3036	0.1980	0.0701	0.4284	0.8589	1.5563	1.3368
	0.1665	0.2933	0.4343	0.1059	0.8279	0.7734	0.6403
	0.2484	0.2931	0.1153	0.3433	0.8327	1.2633	1.0519
	0.4818	0.1572	0.3023	0.0587	0.9228	0.7229	0.6671

Table 4.27 (Cont'd.): Densities and Viscosities of the Quaternary System: Chlorobenzene (1) + Octane (2) + Ethylbenzene (3) + 1-Hexanol (4).

T (K)	x_1	x_2	x_3	x_4	Density kg/L	Kinematic Viscosity x10^6 (m^2/s)	Absolute Viscosity (mPa.s)
308.15	1.0000	0.0000	0.0000	0.0000	1.0910	0.6249	0.6817
	0.0000	1.0000	0.0000	0.0000	0.6893	0.6577	0.4534
	0.0000	0.0000	1.0000	0.0000	0.8534	0.6558	0.5596
	0.0000	0.0000	0.0000	1.0000	0.8073	4.1974	3.3887
	0.1200	0.1081	0.1241	0.6478	0.8239	1.8116	1.4925
	0.2516	0.2441	0.2574	0.2468	0.8381	0.8247	0.6912
	0.3036	0.1980	0.0701	0.4284	0.8499	1.1346	0.9643
	0.1665	0.2933	0.4343	0.1059	0.8187	0.6900	0.5649
	0.2484	0.2931	0.1153	0.3433	0.8236	0.9634	0.7934
	0.4818	0.1572	0.3023	0.0587	0.9130	0.6461	0.5900
313.15	1.0000	0.0000	0.0000	0.0000	1.0852	0.5871	0.6371
	0.0000	1.0000	0.0000	0.0000	0.6855	0.6276	0.4302
	0.0000	0.0000	1.0000	0.0000	0.8492	0.6244	0.5303
	0.0000	0.0000	0.0000	1.0000	0.8040	3.6701	2.9507
	0.1200	0.1081	0.1241	0.6478	0.8201	1.6627	1.3636
	0.2516	0.2441	0.2574	0.2468	0.8339	0.8087	0.6744
	0.3036	0.1980	0.0701	0.4284	0.8457	1.0963	0.9272
	0.1665	0.2933	0.4343	0.1059	0.8145	0.6460	0.5261
	0.2484	0.2931	0.1153	0.3433	0.8194	0.9493	0.7779
	0.4818	0.1572	0.3023	0.0587	0.9084	0.6128	0.5566

Table 4.28: Densities and Viscosities of the Quaternary System: Chlorobenzene (1) + p-Xylene (2) + Ethylbenzene (3) + 1-Hexanol (4).

T (K)	x_1	x_2	x_3	x_4	Density kg/L	Kinematic Viscosity x10^6 (m^2/s)	Absolute Viscosity (mPa.s)
293.15	1.0000	0.0000	0.0000	0.0000	1.1067	0.7260	0.8035
	0.0000	1.0000	0.0000	0.0000	0.8613	0.7616	0.6560
	0.0000	0.0000	1.0000	0.0000	0.8674	0.7712	0.6689
	0.0000	0.0000	0.0000	1.0000	0.8184	6.5298	5.3443
	0.1157	0.1128	0.1168	0.6547	0.8577	2.6296	2.2555
	0.2569	0.2400	0.2543	0.2488	0.9062	1.0514	0.9528
	0.2964	0.2000	0.0708	0.4329	0.9056	1.6835	1.5246
	0.1544	0.2946	0.4386	0.1124	0.8912	0.8664	0.7722
	0.2541	0.2827	0.1216	0.3416	0.9006	1.3543	1.2197
	0.4818	0.1545	0.2989	0.0647	0.9673	0.7991	0.7730
298.15	1.0000	0.0000	0.0000	0.0000	1.1013	0.7000	0.7709
	0.0000	1.0000	0.0000	0.0000	0.8565	0.7167	0.6139
	0.0000	0.0000	1.0000	0.0000	0.8625	0.7311	0.6306
	0.0000	0.0000	0.0000	1.0000	0.8144	5.6040	4.5641
	0.1157	0.1128	0.1168	0.6547	0.8533	2.2886	1.9529
	0.2569	0.2400	0.2543	0.2488	0.9013	0.9765	0.8801
	0.2964	0.2000	0.0708	0.4329	0.9008	1.5029	1.3538
	0.1544	0.2946	0.4386	0.1124	0.8863	0.8117	0.7194
	0.2541	0.2827	0.1216	0.3416	0.8958	1.2265	1.0987
	0.4818	0.1545	0.2989	0.0647	0.9622	0.7623	0.7335

Table 4.28 (Cont'd.): Densities and Viscosities of the Quaternary System: Chlorobenzene (1) + p-Xylene (2) + Ethylbenzene (3) + 1-Hexanol (4).

T (K)	x_1	x_2	x_3	x_4	Density kg/L	Kinematic Viscosity x10^6 (m^2/s)	Absolute Viscosity (mPa.s)
308.15	1.0000	0.0000	0.0000	0.0000	1.0910	0.6249	0.6817
	0.0000	1.0000	0.0000	0.0000	0.8476	0.6368	0.5398
	0.0000	0.0000	1.0000	0.0000	0.8534	0.6558	0.5596
	0.0000	0.0000	0.0000	1.0000	0.8073	4.1974	3.3887
	0.1157	0.1128	0.1168	0.6547	0.8449	1.8569	1.5688
	0.2569	0.2400	0.2543	0.2488	0.8921	0.8479	0.7564
	0.2964	0.2000	0.0708	0.4329	0.8918	1.1675	1.0412
	0.1544	0.2946	0.4386	0.1124	0.8770	0.7217	0.6329
	0.2541	0.2827	0.1216	0.3416	0.8867	0.9862	0.8745
	0.4818	0.1545	0.2989	0.0647	0.9525	0.6679	0.6362
313.15	1.0000	0.0000	0.0000	0.0000	1.0852	0.5871	0.6371
	0.0000	1.0000	0.0000	0.0000	0.8434	0.6066	0.5116
	0.0000	0.0000	1.0000	0.0000	0.8492	0.6244	0.5303
	0.0000	0.0000	0.0000	1.0000	0.8040	3.6701	2.9507
	0.1157	0.1128	0.1168	0.6547	0.8410	1.6770	1.4103
	0.2569	0.2400	0.2543	0.2488	0.8877	0.7937	0.7046
	0.2964	0.2000	0.0708	0.4329	0.8875	1.0741	0.9533
	0.1544	0.2946	0.4386	0.1124	0.8726	0.6748	0.5889
	0.2541	0.2827	0.1216	0.3416	0.8824	0.9159	0.8082
	0.4818	0.1545	0.2989	0.0647	0.9477	0.6319	0.5988

Table 4.29: Densities and Viscosities of the Quaternary System: Chlorobenzene (1) + p-Xylene (2) + Octane (3) + 1-Hexanol (4).

T (K)	x_1	x_2	x_3	x_4	Density kg/L	Kinematic Viscosity x10^6 (m^2/s)	Absolute Viscosity (mPa.s)
293.15	1.0000	0.0000	0.0000	0.0000	1.1067	0.7260	0.8035
	0.0000	1.0000	0.0000	0.0000	0.8613	0.7616	0.6560
	0.0000	0.0000	1.0000	0.0000	0.7025	0.7709	0.5416
	0.0000	0.0000	0.0000	1.0000	0.8184	6.5298	5.3443
	0.1178	0.1164	0.1098	0.6560	0.8352	2.8335	2.3664
	0.2598	0.2517	0.2467	0.2418	0.8523	1.0768	0.9178
	0.2967	0.2085	0.0637	0.4311	0.8908	1.4851	1.3230
	0.1743	0.2964	0.4192	0.1102	0.8094	0.8103	0.6558
	0.2567	0.3006	0.1120	0.3308	0.8760	1.3507	1.1832
	0.4838	0.1632	0.2882	0.0649	0.8963	0.7538	0.6756
298.15	1.0000	0.0000	0.0000	0.0000	1.1013	0.7000	0.7709
	0.0000	1.0000	0.0000	0.0000	0.8565	0.7167	0.6139
	0.0000	0.0000	1.0000	0.0000	0.6980	0.7305	0.5099
	0.0000	0.0000	0.0000	1.0000	0.8144	5.6040	4.5641
	0.1178	0.1164	0.1098	0.6560	0.8307	2.5212	2.0945
	0.2598	0.2517	0.2467	0.2418	0.8475	0.9576	0.8115
	0.2967	0.2085	0.0637	0.4311	0.8861	1.4299	1.2669
	0.1743	0.2964	0.4192	0.1102	0.8046	0.7672	0.6173
	0.2567	0.3006	0.1120	0.3308	0.8712	1.1608	1.0113
	0.4838	0.1632	0.2882	0.0649	0.8912	0.7140	0.6363

Table 4.29 (Cont'd.): Densities and Viscosities of the Quaternary System: Chlorobenzene (1) + p-Xylene (2) + Octane (3) + 1-Hexanol (4).

T (K)	x_1	x_2	x_3	x_4	Density kg/L	Kinematic Viscosity x10^6 (m^2/s)	Absolute Viscosity (mPa.s)
308.15	1.0000	0.0000	0.0000	0.0000	1.0910	0.6249	0.6817
	0.0000	1.0000	0.0000	0.0000	0.8476	0.6368	0.5398
	0.0000	0.0000	1.0000	0.0000	0.6893	0.6577	0.4534
	0.0000	0.0000	0.0000	1.0000	0.8073	4.1974	3.3887
	0.1178	0.1164	0.1098	0.6560	0.8223	1.9635	1.6146
	0.2598	0.2517	0.2467	0.2418	0.8383	0.8607	0.7215
	0.2967	0.2085	0.0637	0.4311	0.8770	1.2296	1.0784
	0.1743	0.2964	0.4192	0.1102	0.7955	0.6829	0.5432
	0.2567	0.3006	0.1120	0.3308	0.8621	1.0245	0.8832
	0.4838	0.1632	0.2882	0.0649	0.8815	0.6403	0.5644
313.15	1.0000	0.0000	0.0000	0.0000	1.0852	0.5871	0.6371
	0.0000	1.0000	0.0000	0.0000	0.8434	0.6066	0.5116
	0.0000	0.0000	1.0000	0.0000	0.6855	0.6276	0.4302
	0.0000	0.0000	0.0000	1.0000	0.8040	3.6701	2.9507
	0.1178	0.1164	0.1098	0.6560	0.8185	1.6567	1.3560
	0.2598	0.2517	0.2467	0.2418	0.8341	0.7944	0.6625
	0.2967	0.2085	0.0637	0.4311	0.8728	1.1398	0.9948
	0.1743	0.2964	0.4192	0.1102	0.7913	0.6634	0.5250
	0.2567	0.3006	0.1120	0.3308	0.8578	0.9368	0.8036
	0.4838	0.1632	0.2882	0.0649	0.8769	0.6216	0.5451

Table 4.30: Densities and Viscosities of the Quinary System: Chlorobenzene (1) + p-Xylene (2) + Octane (3) + Ethylbenzene (4) + 1-Hexanol (5).

T (K)	x_1	x_2	x_3	x_4	Density kg/L	Kinematic Viscosity x10^6 (m^2/s)	Absolute Viscosity (mPa.s)
293.15	1.0000	0.0000	0.0000	0.0000	1.1067	0.7260	0.8035
	0.0000	1.0000	0.0000	0.0000	0.8613	0.7616	0.6560
	0.0000	0.0000	1.0000	0.0000	0.7025	0.7709	0.5416
	0.0000	0.0000	0.0000	1.0000	0.8674	0.7712	0.6689
	0.0000	0.0000	0.0000	0.0000	0.8184	6.5298	5.3443
	0.1584	0.2481	0.2462	0.1987	0.8376	0.8559	0.7168
	0.1632	0.1130	0.2441	0.1094	0.8296	1.4709	1.2203
	0.2514	0.1573	0.2424	0.0668	0.8502	1.1489	0.9768
	0.2577	0.2485	0.1525	0.1886	0.8761	0.8782	0.7693
	0.1696	0.2889	0.1958	0.2778	0.8535	0.7745	0.6610
298.15	1.0000	0.0000	0.0000	0.0000	1.1013	0.7000	0.7709
	0.0000	1.0000	0.0000	0.0000	0.8565	0.7167	0.6139
	0.0000	0.0000	1.0000	0.0000	0.6980	0.7305	0.5099
	0.0000	0.0000	0.0000	1.0000	0.8625	0.7311	0.6306
	0.0000	0.0000	0.0000	0.0000	0.8144	5.6040	4.5641
	0.1584	0.2481	0.2462	0.1987	0.8327	0.8382	0.6980
	0.1632	0.1130	0.2441	0.1094	0.8249	1.2812	1.0569
	0.2514	0.1573	0.2424	0.0668	0.8454	1.0624	0.8981
	0.2577	0.2485	0.1525	0.1886	0.8712	0.8271	0.7206
	0.1696	0.2889	0.1958	0.2778	0.8486	0.7276	0.6174

*$x_5=1-x_1-x_2-x_3-x_4$

Table 4.30 (Cont'd.): Densities and Viscosities of the Quinary System: Chlorobenzene (1) + p-Xylene (2) + Octane (3) + Ethylbenzene (4) + 1-Hexanol (5).

T (K)	x_1	x_2	x_3	x_4	Density kg/L	Kinematic Viscosity x10^6 (m^2/s)	Absolute Viscosity (mPa.s)
308.15	1.0000	0.0000	0.0000	0.0000	1.0910	0.6249	0.6817
	0.0000	1.0000	0.0000	0.0000	0.8476	0.6368	0.5398
	0.0000	0.0000	1.0000	0.0000	0.6893	0.6577	0.4534
	0.0000	0.0000	0.0000	1.0000	0.8534	0.6558	0.5596
	0.0000	0.0000	0.0000	0.0000	0.8073	4.1974	3.3887
	0.1584	0.2481	0.2462	0.1987	0.8236	0.7107	0.5854
	0.1632	0.1130	0.2441	0.1094	0.8160	1.0657	0.8696
	0.2514	0.1573	0.2424	0.0668	0.8363	0.9483	0.7931
	0.2577	0.2485	0.1525	0.1886	0.8618	0.7347	0.6332
	0.1696	0.2889	0.1958	0.2778	0.8393	0.6543	0.5491
313.15	1.0000	0.0000	0.0000	0.0000	1.0852	0.5871	0.6371
	0.0000	1.0000	0.0000	0.0000	0.8434	0.6066	0.5116
	0.0000	0.0000	1.0000	0.0000	0.6855	0.6276	0.4302
	0.0000	0.0000	0.0000	1.0000	0.8492	0.6244	0.5303
	0.0000	0.0000	0.0000	0.0000	0.8040	3.6701	2.9507
	0.1584	0.2481	0.2462	0.1987	0.8194	0.6725	0.5511
	0.1632	0.1130	0.2441	0.1094	0.8120	1.0148	0.8240
	0.2514	0.1573	0.2424	0.0668	0.8321	0.8503	0.7075
	0.2577	0.2485	0.1525	0.1886	0.8574	0.6898	0.5915
	0.1696	0.2889	0.1958	0.2778	0.8351	0.6036	0.5041

CHAPTER 5

DISCUSSION

The experimental kinematic viscosity data reported were used to test the predictive capabilities of selected viscosity prediction models. As stated earlier, the tested models are: the generalized McAllister three-body interaction model, the *pseudo*-binary McAllister model, the GC-UNIMOD model, the generalized corresponding states principle (GCSP) model, and the Allan and Teja correlation. In addition to the aforementioned models another viscosity prediction model based on the artificial neural network has also been investigated using the current experimental data as well as other sets of data reported in the literature

The predictive capabilities of the viscosity models are compared in terms of % average absolute deviation (% AAD), and the maximum percentage deviation of the model from experimental data (% MAX). The % AAD is calculated with the help of the following equation:

$$\%\mathrm{AAD} = \frac{1}{n}\left(\sum \frac{\left|\nu_i^{\mathrm{measured}} - \nu_i^{\mathrm{predicted}}\right|}{\nu_i^{\mathrm{measured}}}\right) \times 100 \tag{5.1}$$

The % MAX is given by the following equation:

$$\%\mathrm{MAX} = \mathrm{MAX}\left(\frac{\nu_i^{\mathrm{measured}} - \nu_i^{\mathrm{predicted}}}{\nu_i^{\mathrm{measured}}}\right) \times 100 \tag{5.2}$$

where n is the number of experimental points and ν is the kinematic viscosity.

5.1 Testing the Predictive Capabilities of the Generalized McAllister Three-Body Interaction Model.

The experimental data obtained in this study are compared to those predicted by the generalized McAllister three-body interaction model. The model's performance is evaluated in terms of the AAD% values. In addition to the kinematic viscosity data reported previously, the molecular weights as well as values for the parameters N or ECN for the pure components are needed to predict a mixture's viscosity using this model. These values are listed in Table 5.1. The ECN values were calculated using equation (2.27).

Equation (2.27) overestimates the ECN of 1-hexanol because of its relatively high viscosity value at 308.15 K. The equation gave a value of 17.5 for 1-hexanol's ECN, whereas it only contains 6 carbons atoms and one oxygen atom that is slightly bigger than carbon in term of size. Therefore, half the predicted ECN value will be used in this model. Tables 5.2 through 5.4 summarize these results obtained for binary, ternary, quaternary, and quinary systems, respectively.

The use of the McAllister three body interaction model successfully predicted the values of the kinematic viscosity of binary mixtures investigated in this study with an average %AAD of 3.94. For ternary, quaternary, and quinary mixtures; this model was able to predict the kinematic viscosity value with an error of 3.97, 3.89, and 4.02 , respectively in terms of %AAD.

Table 5.1: Effective Carbon Number and Molecular Weights of the Pure Components.

Components	Molecular	ECN
Chlorobenzene	112.559 (1)	7.63
p-Xylene	106.168 (1)	7.73
Octane	114.232 (1)	8
EythlBenzene	106.168 (1)	7.88
1-Hexanol	102.177 (1)	17.5

(1) Reid *et al.* (1987)

Table 5.2: Results of Testing the McAllister Model Using the Experimental Viscosity Data on Binary Systems.

System	Temperature (K)	% AAD	% MAX
Chlorobenzene (1) + p-Xylene (2)	293.15	4.55	7.98
	298.15	5.37	9.21
	308.13	5.08	8.96
	313.15	6.2	10.2
Chlorobenzene (1) + Octane (2)	293.15	2.54	4.08
	298.15	1.92	3.53
	308.13	2.29	4.06
	313.15	2.03	3.63
Chlorobenzene (1) + Ethylbenzene (2)	293.15	5.65	9.72
	298.15	5.38	9.27
	308.13	6.33	10.68
	313.15	6.75	11.02
Chlorobenzene (1) + 1-Hexanol (2)	293.15	2.18	8.02
	298.15	1.67	4.61
	308.13	5.4	11.39
	313.15	4.67	10.01
p-Xylene (1) + Octane (2)	293.15	1.62	2.99
	298.15	1.8	3.24
	308.13	2.36	4.09
	313.15	2.53	4.4

Table 5.2 (Cont'd.): Results of Testing the McAllister Model Using the Experimental Viscosity Data on Binary Systems.

System	Temperature (K)	% AAD	% MAX
p-Xylene (1) + Ethylbenzene (2)	293.15	5.57	9.3
	298.15	5.71	9.28
	308.13	6.04	9.66
	313.15	5.99	9.6
p-Xylene (1) + 1-Hexanol (2)	293.15	3.56	7.48
	298.15	4	9.35
	308.13	4.23	7.67
	313.15	4.61	9
Octane (1) + Ethylbenzene (2)	293.15	2.57	4.45
	298.15	2.6	4.55
	308.13	2.99	4.89
	313.15	3.09	4.98
Octane (1) + 1-Hexanol (2)	293.15	4.22	12.29
	298.15	4.22	7.12
	308.13	3.73	9.52
	313.15	3.6	9.37
Ethylbenzene (1) + 1-Hexanol (2)	293.15	3.37	8.68
	298.15	5.76	14.84
	308.13	1.9	4.26
	313.15	3.54	7.59

Table 5.3: Results of Testing the McAllister Model Using the Experimental Viscosity Data on Ternary Systems.

System	Temperature (K)	% AAD	% MAX
Chlorobenzene (1) + p-Xylene (2) + Octane (3)	293.15	3.11	6.87
	298.15	2.85	6
	308.13	3.24	6.65
	313.15	3.84	7.32
Chlorobenzene (1) + Octane (2) + Ethylbenzene (3)	293.15	3.46	6.59
	298.15	2.73	5.54
	308.13	3.27	5.88
	313.15	3.23	5.56
Chlorobenzene (1) + p-Xylene (2) + Ethylbenzene (3)	293.15	5.58	8.82
	298.15	6.26	10.37
	308.13	6.62	10.84
	313.15	6.89	11.73
Chlorobenzene (1) + Octane (2) + 1-Hexanol (3)	293.15	1.83	5.73
	298.15	4	11.59
	308.13	2.87	8.96
	313.15	5.96	14.24
Chlorobenzene (1) + Ethylbenzene (2) + 1-Hexanol (3)	293.15	4.97	12.27
	298.15	4.3	10.16
	308.13	4.56	10.56
	313.15	3.94	9.55

Table 5.3 (Cont'd.): Results of Testing the McAllister Model Using the Experimental Viscosity Data on Ternary Systems.

System	Temperature (K)	% AAD	% MAX
Chlorobenzene (1) + p-Xylene (2) + 1-Hexanol (3)	293.15	4.39	8.42
	298.15	4.57	9.42
	308.13	5.08	11.79
	313.15	4.57	10.73
p-Xylene (1) + Octan (2) Ethylbenzene (3)	293.15	2.34	4.31
	298.15	2.56	4.62
	308.13	3.01	5.3
	313.15	3.18	5.46
p-Xylene (1) + Ethylbenzene (2) + 1-Hexanol (3)	293.15	4.37	11.02
	298.15	4.53	9.53
	308.13	3.73	11.78
	313.15	4.55	9.8
p-Xylene (1) + Octan (2) + 1-Hexanol (3)	293.15	4.71	9.78
	298.15	3.19	7.18
	308.13	3.61	9.36
	313.15	2.91	8.72
Octan (1) + Ethylbenzene (2) + 1-Hexanol (3)	293.15	3.9	7.86
	298.15	3.69	9.96
	308.13	2.8	6.62
	313.15	3.4	9.94

Table 5.4: Results of Testing the McAllister Model Using the Experimental Viscosity Data on Quaternary and Quinary Systems.

System	Temperature (K)	% AAD	% MAX
Chlorobenzene (1) + p-Xylene (2) + Octane (3) + Ethylbenzene (4)	293.15	3.23	8.08
	298.15	2.91	7.66
	308.13	3.29	8.03
	313.15	3.68	8.22
p-Xylene (1) + Octane (2) + Ethylbenzene (3) + 1-Hexanol (4)	293.15	4.53	21.71
	298.15	3.84	13.76
	308.13	2.5	9.47
	313.15	4.74	15.47
Chlorobenzene (1) + Octane (2) + Ethylbenzene (3) + 1-Hexanol (4)	293.15	2.99	13.08
	298.15	3.55	13.36
	308.13	6.23	16.47
	313.15	4.06	9.22
Chlorobenzene (1) + p-Xylene (2) + Ethylbenzene (3) + 1-Hexanol (4)	293.15	3.49	12.23
	298.15	4.14	12.04
	308.13	4.68	12.41
	313.15	4.51	11.7
Chlorobenzene (1) + p-Xylene (2) + Octane (3) + 1-Hexanol (4)	293.15	4.22	16.78
	298.15	4.69	12.54
	308.13	3.15	7.24
	313.15	3.35	10.39

Table 5.4 (Cont'd.): Results of Testing the McAllister Model Using the Experimental Viscosity Data on Quaternary and Quinary Systems.

System	Temperature (K)	% AAD	% MAX
Chlorobenzene (1) + p-Xylene (2) + Ethylbenzene (3) + 1-Hexanol (4)	293.15	3.49	12.23
	298.15	4.14	12.04
	308.13	4.68	12.41
	313.15	4.51	11.7
Chlorobenzene (1) + p-Xylene (2) + Octane (3) + Ethylbenzene (4) + 1-Hexanol (5)	293.15	4.27	12.53
	298.15	4.25	10.8
	308.13	3.71	11.4
	313.15	3.85	9.5

5.2 Testing the Predictive Capabilities of the *Pseudo-Binary* McAllister Model

The *pseudo-binary* McAllister model discussed in Section 2.3 is tested using the experimental kinematic viscosity data of ternary, quaternary and quinary systems investigated in the present study. Obviously, the *pseudo-binary* McAllister model when tested using the binary mixtures data would give the same results as the generalized McAllister model. Tables 5.5 through 5.6 report the results of testing the *pseudo-binary* McAllister model for the ternary, quaternary and quinary systems, respectively.

Table 5.5: Results of Testing the *Pseudo-Binary* McAllister Model Using the Experimental Viscosity Data on Ternary Systems.

System	Temperature (K)	% AAD	% MAX
Chlorobenzene (1) + p-Xylene (2) Octane (3)	293.15	2.79	7.25
	298.15	2.56	6.39
	308.13	2.85	7.03
	313.15	3.42	7.71
Chlorobenzene (1) + Octane (2) + Ethylbenzene (3)	293.15	3.11	6.87
	298.15	2.56	5.48
	308.13	2.92	5.92
	313.15	2.88	5.57
Chlorobenzene (1) + p-Xylene (2) + Ethylbenzene (3)	293.15	5.23	8.85
	298.15	5.91	10.66
	308.13	6.27	11.33
	313.15	6.54	12.36
Chlorobenzene (1) + Octane (2) + 1-Hexanol (3)	293.15	2.19	6.87
	298.15	4.34	10.78
	308.13	3.22	8.17
	313.15	6.48	15.04
Chlorobenzene (1) + Ethylbenzene (2) + 1-Hexanol (3)	293.15	5.28	12.83
	298.15	4.12	10.02
	308.13	4.88	10.53
	313.15	4.29	10.1

Table 5.5 (Cont'd.): Results of Testing the *Pseudo-Binary* McAllister Model Using the Experimental Viscosity Data on Ternary Systems.

System	Temperature (K)	% AAD	% MAX
Chlorobenzene (1) + p-Xylene (2) + 1-Hexanol (3)	293.15	4.73	10.26
	298.15	4.92	10.89
	308.13	5.43	12.46
	313.15	4.91	11.39
p-Xylene (1) + Octane (2) Ethylbenzene (3)	293.15	1.84	4.51
	298.15	2.06	4.85
	308.13	2.52	5.67
	313.15	2.69	5.75
p-Xylene (1) + Ethylbenzene (2) + 1-Hexanol (3)	293.15	4.78	10.13
	298.15	4.93	11.02
	308.13	3.66	10.98
	313.15	4.98	13.54
p-Xylene (1) + Octane (2) + 1-Hexanol (3)	293.15	5.15	10.4
	298.15	3.62	9.02
	308.13	4.07	9.39
	313.15	3.32	8.67
Octane (1) + Ethylbenzene (2) + 1-Hexanol (3)	293.15	4.26	9.54
	298.15	4.04	10.72
	308.13	3.15	6.49
	313.15	3.73	9.8

Table 5.6: Results of Testing the *Pseudo-Binary* McAllister Model Using the Experimental Viscosity Data on Quaternary and Quinary Systems.

System	Temperature (K)	% AAD	% MAX
Chlorobenzene (1) + p-Xylene (2) + Octane (3) + Ethylbenzene (4)	293.15	2.46	7.32
	298.15	2.14	6.89
	308.13	2.39	7.27
	313.15	2.74	7.46
p-Xylene (1) + Octane (2) + Ethylbenzene (3) + 1-Hexanol (4)	293.15	5.5	22.62
	298.15	4.99	15.45
	308.13	3.48	10.98
	313.15	5.88	17.85
Chlorobenzene (1) + Octane (2) + Ethylbenzene (3) + 1-Hexanol (4)	293.15	4.02	14.42
	298.15	4.59	17.5
	308.13	7.29	18.12
	313.15	5.23	12.67
Chlorobenzene (1) + p-Xylene (2) + Ethylbenzene (3) + 1-Hexanol (4)	293.15	4.69	13.41
	298.15	5.35	15.55
	308.13	5.89	13.81
	313.15	5.72	12.96

Table 5.6 (Cont'd.): Results of Testing the *Pseudo-Binary* McAllister Model Using the Experimental Viscosity Data on Quaternary and Quinary Systems.

System	Temperature (K)	% AAD	% MAX
Chlorobenzene (1) + p-Xylene (2) + Octane (3) + 1-Hexanol (4)	293.15	5.18	17.58
	298.15	5.65	13.72
	308.13	4.11	9.4
	313.15	4.51	14.44
Chlorobenzene (1) + p-Xylene (2) + Octane (3) + Ethylbenzene (4) + 1-Hexanol (5)	293.15	5.34	15.76
	298.15	5.33	13.74
	308.13	4.79	14.62
	313.15	4.92	12.65

5.3 Testing the Predictive Capabilities of the Generalized Corresponding States Principle (GCSP) Model.

The experimental kinematic viscosity values of the binary, ternary, quaternary, and quinary systems investigated in the present study are compared with those predicted by the generalized corresponding states principle model, discussed earlier in Section 2.4. The generalized corresponding states principle model uses some physical properties of the pure components used to constitute the mixtures. For the components used in the present study those values are listed in Table 5.7.

The results of testing the generalized corresponding states principle model are reported in Tables 5.8 through 5.10. The predicted kinematic viscosity by the GCSP depends heavily on the selection of the reference fluids when the number of components exceeds 2. In other words, the selection of the reference fluid, as was indicated earlier by Wu and Asfour (1992), significantly affects the predicted viscosity values. The results of testing reported in Tables 5.8 through 5.10 are those showing the smallest error amongst all the results obtained from the different selections of the reference fluids.

Table 5.7: Physical Properties of the Pure Components Used in Kinematic Viscosity Prediction by the Generalized Corresponding States Principle (GCSP) Model.

Components	Molecular Weight	Tc (K)	Pc (atm)	Acentric Factor
Chlorobenzene	112.559 (1)	632.4 (1)	44.6 (1)	0.249 (1)
p-Xylene	106.168 (1)	616.2 (1)	34.6 (1)	0.320(1)
Octane	114.232 (1)	568.8 (1)	24.6 (1)	0.398 (1)
EythlBenzene	106.168 (1)	617.2 (1)	35.5 (1)	0.302 (1)
1-Hexanol	102.177 (1)	611 (1)	40.0 (1)	0.560 (1)

(1) Reid *et al.* (1987)

Table 5.8: Results of Testing the Generalized Corresponding States Principle (GCSP) Model Using the Experimental Viscosity Data on Binary Systems.

System	Temperature (K)	% AAD	% MAX
Chlorobenzene (1) + p-Xylene (2)	293.15	2.32	4.23
	298.15	0.79	1.59
	308.13	1.17	2.30
	313.15	0.37	0.72
Chlorobenzene (1) + Octane (2)	293.15	5.52	7.19
	298.15	6.47	8.21
	308.13	5.91	7.49
	313.15	6.28	7.85
Chlorobenzene (1) + Ethylbenzene (2)	293.15	0.52	1.37
	298.15	0.83	1.73
	308.13	0.64	1.16
	313.15	0.97	1.53
Chlorobenzene (1) + 1-Hexanol (2)	293.15	10.81	14.89
	298.15	10.54	14.52
	308.13	15.63	21.91
	313.15	14.67	20.36
p-Xylene (1) + Octane (2)	293.15	6.64	8.57
	298.15	6.29	8.06
	308.13	5.45	6.81
	313.15	5.22	6.71

Table 5.8 (Cont'd.): Results of Testing the Generalized Corresponding States Principle (GCSP) Model Using the Experimental Viscosity Data on Binary Systems.

System	Temperature (K)	% AAD	% MAX
p-Xylene (1) + Ethylbenzene (2)	293.15	0.75	1.68
	298.15	0.56	1.13
	308.13	0.18	0.40
	313.15	0.23	0.65
p-Xylene (1) + 1-Hexanol (2)	293.15	9.60	12.55
	298.15	10.41	16.28
	308.13	10.79	13.43
	313.15	11.04	16.90
Octane (1) + Ethylbenzene (2)	293.15	5.20	6.99
	298.15	5.17	7.01
	308.13	4.66	6.41
	313.15	4.53	6.11
Octane (1) + 1-Hexanol (2)	293.15	5.67	13.73
	298.15	6.33	8.92
	308.13	6.38	10.68
	313.15	6.14	10.83
Ethylbenzene (1) + 1-Hexanol (2)	293.15	10.06	15.89
	298.15	13.16	23.18
	308.13	7.76	11.38
	313.15	10.60	16.39

Table 5.9: Results of Testing the Generalized Corresponding States Principle (GCSP) Model Using the Experimental Viscosity Data on Ternary Systems.

System	Temperature (K)	% AAD	% MAX
Chlorobenzene (1) + p-Xylene (2) + Octane (3)	293.15	5.35	7.17
	298.15	4.49	6.39
	308.13	3.28	4.98
	313.15	2.90	4.79
Chlorobenzene (1) + Octane (2) + Ethylbenzene (3)	293.15	4.72	6.87
	298.15	6.80	13.62
	308.13	4.40	6.02
	313.15	5.13	6.32
Chlorobenzene (1) + p-Xylene (2) + Ethylbenzene (3)	293.15	0.93	1.99
	298.15	0.64	1.44
	308.13	0.84	1.84
	313.15	1.03	2.64
Chlorobenzene (1) + Octane (2) + 1-Hexanol (3)	293.15	34.83	75.03
	298.15	31.03	73.15
	308.13	29.38	68.75
	313.15	24.59	65.10
Chlorobenzene (1) + Ethylbenzene (2) + 1-Hexanol (3)	293.15	7.72	11.35
	298.15	5.92	11.27
	308.13	7.23	9.79
	313.15	6.80	8.04

Table 5.9 (Cont'd.): Results of Testing the Generalized Corresponding States Principle (GCSP) Model Using the Experimental Viscosity Data on Ternary Systems.

System	Temperature (K)	% AAD	% MAX
Chlorobenzene (1) + p-Xylene (2) + 1-Hexanol (3)	293.15	11.04	21.36
	298.15	11.06	20.54
	308.13	9.12	19.34
	313.15	8.53	17.73
p-Xylene (1) + Octane (2) + Ethylbenzene (3)	293.15	6.15	7.99
	298.15	4.67	6.18
	308.13	2.33	3.11
	313.15	2.14	2.73
p-Xylene (1) + Ethylbenzene (2) + 1-Hexanol (3)	293.15	8.74	16.09
	298.15	9.03	14.60
	308.13	7.49	17.25
	313.15	9.71	13.99
p-Xylene (1) + Octane (2) + 1-Hexanol (3)	293.15	22.83	41.03
	298.15	22.80	40.79
	308.13	19.57	34.08
	313.15	18.62	35.20
Octane (1) + Ethylbenzene (2) + 1-Hexanol (3)	293.15	21.36	46.24
	298.15	20.14	45.70
	308.13	18.29	44.43
	313.15	16.23	42.17

Table 5.10: Results of Testing the Generalized Corresponding States Principle (GCSP) Model Using the Experimental Viscosity Data on Quaternary and Quinary Systems.

System	Temperature (K)	% AAD	% MAX
Chlorobenzene (1) + p-Xylene (2) + Octane (3) + Ethylbenzene (4)	293.15	3.90	7.42
	298.15	3.64	6.99
	308.13	2.50	5.91
	313.15	2.42	4.61
p-Xylene (1) + Octane (2) + Ethylbenzene (3) + 1-Hexanol (4)	293.15	28.82	45.80
	298.15	26.94	37.90
	308.13	22.54	30.73
	313.15	23.53	43.36
Chlorobenzene (1) + Octane (2) + Ethylbenzene (3) + 1-Hexanol (4)	293.15	21.99	34.48
	298.15	22.20	36.28
	308.13	26.89	40.65
	313.15	22.82	32.88
Chlorobenzene (1) + p-Xylene (2) + Ethylbenzene (3) + 1-Hexanol (4)	293.15	7.45	22.86
	298.15	7.30	23.24
	308.13	6.95	20.91
	313.15	6.77	19.67
Chlorobenzene (1) + p-Xylene (2) + Octane (3) + 1-Hexanol (4)	293.15	15.42	43.26
	298.15	15.46	39.85
	308.13	12.52	35.14
	313.15	13.06	30.32

Table 5.10 (Cont'd.): Results of Testing the Generalized Corresponding States Principle (GCSP) Model Using the Experimental Viscosity Data on Quaternary And Quinary Systems.

System	Temperature (K)	% AAD	% MAX
Chlorobenzene (1) + p-Xylene (2) + Octane (3) + Ethylbenzene (4) + 1-Hexanol (5)	293.15	18.16	27.68
	298.15	17.27	23.50
	308.13	15.66	23.64
	313.15	16.24	22.23

5.4 Testing the Predictive Capabilities of the GC-UNIMOD Model

The GC-UNIMOD discussed in Section 2.5 is tested using the experimental kinematic viscosity data of the binary, ternary, quaternary, and quinary systems under investigation. Pure components were broken down to different functional groups. Table 5.11 shows the number of the different functional groups constituting the pure components used in this study. Tables 5.12 through 5.14 report the results of testing the GC-UNIMOD model.

As described in details in Section 2.5, the GC-UNIMOD model is represented by a formula that consists of two parts; namely, the combinatorial part and the residual part. Nhaesi (1998) and Hussein (2007) have concluded that the residual part of the equation does not significantly affect the final outcome of the model, and it is reasonable to set this part equal to zero (R=0).

5.5 Testing the Predictive Capability of the Allan and Teja Correlation

The Allan and Teja Correlation discussed in Section 2.6 is tested using the experimental kinematic viscosity data on the investigated binary, ternary, quaternary , and quinary systems. Tables 5.15 through 5.17 report the results of testing the Allan and Teja Correlation.

Table 5.11: The Breakdown of the Pure Components used in the Present Study into Functional Groups as Used in the GC-UNIMOD.

	Group k						
Component	CH_3	CH_2	ACH	$ACCH_3$	$ACCH_2$	OH	ACCl
Chlorobenzene			5				1
p-Xylene			4	2			
Octane	2	6					
EythlBenzene	1		5		1		
1-Hexanol	1	5				1	

Table 5.12: Results of Testing the GC-UNIMOD Model Using the Experimental Viscosity Data of the Binary Systems.

System	Temperature (K)	% AAD	% MAX
Chlorobenzene (1) + p-Xylene (2)	293.15	2.23	4.16
	298.15	0.64	1.5
	308.13	1.06	2.22
	313.15	0.51	0.85
Chlorobenzene (1) + Octane (2)	293.15	3.61	2.51
	298.15	4.48	5.66
	308.13	3.94	4.96
	313.15	4.37	5.21
Chlorobenzene (1) + Ethylbenzene (2)	293.15	0.5	1.32
	298.15	0.75	1.68
	308.13	0.69	1.26
	313.15	1.05	1.63
Chlorobenzene (1) + 1-Hexanol (2)	293.15	22.2	30.5
	298.15	21.09	28.34
	308.13	25.33	34.8
	313.15	23.75	31.47
p-Xylene (1) + Octane (2)	293.15	5.56	7.18
	298.15	5.24	6.69
	308.13	4.44	5.57
	313.15	4.22	5.42

Table 5.12 (Cont'd.): Results of Testing the GC-UNIMOD Model using the Experimental Viscosity Data of the Binary Systems.

System	Temperature (K)	% AAD	% MAX
p-Xylene (1) + Ethylbenzene (2)	293.15	0.73	1.11
	298.15	0.55	1.11
	308.13	0.18	0.38
	313.15	0.21	0.62
p-Xylene (1) + 1-Hexanol (2)	293.15	23.48	31.38
	298.15	23.67	32.17
	308.13	22.82	29.34
	313.15	22.38	32.62
Octane (1) + Ethylbenzene (2)	293.15	3.92	5.33
	298.15	3.88	5.33
	308.13	3.39	4.71
	313.15	3.26	4.48
Octane (1) + 1-Hexanol (2)	293.15	14.89	26.22
	298.15	15.2	20.26
	308.13	14.34	18.62
	313.15	13.64	19.06
Ethylbenzene (1) + 1-Hexanol (2)	293.15	23.68	32.97
	298.15	24.71	38.08
	308.13	18.88	25.88
	313.15	21.36	31.49

Table 5.13: Results of Testing the GC-UNIMOD Model Using the Experimental Viscosity Data of the Ternary Systems.

System	Temperature (K)	% AAD	% MAX
Chlorobenzene (1) + p-Xylene (2) + Octane (3)	293.15	3.67	5.11
	298.15	4.02	5.39
	308.13	3.46	4.52
	313.15	2.59	3.96
Chlorobenzene (1) + Octane (2) + Ethylbenzene (3)	293.15	3.08	4.57
	298.15	4.76	11.17
	308.13	3.34	4.55
	313.15	3.47	4.78
Chlorobenzene (1) + p-Xylene (2) + Ethylbenzene (3)	293.15	0.86	1.89
	298.15	0.62	1.55
	308.13	1.03	2.3
	313.15	1.45	3.42
Chlorobenzene (1) + Octane (2) + 1-Hexanol (3)	293.15	17.78	23.41
	298.15	21.69	30.54
	308.13	19.12	26.37
	313.15	24.16	32.59
Chlorobenzene (1) + Ethylbenzene (2) + 1-Hexanol (3)	293.15	32.35	48.98
	298.15	28.6	44.16
	308.13	27.41	40.85
	313.15	25.4	25.4

Table 5.13 (Cont'd.): Results of Testing the GC-UNIMOD Model Using the Experimental Viscosity Data of the Ternary Systems.

System	Temperature (K)	% AAD	% MAX
Chlorobenzene (1) + p-Xylene (2) + 1-Hexanol (3)	293.15	30.73	41.7
	298.15	29.3	37.48
	308.13	27.86	38.27
	313.15	26.03	37.43
p-Xylene (1) + Octane (2) + Ethylbenzene (3)	293.15	4.05	6.59
	298.15	4.68	6.31
	308.13	4.02	5.46
	313.15	3.77	5.05
p-Xylene (1) + Ethylbenzene (2) + 1-Hexanol (3)	293.15	29.81	32.84
	298.15	29.2	34.23
	308.13	25.32	31.63
	313.15	26.74	30.5
p-Xylene (1) + Octane (2) + 1-Hexanol (3)	293.15	22.74	30.81
	298.15	19.88	23.95
	308.13	19.84	28.09
	313.15	18.56	27.56
Octane (1) + Ethylbenzene (2) + 1-Hexanol (3)	293.15	28.54	37.92
	298.15	27.33	39.28
	308.13	24.14	31.91
	313.15	24.4	34.96

Table 5.14: Results of Testing the GC-UNIMOD Model Using the Experimental Viscosity Data on Quaternary and Quinary Systems.

System	Temperature (K)	% AAD	% MAX
Chlorobenzene (1) + p-Xylene (2) + Octane (3) + Ethylbenzene (4)	293.15	2.23	4.78
	298.15	2.14	4.79
	308.13	1.85	4.13
	313.15	2.12	3.59
p-Xylene (1) + Octane (2) + Ethylbenzene (3) + 1-Hexanol (4)	293.15	24.99	45.77
	298.15	23.35	33.19
	308.13	19.47	26.78
	313.15	23.45	33.12
Chlorobenzene (1) + Octane (2) + Ethylbenzene (3) + 1-Hexanol (4)	293.15	22.59	33.47
	298.15	22.99	35.11
	308.13	27.19	36.84
	313.15	22.48	28.97
Chlorobenzene (1) + p-Xylene (2) + Ethylbenzene (3) + 1-Hexanol (4)	293.15	29.68	40.4
	298.15	29.52	40.32
	308.13	28.51	40.79
	313.15	26.7	39.27
Chlorobenzene (1) + p-Xylene (2) + Octane (3) + 1-Hexanol (4)	293.15	23.51	47.24
	298.15	23.45	37.74
	308.13	18.88	29.76
	313.15	18.37	28.76

Table 5.14 (Cont'd.): Results of Testing the GC-UNIMOD Model Using the Experimental Viscosity Data on Quaternary and Quinary Systems.

System	Temperature (K)	% AAD	% MAX
Chlorobenzene (1) + p-Xylene (2) + Octane (3) + Ethylbenzene (4) + 1-Hexanol (5)	293.15	21.36	28.78
	298.15	20.7	29.97
	308.13	18.18	29.22
	313.15	17.77	24.19

Table 5.15: Results of Testing the Allan and Teja Correlation Using the Experimental Viscosity Data of the Binary Systems.

System	Temperature (K)	% AAD	% MAX
Chlorobenzene (1) + p-Xylene (2)	293.15	29.17	41.02
	298.15	30.16	39.16
	308.13	29.01	38.48
	313.15	29.29	37.53
Chlorobenzene (1) + Octane (2)	293.15	16.54	38.24
	298.15	16.47	39.16
	308.13	16.37	38.48
	313.15	15.58	37.53
Chlorobenzene (1) + Ethylbenzene (2)	293.15	29.4	38.24
	298.15	29.8	39.26
	308.13	29.88	38.48
	313.15	29.66	37.53
Chlorobenzene (1) + 1-Hexanol (2)	293.15	65.67	87.48
	298.15	65.18	86.27
	308.13	60.9	83.67
	313.15	59.64	82.31
p-Xylene (1) + Octane (2)	293.15	6.4	22.31
	298.15	6.33	21.71
	308.13	6.17	20.35
	313.15	6.28	20.3

Table 5.15 (Cont'd.): Results of Testing the Allan and Teja Correlation Using the Experimental Viscosity Data on Binary Systems.

System	Temperature (K)	% AAD	% MAX
p-Xylene (1) + Ethylbenzene (2)	293.15	20.98	22.31
	298.15	20.83	21.71
	308.13	20.2	20.35
	313.15	20.12	20.32
p-Xylene (1) + 1-Hexanol (2)	293.15	60.22	87.48
	298.15	58.69	86.27
	308.13	55.57	83.67
	313.15	54.18	82.31
Octane (1) + Ethylbenzene (2)	293.15	6.1	19.78
	298.15	6.16	19.86
	308.13	6.22	19.42
	313.15	6.36	19.43
Octane (1) + 1-Hexanol (2)	293.15	52.09	87.48
	298.15	50.48	86.27
	308.13	47.94	83.67
	313.15	46.61	82.31
Ethylbenzene (1) + 1-Hexanol (2)	293.15	59.24	87.48
	298.15	61.02	86.27
	308.13	55.92	83.67
	313.15	53.74	82.31

Table 5.16: Results of Testing the Allan and Teja Correlation Using the Experimental Viscosity Data of the Ternary Systems.

System	Temperature (K)	% AAD	% MAX
Chlorobenzene (1) +p-xylene (2) + Octane (3)	293.15	14.91	32.86
	298.15	15.1	34.1
	308.13	14.78	33.52
	313.15	14.94	32.61
Chlorobenzene (1) + Octane (2) + Ethylbenzene (3)	293.15	15.88	32.86
	298.15	15.47	34.1
	308.13	15.88	33.52
	313.15	15.47	32.61
Chlorobenzene (1) + p-Xylene (2) + Ethylbenzene (3)	293.15	23.7	32.86
	298.15	24.66	34.1
	308.13	24.24	33.52
	313.15	24.11	32.61
Chlorobenzene (1) + Octane (2) + 1-Hexanol (3)	293.15	43.33	87.48
	298.15	41.31	86.27
	308.13	39.9	83.67
	313.15	36.7	82.31
Chlorobenzene (1) + Ethylbenzene (2) + 1-Hexanol (3)	293.15	47.09	87.48
	298.15	46.9	86.27
	308.13	44.53	83.67
	313.15	43.59	82.31

Table 5.16 (Cont'd.): Results of Testing the Allan and Teja Correlation Using the Experimental Viscosity Data of the Ternary Systems.

System	Temperature (K)	% AAD	% MAX
Chlorobenzene (1) + p-Xylene (2) + 1-Hexanol (3)	293.15	45.99	87.48
	298.15	45.8	86.27
	308.13	43.18	83.67
	313.15	42.18	82.31
p-Xylene (1) + Octane (2) + Ethylbenzene (3)	293.15	8.7	19.78
	298.15	8.73	19.86
	308.13	8.49	19.42
	313.15	8.69	19.43
p-Xylene (1) + Ethylbenzene (2) + 1-Hexanol (3)	293.15	42.38	87.48
	298.15	41.04	86.27
	308.13	39.04	83.67
	313.15	37.67	82.31
p-Xylene (1) + Octane (2) + 1-Hexanol (3)	293.15	36.6	87.48
	298.15	36.06	86.27
	308.13	33.36	83.67
	313.15	32.74	82.31
Octane (1) + Ethylbenzene (2) + 1-Hexanol (3)	293.15	36.91	87.48
	298.15	36.05	86.27
	308.13	34.2	83.67
	313.15	32.71	82.31

Table 5.17: Results of Testing the Allan and Teja Correlation Using the Experimental Viscosity Data on Quaternary and Quinary Systems.

System	Temperature (K)	% AAD	% MAX
Chlorobenzene (1) + p-Xylene (2) + Octane (3) + Ethylbenzene (4)	293.15	16.11	32.86
	298.15	16.1	34.1
	308.13	15.85	33.52
	313.15	15.95	32.61
p-Xylene (1) + Octane (2) + Ethylbenzene (3) + 1-Hexanol (4)	293.15	36.54	87.48
	298.15	36.26	87.12
	308.13	34.17	83.67
	313.15	32.11	82.31
Chlorobenzene (1) + Octane (2) + Ethylbenzene (3) + 1-Hexanol (4)	293.15	40.36	87.48
	298.15	39.54	86.27
	308.13	36.16	83.67
	313.15	36.15	82.31
Chlorobenzene (1) + p-Xylene (2) + Ethylbenzene (3) + 1-Hexanol (4)	293.15	44.04	87.48
	298.15	43.22	86.27
	308.13	40.7	83.67
	313.15	39.76	82.31
Chlorobenzene (1) + p-Xylene (2) + Octane (3) + 1-Hexanol (4)	293.15	38.89	87.48
	298.15	37.9	86.27
	308.13	36.63	83.67
	313.15	35.8	82.31

Table 5.17 (Cont'd.): Results of Testing the Allan and Teja Correlation Using the Experimental Viscosity Data of the Quaternary and Quinary Systems.

System	Temperature (K)	% AAD	% MAX
Chlorobenzene (1) + p-Xylene (2) + Octane (3) + Ethylbenzene (4) + 1-Hexanol (5)	293.15	31.69	87.48
	298.15	31.28	86.27
	308.13	29.77	83.67
	313.15	28.77	82.31

5.6 Testing the Predictive Capability of the ANN Technique

The predictive capability of the ANN technique is tested using data generated in the present study as well as a collection of data sets previously reported by other researchers on *n*-alkanes and 1-alkanol liquid mixtures. The following subsections discuss the ANN selection, design, and operation. In addition, a detailed discussion of the liquid classification is presented as well as the procedure followed to extend the applicability of this technique to multi-components liquid mixtures.

5.6.1 ANN selection and design

The first step of this analysis was the selection of appropriate networks structure that is suitable for this type of analysis. El-Sayed (2009) suggested that a multilayer feedforward neural network with one hidden layer is a suitable choice for predicting the viscosity of liquid mixtures. This is due to the nonlinear nature of the relationship of viscosity with other independent variables.

In this type of network, three layers of neurons are interconnected. The first layer is the input layer of six neurons each one receives the value of one input parameter. Experimentally, it was determined that one hidden layer with four neurons adequately predicts the viscosity. Each neuron in the input layer is connected to the four neurons in the hidden layer where the actual data processing occurs. The third layer is the output layer that consists of one neuron that gives the predicted kinematic viscosity value of the mixture.

The six inputs of the input layer correspond to molar fractions, molecular weights, and kinematic viscosities values of the two components that compose the binary mixture. The input values must be between 0 and 1. Therefore, the original input values must be normalised using highest value of molecular weights, and kinematic viscosities of the two components that compose the binary mixture. This network's structure is limited to binary mixtures only. The artificial neural networks (ANN) were built, trained, tested, and operated using the public domain simple software "Joone". The software was downloaded from www.Joone.org.

5.6.2 ANN and multi-components liquid mixtures

For multi-components liquid mixtures a combination of separate networks "*modular binary networks*" are used. Each network "*module*" reduces two components into one *pseudo-component*. Which is coupled with another component "or another *pseudo-component*" enters a new network. This procedure is repeated until the mixture is reduced into a two-component mixture. There will be different possibilities of arranging the components and different alternatives of arranging modules. As a result of this, several combinations possibilities can be used to predict the kinematic viscosities of multi-components liquid mixtures.

The number of arrangement possibilities increases with the increase of the number of components in the mixture. For example, for ternary mixtures of component A, B, and C, two modules are needed. The first one will reduce two components into one pseudo component that is used with the third component by the second module to predict the mixture's kinematic viscosity. Three different combination possibilities exist when dealing with ternary mixture and are shown in Table 5.18.

For quaternary mixtures, three binary modules are used in two different arrangements to reduce the mixture into a *pseudo*-binary mixture. The two alternatives are shown in the block diagram in Figure 5.1. Alternative one uses one binary module to reduce the first two components in the mixture to a *pseudo*- component 1. The second module combines the output of first module with the third component and results in a second *pseudo* component which enters a third binary module with the fourth component to predict the viscosity of the quaternary mixture.

The second alternative uses two binary modules separately to reduce the first and last two components in the mixture to *pseudo*- component 1 and 2. These two *pseudo* components enter the third module to predict the viscosity of the quaternary mixture. Each one of the two arrangement alternatives uses different component arrangements. This results in 18 combination possibilities for the same quaternary mixtures as summarized in Table 5.19 below.

The building block of the binary module is the neural network that is trained using the binary mixtures' data for a certain type of liquids. Liquid classification is the most challenging task in developing viscosity prediction artificial neural networks. In the present study, the starting point was the use of n-alkanes and 1-alkanols data reported earlier to examine the possibility of developing just a single neural network that can be used in predicting their viscosities or if there is a need to develop two separate networks for each type of liquids.

Table 5.18: The Different Combination Possibilities of the Ternary Mixtures of A, B, and C When Modular Binary Neural Networks are Used for the Kinematic Viscosity Prediction.

Possibility no.	Input to module ===>	Comp1+Comp2	(P-C 1)+Comp3
	Comp1+Comp2	Output of Module 1	Output of Module 2
	Comp. arrangement possibilities	Pseudo-Comp1 (P-C1)	
1	A+B+C	AB	ABC
2	A+C+B	AC	ACB
3	C+B+A	CB	CBA

Table 5.19: The Different Combination Possibilities of the Quaternary Mixtures of A, B, C, and D when the Modular Binary Neural Networks are Used for Kinematic Viscosity Prediction.

1st Alternative				
Possibility no.	Input to module =>	Comp1+Comp2	(P-C 1) +Comp3	(P-C 2)+Comp4
	Comp1+Comp2 +Comp3+Comp4	Output of Module 1	Output of Module 2	Output of Module 3
	Comp arrangement possibilities	Pseudo-Comp1 (P-C1)	Pseudo-Comp 2 (P-C2)	
1	A+B+C+D	AB	ABC	ABCD
2	A+B+D+C	AB	ABD	ABDC
3	A+C+B+D	AC	ACB	ACBD
4	A+C+D+B	AC	ACD	ACDB
5	A+D+B+C	AD	ADB	ADBC
6	A+D+C+B	AD	ADC	ADCB
7	B+C+A+D	BC	BCA	BCAD
8	B+C+D+A	BC	BCD	BCDA
9	B+D+A+C	BD	BDA	BDAC
10	B+D+C+A	BD	BDC	BDCA
11	C+D+A+B	CD	CDA	CDAB
12	C+D+B+A	CD	CDB	CDBA

Table 5.19 (Cont'd.): The Different Combination Possibilities of the Quaternary Mixtures of A, B, C, and D when Modular Binary Neural Networks are Used for Kinematic Viscosity Prediction.

2nd Alternative				
Possibility no.	Input to module =>	Comp1+Comp 2	Comp3+Comp4	(P-C 1)+(P-C2)
	Comp1+Comp2 +Comp3+Comp4	Output of Module 1	Output of Module 2	Output of Module 3
	Comp arrangement possibilities	Pseudo-Comp1	Pseudo-Comp 2	
13	A+B+C+D	AB	CD	ABCD
14	A+C+B+D	AC	BD	ACBD
15	A+D+B+C	AD	BC	ADBC
16	B+C+A+D	BC	AD	BCAD
17	B+D+A+C	BD	AC	BDAC
18	C+D+A+B	CD	AB	CDAB

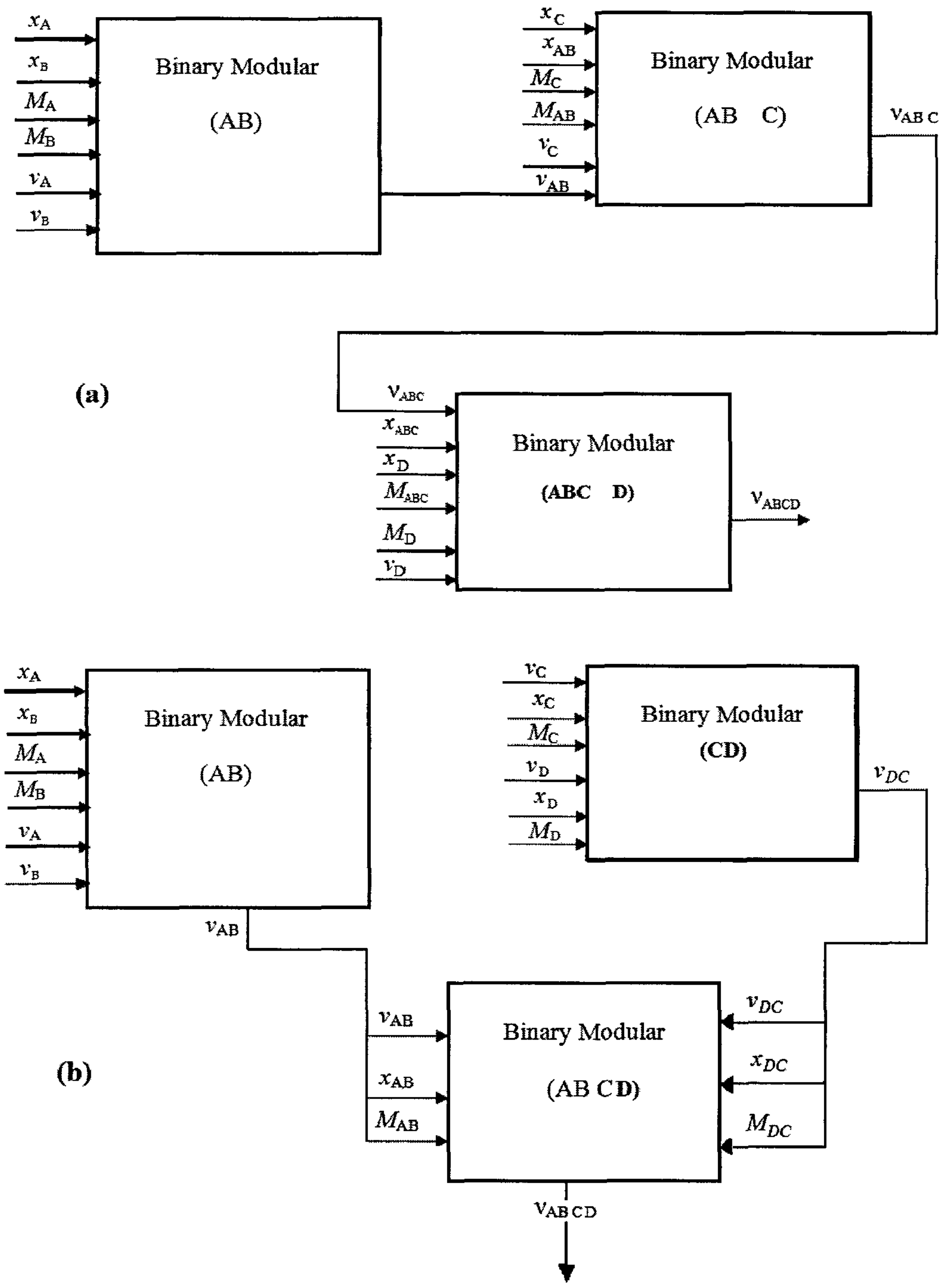

Figure 5.1: A Block Diagram of Two Arrangements of the Binary Modular Network Used for the Quaternary Mixtures.

The first trial was done by training the network using n-alkanes data. Then the network is tested first using 1-alkans data then using 1-alkanol data. This network is called the n-alkanes network. The second trial was done by training the network, named the 1-alkanols network, using 1-alkanols data. Then the network is tested first using the 1-alkanols data then using the n-alkanes data. A third trial was done by training the network using a mix of the n-alkanes and 1-alkanols data. This mixed network is tested using the remaining portions of n-alkanes and 1-alkanols data.

The *n*-alkanes binary data were obtained from Cooper (1998) and Wu (1992) as shown in table 5.20 at the four temperature levels of 293.15, 298.15, 308.15, and 313.15 K. Half of the data from Cooper were used to train the *n*-alkanes network. The other portion of Cooper's data were used to test the predictive capabilities of the trained *n*-alkanes network (test one). Then, the *n*-alkanes data reported by Wu (1992) that the network had not seen during training were used to test the predictive capabilities of the *n*-alkanes network (test two). The second test was done to ensure that the networks work with new data and it is not memorizing results. Table 5.19 summarizes the binary mixtures' data used in the development of the *n*-alkanes neural network.

Similarly, the 1-alkanols network was developed using binary data reported by Hussein (2007) and Shan (2000) at the four temperature levels of 293.15, 298.15, 308.15, and 313.15 K. Half of the data from Hussein (2007) were used to train the network, and the other half was used to test the predictive capabilities of the trained 1-alkanols network (test one). Then, the 1-alkanols data reported by Shan (2000) were used to perform a second test of the 1-alkanols network (test two). Table 5.21 summarizes the binary mixtures' data used in the development of the 1-alkanols neural network.

Furthermore, the trained n-alkanes binary network was used to predict the kinematic viscosity of 1-alkanols mixtures (additional test 1) using the same binary data reported by Hussein (2007) and Shan (2000). This additional test was performed to examine the possibility of using the different networks with other types of liquids other than those that were used to train the network.

The third developed binary network is a mixed network. It was developed using binary data reported by the four previous researchers. Half of the data from Hussein (2007) and Cooper (1988) were used to train the network, and the other half was used to test the network (mixed test 1). Then, experimental data reported by Shan (2000) and Wu (1992) were used to perform a second test of the 1-alkanols network (mixed test 2). The same mixed network was then tested using the same data in training and testing but they were randomized before using them.

The predicted kinematic viscosities from the different neural networks were compared with the corresponding experimental values. The absolute average deviation (%ADD) was calculated. For each trial the overall %AAD value for each test was calculated. Table 5.22 summarizes the result obtained for these different tests of the predictive capabilities of the different binary network.

Table 5.20: The *n*-Alkanes Data Used in Training and Testing the n-Alkanes Binary Network Used for Kinematic Viscosity Prediction.

Binary data From Cooper (1988)	Binary data From Wu (1992)
Hexane (1) + Heptane (2)	Octane (1) + Undecane (2)
Hexane (1) + Octane (2)	Octane (1) + Tridecane (2)
Hexane (1) + Decane (2)	Octane (1) + Pentadecane (2)
Heptane (1) + Octane (2)	Decane (1) + Pentadecane (2)
Heptane (1) + Decane (2)	Undecane (1) + Pentadecane (2)
Heptane (1) + Dodecane (2)	Tridecane (1) + Pentadecane (2)
Heptane (1) + Ttetradecane (2)	Decane (1) + Tridecane (2)
Octane (1) + Decane (2)	Undecane (1) + Tridecane (2)
Octane (1) + Tetradecane (2)	
Tetradecane (1) + Hexadecane (2)	

Table 5.21: The 1-Alkanols Data Used in Training and Testing the 1-Alkanols Binary Network Used for Kinematic Viscosity Prediction.

Binary data From Hussein (2007)	Binary data From Shan (2000)
1-Propanol (1) + 1-Pentanol (2)	1-Propanol (1) + 1-Butanol (2)
1-Propanol (1) + 1-Heptanol (2)	1-Propanol (1) + 1-Pentanol (2)
1-Propanol (1) + 1-Nonanol (2)	1-Butanol (1) + 1-Pentanol (2)
1-Propanol (1) + 1-Undecanol (2)	1-Butanol (1) + 1-Nonanol (2)
1-Pentanol (1) + 1-Heptanol (2)	1-Butanol (1) + 1-Decanol (2)
1-Pentanol (1) + 1-Nonanol (2)	1-Pentanol (1) + 1-Octanol (2)
1-Pentanol (1) + 1-Undecanol (2)	1-Heptanol (1) + 1-Octanol (2)
1-Heptanol (1) + 1-Nonanol (2)	1-Nonanol (1) + 1-Decanol (2)
1-Heptanol (1) + 1-Undecanol (2)	1-Decanol (1) + 1-Undecanol (2)
1-Nonanol (1) + 1-Undecanol (2)	

Table 5.22: Summary of the Overall %AAD Values Obtained from Testing the Three Binary Networks.

Test no.	Binary network name			
	n-alkanes	1-Alkanols	Mixed network	Mixed network (Randomized)
Test 1	1.8	1.8	N/A	N/A
Test 2	1.9	2.6	N/A	N/A
Mixed test 1	N/A	N/A	5.2	4.0
Mixed test 2	N/A	N/A	3.6	3.2
Additional test 1	15.6	N/A	N/A	N/A

As seen from data reported in Table 5.22, the separation of the liquid mixtures into two groups gave the best results in terms of the %AAD. Therefore, the two binary networks developed for *n*-alkanes and 1-alkanols are used for viscosity prediction for ternary, quaternary, and quinary liquid mixtures. The *modular* binary networks procedure described at the beginning of this section is used in this analysis.

The building blocks of these networks are either the n-alkane or the 1-alkanole networks. All the different combination arrangements described above for ternary mixtures and those summarized in Table 5.19 for quaternary mixtures are considered for testing. n-alkane ternary data were taken from Wu (1992) and 1-alkanols data were taken from Hussein (2007), Shan (2000), and Youssef (2007). The 1-alkanol quaternary system data were taken from Hussein (2007).

5.6.3 ANN and the present multi-components regular liquid mixtures

The current experimental kinematic viscosity values of the binary, ternary, quaternary, and quinary regular liquid systems under investigation, were compared with those predicted by an artificial neural network (ANN). The ANNs used for these systems have the same structure and were trained in the same way of the previously discussed networks in Subsections 5.6.1 and 5.6.2. The developed ANNs use some physical properties of the pure components used to compose the mixtures. For the components used in the present study those values are listed in Table 5.7.

Table 5.23: Results of Testing the ANN Technique Using the Literature Viscosity Data of Ternary Systems (TS) of *n*-alkanes.

System	Combination (%AAD)		
	AB-C	AC-B	BC-A
Octane (1) + Undecane (2)+ Tridecane (3)	3.2	2.9	2.2
Octane (1) + Undecane (2)+ Pentadecane (3)	1.3	1.2	1.2
Octane (1) + Tridecane (2)+ Pentadecane (3)	2.1	2.2	1.1
Decane (1)+ Tridecane (2)+ Pentadecane (3)	2.7	2.7	1.8
Undecane (1)+ Tridecane (2)+ Pentadecane (3)	2.8	2.7	2.1

Table 5.24: Results of Testing the ANN Technique Using the Literature Viscosity Data of the Ternary Systems (TS) of 1-Alkanols.

System	Combination (%AAD)		
	AB-C	AC-B	BC-A
1-Propanol (1) +1-Pentanol (2) + 1-Heptanol (3)	2.6	2.3	1.9
1-Propanol (1) +1-Pentanol (2) + 1-Nonanol (3)	3.6	4.1	3.5
1-Propanol (1) + 1-Pentanol (2) + 1-Undecanol (3)	2.2	2.6	2.3
1-Propanol (1) + 1-Pentanol (2) + 1-Nonanol (3)	2.6	2.4	1.9
1-Propanol (1) + 1-Heptanol (2) + 1-Undecanol (3)	3.4	2.1	2.5
1-Propanol (1) + 1-Nonanol (2) + 1-Undecanol (3)	3.5	2.5	2.2
1-Pentanol (1) + 1-Heptanol (2) + 1-Nonanol (3)	2.2	2.5	2.7
1-Pentanol (1) + 1-Heptanol (2) + 1-Undecanol (3)	1.8	2.2	2.1
1-Pentanol (1) + 1-Nonanol (2) + 1-Undecanol (3)	3.0	2.0	2.3

Table 5.24 (Cont'd.): Results of Testing the ANN Technique Using the Literature Viscosity Data of the Ternary Systems (TS) of 1-Alkanols.

System	Combination (%AAD)		
	AB-C	AC-B	BC-A
1-Heptanol (1) + 1-Nonanol (2) + 1-Undecanol (3)	1.9	1.8	1.2
1-Propanol (1) + 1-Butanol (2) + 1-Pentanol (3)	2.1	2.2	2.3
1-Butanol (1) + 1-Nonanol (2) + 1-Undecanol (3)	2.5	2.5	4.6
1-Propanol (1) +1-Butanol (2) + 1-Heptanol (3)	5.0	4.7	5.0
1-Propanol (1) +1-Butanol (2) + 1-Decanol (3)	16.6	18.4	18.6
1-Propanol (1) +1-Butanol (2) + 1-Undecanol (3)	4.6	3.8	4.1
1-Propanol (1) + 1-Heptanol (2) + 1-Decanol (3)	2.7	3.3	4.2
1-Propanol (1) +1-Heptanol (2) + 1-Undecanol (3)	5.0	4.1	4.8
1-Propanol (1) + 1-Decanol (2) + 1-Undecanol (3)	5.9	6.5	7.4

Table 5.24 (Cont'd.): Results of Testing the ANN Technique Using the Literature Viscosity Data of the Ternary Systems (TS) of 1-Alkanols.

System	Combination (%AAD)		
	AB-C	AC-B	BC-A
1-Propanol (1) + 1-Heptanol (2) + 1-Decanol (3)	2.6	3.7	4.9
1-Butanol (1) + 1-Heptanol (2) + 1-Undecanol (3)	3.8	4.8	5.4
1-Butanol (1) + 1-Decanol (2) + 1-Undecanol (3)	4.0	5.0	6.9
1-Heptanol (1) + 1-Decanol (2) + 1-Undecanol (3)	4.0	5.1	6.0

Table 5.24 (Cont'd.): Results of Testing the ANN Technique Using the Literature Viscosity Data of the Quaternary Systems (QS) of 1-Alkanols.

Combination	1st Alternative (%AAD)				
	QS1	QS2	QS3	QS4	QS5
ABCD	3.4	3.1	3.5	3.7	2.7
ABDC	3.6	2.1	2.8	2.7	1.8
ACBD	3.0	2.9	2.8	3.4	2.8
ACDB	3.0	1.7	2.0	2.1	1.7
ADBC	3.6	2.3	2.3	2.1	1.8
ADCB	3.3	2.1	2.2	1.5	1.7
BCAD	2.8	2.6	2.6	2.8	2.4
BCDA	2.8	1.4	1.9	2.3	2.4
BDAC	3.6	2.7	2.7	2.3	2.2
BDCA	3.8	2.9	3.0	3.3	3.1
CDAB	3.4	2.5	4.2	2.9	3.3
CDBA	3.6	2.7	4.7	4.1	4.3

Table 5.24 (Cont'd.): Results of Testing the ANN Technique Using the Literature Viscosity Data on Quaternary Systems (QS) of 1-alkanols.

Combination	2nd Alternative (%AAD)				
	QS1	QS2	QS3	QS4	QS5
ABCD	3.1	1.8	1.9	1.0	1.0
ACBD	3.1	2.4	2.1	1.7	1.2
ADBC	3.1	2.2	1.4	1.7	1.1
BCAD	2.9	2.0	1.5	1.8	1.2
BDAC	3.2	2.3	2.0	1.7	1.1
CDAB	3.0	1.5	2.3	1.1	1.0

QS1: 1-Propanol (1) + 1-Pentanol (2) + 1-Heptanol (3) + 1-Nonanol (4)

QS2: 1-Propanol (1) + 1-Pentanol (2) + 1-Heptanol (3) + 1-Undecanol (4)

QS3: 1-Propanol (1) + 1-Pentanol (2) + 1-Nonanol (3) + 1-Undecanol (4)

QS4: 1-Propanol (1) + 1-Heptanol (2) + 1-Nonanol (3) + 1-Undecanol (4)

QS5: 1-Pentanol (1) + 1-Heptanol (2) + 1-Nonanol (3) + 1-Undecanol (4)

One third of the binary data of the present study were used to train a new network called the regular network. Once the training procedure was completed, the remaining binary mixture data were used to test the network. The results of testing the network using the binary systems are reported in Tables 5.25.

Since the overall %AAD value of testing the regular network is relatively high, further classification of liquid mixtures was tested by developing two separate networks for two groups of liquid mixtures. Since 1-hexanol has a relatively very high viscosity value when compared to other pure components used to constitute the mixtures in the present study, which increases the sensitivity of the normalized values of viscosities of the other components. The criterion of liquid mixtures' further classification is whether a mixture contains 1-hexanol or not.

Two separate networks were developed. The first one is called the regular 1-hexanol network is for mixtures with 1-hexanol and the other is called the regular non 1-hexanol network and is used for non 1-hexanol mixtures. They were designed, built, and trained as the previous networks. The only difference between the two networks is the normalization factor for viscosity values which represents the highest values of viscosity for the pure liquids used in the study.

Table 5.25: Results of Testing the Regular ANN using the Collected Experimental Viscosity Data of the Binary Systems.

System	Temperature (K)	% AAD
Chlorobenzene (1) + p-Xylene (2)	293.15	29.1
	298.15	29.1
	308.13	32.3
	313.15	33.7
Chlorobenzene (1) + Octane (2)	293.15	42.8
	298.15	40.0
	308.13	35.3
	313.15	32.5
Chlorobenzene (1) + Ethylbenzene (2)	293.15	27.0
	298.15	27.5
	308.13	29.6
	313.15	31.3
Chlorobenzene (1) + 1-Hexanol (2)	293.15	18.8
	298.15	15.2
	308.13	17.8
	313.15	17.8
p-Xylene (1) + Octane (2)	293.15	44.2
	298.15	41.4
	308.13	36.4
	313.15	34.4
p-Xylene (1) + Ethylbenzene (2)	293.15	27.3
	298.15	27.1
	308.13	28.8
	313.15	30.3
p-Xylene (1) + 1-Hexanol (2)	293.15	15.5
	298.15	14.6
	308.13	12.7
	313.15	13.0
Octane (1) + Ethylbenzene (2)	293.15	27.4
	298.15	28.3
	308.13	31.9
	313.15	34.0
Octane (1) + 1-Hexanol (2)	293.15	16.3
	298.15	15.1
	308.13	12.2
	313.15	12.5
Ethylbenzene (1) + 1-Hexanol (2)	293.15	15.5
	298.15	13.4
	308.13	13.0
	313.15	12.0
Overall		25.4

Table 5.26: Results of Testing the Regular 1-Hexanol ANN Using the Collected Experimental Viscosity Data of the Binary Systems.

System	Temperature (K)	% AAD
Chlorobenzene (1) + 1-Hexanol (2)	293.15	2.8
	298.15	2.5
	308.13	2.7
	313.15	2.3
p-Xylene (1) + 1-Hexanol (2)	293.15	4.4
	298.15	1.7
	308.13	1.50
	313.15	3.9
Octane (1) + 1-Hexanol (2)	293.15	4.3
	298.15	2.1
	308.13	4.7
	313.15	5.0
Ethylbenzene (1) + 1-Hexanol (2)	293.15	4.1
	298.15	5.0
	308.13	3.1
	313.15	2.3
Overall		3.3

Table 5.27: Results of Testing the Regular Non 1-Hexanol ANN Using the Collected Experimental Viscosity Data of the Binary Systems.

System	Temperature (K)	% AAD
Chlorobenzene (1) + p-Xylene (2)	293.15	1.1
	298.15	1.2
	308.13	1.1
	313.15	1.6
Chlorobenzene (1) + Octane (2)	293.15	2.5
	298.15	2.0
	308.13	2.0
	313.15	1.3
Chlorobenzene (1) + Ethylbenzene (2)	293.15	1.9
	298.15	1.6
	308.13	2.0
	313.15	2.1
p-Xylene (1) + Octane (2)	293.15	1.4
	298.15	1.4
	308.13	1.5
	313.15	1.4
p-Xylene (1) + Ethylbenzene (2)	293.15	1.1
	298.15	1.1
	308.13	1.1
	313.15	1.0
Octane (1) + Ethylbenzene (2)	293.15	1.7
	298.15	1.8
	308.13	1.9
	313.15	2.0
Overall		1.6

Since the further classification of mixtures gave a better performance of the ANNs, this approach will be combined with the "*modular binary networks*" described above for the prediction of the viscosity values of the multi-components liquid mixtures. As stated before, for multi-component liquid mixtures there are different possibilities of arranging the components and different alternatives of arranging modules. Consequently, several combination possibilities are considered for the prediction of the kinematic viscosities of multi-component liquid mixtures. The number of possibilities depends on the number of components in the mixture as summarized in Tables 5.18 and 5.19. The building block of the binary module is either the regular 1-hexanol or the regular non 1-hexanol neural network that is trained using the binary mixtures' data for a certain type of liquids.

Table 5.28: Results of Testing the Regular ANNs Using the Collected Experimental Viscosity Data of the Ternary Systems.

System	Network Name	Temperature (K)	Combination (%AAD)		
			AB-C	AC-B	CB-A
Chlorobenzene (1) + p-Xylene (2) + Octane (3)	Regular Non 1-Hexanol	293.15	1.3	3.1	0.9
		298.15	1.3	3.1	0.9
		308.13	1.5	3.1	1.2
		313.15	1.5	3.1	0.9
Chlorobenzene (1) + Octane (2) + Ethylbenzene (3)	Regular Non 1-Hexanol	293.15	1.6	3.2	6.0
		298.15	2.1	3.0	4.4
		308.13	1.2	2.8	5.1
		313.15	1.3	2.0	4.7
Chlorobenzene (1) + p-Xylene (2) + Ethylbenzene (3)	Regular Non1-Hexanol	293.15	1.9	2.4	6.7
		298.15	3.1	3.9	7.4
		308.15	2.8	3.8	7.4
		313.15	2.4	3.4	7.4
Chlorobenzene (1) + Octane (2) + 1-Hexanol (3)	Mixed Network	293.15	30.2	72.9	64.8
		298.15	29.4	70.0	60.8
		308.13	23.0	66.1	56.1
		313.15	26.6	62.0	51.3
Chlorobenzene (1) + Ethylbenzene (2) + 1-Hexanol (3)	Mixed Network	293.15	34.1	52.2	64.3
		298.15	27.0	49.3	62.2
		308.13	23.1	41.2	56.5
		313.15	22.3	38.1	53.7

Table 5.28 (Cont'd.): Results of Testing the Regular ANNs Using the Collected Experimental Viscosity Data of the Ternary Systems.

System	Network Name	Temperature (K)	Combinations (%AAD)		
			AB-C	AC-B	CB-A
Chlorobenzene (1) + p-Xylene (2) + 1-Hexanol (3)	Mixed Network	293.15	33.9	52.1	64.5
		298.15	26.1	48.6	61.9
		308.13	24.8	40.4	55.9
		313.15	24.0	38.1	53.1
p-Xylene (1) + Octane (2) + Ethylbenzene (3)	Regular non 1-Hexanol	293.15	0.9	2.0	0.8
		298.15	0.8	2.2	1.0
		308.13	0.8	2.2	1.1
		313.15	0.7	2.1	1.0
p-Xylene (1) + Ethylbenzene (2) + 1-Hexanol (3)	Mixed Network	293.15	28.1	54.1	48.0.
		298.15	23.7	50.1	43.9
		308.13	20.4	42.8	36.0
		313.15	18.4	38.9	31.4
p-Xylene (1) + Octane (2) + 1-Hexanol (3)	Mixed Network	293.15	31.7	72.8	45.3
		298.15	24.1	71.0	42.0
		308.15	22.6	66.5	32.9
		313.15	20.1	64.5	29.4
Octane (1) + Ethylbenzene (2) + 1-Hexanol (3)	Mixed Network	293.15	29.8	53.1	69.3
		298.15	23.9	49.9	67.2
		308.13	19.6	43.0	62.8
		313.15	20.0	38.6	59.9
Overall			15.8	33.0	33.2

Table 5.29: Results of Testing the Regular ANNs Using the Collected Experimental Viscosity Data of the Quaternary System: Chlorobenzene-pXylene-Octane-Ethylbenzene.

	1st Alternative (%AAD)				
	Temperature (K)				
	293.15 K	298.15 K	308.15 K	313.15 K	Avg % AAD
ABCD	2.7	2.4	2.3	2.3	2.4
ABDC	4.0	3.7	3.5	3.4	3.6
ACBD	2.6	2.3	2.2	2.2	2.3
ACDB	2.4	2.1	2.1	2.1	2.2
ADBC	4.1	4.0	3.9	3.8	4.0
ADCB	2.5	2.3	2.4	2.4	2.4
BCAD	3.2	2.8	2.7	2.7	2.8
BCDA	6.7	5.5	5.6	6.1	6.0
BDAC	6.0	5.5	5.4	5.4	5.6
BDCA	7.6	6.5	6.6	7.0	6.9
CDAB	2.9	2.6	2.8	2.8	2.8
CDBA	6.3	5.3	5.5	6.0	5.8
	2nd Alternative				
ABCD	3.6	3.0	2.7	2.4	2.9
ACBD	3.5	2.9	2.5	2.2	2.6
ADBC	5.8	5.3	5.0	4.8	5.3
BCAD	5.1	4.4	4.0	3.8	4.3
BDAC	7.5	6.9	6.6	6.5	6.9
CDAB	7.3	6.6	6.3	6.1	6.6

Table 5.30: Results of Testing the Regular ANNs Using the Collected Experimental Viscosity Data of the Quaternary System: p-Xylene + Octane +-Ethylbenzene + 1-Hexanol.

Combination	1st Alternative (%AAD)				
	Temperature (K)				
	293.15	298.15	308.15	313.15	Avg
ABCD	11.5	9.5	6.9	11.6	9.9
ABDC	28.9	29.5	30.8	31.6	30.2
ACBD	16.3	14.4	10.0	15.8	14.1
ACDB	13.9	18.6	22.2	26.3	20.2
ADBC	37.5	37.7	38.2	40.2	38.4
ADCB	29.9	30.6	32.1	34.4	31.8
BCAD	11.8	9.6	7.1	10.7	9.8
BCDA	29.3	27.7	27.1	23.1	26.8
BDAC	39.5	39.5	40.0	39.2	39.6
BDCA	42.7	39.4	36.7	34.5	38.3
CDAB	16.7	19.5	24.8	29.9	22.7
CDBA	27.7	27.0	26.4	25.8	26.7
	2nd Alternative (%AAD)				
ABCD	19.4	25.5	33.8	46.2	31.2
ACBD	17.9	25.3	35.2	48.1	31.6
ADBC	49.9	55.7	59.8	66.3	57.9
BCAD	15.5	20.0	29.6	41.2	26.6
BDAC	46.5	50.6	55.3	60.6	53.2
CDAB	1843.0	1389.6	202.5	176.1	902.8

Table 5.31: Results of Testing the Regular ANNs Using the Collected Experimental Viscosity Data of Quaternary System: Chlorobenzene + Octane + Ethylbenzene + 1-Hexanol.

Combination	1st Alternative (%AAD)				
	Temperature (K)				
	293.15	298.15	308.15	313.15	Avg
ABCD	12.8	9.8	9.1	7.4	9.8
ABDC	27.1	30.3	27.3	29.4	28.5
ACBD	17.2	11.8	14.2	12.2	13.8
ACDB	16.3	17.3	23.0	24.4	20.2
ADBC	35.8	38.5	35.0	37.1	36.6
ADCB	28.5	30.7	29.7	31.7	30.1
BCAD	19.3	13.8	16.2	14.2	15.9
BCDA	20.3	21.5	25.8	27.2	23.7
BDAC	37.0	40.0	36.8	38.7	38.1
BDCA	35.2	37.6	36.1	38.3	36.8
CDAB	20.2	21.2	31.1	32.7	26.3
CDBA	24.1	23.5	35.1	36.9	29.9
	2nd Alternative				
ABCD	18.7	22.5	36.0	39.3	29.1
ACBD	19.5	22.7	38.7	42.4	30.8
ADBC	50.2	50.9	58.6	60.8	55.1
BCAD	25.5	29.8	48.6	52.7	39.2
BDAC	56.4	54.9	68.7	70.9	62.7
CDAB	1973.5	1493.1	257.7	208.8	983.2

Table 5.32: Results of Testing the Regular ANNs Using the Collected Experimental Viscosity Data of Quaternary System: Chlorobenzene + pXylene + Ethylbenzene + 1-Hexanol.

Combination	1st Alternative (%AAD)				
	Temperature (K)				
	293.15	298.15	308.15	313.15	Avg
ABCD	12.9	8.6	7.4	8.8	9.4
ABDC	27.9	28.5	27.9	28.0	28.1
ACBD	12.9	8.4	8.3	9.5	9.8
ACDB	21.3	21.7	17.5	15.5	19.0
ADBC	38.1	36.8	35.3	35.0	36.3
ADCB	35.4	33.8	27.7	25.5	30.6
BCAD	22.1	16.8	16.6	18.1	18.4
BCDA	19.0	20.1	25.9	30.1	23.8
BDAC	37.1	37.5	36.7	38.3	37.4
BDCA	34.5	34.7	36.1	37.4	35.7
CDAB	16.2	17.3	16.8	18.6	17.2
CDBA	21.2	21.8	27.1	31.7	25.5
	2nd Alternative				
ABCD	15.3	18.2	28.7	35.5	24.4
ACBD	14.1	15.5	24.8	31.8	21.6
ADBC	43.9	44.8	50.3	53.8	48.2
BCAD	29.5	33.8	49.9	58.3	42.9
BDAC	59.8	60.0	70.5	76.1	66.6
CDAB	1905.4	1379.5	214.9	182.8	920.7

Table 5.33: Results of Testing the Regular ANNs Using the Present Experimental Viscosity Data of Quaternary System: Chlorobenzene + p-Xylene + Octane + 1-Hexanol in Terms of % AAD of 1-Alkanols.

Combination	1st Alternative (%AAD)				
	Temperature (K)				
	293.15	298.15	308.15	313.15	Avg.
ABCD	19.41	15.90	13.79	16.45	16.39
ABDC	33.42	35.43	38.02	37.21	36.02
ACBD	15.41	11.99	9.85	12.49	12.44
ACDB	18.72	17.61	16.63	16.75	17.43
ADBC	39.93	41.86	45.01	44.68	42.87
ADCB	31.02	28.76	28.60	27.79	29.04
BCAD	25.27	21.50	19.22	21.97	21.99
BCDA	26.35	27.41	32.44	35.04	30.31
BDAC	44.82	47.25	50.82	50.53	48.36
BDCA	39.95	41.94	44.66	45.80	43.09
CDAB	16.04	17.80	20.62	22.40	19.22
CDBA	24.99	27.18	33.19	36.56	30.48
	2nd Alternative				
ABCD	30.05	34.55	45.51	53.53	40.91
ACBD	19.35	24.74	36.01	44.37	31.12
ADBC	58.46	63.89	68.97	70.82	65.53
BCAD	43.74	50.20	63.99	73.55	57.87
BDAC	82.77	86.36	93.70	97.44	90.07
CDAB	1936.53	1488.92	251.86	216.09	973.35

Table 5.34: Results of Testing the Regular ANNs Using the Present Experimental Viscosity Data on Quinary Systems in Terms of % AAD.

System	Temperature (K)	Combination
		AB-C-D-E
Chlorobenzene (1) + p-Xylene (2) + Octane (3) + Ethylbenzene (4) + 1-Hexanol (5)	293.15	11.7
	298.15	12.77
	308.13	11.33
	313.15	12.94

5.7 Analysis of the Results

Six different viscosity prediction methods were subjected to testing, in the present study, to determine their predictive capabilities. The tests showed a variation in their performance and accuracy in predicting liquid mixtures viscosities. A few points have to be indicated here before proceeding with the analysis of the obtained results.

When using the GC-UNIMOD model, the residual part was set equal to zero. This assumption is based on the outcome of different studies conducted by other researcher indicated earlier. The second assumption is when the ANN technique was used to predict the viscosity of quinary systems of component A, B, C, D, and E, one combination was used that is AB-C-D-E among several other combinations based on the finding from other types of multi-components systems that this combination gives the best viscosity prediction.

The average %AAD values obtained for the systems under investigation are summarized in Table 5.35 and in Figures 5.2 through 5.5. These provide a comparison of the predictive capabilities of the models tested in terms of the percentage absolute average deviation for binary, ternary, quaternary, quinary and an overall comparison, respectively.

Table 5.35: Overall Comparison of the Predictive Capabilities of the Tested Viscosity Model in Terms of % AAD.

Tested Model	Binary Systems	Ternary Systems	Quaternary Systems	Quinary Systems	Overall
G-McAllister 3-Bodies	3.9	4.0	3.9	4.0	3.9
Pseudo-Binary McAllister	3.9	4.0	4.6	5.1	4.3
GCSP	5.9	12.5	14.7	16.8	10.0
GC-UNIMOD (R=0)	9.8	16.4	19.7	19.5	14.6
Allan and Teja	33.5	30.3	33.6	30.4	32.2
ANN	2.3	15.8	9.6	12.2	9.3

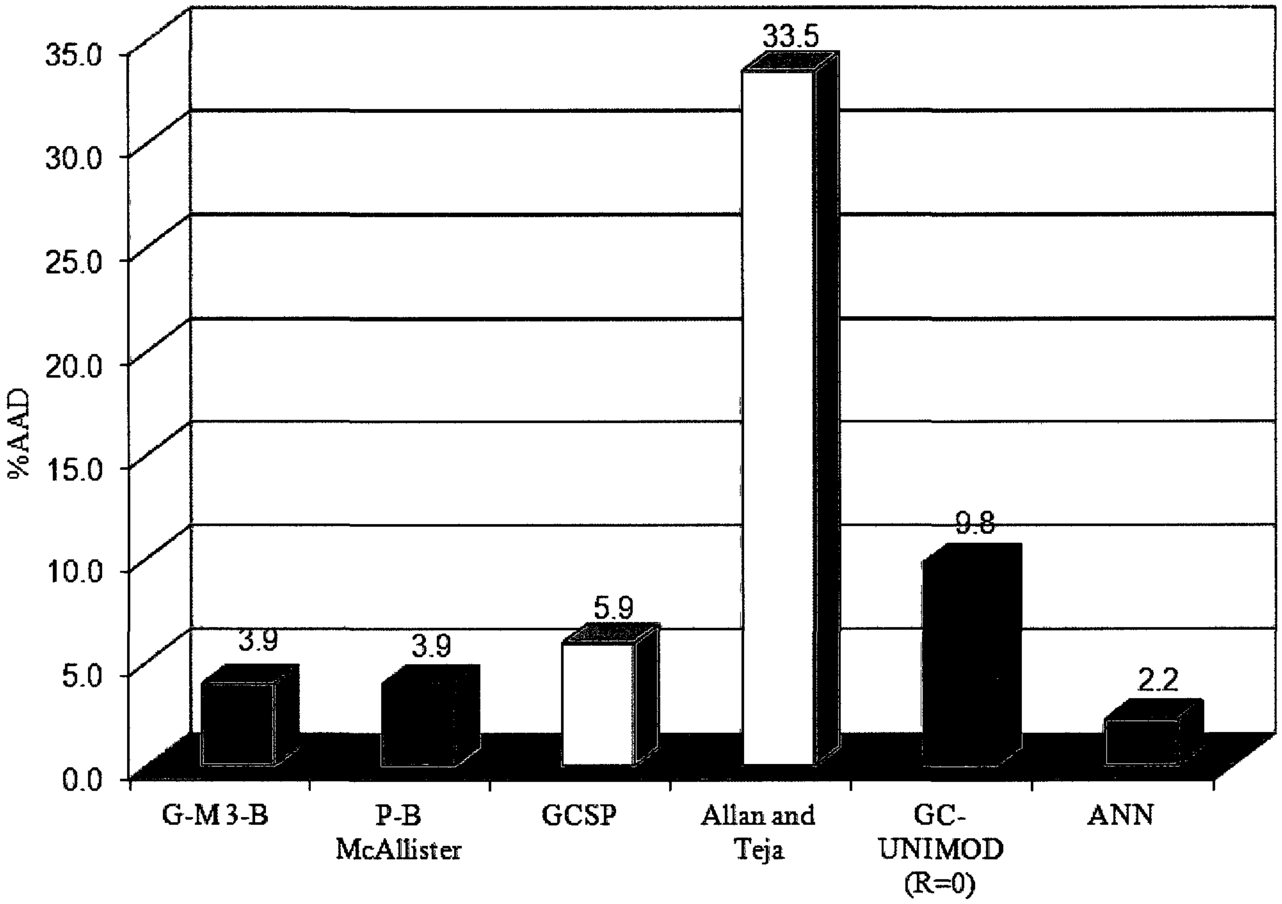

Figure 5.1: Predictive Capabilities of the Tested Viscosity Model for Binary Systems

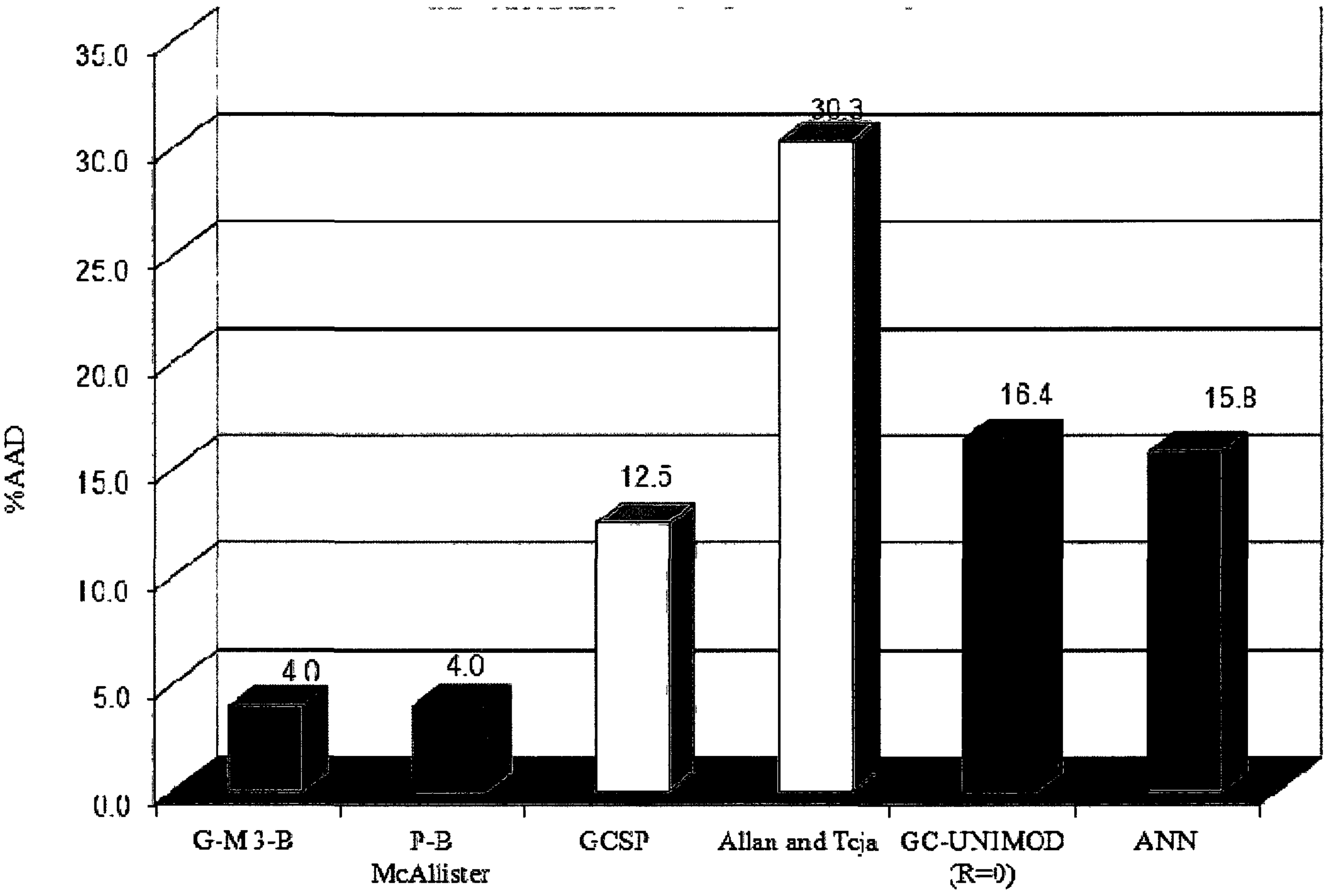

Figure 5.2: Predictive Capabilities of the Tested Viscosity Model for Ternary Systems

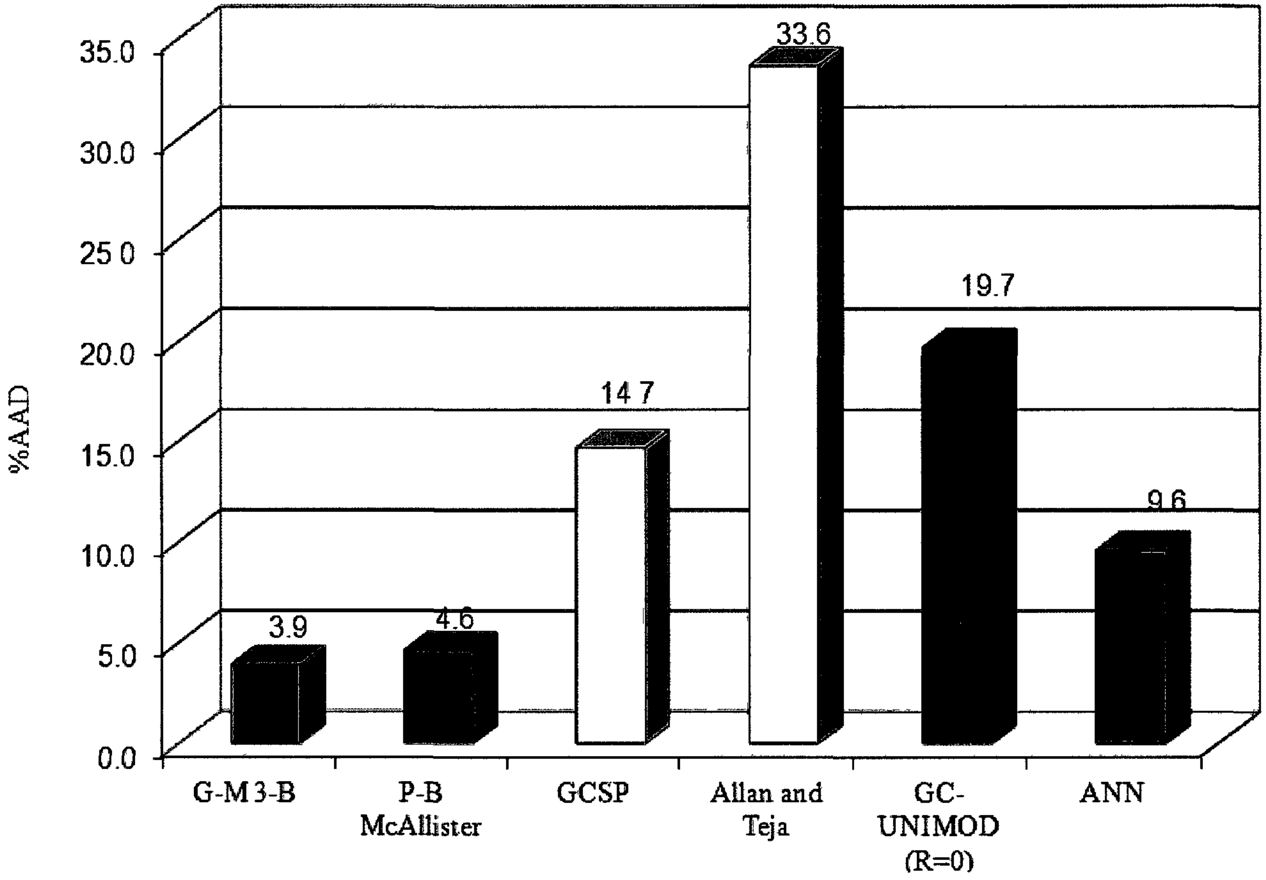

Figure 5.3: Predictive Capabilities of the Tested Viscosity Model for Quaternary Systems

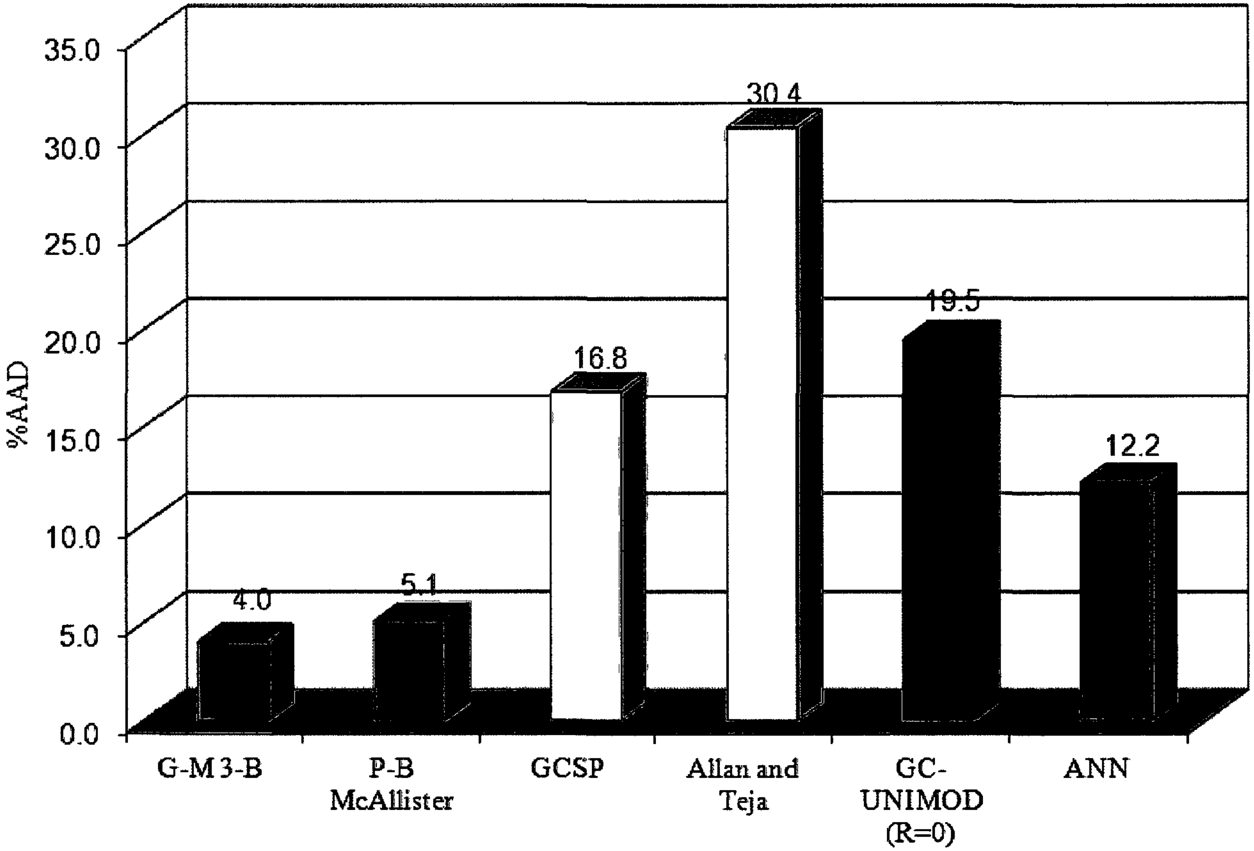

Figure 5.4: Predictive Capabilities of the Tested Viscosity Model for Quinary Systems

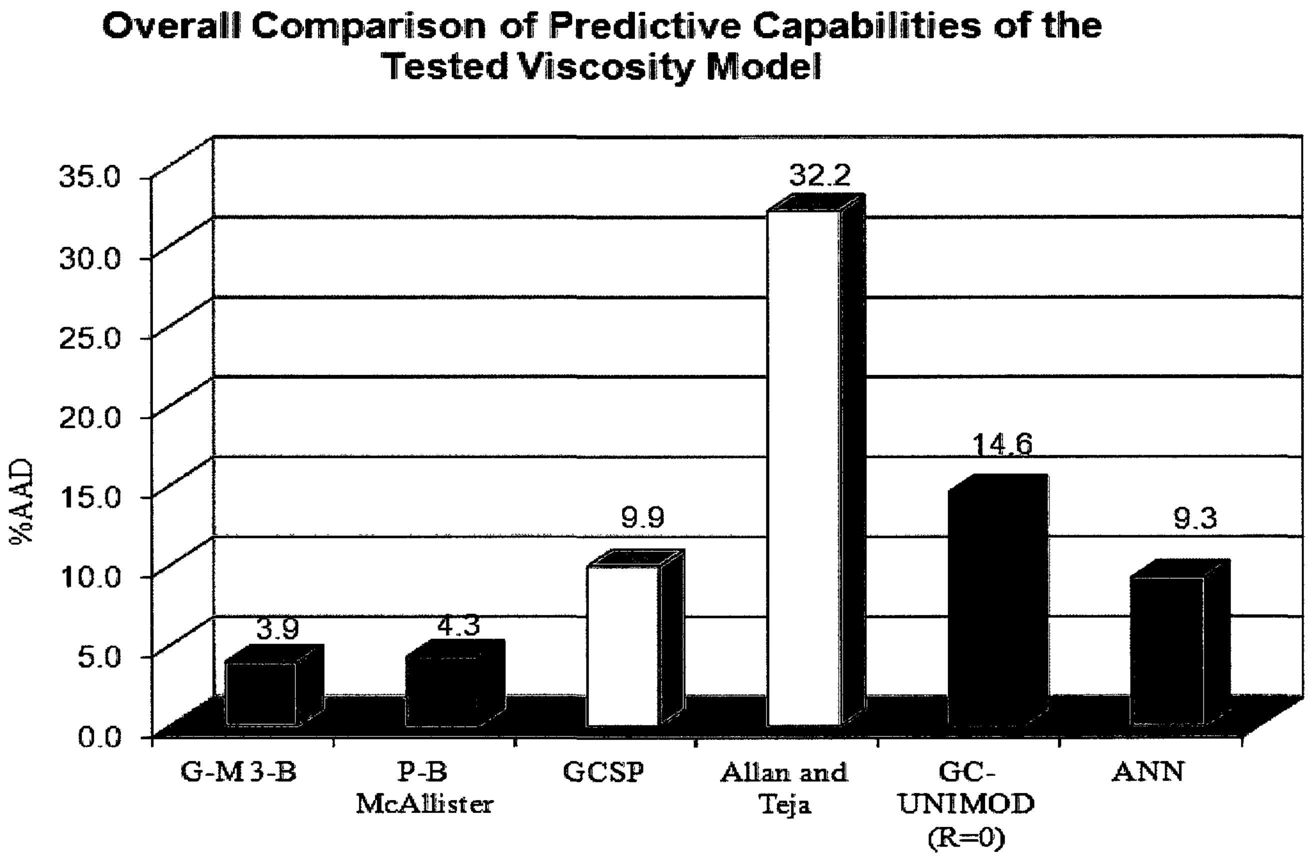

Figure 5.5: Overall Comparison of Predictive Capabilities of the Tested Viscosity Model

In light of the results reported in Table 5.35 and Figures 5.2 through 5.6, the Generalized McAllister Model reported by Nhaesi and Asfour (2000a), and the *Pseudo-binary* McAllister model reported by Nhaesi and Asfour (2000b) outperformed the rest of the models. They have successfully predicted the kinematic viscosity of the systems under investigation with the lowest overall average percentage absolute deviation values of 3.94 % and 4.26 %, respectively. This is consistent with earlier findings by other researchers in our group that these models gave the best kinematic viscosity predictions for different types of multi-components liquid mixtures.

Another important result obtained here is that employing the *pseudo-binary* approach did not significantly increase the error but provided a noteworthy simplification and dramatically reduces the computational steps needed.

The only shortcoming of the generalized McAllister three-body interaction model is that it does not result in good predictions in the cases where the difference in molecular size is relatively high. For such cases a generalized version of four-body interaction model is of great importance and therefore it needs to be developed.

The artificial neural networks (ANNs) technique predicted the kinematic viscosity of the mixtures under investigation with an overall average %AAD of 9.3 This makes it the third best method and the best correlative method investigated.

The generalized corresponding states principle (GCSP) model showed the third best performance among the selected semi-theoretical models slightly after the ANN technique. This model has predicted the kinematic viscosities of the investigated mixtures with an overall average %AAD value of 10.0.

The GC-UNIMOD (with R=0) was the last best performer among the selected semi-theoretical models. The GC-UNIMOD predicted the kinematic viscosities of the investigated mixtures with an overall average %AAD of 14.6.

The Allan and Teja correlation predicted the kinematic viscosity of the investigated mixture with relatively high overall percentage average absolute deviation of 32.2. This is a relatively high error value that makes this model by far the worst performer compared to other viscosity prediction models.

These results also show that the best three models are those that classify the multi-components liquid mixtures into different classes based on structure. The best two performers classify the liquid mixture into three different types *viz*; *n*-alkanes, regular, and associated solutions.

The same approach was used when developing a different neural networks each were trained using data of different types of liquids, where liquids with similar structure use the same network that is trained using data of liquids that belong to the same class of liquids. Moreover, careful examination of the data reported in Table 5.35 shows that the models' order in terms of performance for binary, ternary, quaternary, and quinary mixtures was almost the same. Based on this finding one may criticise the basis of the group contribution approach that assumes that the functional group will have the same effect regardless of the class of liquid or the component's structure.

The use of the artificial neural network technique is simple when applied to binary mixtures and as the number of components in the mixture increases the complexity of the model increases that employs the binary modular approach. This is mainly due to the several combinations of the components and the different arrangement possibilities of the binary modules. From previous experience, each combination gives different performance without a clear criterion that can predict the best combination with the least error. With this in mind, the different components were arranged in terms of their kinematic viscosity starting with the one that has the lowest kinematic viscosity value and so on. Using this liquids arrangement and arranging the binary modules in series gave the best performance of this technique. This rule is still a preliminary one that requires additional testing with different types of liquids. Once certain criterion for selecting the combination that gives the best prediction is well established, the main obstacle of using ANN for multi-components' viscosity prediction calculations disappears.

The use of artificial neural networks in viscosity prediction is still a new area that has a room for improvement. The effect of different parameters on mixture's viscosity can be investigated using this technique but it requires a detailed weight analysis study, which can be a potential topic for future studies.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The kinematic viscosities and densities of the pure components and the quinary system: Chlorobenzene + p-xylene + Octane + ethylbenzene + 1-hexanol and its ten binary, ten ternary, and five quaternary subsystems were experimentally measured over the entire composition range at 293.15, 298.15, 308.15, and 313.15 K.

The densities and viscosities of the pure components employed in the present study were compared to their corresponding values reported in the literature. They were found to be in excellent agreement with the corresponding literature values.

The measured kinematic viscosity values of the liquid mixtures reported in the present work were used to test the predictive capabilities of a selected group of viscosity models. The models tested were: (i) the generalized McAllister three-body interaction model, (ii) the *Pseudo-binary* McAllister model, (iii) the GC-UNIMOD model, (iv) the generalized corresponding states principle (GCSP) model, (v) the Allan and Teja correlation, and (iv) the artificial neural network technique (ANN). The predictive capability of each of the viscosity models was determined by calculating the percent average absolute deviation (%AAD) value between the experimental and the predicted values.

The two models based on the original McAllister model, *viz;* the generalized McAllister model reported by Nhaesi and Asfour (2000a), and the *pseudo-binary* McAllister model reported by Nhaesi and Asfour (2000b), showed the best overall predictive capability of all models. Their overall percentage average absolute deviation values were 3.9 and 4.3 %, respectively.

The artificial neural networks (ANNs) technique ranked as the third best model with an overall average %AAD of 9.3 followed by the generalized corresponding states principle (GCSP) model that predicted the kinematic viscosities of the investigated mixtures with an overall average %AAD value of 10.0.

The GC-UNIMOD predicted the kinematic viscosities of the mixtures under investigation with an overall average %AAD of 14.6, whereas the Allan and Teja correlation predicted the kinematic viscosity of the investigated mixture with the highest overall %AAD value of 32.2.

It is noted that those models that classify the multi-components liquid mixtures into different groups or classes based on their structure performed better than the *one-size fits all* models. Therefore one can conclude that liquids with different structures cannot be treated in the same way.

6.2 Recommendations

In light of the results obtained in the present study, the following suggestions are made for further studies:

1. A generalized four-body interaction McAllister predictive viscosity model for multi-component liquid mixtures needs to be developed in a similar way to that reported earlier

by Nhaesi and Asfour (2000a) for the case of three-body interaction model. This is required to deal with multi-component liquid mixtures containing components that significantly differ in size.

2. The applicability of the ANN and the binary modular approach in the case of the multi-components liquid mixtures' viscosity predictions must be tested using other data sets of additional types of mixtures.

3. Testing the suggested criterion of arranging pure components composing the mixture based on their viscosity values for selecting the combination that gives the best viscosity prediction for multi-components' viscosity prediction using data of additional types of mixtures.

4. Testing other possible criteria that can lead to selecting the combination that gives the best viscosity prediction for multi-components' viscosity prediction.

5. Additional experimental data on viscosity and density is always a great addition to the literature specially those for quaternary and quinary system. Therefore it is recommended to conduct future studies that provide such data sets on systems that have not been studied before and use those data to test viscosity models.

Nomenclature

a	group interaction energy parameter
B	constant generally used as a parameter
C	constant generally used as a parameter
D	constant generally used as a parameter
E	constant generally used as a parameter
ECN	Effective carbon number
f	shear force
Δ^*G	Activation energy of viscous flow per g-mol, J/mol
Δ^*G_o	activation energy of viscous flow per molecule
h	Plank's constant
i	index number
j	index number
K	index number
K	Boltzman's constant
M	molecular weight, mol
N	Number of components of the mixture; number of interaction parameters, number of experimental points
N	Avogadro 's number, carbon atoms number.
P	Pressure
Q	Area parameter of molecules
Q	Area parameter of a group

R	Universal gas constant
R	Rate of a liquid molecule moving under shear stress
r_0	Rate of liquid molecule moving as a result of thermal fluctuation
T	Efflux time
T	Absolute temperature
V	molar volume of the liquid,
X	Mole fraction
Z	Compressibility factor

Greek Letters

μ	Absolute viscosity
$\lambda_1, \lambda_2, \lambda_3$	intermolecular distance used in Eyring's theory
N	Kinematic viscosity, m^2/s
v_k	number of groups in molecule
v_{12}	McAllister three-body model binary interaction parameter
v_{21}	McAllister three-body model binary interaction parameter
v_{123}	McAllister three-body model interaction parameter
v_{1112}	McAllister four-body model interaction parameter
v_{2221}	McAllister four-body model interaction parameter
v_{1122}	McAllister four-body model interaction parameter
ξ_{ij}	binary interaction parameter in the Generalized Corresponding Principle
ξ_i^0	binary interaction parameter in the Generalized Corresponding Principle for pure component
ρ	density

T	oscillation period in seconds of the density meter, shear stress
Φ	shape factor, volume fraction
Φ_{ji}	local volume fraction of component j around cental molecule i
Ω	acentric factor
Ξ_{ki}	group property in GC-UNIMOD model
Ψ_{ki}	group residual viscosity in the GC-UNIMOD

Subscripts

1, 2, 3	refer to various components in the mixture
C	critical properties
i, j	refer to ith and j th component in the mixture, respectively
ij	refer to interaction type i-j
ijk	refer to interaction of type i-j-k
r1	refers to the reference fluid 1
r2	refers to the reference fluid 2
r3	refers to the reference fluid 3
r4	refers to the reference fluid 4
r	reduced properties

Acronyms

AAD	average absolute deviation

ECN	Effective carbon number
GC-UNIMOD	Group Contribution-Viscosity thermodynamics Model
GCSP	Generalized Corresponding States Principle
MAX	maximum deviation, %

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APPENDIX A

RAW DATA OF VISCOSITY AND DENSITY MEASUREMENTS

Table A.1: Raw Data of Viscosity and Density Measurements for the Binary System: Chlorobenzene (1) + p-Xylene (2).

T (K)	x_1	Viscometer number	Efflux time (s)	Oscillation period (s)	T (K)	Viscometer number	Efflux time (s)	Oscillation period (s)
293.15	0.1085	25 [B349]	420.74	0.7364	298.15	25 [B349]	401.56	0.7353
	0.2083	25 [B350]	422.91	0.7403		25 [B350]	407.05	0.7392
	0.3097	25 [B366]	384.92	0.7444		25 [B366]	370.39	0.7433
	0.3882	25 [B349]	414.71	0.7476		25 [B349]	400.58	0.7465
	0.5098	25 [B350]	417.44	0.7528		25 [B350]	403.12	0.7517
	0.6180	25 [B366]	384.59	0.7576		25 [B366]	366.64	0.7565
	0.7055	25 [B349]	412.42	0.7612		25 [B349]	399.16	0.7600
	0.7907	25 [B350]	415.47	0.7656		25 [B350]	398.83	0.7644
	0.8829	25 [B366]	384.36	0.7700		25 [B366]	365.31	0.7688
308.15	0.1085	25 [B349]	356.43	0.7332		25 [B349]	342.29	0.7322
	0.2083	25 [B350]	360.34	0.7371	313.15	25 [B350]	347.42	0.7360
	0.3097	25 [B366]	335.32	0.7411		25 [B366]	318.83	0.7401
	0.3882	25 [B349]	355.04	0.7446		25 [B349]	340.99	0.7433
	0.5098	25 [B350]	357.04	0.7495		25 [B350]	343.41	0.7484
	0.6180	25 [B366]	332.45	0.7542		25 [B366]	315.52	0.7531
	0.7055	25 [B349]	354.17	0.7578		25 [B349]	338.42	0.7566
	0.7907	25 [B350]	353.98	0.7621		25 [B350]	339.91	0.7609
	0.8829	25 [B366]	324.16	0.7665		25 [B366]	311.94	0.7653

Table A.2: Raw Data of Viscosity and Density Measurements for the Binary System: Chlorobenzene (1) + Octane (2).

T (K)	x_1	Viscometer number	Efflux time (s)	Oscillation period (s)	T (K)	Viscometer number	Efflux time (s)	Oscillation period (s)
293.15	0.1467	25 [B349]	423.20	0.7102	298.15	25 [B349]	400.79	0.7091
	0.2763	25 [B350]	416.92	0.7175		25 [B350]	394.92	0.7164
	0.3416	25 [B366]	380.20	0.7213		25 [B366]	360.39	0.7203
	0.4192	25 [B349]	403.39	0.7264		25 [B349]	382.42	0.7253
	0.5096	25 [B350]	402.79	0.7325		25 [B350]	381.77	0.7314
	0.6071	25 [B366]	370.47	0.7397		25 [B366]	350.93	0.7386
	0.7067	25 [B349]	397.75	0.7477		25 [B349]	376.69	0.7466
	0.7983	25 [B350]	402.97	0.7557		25 [B350]	381.34	0.7545
	0.8932	25 [B366]	374.87	0.7647		25 [B366]	355.40	0.7636
308.15	0.1467	25 [B349]	361.78	0.7071	313.15	25 [B349]	341.55	0.7060
	0.2763	25 [B350]	356.79	0.7143		25 [B350]	336.14	0.7133
	0.3416	25 [B366]	325.81	0.7181		25 [B366]	306.58	0.7171
	0.4192	25 [B349]	345.78	0.7232		25 [B349]	325.59	0.7221
	0.5096	25 [B350]	345.39	0.7293		25 [B350]	325.36	0.7282
	0.6071	25 [B366]	317.10	0.7364		25 [B366]	298.42	0.7353
	0.7067	25 [B349]	340.63	0.7443		25 [B349]	320.78	0.7432
	0.7983	25 [B350]	344.06	0.7522		25 [B350]	323.71	0.7511
	0.8932	25 [B366]	319.65	0.7612		25 [B366]	300.36	0.7601

Table A.3: Raw Data of Viscosity and Density Measurements for the Binary System: Chlorobenzene (1) + Ethylbenzene (2).

T (K)	x_1	Viscometer number	Efflux time (s)	Oscillation period (s)	T (K)	Viscometer number	Efflux time (s)	Oscillation period (s)
293.15	0.1114	25 [B349]	429.44	0.7375	298.15	25 [B349]	409.81	0.7364
	0.2250	25 [B350]	432.74	0.7419		25 [B350]	411.62	0.7409
	0.2984	25 [B366]	395.67	0.7448		25 [B366]	379.31	0.7438
	0.4194	25 [B349]	426.15	0.7498		25 [B349]	406.43	0.7487
	0.4982	25 [B350]	428.35	0.7531		25 [B350]	407.73	0.7520
	0.5984	25 [B366]	393.82	0.7574		25 [B366]	374.63	0.7562
	0.6891	25 [B349]	418.88	0.7614		25 [B349]	399.30	0.7602
	0.7894	25 [B350]	420.63	0.7659		25 [B350]	399.42	0.7647
	0.8840	25 [B366]	384.51	0.7703		25 [B366]	365.60	0.7691
308.15	0.1114	25 [B349]	372.58	0.7344		25 [B349]	354.48	0.7333
	0.2250	25 [B350]	375.23	0.7387	313.15	25 [B350]	356.85	0.7376
	0.2984	25 [B366]	344.98	0.7416		25 [B366]	327.78	0.7405
	0.4194	25 [B349]	369.18	0.7465		25 [B349]	349.49	0.7454
	0.4982	25 [B350]	371.33	0.7497		25 [B350]	352.10	0.7486
	0.5984	25 [B366]	339.45	0.7540		25 [B366]	321.87	0.7529
	0.6891	25 [B349]	361.59	0.7579		25 [B349]	343.50	0.7568
	0.7894	25 [B350]	361.43	0.7624		25 [B350]	343.80	0.7613
	0.8840	25 [B366]	329.88	0.7668		25 [B366]	313.59	0.7656

Table A.4: Raw Data of Viscosity and Density Measurements for the Binary System: Chlorobenzene (1) + 1-Hexanol (2).

T (K)	x_1	Viscometer number	Efflux time (s)	Oscillation period (s)	T (K)	Viscometer number	Efflux time (s)	Oscillation period (s)
293.15	0.1271	75 [K95]	527.68	0.7302	298.15	75 [K95]	455.89	0.7293
	0.2264	75 [K96]	419.17	0.7348		75 [K96]	365.33	0.7339
	0.3205	50 [B830]	705.04	0.7393		50 [B830]	604.59	0.7383
	0.4111	50 [B831]	587.31	0.7437		50 [B831]	526.58	0.7427
	0.5110	50 [B830]	443.28	0.7487		50 [B830]	409.73	0.7476
	0.6021	50 [B831]	383.39	0.7534		50 [B831]	350.52	0.7523
	0.7022	25 [B349]	703.65	0.7587		25 [B349]	677.83	0.7576
	0.7953	25 [B350]	594.42	0.7638		25 [B350]	553.24	0.7627
	0.8874	25 [B366]	438.79	0.7691		25 [B366]	446.76	0.7679
308.15	0.1271	75 [K95]	346.78	0.7274		75 [K95]	305.50	0.7265
	0.2264	75 [K96]	283.11	0.7319	313.15	75 [K96]	251.29	0.7309
	0.3205	50 [B830]	477.74	0.7363		50 [B830]	428.28	0.7353
	0.4111	50 [B831]	406.51	0.7406		50 [B831]	366.96	0.7396
	0.5110	50 [B830]	315.26	0.7455		50 [B830]	290.06	0.7444
	0.6021	50 [B831]	272.04	0.7501		50 [B831]	253.40	0.7490
	0.7022	25 [B349]	520.22	0.7553		25 [B349]	484.40	0.7542
	0.7953	25 [B350]	451.69	0.7604		25 [B350]	423.49	0.7592
	0.8874	25 [B366]	363.32	0.7656		25 [B366]	342.28	0.7644

Table A.5: Raw Data of Viscosity and Density Measurements for the Binary System: p-Xylene (1) + Octane (2).

T (K)	x_1	Viscometer number	Efflux time (s)	Oscillation period (s)	T (K)	Viscometer number	Efflux time (s)	Oscillation period (s)
293.15	0.1335	25 [B349]	424.38	0.7059	298.15	25 [B349]	401.96	0.7048
	0.2243	25 [B350]	422.26	0.7081		25 [B350]	400.41	0.7071
	0.3336	25 [B366]	381.73	0.7110		25 [B366]	361.86	0.7100
	0.3985	25 [B349]	407.70	0.7127		25 [B349]	386.28	0.7117
	0.4986	25 [B350]	407.42	0.7156		25 [B350]	386.40	0.7145
	0.5856	25 [B366]	374.65	0.7182		25 [B366]	355.00	0.7171
	0.6830	25 [B349]	402.55	0.7212		25 [B349]	381.62	0.7202
	0.7750	25 [B350]	408.52	0.7242		25 [B350]	386.77	0.7232
	0.8707	25 [B366]	381.57	0.7275		25 [B366]	360.98	0.7265
308.15	0.1335	25 [B349]	362.92	0.7028		25 [B349]	345.83	0.7018
	0.2243	25 [B350]	360.86	0.7051	313.15	25 [B350]	345.32	0.7041
	0.3336	25 [B366]	327.48	0.7079		25 [B366]	312.28	0.7069
	0.3985	25 [B349]	349.52	0.7097		25 [B349]	333.54	0.7086
	0.4986	25 [B350]	349.42	0.7125		25 [B350]	333.53	0.7115
	0.5856	25 [B366]	321.44	0.7151		25 [B366]	306.29	0.7140
	0.6830	25 [B349]	344.85	0.7181		25 [B349]	328.63	0.7171
	0.7750	25 [B350]	349.17	0.7211		25 [B350]	332.78	0.7201
	0.8707	25 [B366]	325.29	0.7244		25 [B366]	309.77	0.7234

Table A.6: Raw Data of Viscosity and Density Measurements for the Binary System: p-Xylene (1) + Ethylbenzene (2).

T (K)	x_1	Viscometer number	Efflux time (s)	Oscillation period (s)	T (K)	Viscometer number	Efflux time (s)	Oscillation period (s)
293.15	0.1235	25 [B349]	436.32	0.7332	298.15	25 [B349]	413.16	0.7322
	0.2082	25 [B350]	438.57	0.7331		25 [B350]	416.38	0.7321
	0.3060	25 [B366]	404.10	0.7330		25 [B366]	382.51	0.7320
	0.4007	25 [B349]	433.86	0.7329		25 [B349]	410.66	0.7319
	0.5051	25 [B350]	436.66	0.7328		25 [B350]	412.54	0.7318
	0.5963	25 [B366]	401.18	0.7327		25 [B366]	378.99	0.7317
	0.6805	25 [B349]	429.65	0.7326		25 [B349]	406.31	0.7316
	0.7752	25 [B350]	432.72	0.7325		25 [B350]	409.13	0.7315
	0.8513	25 [B366]	397.06	0.7324		25 [B366]	375.67	0.7314
308.15	0.1235	25 [B349]	372.43	0.7301		25 [B349]	353.22	0.7290
	0.2082	25 [B350]	374.24	0.7300	313.15	25 [B350]	355.88	0.7290
	0.3060	25 [B366]	343.59	0.7299		25 [B366]	326.82	0.7289
	0.4007	25 [B349]	368.48	0.7298		25 [B349]	350.35	0.7288
	0.5051	25 [B350]	370.50	0.7297		25 [B350]	352.09	0.7286
	0.5963	25 [B366]	340.44	0.7296		25 [B366]	323.94	0.7286
	0.6805	25 [B349]	364.64	0.7295		25 [B349]	346.53	0.7285
	0.7752	25 [B350]	366.71	0.7294		25 [B350]	348.52	0.7284
	0.8513	25 [B366]	337.15	0.7293		25 [B366]	320.06	0.7283

Table A.7: Raw Data of Viscosity and Density Measurements for the Binary System: p-Xylene (1) + 1-Hexanol (2).

T (K)	x_1	Viscometer number	Efflux time (s)	Oscillation period (s)	T (K)	Viscometer number	Efflux time (s)	Oscillation period (s)
293.15	0.1273	75 [K95]	524.10	0.7256	298.15	75 [K95]	431.76	0.7246
	0.2049	75 [K96]	422.82	0.7262		75 [K96]	374.58	0.7252
	0.3086	50 [B830]	709.86	0.7270		50 [B830]	630.60	0.7260
	0.4047	50 [B831]	596.27	0.7277		50 [B831]	522.37	0.7267
	0.5064	50 [B830]	448.40	0.7284		50 [B830]	412.44	0.7274
	0.5913	50 [B831]	393.09	0.7291		50 [B831]	348.84	0.7281
	0.6856	25 [B349]	753.89	0.7298		25 [B349]	656.05	0.7283
	0.7803	25 [B350]	614.23	0.7305		25 [B350]	576.75	0.7295
	0.8733	25 [B366]	472.01	0.7312		25 [B366]	457.10	0.7302
308.15	0.1273	75 [K95]	330.34	0.7228		75 [K95]	291.38	0.7218
	0.2049	75 [K96]	279.50	0.7233	313.15	75 [K96]	249.79	0.7224
	0.3086	50 [B830]	489.67	0.7241		50 [B830]	428.90	0.7231
	0.4047	50 [B831]	416.81	0.7247		50 [B831]	402.60	0.7238
	0.5064	50 [B830]	334.43	0.7255		50 [B830]	290.94	0.7245
	0.5913	50 [B831]	289.75	0.7261		50 [B831]	271.75	0.7250
	0.6856	25 [B349]	574.87	0.7267		25 [B349]	518.97	0.7257
	0.7803	25 [B350]	499.17	0.7274		25 [B350]	464.82	0.7264
	0.8733	25 [B366]	387.66	0.7281		25 [B366]	370.63	0.7271

Table A.8: Raw Data of Viscosity and Density Measurements for the Binary System: Octane (1) + Ethylbenzene (2).

T (K)	x_1	Viscometer number	Efflux time (s)	Oscillation period (s)	T (K)	Viscometer number	Efflux time (s)	Oscillation period (s)
293.15	0.1124	25 [B349]	426.43	0.7289	298.15	25 [B349]	403.42	0.7279
	0.2141	25 [B350]	422.39	0.7252		25 [B350]	400.30	0.7242
	0.3059	25 [B366]	385.56	0.7220		25 [B366]	365.62	0.7210
	0.4028	25 [B349]	411.50	0.7189		25 [B349]	390.29	0.7178
	0.4942	25 [B350]	416.66	0.7160		25 [B350]	395.53	0.7150
	0.5890	25 [B366]	384.62	0.7132		25 [B366]	364.51	0.7122
	0.6796	25 [B349]	416.64	0.7107		25 [B349]	395.85	0.7097
	0.7456	25 [B350]	423.60	0.7090		25 [B350]	401.93	0.7080
	0.8581	25 [B366]	397.25	0.7061		25 [B366]	376.12	0.7051
308.15	0.1124	25 [B349]	363.86	0.7258		25 [B349]	347.20	0.7248
	0.2141	25 [B350]	361.62	0.7221	313.15	25 [B350]	344.73	0.7211
	0.3059	25 [B366]	330.59	0.7189		25 [B366]	315.26	0.7179
	0.4028	25 [B349]	353.29	0.7158		25 [B349]	336.86	0.7147
	0.4942	25 [B350]	356.90	0.7130		25 [B350]	340.42	0.7119
	0.5890	25 [B366]	329.59	0.7102		25 [B366]	314.97	0.7092
	0.6796	25 [B349]	358.17	0.7077		25 [B349]	341.43	0.7067
	0.7456	25 [B350]	366.64	0.7059		25 [B350]	346.82	0.7049
	0.8581	25 [B366]	339.77	0.7031		25 [B366]	323.73	0.7021

Table A.9: Raw Data of Viscosity and Density Measurements for the Binary System: Octane (1) + 1-Hexanol (2).

T (K)	x_1	Viscometer number	Efflux time (s)	Oscillation period (s)	T (K)	Viscometer number	Efflux time (s)	Oscillation period (s)
293.15	0.1104	75 [K96]	530.83	0.7216	298.15	75 [K96]	460.55	0.7206
	0.2173	75 [K95]	420.51	0.7188		75 [K95]	360.10	0.7179
	0.3144	75 [K96]	335.29	0.7165		75 [K96]	290.38	0.7155
	0.4188	50 [B830]	530.11	0.7140		50 [B830]	484.13	0.7131
	0.5031	50 [B831]	467.93	0.7121		50 [B831]	425.63	0.7112
	0.5951	25 [B349]	843.79	0.7102		25 [B349]	804.83	0.7092
	0.6975	50 [B830]	324.99	0.7081		50 [B830]	287.31	0.7071
	0.7890	25 [B350]	602.19	0.7064		25 [B350]	564.17	0.7054
	0.8764	25 [B349]	526.81	0.7048		25 [B349]	485.48	0.7038
308.15	0.1104	75 [K96]	352.45	0.7188		75 [K96]	311.17	0.7179
	0.2173	75 [K95]	261.48	0.7160	313.15	75 [K95]	233.30	0.7151
	0.3144	75 [K96]	236.72	0.7136		75 [K96]	220.30	0.7126
	0.4188	50 [B830]	394.67	0.7111		50 [B830]	359.97	0.7101
	0.5031	50 [B831]	348.81	0.7092		50 [B831]	324.13	0.7082
	0.5951	25 [B349]	698.52	0.7072		25 [B349]	623.26	0.7063
	0.6975	50 [B830]	237.65	0.7052		50 [B830]	231.26	0.7042
	0.7890	25 [B350]	494.97	0.7034		25 [B350]	471.21	0.7024
	0.8764	25 [B349]	448.02	0.7018		25 [B349]	406.02	0.7008

Table A.10: Raw Data of Viscosity and Density Measurements for the Binary System: Ethylbenzene (1) + 1-Hexanol (2).

T (K)	x_1	Viscometer number	Efflux time (s)	Oscillation period (s)	T (K)	Viscometer number	Efflux time (s)	Oscillation period (s)
293.15	0.1257	75 [K95]	503.66	0.7256	298.15	75 [K95]	476.49	0.7247
	0.2131	75 [K96]	405.29	0.7264		75 [K96]	394.25	0.7254
	0.2997	50 [B830]	729.78	0.7271		50 [B830]	685.49	0.7261
	0.4063	50 [B831]	598.76	0.7280		50 [B831]	554.47	0.7270
	0.5064	50 [B830]	458.31	0.7288		50 [B830]	429.71	0.7278
	0.5960	50 [B831]	400.32	0.7296		50 [B831]	396.26	0.7286
	0.6853	25 [B349]	727.17	0.7304		25 [B349]	707.89	0.7295
	0.7906	25 [B350]	625.53	0.7313		25 [B350]	614.72	0.7303
	0.8956	25 [B366]	474.78	0.7323		25 [B366]	469.73	0.7313
308.15	0.1257	75 [K95]	334.38	0.7228		75 [K95]	295.18	0.7218
	0.2131	75 [K96]	301.32	0.7235	313.15	75 [K96]	265.93	0.7226
	0.2997	50 [B830]	531.01	0.7242		50 [B830]	443.67	0.7232
	0.4063	50 [B831]	425.75	0.7250		50 [B831]	384.62	0.7241
	0.5064	50 [B830]	352.60	0.7259		50 [B830]	298.29	0.7249
	0.5960	50 [B831]	307.04	0.7266		50 [B831]	277.69	0.7256
	0.6853	25 [B349]	594.03	0.7273		25 [B349]	549.83	0.7263
	0.7906	25 [B350]	502.66	0.7282		25 [B350]	457.08	0.7272
	0.8956	25 [B366]	396.60	0.7292		25 [B366]	368.03	0.7281

Table A.11: Raw Data of Viscosity and Density Measurements for the Ternary System:

Chlorobenzene (1) + p-Xylene (2) + Octane (3).

T (K)	x_1	x_2	Viscometer number	Efflux time (s)	Oscillation period (s)
293.15	0.1320	0.1764	25 [B349]	411.79	0.7141
	0.2162	0.6230	25 [B350]	413.43	0.7342
	0.3436	0.3172	25 [B366]	374.52	0.7322
	0.4115	0.1989	25 [B349]	401.87	0.7327
	0.4979	0.3787	25 [B350]	414.65	0.7467
	0.5905	0.2443	25 [B366]	380.12	0.7486
	0.6868	0.1045	25 [B349]	402.22	0.7506
298.15	0.1320	0.1764	25 [B349]	390.36	0.7131
	0.2162	0.6230	25 [B350]	392.84	0.7331
	0.3436	0.3172	25 [B366]	354.75	0.7311
	0.4115	0.1989	25 [B349]	382.16	0.7316
	0.4979	0.3787	25 [B350]	391.81	0.7456
	0.5905	0.2443	25 [B366]	362.75	0.7475
	0.6868	0.1045	25 [B349]	380.84	0.7495
308.15	0.1320	0.1764	25 [B349]	352.66	0.7110
	0.2162	0.6230	25 [B350]	353.82	0.7310
	0.3436	0.3172	25 [B366]	320.46	0.7289
	0.4115	0.1989	25 [B349]	346.38	0.7295
	0.4979	0.3787	25 [B350]	352.66	0.7434
	0.5905	0.2443	25 [B366]	323.27	0.7453
	0.6868	0.1045	25 [B349]	342.75	0.7473
313.15	0.1320	0.1764	25 [B349]	336.20	0.7100
	0.2162	0.6230	25 [B350]	336.34	0.7299
	0.3436	0.3172	25 [B366]	305.40	0.7279
	0.4115	0.1989	25 [B349]	331.35	0.7284
	0.4979	0.3787	25 [B350]	335.49	0.7423
	0.5905	0.2443	25 [B366]	307.27	0.7442
	0.6868	0.1045	25 [B349]	330.76	0.7461

Table A.12: Raw Data of Viscosity and Density Measurements for the Ternary System: Chlorobenzene (1) + Octane (2) + Ethylbenzene (3).

T (K)	x_1	x_2	Viscometer number	Efflux time (s)	Oscillation period (s)
293.15	0.1609	0.1551	25 [B350]	425.01	0.7330
	0.2256	0.6265	25 [B366]	381.91	0.7188
	0.3318	0.3343	25 [B349]	407.88	0.7322
	0.3999	0.2162	25 [B350]	417.52	0.7393
	0.4913	0.4011	25 [B366]	373.79	0.7352
	0.5621	0.2857	25 [B349]	403.84	0.7425
	0.6802	0.1191	25 [B350]	415.82	0.7548
298.15	0.1609	0.1551	25 [B350]	404.17	0.7320
	0.2256	0.6265	25 [B366]	361.89	0.7178
	0.3318	0.3343	25 [B349]	363.89	0.7311
	0.3999	0.2162	25 [B350]	394.23	0.7382
	0.4913	0.4011	25 [B366]	354.14	0.7341
	0.5621	0.2857	25 [B349]	382.19	0.7414
	0.6802	0.1191	25 [B350]	393.06	0.7537
308.15	0.1609	0.1551	25 [B350]	363.99	0.7298
	0.2256	0.6265	25 [B366]	327.20	0.7157
	0.3318	0.3343	25 [B349]	349.14	0.7290
	0.3999	0.2162	25 [B350]	355.20	0.7361
	0.4913	0.4011	25 [B366]	320.26	0.7320
	0.5621	0.2857	25 [B349]	345.29	0.7392
	0.6802	0.1191	25 [B350]	353.94	0.7514
313.15	0.1609	0.1551	25 [B350]	345.71	0.7288
	0.2256	0.6265	25 [B366]	311.95	0.7147
	0.3318	0.3343	25 [B349]	332.81	0.7279
	0.3999	0.2162	25 [B350]	329.61	0.7350
	0.4913	0.4011	25 [B366]	305.22	0.7309
	0.5621	0.2857	25 [B349]	329.01	0.7380
	0.6802	0.1191	25 [B350]	327.84	0.7503

Table A.13: Raw Data of Viscosity and Density Measurements for the Ternary System: Chlorobenzene (1) + p-Xylene (2) + Ethylbenzene (3).

T (K)	x_1	x_2	Viscometer number	Efflux time (s)	Oscillation period (s)
293.15	0.1254	0.1579	25 [B366]	406.85	0.7379
	0.2246	0.6279	25 [B349]	429.21	0.7411
	0.3456	0.3375	25 [B350]	421.56	0.7463
	0.4094	0.1825	25 [B366]	394.86	0.7491
	0.5094	0.3842	25 [B349]	419.14	0.7530
	0.5909	0.2528	25 [B350]	420.41	0.7566
	0.6871	0.1116	25 [B366]	385.83	0.7611
298.15	0.1254	0.1579	25 [B366]	384.37	0.7369
	0.2246	0.6279	25 [B349]	405.81	0.7401
	0.3456	0.3375	25 [B350]	413.86	0.7452
	0.4094	0.1825	25 [B366]	380.39	0.7480
	0.5094	0.3842	25 [B349]	401.93	0.7519
	0.5909	0.2528	25 [B350]	411.56	0.7555
	0.6871	0.1116	25 [B366]	373.04	0.7599
308.15	0.1254	0.1579	25 [B366]	345.51	0.7347
	0.2246	0.6279	25 [B349]	363.94	0.7379
	0.3456	0.3375	25 [B350]	371.98	0.7430
	0.4094	0.1825	25 [B366]	344.00	0.7458
	0.5094	0.3842	25 [B349]	360.57	0.7496
	0.5909	0.2528	25 [B350]	370.70	0.7533
	0.6871	0.1116	25 [B366]	334.68	0.7576
313.15	0.1254	0.1579	25 [B366]	328.09	0.7337
	0.2246	0.6279	25 [B349]	345.77	0.7369
	0.3456	0.3375	25 [B350]	355.41	0.7419
	0.4094	0.1825	25 [B366]	323.71	0.7447
	0.5094	0.3842	25 [B349]	342.23	0.7485
	0.5909	0.2528	25 [B350]	353.90	0.7521
	0.6871	0.1116	25 [B366]	317.84	0.7565

Table A.14: Raw Data of Viscosity and Density Measurements for the Ternary System: Chlorobenzene (1) + Octane (2) + 1-Hexanol (3).

T (K)	x_1	x_2	Viscometer number	Efflux time (s)	Oscillation period (s)
293.15	0.1275	0.1592	75 [K95]	352.52	0.7256
	0.2251	0.6159	25 [B349]	529.47	0.7179
	0.3302	0.3273	50 [B830]	343.82	0.7295
	0.3863	0.2206	50 [B831]	378.08	0.7354
	0.4893	0.3979	25 [B350]	487.83	0.7343
	0.5880	0.2541	25 [B350]	477.05	0.7433
	0.6732	0.1193	25 [B366]	566.50	0.7524
298.15	0.1275	0.1592	75 [K95]	308.73	0.7247
	0.2251	0.6159	25 [B349]	498.67	0.7169
	0.3302	0.3273	50 [B830]	306.52	0.7284
	0.3863	0.2206	50 [B831]	340.18	0.7343
	0.4893	0.3979	25 [B350]	449.51	0.7332
	0.5880	0.2541	25 [B350]	429.84	0.7422
	0.6732	0.1193	25 [B366]	473.04	0.7512
308.15	0.1275	0.1592	75 [K95]	237.62	0.7227
	0.2251	0.6159	25 [B349]	445.94	0.7148
	0.3302	0.3273	50 [B830]	256.64	0.7263
	0.3863	0.2206	50 [B831]	278.66	0.7322
	0.4893	0.3979	25 [B350]	397.45	0.7310
	0.5880	0.2541	25 [B350]	408.80	0.7400
	0.6732	0.1193	25 [B366]	417.68	0.7490
313.15	0.1275	0.1592	75 [K95]	204.44	0.7218
	0.2251	0.6159	25 [B349]	394.28	0.7137
	0.3302	0.3273	50 [B830]	211.42	0.7253
	0.3863	0.2206	50 [B831]	245.42	0.7312
	0.4893	0.3979	25 [B350]	367.57	0.7299
	0.5880	0.2541	25 [B350]	360.24	0.7389
	0.6732	0.1193	25 [B366]	400.84	0.7479

Table A.15: Raw Data of Viscosity and Density Measurements for the Ternary System: Chlorobenzene (1) + Ethylbenzene (2) + 1-Hexanol (3).

T (K)	x_1	x_2	Viscometer number	Efflux time (s)	Oscillation period (s)
293.15	0.1234	0.1548	75 [K95]	344.71	0.7314
	0.2161	0.6241	25 [B350]	528.90	0.7400
	0.3395	0.3259	50 [B830]	295.65	0.7432
	0.3993	0.2028	50 [B831]	350.62	0.7450
	0.4975	0.3854	25 [B366]	455.42	0.7517
	0.5856	0.2553	25 [B349]	519.37	0.7550
	0.6839	0.1117	25 [B349]	556.76	0.7588
298.15	0.1234	0.1548	75 [K95]	330.07	0.7305
	0.2161	0.6241	25 [B350]	499.30	0.7389
	0.3395	0.3259	50 [B830]	282.11	0.7421
	0.3993	0.2028	50 [B831]	326.61	0.7439
	0.4975	0.3854	25 [B366]	426.50	0.7506
	0.5856	0.2553	25 [B349]	485.38	0.7539
	0.6839	0.1117	25 [B349]	523.62	0.7577
308.15	0.1234	0.1548	75 [K95]	237.49	0.7285
	0.2161	0.6241	25 [B350]	434.49	0.7368
	0.3395	0.3259	50 [B830]	234.36	0.7400
	0.3993	0.2028	50 [B831]	270.97	0.7418
	0.4975	0.3854	25 [B366]	376.66	0.7484
	0.5856	0.2553	25 [B349]	425.13	0.7517
	0.6839	0.1117	25 [B349]	456.07	0.7554
313.15	0.1234	0.1548	75 [K95]	214.79	0.7275
	0.2161	0.6241	25 [B350]	409.37	0.7357
	0.3395	0.3259	50 [B830]	216.96	0.7389
	0.3993	0.2028	50 [B831]	251.56	0.7407
	0.4975	0.3854	25 [B366]	356.64	0.7473
	0.5856	0.2553	25 [B349]	400.03	0.7506
	0.6839	0.1117	25 [B349]	423.47	0.7543

Table A.16: Raw Data of Viscosity and Density Measurements for the Ternary System: Chlorobenzene (1) + p-Xylene (2) + 1-Hexanol (3).

T (K)	x_1	x_2	Viscometer number	Efflux time (s)	Oscillation period (s)
293.15	0.1189	0.1549	75 [K95]	343.01	0.7311
	0.2142	0.6302	25 [B350]	510.90	0.7392
	0.3346	0.3262	50 [B830]	317.13	0.7246
	0.4072	0.2051	50 [B831]	357.99	0.7452
	0.4884	0.3925	25 [B366]	448.78	0.7508
	0.5880	0.2474	25 [B349]	518.00	0.7547
	0.6805	0.1135	25 [B350]	560.45	0.7585
298.15	0.1189	0.1549	75 [K95]	301.68	0.7301
	0.2142	0.6302	25 [B350]	476.97	0.7382
	0.3346	0.3262	50 [B830]	294.43	0.7415
	0.4072	0.2051	50 [B831]	332.49	0.7441
	0.4884	0.3925	25 [B366]	420.56	0.7497
	0.5880	0.2474	25 [B349]	482.79	0.7536
	0.6805	0.1135	25 [B350]	521.58	0.7574
308.15	0.1189	0.1549	75 [K95]	236.93	0.7282
	0.2142	0.6302	25 [B350]	420.97	0.7360
	0.3346	0.3262	50 [B830]	230.30	0.7394
	0.4072	0.2051	50 [B831]	265.05	0.7420
	0.4884	0.3925	25 [B366]	370.74	0.7475
	0.5880	0.2474	25 [B349]	423.73	0.7514
	0.6805	0.1135	25 [B350]	455.90	0.7551
313.15	0.1189	0.1549	75 [K95]	213.56	0.7272
	0.2142	0.6302	25 [B350]	394.94	0.7350
	0.3346	0.3262	50 [B830]	214.37	0.7383
	0.4072	0.2051	50 [B831]	244.62	0.7409
	0.4884	0.3925	25 [B366]	349.49	0.7464
	0.5880	0.2474	25 [B349]	397.78	0.7503
	0.6805	0.1135	25 [B350]	425.52	0.7540

Table A.17: Raw Data of Viscosity and Density Measurements for the Ternary System: p-Xylene (1) + Octane (2) + Ethylbenzene (3).

T (K)	x_1	x_2	Viscometer number	Efflux time (s)	Oscillation period (s)
293.15	0.1088	0.1584	25 [B366]	391.78	0.7271
	0.2021	0.6300	25 [B349]	411.62	0.7120
	0.3289	0.3274	25 [B350]	412.70	0.7211
	0.3836	0.2069	25 [B366]	384.69	0.7251
	0.4854	0.3922	25 [B349]	404.81	0.7189
	0.5719	0.2618	25 [B350]	411.02	0.7231
	0.6667	0.1163	25 [B366]	387.20	0.7282
298.15	0.1088	0.1584	25 [B366]	371.20	0.7261
	0.2021	0.6300	25 [B349]	390.29	0.7110
	0.3289	0.3274	25 [B350]	391.05	0.7201
	0.3836	0.2069	25 [B366]	364.44	0.7241
	0.4854	0.3922	25 [B349]	383.72	0.7179
	0.5719	0.2618	25 [B350]	391.57	0.7221
	0.6667	0.1163	25 [B366]	366.17	0.7271
308.15	0.1088	0.1584	25 [B366]	334.87	0.7240
	0.2021	0.6300	25 [B349]	353.17	0.7090
	0.3289	0.3274	25 [B350]	353.70	0.7180
	0.3836	0.2069	25 [B366]	328.77	0.7220
	0.4854	0.3922	25 [B349]	346.88	0.7158
	0.5719	0.2618	25 [B350]	351.57	0.7200
	0.6667	0.1163	25 [B366]	329.82	0.7251
313.15	0.1088	0.1584	25 [B366]	319.42	0.7230
	0.2021	0.6300	25 [B349]	336.83	0.7079
	0.3289	0.3274	25 [B350]	337.16	0.7170
	0.3836	0.2069	25 [B366]	313.42	0.7210
	0.4854	0.3922	25 [B349]	331.11	0.7148
	0.5719	0.2618	25 [B350]	335.65	0.7190
	0.6667	0.1163	25 [B366]	314.12	0.7240

Table A.18: Raw Data of Viscosity and Density Measurements for the Ternary System: p-Xylene (1) + Ethylbenzene (2) + 1-Hexanol (3).

T (K)	x_1	x_2	Viscometer number	Efflux time (s)	Oscillation period (s)
293.15	0.1113	0.1693	75 [K95]	347.28	0.7268
	0.2029	0.6321	25 [B349]	540.77	0.7315
	0.3175	0.3394	50 [B830]	327.67	0.7298
	0.3896	0.2146	50 [B831]	388.95	0.7293
	0.4764	0.4000	25 [B349]	487.48	0.7316
	0.5722	0.2644	25 [B350]	516.85	0.7312
	0.6561	0.1290	25 [B366]	531.08	0.7307
298.15	0.1113	0.1693	75 [K95]	318.54	0.7259
	0.2029	0.6321	25 [B349]	488.60	0.7305
	0.3175	0.3394	50 [B830]	298.81	0.7288
	0.3896	0.2146	50 [B831]	342.34	0.7283
	0.4764	0.4000	25 [B349]	457.03	0.7306
	0.5722	0.2644	25 [B350]	483.31	0.7302
	0.6561	0.1290	25 [B366]	496.29	0.7296
308.15	0.1113	0.1693	75 [K95]	258.13	0.7240
	0.2029	0.6321	25 [B349]	424.94	0.7284
	0.3175	0.3394	50 [B830]	258.80	0.7268
	0.3896	0.2146	50 [B831]	297.67	0.7263
	0.4764	0.4000	25 [B349]	404.61	0.7285
	0.5722	0.2644	25 [B350]	425.87	0.7281
	0.6561	0.1290	25 [B366]	417.34	0.7276
313.15	0.1113	0.1693	75 [K95]	204.85	0.7230
	0.2029	0.6321	25 [B349]	405.19	0.7274
	0.3175	0.3394	50 [B830]	237.48	0.7258
	0.3896	0.2146	50 [B831]	270.33	0.7253
	0.4764	0.4000	25 [B349]	367.57	0.7275
	0.5722	0.2644	25 [B350]	401.06	0.7270
	0.6561	0.1290	25 [B366]	402.18	0.7265

Table A.19: Raw Data of Viscosity and Density Measurements for the Ternary System:

p-Xylene (1) + Octane (2) + 1-Hexanol (3).

T (K)	x_1	x_2	Viscometer number	Efflux time (s)	Oscillation period (s)
293.15	0.1076	0.1620	75 [K96]	359.84	0.7210
	0.2190	0.6234	25 [B349]	521.15	0.7110
	0.3121	0.3365	50 [B830]	322.52	0.7185
	0.3976	0.2265	50 [B831]	347.09	0.7217
	0.4918	0.3994	25 [B349]	491.77	0.7178
	0.5825	0.2564	25 [B350]	541.82	0.7219
	0.6740	0.1227	25 [B366]	529.98	0.7261
298.15	0.1076	0.1620	75 [K96]	327.02	0.7201
	0.2190	0.6234	25 [B349]	491.89	0.7100
	0.3121	0.3365	50 [B830]	302.50	0.7175
	0.3976	0.2265	50 [B831]	338.10	0.7207
	0.4918	0.3994	25 [B349]	453.88	0.7168
	0.5825	0.2564	25 [B350]	501.46	0.7209
	0.6740	0.1227	25 [B366]	505.32	0.7251
308.15	0.1076	0.1620	75 [K96]	265.21	0.7182
	0.2190	0.6234	25 [B349]	442.58	0.7080
	0.3121	0.3365	50 [B830]	247.33	0.7155
	0.3976	0.2265	50 [B831]	266.47	0.7187
	0.4918	0.3994	25 [B349]	410.85	0.7147
	0.5825	0.2564	25 [B350]	434.74	0.7188
	0.6740	0.1227	25 [B366]	418.13	0.7231
313.15	0.1076	0.1620	75 [K96]	231.03	0.7172
	0.2190	0.6234	25 [B349]	415.32	0.7070
	0.3121	0.3365	50 [B830]	239.86	0.7145
	0.3976	0.2265	50 [B831]	246.16	0.7177
	0.4918	0.3994	25 [B349]	374.80	0.7137
	0.5825	0.2564	25 [B350]	416.83	0.7178
	0.6740	0.1227	25 [B366]	410.47	0.7221

Table A.20: Raw Data of Viscosity and Density Measurements for the Ternary System: Octane (1) + Ethylbenzene (2) + 1-Hexanol (3).

T (K)	x_1	x_2	Viscometer number	Efflux time (s)	Oscillation period (s)
293.15	0.1133	0.1586	75 [K95]	361.20	0.7228
	0.2104	0.6310	25 [B349]	488.29	0.7239
	0.3249	0.3297	50 [B830]	321.09	0.7186
	0.3987	0.2028	50 [B831]	382.87	0.7159
	0.4949	0.3942	25 [B349]	474.63	0.7151
	0.5751	0.2621	25 [B350]	547.61	0.7124
	0.6762	0.1153	25 [B366]	556.50	0.7093
298.15	0.1133	0.1586	75 [K95]	325.19	0.7218
	0.2104	0.6310	25 [B349]	466.92	0.7229
	0.3249	0.3297	50 [B830]	290.36	0.7176
	0.3987	0.2028	50 [B831]	338.53	0.7149
	0.4949	0.3942	25 [B349]	461.43	0.7141
	0.5751	0.2621	25 [B350]	496.81	0.7114
	0.6762	0.1153	25 [B366]	527.63	0.7083
308.15	0.1133	0.1586	75 [K95]	251.90	0.7199
	0.2104	0.6310	25 [B349]	427.15	0.7208
	0.3249	0.3297	50 [B830]	255.69	0.7156
	0.3987	0.2028	50 [B831]	287.03	0.7129
	0.4949	0.3942	25 [B349]	391.25	0.7121
	0.5751	0.2621	25 [B350]	438.67	0.7094
	0.6762	0.1153	25 [B366]	462.41	0.7063
313.15	0.1133	0.1586	75 [K95]	227.70	0.7189
	0.2104	0.6310	25 [B349]	399.08	0.7198
	0.3249	0.3297	50 [B830]	241.21	0.7146
	0.3987	0.2028	50 [B831]	256.59	0.7119
	0.4949	0.3942	25 [B349]	370.77	0.7110
	0.5751	0.2621	25 [B350]	400.71	0.7084
	0.6762	0.1153	25 [B366]	423.39	0.7053

Table A.21: Raw Data of Viscosity and Density Measurements for the Quaternary System:

Chlorobenzene (1) + p-Xylene (2) + Octane (3) + Ethylbenzene (4).

T (K)	x_1	x_2	x_3	Viscometer number	Efflux time (s)	Oscillation period (s)
293.15	0.1193	0.1173	0.1153	25 [B349]	428.21	0.7330
	0.2608	0.2519	0.2428	50 [B830]	414.13	0.7330
	0.2993	0.2088	0.0678	25 [B366]	395.99	0.7416
	0.1715	0.2989	0.4284	25 [B349]	404.15	0.7233
	0.2601	0.2941	0.1113	25 [B350]	423.31	0.7380
	0.4831	0.1615	0.2913	25 [B366]	374.84	0.7391
298.15	0.1193	0.1173	0.1153	25 [B349]	401.44	0.7319
	0.2608	0.2519	0.2428	50 [B830]	391.78	0.7319
	0.2993	0.2088	0.0678	25 [B366]	374.58	0.7405
	0.1715	0.2989	0.4284	25 [B349]	383.49	0.7222
	0.2601	0.2941	0.1113	25 [B350]	400.10	0.7370
	0.4831	0.1615	0.2913	25 [B366]	355.32	0.7380
308.15	0.1193	0.1173	0.1153	25 [B349]	362.16	0.7298
	0.2608	0.2519	0.2428	50 [B830]	355.35	0.7297
	0.2993	0.2088	0.0678	25 [B366]	336.74	0.7383
	0.1715	0.2989	0.4284	25 [B349]	346.43	0.7201
	0.2601	0.2941	0.1113	25 [B350]	360.13	0.7348
	0.4831	0.1615	0.2913	25 [B366]	320.51	0.7359
313.15	0.1193	0.1173	0.1153	25 [B349]	351.43	0.7288
	0.2608	0.2519	0.2428	50 [B830]	336.64	0.7287
	0.2993	0.2088	0.0678	25 [B366]	319.78	0.7373
	0.1715	0.2989	0.4284	25 [B349]	330.45	0.7191
	0.2601	0.2941	0.1113	25 [B350]	342.59	0.7338
	0.4831	0.1615	0.2913	25 [B366]	305.32	0.7348

Table A.22: Raw Data of Viscosity and Density Measurements for the Quaternary System: p-Xylene (1) + Octane (2) + Ethylbenzene (3) + 1-Hexanol (4).

T (K)	x_1	x_2	x_3	Viscometer number	Efflux time (s)	Oscillation period (s)
293.15	0.1108	0.1129	0.1155	75 [K95]	312.72	0.7232
	0.2421	0.2504	0.2551	25 [B349]	658.74	0.7216
	0.2899	0.2023	0.0776	50 [B830]	388.75	0.7218
	0.1558	0.2855	0.4394	25 [B350]	522.11	0.7216
	0.2445	0.2934	0.1246	50 [B831]	343.20	0.7195
	0.4743	0.1553	0.3043	25 [B366]	407.72	0.7263
298.15	0.1108	0.1129	0.1155	75 [K95]	273.44	0.7223
	0.2421	0.2504	0.2551	25 [B349]	555.85	0.7206
	0.2899	0.2023	0.0776	50 [B830]	351.98	0.7208
	0.1558	0.2855	0.4394	25 [B350]	464.11	0.7205
	0.2445	0.2934	0.1246	50 [B831]	308.65	0.7185
	0.4743	0.1553	0.3043	25 [B366]	384.81	0.7253
308.15	0.1108	0.1129	0.1155	75 [K95]	225.51	0.7203
	0.2421	0.2504	0.2551	25 [B349]	494.89	0.7186
	0.2899	0.2023	0.0776	50 [B830]	289.53	0.7188
	0.1558	0.2855	0.4394	25 [B350]	415.70	0.7185
	0.2445	0.2934	0.1246	50 [B831]	266.86	0.7165
	0.4743	0.1553	0.3043	25 [B366]	344.85	0.7232
313.15	0.1108	0.1129	0.1155	75 [K95]	176.86	0.7194
	0.2421	0.2504	0.2551	25 [B349]	437.43	0.7175
	0.2899	0.2023	0.0776	50 [B830]	275.75	0.7178
	0.1558	0.2855	0.4394	25 [B350]	374.88	0.7174
	0.2445	0.2934	0.1246	50 [B831]	240.92	0.7155
	0.4743	0.1553	0.3043	25 [B366]	327.05	0.7221

Table A.23: Raw Data of Viscosity and Density Measurements for the Quaternary System: Chlorobenzene (1) + Octane (2) + Ethylbenzene (3) + 1-Hexanol (4).

T (K)	x_1	x_2	x_3	Viscometer number	Efflux time (s)	Oscillation period (s)
293.15	0.1200	0.1081	0.1241	75 [K95]	288.28	0.7278
	0.2516	0.2441	0.2574	25 [B349]	592.55	0.7306
	0.3036	0.1980	0.0701	50 [B830]	404.77	0.7327
	0.1665	0.2933	0.4343	25 [B350]	498.00	0.7270
	0.2484	0.2931	0.1153	50 [B831]	325.08	0.7279
	0.4818	0.1572	0.3023	25 [B366]	406.51	0.7443
298.15	0.1200	0.1081	0.1241	75 [K95]	243.54	0.7268
	0.2516	0.2441	0.2574	25 [B349]	579.18	0.7296
	0.3036	0.1980	0.0701	50 [B830]	370.00	0.7317
	0.1665	0.2933	0.4343	25 [B350]	442.87	0.7260
	0.2484	0.2931	0.1153	50 [B831]	309.15	0.7269
	0.4818	0.1572	0.3023	25 [B366]	382.01	0.7432
308.15	0.1200	0.1081	0.1241	75 [K95]	195.99	0.7248
	0.2516	0.2441	0.2574	25 [B349]	468.70	0.7275
	0.3036	0.1980	0.0701	50 [B830]	267.83	0.7296
	0.1665	0.2933	0.4343	25 [B350]	395.66	0.7239
	0.2484	0.2931	0.1153	50 [B831]	235.50	0.7248
	0.4818	0.1572	0.3023	25 [B366]	341.86	0.7410
313.15	0.1200	0.1081	0.1241	75 [K95]	179.65	0.7239
	0.2516	0.2441	0.2574	25 [B349]	459.39	0.7264
	0.3036	0.1980	0.0701	50 [B830]	258.91	0.7286
	0.1665	0.2933	0.4343	25 [B350]	370.05	0.7228
	0.2484	0.2931	0.1153	50 [B831]	232.35	0.7237
	0.4818	0.1572	0.3023	25 [B366]	323.94	0.7399

Table A.24: Raw Data of Viscosity and Density Measurements for the Quaternary System: Chlorobenzene (1) + p-Xylene (2) + Ethylbenzene (3) + 1-Hexanol (4).

T (K)	x_1	x_2	x_3	Viscometer number	Efflux time (s)	Oscillation period (s)
293.15	0.1157	0.1128	0.1168	75 [K95]	283.98	0.7316
	0.2569	0.2400	0.2543	25 [B349]	597.69	0.7404
	0.2964	0.2000	0.0708	50 [B830]	397.34	0.7403
	0.1544	0.2946	0.4386	25 [B350]	496.11	0.7377
	0.2541	0.2827	0.1216	50 [B831]	331.35	0.7394
	0.4818	0.1545	0.2989	25 [B366]	422.70	0.7514
298.15	0.1157	0.1128	0.1168	75 [K95]	250.94	0.7306
	0.2569	0.2400	0.2543	25 [B349]	555.03	0.7394
	0.2964	0.2000	0.0708	50 [B830]	357.32	0.7393
	0.1544	0.2946	0.4386	25 [B350]	465.04	0.7366
	0.2541	0.2827	0.1216	50 [B831]	300.13	0.7384
	0.4818	0.1545	0.2989	25 [B366]	402.72	0.7503
308.15	0.1157	0.1128	0.1168	75 [K95]	201.11	0.7287
	0.2569	0.2400	0.2543	25 [B349]	481.81	0.7372
	0.2964	0.2000	0.0708	50 [B830]	275.59	0.7372
	0.1544	0.2946	0.4386	25 [B350]	413.96	0.7345
	0.2541	0.2827	0.1216	50 [B831]	241.09	0.7363
	0.4818	0.1545	0.2989	25 [B366]	353.27	0.7481
313.15	0.1157	0.1128	0.1168	75 [K95]	181.28	0.7277
	0.2569	0.2400	0.2543	25 [B349]	450.91	0.7362
	0.2964	0.2000	0.0708	50 [B830]	253.67	0.7362
	0.1544	0.2946	0.4386	25 [B350]	386.84	0.7335
	0.2541	0.2827	0.1216	50 [B831]	224.20	0.7352
	0.4818	0.1545	0.2989	25 [B366]	333.99	0.7470

Table A.25: Raw Data of Viscosity and Density Measurements for the Quaternary System: Chlorobenzene (1) + p-Xylene (2) + Octane (3) + 1-Hexanol (4).

T (K)	x_1	x_2	x_3	Viscometer number	Efflux time (s)	Oscillation period (s)
293.15	0.1178	0.1164	0.1098	75 [K95]	306.96	0.7275
	0.2598	0.2517	0.2467	25 [B349]	612.16	0.7306
	0.2967	0.2085	0.0637	50 [B830]	350.69	0.7376
	0.1743	0.2964	0.4192	25 [B350]	463.66	0.7227
	0.2567	0.3006	0.1120	50 [B831]	330.47	0.7349
	0.4838	0.1632	0.2882	25 [B366]	398.80	0.7386
298.15	0.1178	0.1164	0.1098	75 [K95]	276.31	0.7265
	0.2598	0.2517	0.2467	25 [B349]	544.30	0.7296
	0.2967	0.2085	0.0637	50 [B830]	339.97	0.7366
	0.1743	0.2964	0.4192	25 [B350]	439.30	0.7217
	0.2567	0.3006	0.1120	50 [B831]	284.04	0.7339
	0.4838	0.1632	0.2882	25 [B366]	377.33	0.7375
308.15	0.1178	0.1164	0.1098	75 [K95]	213.10	0.7246
	0.2598	0.2517	0.2467	25 [B349]	489.06	0.7275
	0.2967	0.2085	0.0637	50 [B830]	290.24	0.7345
	0.1743	0.2964	0.4192	25 [B350]	391.59	0.7196
	0.2567	0.3006	0.1120	50 [B831]	250.49	0.7318
	0.4838	0.1632	0.2882	25 [B366]	338.78	0.7353
313.15	0.1178	0.1164	0.1098	75 [K95]	178.96	0.7236
	0.2598	0.2517	0.2467	25 [B349]	451.27	0.7264
	0.2967	0.2085	0.0637	50 [B830]	269.14	0.7335
	0.1743	0.2964	0.4192	25 [B350]	380.19	0.7186
	0.2567	0.3006	0.1120	50 [B831]	229.30	0.7308
	0.4838	0.1632	0.2882	25 [B366]	328.57	0.7342

Table A.26: Raw Data of Viscosity and Density Measurements for the Quinary System: Chlorobenzene (1) + p-Xylene (2) + Octane (3) + Ethylbenzene (4) + 1-Hexanol (5).

T (K)	x_1	x_2	x_3	x_4	Viscometer number	Efflux time (s)	Oscillation period (s)
293.15	0.1584	0.2481	0.2462	0.1987	25 [B349]	486.41	0.7279
	0.1632	0.1130	0.2441	0.1094	50 [B830]	347.36	0.7265
	0.2514	0.1573	0.2424	0.0668	50 [B831]	281.16	0.7302
	0.2577	0.2485	0.1525	0.1886	25 [B350]	502.87	0.7350
	0.1696	0.2889	0.1958	0.2778	25 [B366]	409.69	0.7308
298.15	0.1584	0.2481	0.2462	0.1987	25 [B349]	476.46	0.7269
	0.1632	0.1130	0.2441	0.1094	50 [B830]	304.67	0.7254
	0.2514	0.1573	0.2424	0.0668	50 [B831]	259.91	0.7292
	0.2577	0.2485	0.1525	0.1886	25 [B350]	473.93	0.7339
	0.1696	0.2889	0.1958	0.2778	25 [B366]	384.45	0.7298
308.15	0.1584	0.2481	0.2462	0.1987	25 [B349]	404.33	0.7248
	0.1632	0.1130	0.2441	0.1094	50 [B830]	251.58	0.7234
	0.2514	0.1573	0.2424	0.0668	50 [B831]	231.81	0.7271
	0.2577	0.2485	0.1525	0.1886	25 [B350]	421.46	0.7318
	0.1696	0.2889	0.1958	0.2778	25 [B366]	346.10	0.7277
313.15	0.1584	0.2481	0.2462	0.1987	25 [B349]	382.13	0.7237
	0.1632	0.1130	0.2441	0.1094	50 [B830]	239.72	0.7224
	0.2514	0.1573	0.2424	0.0668	50 [B831]	208.19	0.7261
	0.2577	0.2485	0.1525	0.1886	25 [B350]	395.55	0.7307
	0.1696	0.2889	0.1958	0.2778	25 [B366]	319.11	0.7266

APPENDIX B

ESTIMATED EXPERIMENTAL ERROR

B.1 Density Measurements

As mentioned earlier in chapter 3, the following equation is used to calculate the densities of the investigated systems for the used density meter:

$$\rho = \frac{AT^2}{1-BT^2} - C \tag{B.1}$$

The error in the calculated density value due to an error in T, the oscillation period, is calculated by taking the first derivative of equation B.1 with respect to T. This gives the following equation:

$$\frac{d\rho}{dT} = \frac{2AT}{(1-BT^2)^2} \tag{B.2}$$

Since the fluctuation in the oscillation period reading, dT, is constant, the maximum possible error in density measurement, dρ, occurs at the maximum value of T. In the presence study the maximum value of T is 0.7923941 at 293.15K and a fluctuation in density meter reading is $dT=1x10^{-5}$. The values of calibration constants at 293.15 K are: A = 3.858834, and B = -2.926511x10^{-2}. Substituting these values into equation (B.2), then the estimated error in density measurement, dρ, is:

$$d\rho = \frac{2\times 3.858834\times 0.7923941}{(1+2.926511\times 10^{-2}\times 0.7923941^2)^2}\times 1\times 10^{-5}$$

$$= 5.89673x10^{-5}$$

B.2 Viscosity Measurements

In similarity to the procedure followed in the previous section, the following viscometer equation suggested by the manufacturer:

$$\nu = Ct - \frac{E}{t^2} \qquad \text{(B.3)}$$

This equation shows that the predicted error in the kinematic viscosity value is due to an error in reading t, the efflux time. The error is calculated by taking the derivative of equation B.3 with respect to t that gives:

$$d\nu = \left(C + 3\frac{E}{t^3} \right) dt \qquad \text{(B.4)}$$

As indicated in Chapter 3, for each sample, measurements of efflux time were taken at least 3 times. The average value of the efflux time readings was used to calculate the viscosity. The differences between successive measurements for each sample are within 0.1% of the efflux time measured by the viscometer. Therefore, the maximum dt value for every viscometer is assumed to be 0.001 x the highest average value of efflux time by the viscometer. The estimated error in the measurement of the kinematic viscosity for each viscometer is reported in Table (B.1).

Table B.1: The Maximum Predicted Error in the Measurement of the Kinematic Viscosity for Each Viscometer

Viscometer No.	Temperature (K)	C x 10^8	E x 10^4	Max. Eff. time (s)	Maximum dv (m^2/s) x 10^9
25 [B349]	293.15	0.1759	-1.0923	843.79	1.4838
25 [B350]	293.15	0.1742	-5.6670	625.53	1.0853
25 [B366]	293.15	0.1892	1.2470	566.50	1.0730
50 [B830]	293.15	0.4242	2.9145	729.78	3.0974
50 [B831]	293.15	0.4089	0.6491	598.76	2.4489
75 [K95]	293.15	0.9119	-32.2289	527.68	4.7772
75 [K96]	293.15	0.8884	-32.5889	530.83	4.6812
100 [C334]	293.15	1.6565	-0.0073	394.19	6.5298

APPENDIX C

EXCESS VOLUME OF INVESTIGATED SYSTEMS

Table C.1: Excess Volume of the Binary System: Chlorobenzene (1) + p-Xylene (2).

T (K)	x_1	Excess Volume	T (K)	Excess Volume
293.15	0.1085	-0.01124	298.15	-0.01570
	0.2083	-0.04050		-0.04232
	0.3097	-0.06416		-0.06421
	0.3882	-0.07010		-0.07031
	0.5098	-0.07208		-0.07014
	0.6180	-0.06455		-0.06654
	0.7055	0.19125		0.19506
	0.7907	-0.03446		-0.03172
	0.8829	-0.02358		-0.02266
308.15	0.1085	-0.01303		-0.01695
	0.2083	-0.03909	313.15	-0.03906
	0.3097	-0.06332		-0.06709
	0.3882	-0.20542		-0.06977
	0.5098	-0.06820		-0.07767
	0.6180	-0.06265		-0.06950
	0.7055	0.19751		0.18495
	0.7907	-0.02824		-0.03680
	0.8829	-0.01796		-0.01796

Table C.2: Excess Volume of the Binary System: Chlorobenzene (1) + Octane (2).

T (K)	x_1	Excess Volume	T (K)	Excess Volume
293.15	0.1467	-0.01398	298.15	-0.00899
	0.2763	-0.08216		-0.09196
	0.3416	0.00268		0.00694
	0.4192	-0.15417		-0.14962
	0.5096	-0.11136		-0.10702
	0.6071	-0.11716		-0.11470
	0.7067	-0.11397		-0.10865
	0.7983	-0.09797		-0.08940
	0.8932	-0.08371		-0.07995
308.15	0.1467	-0.00266	313.15	-0.02816
	0.2763	-0.06236		-0.09559
	0.3416	0.01394		-0.02576
	0.4192	-0.15392		-0.18895
	0.5096	-0.11190		-0.14649
	0.6071	-0.11797		-0.14635
	0.7067	-0.11092		-0.14326
	0.7983	-0.08899		-0.11160
	0.8932	-0.07837		-0.08985

Table C.3: Excess Volume of the Binary System: Chlorobenzene (1) + Ethylbenzene (2).

T (K)	x_1	Excess Volume	T (K)	Excess Volume
293.15	0.1114	-0.04577	298.15	0.00203
	0.2250	-0.08682		-0.08534
	0.2984	-0.10968		-0.10590
	0.4194	-0.13430		-0.13161
	0.4982	-0.13382		-0.12848
	0.5984	-0.13244		-0.13123
	0.6891	-0.11755		-0.11528
	0.7894	-0.09073		-0.08853
	0.8840	-0.05320		-0.05191
308.15	0.1114	-0.04878		-0.04459
	0.2250	-0.08888	313.15	-0.08402
	0.2984	-0.10628		-0.10977
	0.4194	-0.13248		-0.13069
	0.4982	-0.13065		-0.13749
	0.5984	-0.13408		-0.13151
	0.6891	-0.11634		-0.11759
	0.7894	-0.08820		-0.08878
	0.8840	-0.04645		-0.04913

Table C.4: Excess Volume of the Binary System: Chlorobenzene (1) + 1-Hexanol (2).

T (K)	x_1	Excess Volume	T (K)	Excess Volume
293.15	0.1271	-0.17124	298.15	-0.16026
	0.2264	-0.19181		-0.17222
	0.3205	-0.18106		-0.15847
	0.4111	-0.16608		-0.14385
	0.5110	-0.12958		-0.10561
	0.6021	-0.08686		-0.06323
	0.7022	-0.04555		-0.02210
	0.7953	-0.00878		0.01049
	0.8874	0.01283		0.02600
308.15	0.1271	-0.07578	313.15	-0.06242
	0.2264	-0.08308		-0.06587
	0.3205	-0.07243		-0.05686
	0.4111	-0.05965		-0.03662
	0.5110	-0.02689		-0.00805
	0.6021	0.01044		0.02945
	0.7022	0.04247		0.05952
	0.7953	0.06084		0.07571
	0.8874	0.06299		0.07563

Table C.5: Excess Volume of the Binary System: p-Xylene (1) + Octane (2).

T (K)	x_1	Excess Volume	T (K)	Excess Volume
293.15	0.1335	0.02668	298.15	0.02362
	0.2243	-0.01518		-0.02210
	0.3336	0.01622		0.01882
	0.3985	0.01952		0.01971
	0.4986	0.02345		0.02516
	0.5856	0.01614		0.01763
	0.6830	0.01698		0.01706
	0.7750	0.01226		0.00937
	0.8707	0.01368		0.01144
308.15	0.1335	0.03241		0.00934
	0.2243	-0.01394	313.15	-0.02761
	0.3336	0.03036		0.01286
	0.3985	0.02790		0.01338
	0.4986	0.03298		0.01497
	0.5856	0.02714		0.01665
	0.6830	0.02427		0.01476
	0.7750	0.01427		0.01195
	0.8707	0.01750		0.01063

Table C.6: Excess Volume of the Binary System: p-Xylene (1) + Ethylbenzene (2).

T (K)	x_1	Excess Volume	T (K)	Excess Volume
293.15	0.1235	0.00517	298.15	0.00905
	0.2082	0.00346		0.00454
	0.3060	0.00070		0.00061
	0.4007	0.00153		0.00106
	0.5051	-0.00116		-0.00122
	0.5963	-0.01591		-0.01574
	0.6805	-0.00428		-0.00600
	0.7752	-0.00074		-0.00044
	0.8513	-0.00156		0.00064
308.15	0.1235	0.00535	313.15	0.01094
	0.2082	0.00462		0.00902
	0.3060	0.00000		0.00810
	0.4007	0.00461		0.00918
	0.5051	0.00186		0.01100
	0.5963	-0.01941		-0.01078
	0.6805	-0.00075		0.00358
	0.7752	0.00666		0.00746
	0.8513	0.00333		0.00937

Table C.7: Excess Volume of the Binary System: p-Xylene (1) + 1-Hexanol (2).

T (K)	x_1	Excess Volume	T (K)	Excess Volume
293.15	0.1273	-0.04927	298.15	-0.11037
	0.2049	-0.04960		-0.10597
	0.3086	-0.03783		-0.08895
	0.4047	-0.01030		-0.05390
	0.5064	0.02050		-0.02006
	0.5913	0.05259		0.01394
	0.6856	0.07676		0.44756
	0.7803	0.08908		0.05681
	0.8733	0.09396		0.07416
308.15	0.1273	-0.16215	313.15	-0.11168
	0.2049	-0.15359		-0.09670
	0.3086	-0.13160		-0.06725
	0.4047	-0.09662		-0.03325
	0.5064	-0.07206		-0.00183
	0.5913	-0.04244		0.02953
	0.6856	-0.02031		0.04846
	0.7803	-0.01624		0.05752
	0.8733	-0.01748		0.05160

Table C.8: Excess Volume of the Binary System: Octane (1) + Ethylbenzene (2).

T (K)	x_1	Excess Volume	T (K)	Excess Volume
293.15	0.1124	0.09700	298.15	0.09641
	0.2141	0.14134		0.13882
	0.3059	0.17070		0.18101
	0.4028	0.19457		0.19216
	0.4942	0.19138		0.19549
	0.5890	0.19115		0.19309
	0.6796	0.17266		0.16854
	0.7456	0.14576		0.14515
	0.8581	0.09286		0.09193
308.15	0.1124	0.09251		0.09310
	0.2141	0.13632	313.15	0.13611
	0.3059	0.16661		0.15716
	0.4028	0.19030		0.17757
	0.4942	0.19362		0.17694
	0.5890	0.19171		0.17582
	0.6796	0.17463		0.15669
	0.7456	0.14615		0.13019
	0.8581	0.09746		0.08339

Table C.9: Excess Volume of the Binary System: Octane (1) + 1-Hexanol (2).

T (K)	x_1	Excess Volume	T (K)	Excess Volume
293.15	0.1104	-0.10735	298.15	-0.10520
	0.2173	-0.10484		-0.09988
	0.3144	-0.07256		-0.06268
	0.4188	-0.02273		-0.01003
	0.5031	0.03182		0.04040
	0.5951	0.04386		0.05705
	0.6975	0.07621		0.08997
	0.7890	0.09145		0.10284
	0.8764	0.08792		0.09402
308.15	0.1104	-0.03005	313.15	-0.02717
	0.2173	-0.02580		-0.01730
	0.3144	0.01084		0.01257
	0.4188	0.06121		0.06163
	0.5031	0.11317		0.11634
	0.5951	0.12307		0.12571
	0.6975	0.14886		0.15129
	0.7890	0.15851		0.16409
	0.8764	0.15206		0.15605

Table C.10: Excess Volume of the Binary System: Ethylbenzene (1) + 1-Hexanol (2).

T (K)	x_1	Excess Volume	T (K)	Excess Volume
293.15	0.1257	-0.06507	298.15	-0.05465
	0.2131	-0.04283		-0.04166
	0.2997	-0.00720		0.00707
	0.4063	0.04553		0.06068
	0.5064	0.07176		0.08734
	0.5960	0.09870		0.11665
	0.6853	0.10779		0.04384
	0.7906	0.11797		0.13166
	0.8956	0.09199		0.10205
308.15	0.1257	0.02274		0.08369
	0.2131	0.04954	313.15	0.06672
	0.2997	0.08924		0.10953
	0.4063	0.13326		0.15517
	0.5064	0.15823		0.18559
	0.5960	0.18324		0.20137
	0.6853	0.18306		0.20500
	0.7906	0.17334		0.19218
	0.8956	0.12688		0.14555

Table C.11: Raw Data of Viscosity and Density Measurements for the Ternary System:

Chlorobenzene (1) + p-Xylene (2) + Octane (3).

T (K)	x_1	x_2	Excess Volume
293.15	0.1320	0.1764	-0.0210
	0.2162	0.6230	-0.0620
	0.3436	0.3172	-0.0885
	0.4115	0.1989	-0.0929
	0.4979	0.3787	-0.1063
	0.5905	0.2443	-0.1020
	0.6868	0.1045	-0.1070
298.15	0.1320	0.1764	-0.0203
	0.2162	0.6230	-0.0683
	0.3436	0.3172	-0.0933
	0.4115	0.1989	-0.0867
	0.4979	0.3787	-0.1036
	0.5905	0.2443	-0.0969
	0.6868	0.1045	-0.1028
308.15	0.1320	0.1764	-0.0185
	0.2162	0.6230	-0.0658
	0.3436	0.3172	-0.0881
	0.4115	0.1989	-0.0927
	0.4979	0.3787	-0.1016
	0.5905	0.2443	-0.1007
	0.6868	0.1045	-0.1071
313.15	0.1320	0.1764	-0.0477
	0.2162	0.6230	-0.0771
	0.3436	0.3172	-0.1115
	0.4115	0.1989	-0.1157
	0.4979	0.3787	-0.1175
	0.5905	0.2443	-0.1225
	0.6868	0.1045	-0.1269

Table C.12: Excess Volume of the Ternary System:

Chlorobenzene (1) + Octane (2) + Ethylbenzene (3).

T (K)	x_1	x_2	Excess Volume
293.15	0.1609	0.1551	0.0083
	0.2256	0.6265	0.0046
	0.3318	0.3343	-0.0382
	0.3999	0.2162	-0.0725
	0.4913	0.4011	-0.0866
	0.5621	0.2857	-0.0942
	0.6802	0.1191	-0.1130
298.15	0.1609	0.1551	0.0122
	0.2256	0.6265	0.0036
	0.3318	0.3343	-0.0313
	0.3999	0.2162	-0.0700
	0.4913	0.4011	-0.0790
	0.5621	0.2857	-0.0924
	0.6802	0.1191	-0.1105
308.15	0.1609	0.1551	0.0099
	0.2256	0.6265	0.0010
	0.3318	0.3343	-0.0330
	0.3999	0.2162	-0.0729
	0.4913	0.4011	-0.0848
	0.5621	0.2857	-0.0983
	0.6802	0.1191	-0.1096
313.15	0.1609	0.1551	-0.0116
	0.2256	0.6265	-0.0281
	0.3318	0.3343	-0.0594
	0.3999	0.2162	-0.0882
	0.4913	0.4011	-0.1191
	0.5621	0.2857	-0.1201
	0.6802	0.1191	-0.1238

Table C.13: Excess Volume of the Ternary System:

Chlorobenzene (1) + p-Xylene (2) + Ethylbenzene (3).

T (K)	x_1	x_2	Excess Volume
293.15	0.1254	0.1579	-0.0659
	0.2246	0.6279	-0.0646
	0.3456	0.3375	-0.1033
	0.4094	0.1825	-0.1184
	0.5094	0.3842	-0.0954
	0.5909	0.2528	-0.0977
	0.6871	0.1116	-0.0871
298.15	0.1254	0.1579	-0.0633
	0.2246	0.6279	-0.0630
	0.3456	0.3375	-0.1002
	0.4094	0.1825	-0.1131
	0.5094	0.3842	-0.0935
	0.5909	0.2528	-0.0949
	0.6871	0.1116	-0.0850
308.15	0.1254	0.1579	-0.0626
	0.2246	0.6279	-0.0611
	0.3456	0.3375	-0.0989
	0.4094	0.1825	-0.1111
	0.5094	0.3842	-0.0914
	0.5909	0.2528	-0.0903
	0.6871	0.1116	-0.0847
313.15	0.1254	0.1579	-0.0586
	0.2246	0.6279	-0.0657
	0.3456	0.3375	-0.0987
	0.4094	0.1825	-0.1100
	0.5094	0.3842	-0.0934
	0.5909	0.2528	-0.0954
	0.6871	0.1116	-0.0895

Table C.14: Excess Volume of the Ternary System:

Chlorobenzene (1) + Octane (2) + 1-Hexanol (3).

T (K)	x_1	x_2	Excess Volume
293.15	0.1275	0.1592	-0.1399
	0.2251	0.6159	0.0274
	0.3302	0.3273	-0.0484
	0.3863	0.2206	-0.3055
	0.4893	0.3979	-0.0542
	0.5880	0.2541	-0.0578
	0.6732	0.1193	-0.0492
298.15	0.1275	0.1592	-0.1221
	0.2251	0.6159	0.0383
	0.3302	0.3273	-0.0260
	0.3863	0.2206	-0.2853
	0.4893	0.3979	-0.0345
	0.5880	0.2541	-0.0408
	0.6732	0.1193	-0.0291
308.15	0.1275	0.1592	-0.0435
	0.2251	0.6159	0.0869
	0.3302	0.3273	0.0381
	0.3863	0.2206	-0.2199
	0.4893	0.3979	0.0027
	0.5880	0.2541	0.0052
	0.6732	0.1193	0.0211
313.15	0.1275	0.1592	-0.0356
	0.2251	0.6159	0.0846
	0.3302	0.3273	0.0343
	0.3863	0.2206	-0.2165
	0.4893	0.3979	-0.0090
	0.5880	0.2541	-0.0011
	0.6732	0.1193	0.0253

Table C.15: Excess Volume of the Ternary System:

Chlorobenzene (1) + Ethylbenzene (2) + 1-Hexanol (3).

T (K)	x_1	x_2	Excess Volume
293.15	0.1234	0.1548	-0.1258
	0.2161	0.6241	-0.0067
	0.3395	0.3259	-0.0566
	0.3993	0.2028	-0.0853
	0.4975	0.3854	-0.0625
	0.5856	0.2553	-0.0505
	0.6839	0.1117	-0.0213
298.15	0.1234	0.1548	-0.1083
	0.2161	0.6241	0.0102
	0.3395	0.3259	-0.0355
	0.3993	0.2028	-0.0613
	0.4975	0.3854	-0.0492
	0.5856	0.2553	-0.0309
	0.6839	0.1117	0.0007
308.15	0.1234	0.1548	-0.0218
	0.2161	0.6241	0.0498
	0.3395	0.3259	0.0323
	0.3993	0.2028	0.0105
	0.4975	0.3854	-0.0117
	0.5856	0.2553	0.0137
	0.6839	0.1117	0.0465
313.15	0.1234	0.1548	-0.0002
	0.2161	0.6241	0.0639
	0.3395	0.3259	0.0511
	0.3993	0.2028	0.0289
	0.4975	0.3854	-0.0004
	0.5856	0.2553	0.0275
	0.6839	0.1117	0.0587

Table C.16: Excess Volume of the Ternary System:

Chlorobenzene (1) + p-Xylene (2) + 1-Hexanol (3).

T (K)	x_1	x_2	Excess Volume
293.15	0.1189	0.1549	-0.1575
	0.2142	0.6302	-0.0248
	0.3346	0.3262	-0.2327
	0.4072	0.2051	-0.1033
	0.4884	0.3925	-0.0374
	0.5880	0.2474	-0.0367
	0.6805	0.1135	-0.0310
298.15	0.1189	0.1549	-0.1382
	0.2142	0.6302	-0.0152
	0.3346	0.3262	-0.0556
	0.4072	0.2051	-0.0833
	0.4884	0.3925	-0.0236
	0.5880	0.2474	-0.0250
	0.6805	0.1135	-0.0124
308.15	0.1189	0.1549	-0.0494
	0.2142	0.6302	0.0358
	0.3346	0.3262	0.0126
	0.4072	0.2051	-0.0099
	0.4884	0.3925	0.0122
	0.5880	0.2474	0.0216
	0.6805	0.1135	0.0384
313.15	0.1189	0.1549	-0.0336
	0.2142	0.6302	0.0519
	0.3346	0.3262	0.0307
	0.4072	0.2051	0.0174
	0.4884	0.3925	0.0204
	0.5880	0.2474	0.0330
	0.6805	0.1135	0.0502

Table C.17: Excess Volume of the Ternary System:

p-Xylene (1) + Octane (2) + Ethylbenzene (3).

T (K)	x_1	x_2	Excess Volume
293.15	0.1088	0.1584	0.1038
	0.2021	0.6300	0.0921
	0.3289	0.3274	0.1001
	0.3836	0.2069	0.0759
	0.4854	0.3922	0.0534
	0.5719	0.2618	0.0607
	0.6667	0.1163	0.0248
298.15	0.1088	0.1584	0.1037
	0.2021	0.6300	0.0892
	0.3289	0.3274	0.0981
	0.3836	0.2069	0.0793
	0.4854	0.3922	0.0492
	0.5719	0.2618	0.0614
	0.6667	0.1163	0.0256
308.15	0.1088	0.1584	0.1009
	0.2021	0.6300	0.0966
	0.3289	0.3274	0.0993
	0.3836	0.2069	0.0800
	0.4854	0.3922	0.0556
	0.5719	0.2618	0.0575
	0.6667	0.1163	0.0359
313.15	0.1088	0.1584	0.0989
	0.2021	0.6300	0.0768
	0.3289	0.3274	0.0931
	0.3836	0.2069	0.0770
	0.4854	0.3922	0.0445
	0.5719	0.2618	0.0523
	0.6667	0.1163	0.0353

Table C.18: Excess Volume of the Ternary System:

p-Xylene (1) + Ethylbenzene (2) + 1-Hexanol (3).

T (K)	x_1	x_2	Excess Volume
293.15	0.1113	0.1693	-0.0380
	0.2029	0.6321	0.0989
	0.3175	0.3394	0.0705
	0.3896	0.2146	0.0364
	0.4764	0.4000	0.0718
	0.5722	0.2644	0.0684
	0.6561	0.1290	0.0518
298.15	0.1113	0.1693	-0.0246
	0.2029	0.6321	0.1142
	0.3175	0.3394	0.0893
	0.3896	0.2146	0.0752
	0.4764	0.4000	0.0876
	0.5722	0.2644	0.0822
	0.6561	0.1290	0.0586
308.15	0.1113	0.1693	0.0617
	0.2029	0.6321	0.1514
	0.3175	0.3394	0.1572
	0.3896	0.2146	0.1271
	0.4764	0.4000	0.1246
	0.5722	0.2644	0.1265
	0.6561	0.1290	0.1171
313.15	0.1113	0.1693	0.0777
	0.2029	0.6321	0.1734
	0.3175	0.3394	0.1772
	0.3896	0.2146	0.1524
	0.4764	0.4000	0.1406
	0.5722	0.2644	0.1459
	0.6561	0.1290	0.1412

Table C.19: Excess Volume of the Ternary System:

p-Xylene (1) + Octane (2) + 1-Hexanol (3).

T (K)	x_1	x_2	Excess Volume
293.15	0.1076	0.1620	-0.0904
	0.2190	0.6234	0.0905
	0.3121	0.3365	-0.3913
	0.3976	0.2265	-0.2766
	0.4918	0.3994	0.0789
	0.5825	0.2564	0.0755
	0.6740	0.1227	0.0550
298.15	0.1076	0.1620	-0.0768
	0.2190	0.6234	0.1040
	0.3121	0.3365	-0.3766
	0.3976	0.2265	-0.2620
	0.4918	0.3994	0.0908
	0.5825	0.2564	0.0890
	0.6740	0.1227	0.0679
308.15	0.1076	0.1620	0.0030
	0.2190	0.6234	0.1630
	0.3121	0.3365	-0.3165
	0.3976	0.2265	-0.2028
	0.4918	0.3994	0.1433
	0.5825	0.2564	0.1388
	0.6740	0.1227	0.1194
313.15	0.1076	0.1620	0.0106
	0.2190	0.6234	0.1684
	0.3121	0.3365	-0.3076
	0.3976	0.2265	-0.1946
	0.4918	0.3994	0.1476
	0.5825	0.2564	0.1445
	0.6740	0.1227	0.1319

Table C.20: Excess Volume of the Ternary System:

Octane (1) + Ethylbenzene (2) + 1-Hexanol (3).

T (K)	x_1	x_2	Excess Volume
293.15	0.1133	0.1586	-0.0448
	0.2104	0.6310	0.2090
	0.3249	0.3297	0.1654
	0.3987	0.2028	0.1211
	0.4949	0.3942	0.2443
	0.5751	0.2621	0.2054
	0.6762	0.1153	0.1319
298.15	0.1133	0.1586	-0.0324
	0.2104	0.6310	0.2179
	0.3249	0.3297	0.1792
	0.3987	0.2028	0.1342
	0.4949	0.3942	0.2579
	0.5751	0.2621	0.2201
	0.6762	0.1153	0.1415
308.15	0.1133	0.1586	0.0441
	0.2104	0.6310	0.2548
	0.3249	0.3297	0.2340
	0.3987	0.2028	0.1892
	0.4949	0.3942	0.2836
	0.5751	0.2621	0.2602
	0.6762	0.1153	0.1965
313.15	0.1133	0.1586	0.0574
	0.2104	0.6310	0.2655
	0.3249	0.3297	0.2422
	0.3987	0.2028	0.1987
	0.4949	0.3942	0.2869
	0.5751	0.2621	0.2632
	0.6762	0.1153	0.1990

Table C.21: Excess Volume of the Quaternary System:

Chlorobenzene (1) + p-Xylene (2) + Octane (3) + Ethylbenzene (4).

T (K)	x_1	x_2	x_3	Excess Volume
293.15	0.1193	0.1173	0.1153	0.0071
	0.2608	0.2519	0.2428	-0.0408
	0.2993	0.2088	0.0678	-0.0777
	0.1715	0.2989	0.4284	-0.0175
	0.2601	0.2941	0.1113	0.0152
	0.4831	0.1615	0.2913	-0.1023
298.15	0.1193	0.1173	0.1153	0.0090
	0.2608	0.2519	0.2428	-0.0381
	0.2993	0.2088	0.0678	-0.0742
	0.1715	0.2989	0.4284	-0.0178
	0.2601	0.2941	0.1113	0.0150
	0.4831	0.1615	0.2913	-0.0979
308.15	0.1193	0.1173	0.1153	0.0059
	0.2608	0.2519	0.2428	-0.0402
	0.2993	0.2088	0.0678	-0.0802
	0.1715	0.2989	0.4284	-0.0150
	0.2601	0.2941	0.1113	0.0065
	0.4831	0.1615	0.2913	-0.1046
313.15	0.1193	0.1173	0.1153	-0.0020
	0.2608	0.2519	0.2428	-0.0542
	0.2993	0.2088	0.0678	-0.0877
	0.1715	0.2989	0.4284	-0.0337
	0.2601	0.2941	0.1113	-0.0021
	0.4831	0.1615	0.2913	-0.1308

Table C.22: Excess Volume of the Quaternary System:

p-Xylene (1) + Octane (2) + Ethylbenzene (3) + 1-Hexanol (4).

T (K)	x_1	x_2	x_3	Excess Volume
293.15	0.1108	0.1129	0.1155	-0.0166
	0.2421	0.2504	0.2551	0.1555
	0.2899	0.2023	0.0776	0.0554
	0.1558	0.2855	0.4394	0.1947
	0.2445	0.2934	0.1246	0.0994
	0.4743	0.1553	0.3043	0.1063
298.15	0.1108	0.1129	0.1155	-0.0020
	0.2421	0.2504	0.2551	0.1714
	0.2899	0.2023	0.0776	0.0703
	0.1558	0.2855	0.4394	0.2082
	0.2445	0.2934	0.1246	0.1163
	0.4743	0.1553	0.3043	0.1167
308.15	0.1108	0.1129	0.1155	0.0785
	0.2421	0.2504	0.2551	0.2212
	0.2899	0.2023	0.0776	0.1422
	0.1558	0.2855	0.4394	0.2412
	0.2445	0.2934	0.1246	0.1772
	0.4743	0.1553	0.3043	0.1448
313.15	0.1108	0.1129	0.1155	0.0848
	0.2421	0.2504	0.2551	0.2311
	0.2899	0.2023	0.0776	0.1522
	0.1558	0.2855	0.4394	0.2468
	0.2445	0.2934	0.1246	0.1922
	0.4743	0.1553	0.3043	0.1495

Table C.23: Excess Volume of the Quaternary System:

Chlorobenzene (1) + Octane (2) + Ethylbenzene (3) + 1-Hexanol (4).

T (K)	x_1	x_2	x_3	Excess Volume
293.15	0.1200	0.1081	0.1241	-0.0941
	0.2516	0.2441	0.2574	0.0274
	0.3036	0.1980	0.0701	-0.0702
	0.1665	0.2933	0.4343	0.1065
	0.2484	0.2931	0.1153	0.0046
	0.4818	0.1572	0.3023	-0.0330
298.15	0.1200	0.1081	0.1241	-0.0836
	0.2516	0.2441	0.2574	0.0538
	0.3036	0.1980	0.0701	-0.0532
	0.1665	0.2933	0.4343	0.1232
	0.2484	0.2931	0.1153	0.0160
	0.4818	0.1572	0.3023	-0.0194
308.15	0.1200	0.1081	0.1241	-0.0010
	0.2516	0.2441	0.2574	0.0976
	0.3036	0.1980	0.0701	0.0130
	0.1665	0.2933	0.4343	0.1522
	0.2484	0.2931	0.1153	0.0816
	0.4818	0.1572	0.3023	-0.0031
313.15	0.1200	0.1081	0.1241	0.0087
	0.2516	0.2441	0.2574	0.0996
	0.3036	0.1980	0.0701	0.0260
	0.1665	0.2933	0.4343	0.1514
	0.2484	0.2931	0.1153	0.0867
	0.4818	0.1572	0.3023	-0.0072

Table C.24: Excess Volume of the Quaternary System:

Chlorobenzene (1) + p-Xylene (2) + Ethylbenzene (3) + 1-Hexanol (4).

T (K)	x_1	x_2	x_3	Excess Volume
293.15	0.1157	0.1128	0.1168	-0.1112
	0.2569	0.2400	0.2543	-0.0246
	0.2964	0.2000	0.0708	-0.0756
	0.1544	0.2946	0.4386	-0.0030
	0.2541	0.2827	0.1216	-0.0492
	0.4818	0.1545	0.2989	-0.0506
298.15	0.1157	0.1128	0.1168	-0.0968
	0.2569	0.2400	0.2543	-0.0011
	0.2964	0.2000	0.0708	-0.0520
	0.1544	0.2946	0.4386	0.0128
	0.2541	0.2827	0.1216	-0.0288
	0.4818	0.1545	0.2989	-0.0401
308.15	0.1157	0.1128	0.1168	-0.0135
	0.2569	0.2400	0.2543	0.0475
	0.2964	0.2000	0.0708	0.0216
	0.1544	0.2946	0.4386	0.0464
	0.2541	0.2827	0.1216	0.0348
	0.4818	0.1545	0.2989	-0.0215
313.15	0.1157	0.1128	0.1168	0.0100
	0.2569	0.2400	0.2543	0.0635
	0.2964	0.2000	0.0708	0.0389
	0.1544	0.2946	0.4386	0.0641
	0.2541	0.2827	0.1216	0.0540
	0.4818	0.1545	0.2989	-0.0150

Table C.25: Excess Volume of the Quaternary System:

Chlorobenzene (1) + p-Xylene (2) + Octane (3) + 1-Hexanol (4).

T (K)	x_1	x_2	x_3	Excess Volume
293.15	0.1178	0.1164	0.1098	-0.1242
	0.2598	0.2517	0.2467	-0.0195
	0.2967	0.2085	0.0637	-0.0946
	0.1743	0.2964	0.4192	0.0258
	0.2567	0.3006	0.1120	-0.0523
	0.4838	0.1632	0.2882	-0.0480
298.15	0.1178	0.1164	0.1098	-0.1074
	0.2598	0.2517	0.2467	-0.0012
	0.2967	0.2085	0.0637	-0.0719
	0.1743	0.2964	0.4192	0.0427
	0.2567	0.3006	0.1120	-0.0324
	0.4838	0.1632	0.2882	-0.0352
308.15	0.1178	0.1164	0.1098	-0.0277
	0.2598	0.2517	0.2467	0.0398
	0.2967	0.2085	0.0637	-0.0017
	0.1743	0.2964	0.4192	0.0735
	0.2567	0.3006	0.1120	0.0317
	0.4838	0.1632	0.2882	-0.0079
313.15	0.1178	0.1164	0.1098	-0.0191
	0.2598	0.2517	0.2467	0.0504
	0.2967	0.2085	0.0637	0.0123
	0.1743	0.2964	0.4192	0.0713
	0.2567	0.3006	0.1120	0.0421
	0.4838	0.1632	0.2882	-0.0197

Table C.26: Excess Volume of the Quinary System: Chlorobenzene (1) + p-Xylene (2) + Octane (3) + Ethylbenzene (4) + 1-Hexanol (5).

T (K)	x_1	x_2	x_3	x_4	Excess Volume
293.15	0.1584	0.2481	0.2462	0.1987	0.0445
	0.1632	0.1130	0.2441	0.1094	-0.0061
	0.2514	0.1573	0.2424	0.0668	-0.0186
	0.2577	0.2485	0.1525	0.1886	-0.0019
	0.1696	0.2889	0.1958	0.2778	0.0303
298.15	0.1584	0.2481	0.2462	0.1987	0.0605
	0.1632	0.1130	0.2441	0.1094	0.0108
	0.2514	0.1573	0.2424	0.0668	0.0007
	0.2577	0.2485	0.1525	0.1886	0.0103
	0.1696	0.2889	0.1958	0.2778	0.0417
308.15	0.1584	0.2481	0.2462	0.1987	0.0999
	0.1632	0.1130	0.2441	0.1094	0.0731
	0.2514	0.1573	0.2424	0.0668	0.0572
	0.2577	0.2485	0.1525	0.1886	0.0561
	0.1696	0.2889	0.1958	0.2778	0.0662
313.15	0.1584	0.2481	0.2462	0.1987	0.0996
	0.1632	0.1130	0.2441	0.1094	0.0831
	0.2514	0.1573	0.2424	0.0668	0.0622
	0.2577	0.2485	0.1525	0.1886	0.0675
	0.1696	0.2889	0.1958	0.2778	0.0675

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