Prediction of Viscosity of Ionic Liquids using Different Equations

by

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Dissertation submitted in partial fulfillment of

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CERTIFICATION OF APPROVAL

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Approved by,

____

Supervisor
(AP. Dr. Khashayar Nasrifar)

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(LIM HUNG CHIEK)

ABSTRACT

Recently, research emphasis on Ionic Liquid (IL) characterization, properties, and applications are rapidly growing ever since ILs have been accepted as "green-chemicals" and candidates to replace other non-environmental friendly chemicals including solvents and lubricants. The understanding of physical and chemical properties of Ionic Liquids is crucial in identifying its potential applications in the chemical industry. However, the information of IL transport properties especially viscosity has left much to be desired from the academia and chemical industries as viscosity of ILs are a relatively new area of study, compared to other IL properties, such as density. Previous studies involving IL viscosity estimation are limited and based on non-generalized equations that are not applicable for all ILs.

The objective of this research is to identify the best method to predict or estimate viscosity of ILs so that their suitability in various applications can be known without much hassle. A research on prediction of viscosity of Ionic Liquids is presented in this report. The prediction methods will only require the critical properties and acentric factor of the IL as the parameters to estimate its viscosity. A detailed comparison between 5 different generalized correlations is performed to identify the best IL viscosity prediction method among them. 20 ILs with around 100 data points for each method was studied in this project. Generalized equations are identified through comprehensive research on available liquid viscosity methods. The database of parameters such as experimental viscosity and critical property data of ILs are collected from literature/online resources and the calculation of %AAD is done with comparison to the experimental data. The accuracies of the different equations (%AAAD) are then compared against each other. The method that has been identified to be the best prediction method of viscosity of ILs is the Lewis & Squires Method.

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CHAPTER 1

INTRODUCTION

1 INTRODUCTION

1.1 Background Study

Ionic liquids (ILs) are typically defined as organic salts that melt at or below 100 ºC. Another definition of Ionic Liquids is organic salts which are in liquid form at room temperature. ILs results from the combination of several inorganic or organic anions and organic cations. Due to the fact that IL have been accepted as "green chemicals", a huge interest from the chemical industries have been shown in recent times due to its environmental characteristics. ILs are good candidates for replacement of traditional solvents as they have been found to have peculiar properties such as high conductivity, wide range of density and viscosity values, modifiable purity and solubility as well as high thermal and chemical stability. Utilizing ILs is one of the goals of green chemistry because they create a cleaner and more sustainable chemistry and are receiving growing attention as environmental friendly solvents for various synthetic and catalytic processes.

Based on practical and theoretical point of view, an interesting point about ILs is their high viscosity. Viscosity is defined as the internal resistance to flow or a measure of fluid friction of a liquid. Two different viscosity coefficients are commonly used, namely dynamic viscosity and kinematic viscosity. Dynamic viscosity is defined in Pascal-second (pa.s, SI unit) or centipoises (cP, where 1 cP=0.001Pa.s) while kinematic viscosity is the dynamic viscosity divided by the density (usually in m2.s-1 or centistokes). Viscosities ILs are relatively high compared to those of common organic solvents. P.Bonhote.(1996) suggests that viscosity of ILs displays a wide range from 10 to greater than 10,000cP while A. Riddick (1986) states that viscosities of organic solvents typically have room temperature viscosities in the range of 0.2 to 10cP. Knowing the transport properties of ILs is a prerequisite for many tasks met by chemical engineers and scientists such as chemical separation and replacing organic solvents. Moreover, predicting the viscosities of fluids and their mixtures is very crucial in the chemical industries as they need to be identified in the design of heat-transfer equipment, process piping, reactors distillation columns and etc.

1.2 Problem Statement

Although much effort has been focused on the wide range of ILs applications, the basic understanding of their structure-property relationships is of utmost importance but has been neglected since the days of its first discovery in 1914. Understanding of the physical properties, such as viscosity is crucial to assess the suitability of ILs for specific applications, as well as the design of new ILs. Currently, there are very few works that have thoroughly studied the qualitative and quantitative relationships between the structures of ILs and their fundamental properties, especially in regard to their viscosities.

The possible number of ILs formed by the already available cation and anion combinations is extremely high. Hence, to measure the viscosity of each and every IL before its involvement in applications would be impractical. This is due to the fact that the process would be time consuming and economically infeasible. It is also impossible to synthesize all of the ILs to find a suitable ion combination with the desirable viscosity. Thus, the most suitable and effective way of viscosity estimation of ILs has to be determined in order to save time and cost. Viscosity estimations might not give us the actual viscosity of the Ils with very high accuracy but most importantly it will give us an idea of which applications these ILs will be suitable to be used in. Therefore, the study of correlations and comparison between different viscosity predictions is conducted.

1.3 Objective and Scope of Study

The objectives of this research are as follows:

- To review current literature to find the equations that are used to predict viscosity of liquids using their critical properties

- To compare different prediction methods of viscosity of ILs with the actual viscosity and compare their accuracy.
- To determine the best and most accurate generalized correlation in estimating the viscosities of Ionic Liquids.

The scope of study of this research are as follows:

- Viscosity of 20 ILs will be studied in this project.
- Prediction of viscosity of ILs will be done using 5 different generalized correlations.
- The temperature range will be from 283.15K to 363.15K
- Parameters that are involved in the generalized correlations are the acentric factors and critical properties of the respective ILs, such as T_c, T_b, P_c, V_c, ω etc.

1.4 The Relevancy of the Project

This project is geared towards better Ionic Liquid synthesis and applications in the chemical industry. By being able to predict and estimate viscosity of ILs without much hassle, the key applications of ILs can be characterized and determined promptly. Although the accuracy may not match that of the experimental data, the estimation is sufficient in decision making regarding Ionic Liquid applications. The parameters of these generalized correlations that are studied are mainly the acentric properties and critical factors of the respective ILs. These parameters are relatively easy to identify compared to the constants used in non-generalized equations. A similar study on the density of ILs has been done, but up to date, there is no similar study that is done on the viscosity of ILs, therefore this project will greatly benefit the IL industry

1.5 Feasibility of the Project within the Scope and Time Frame

Proper planning and good background research is needed to successfully achieve the objectives of this project. There are more than 3000 repetitions of calculation to be done for the project, and only with proper scheduling, they can be completed. The 7 month time frame is feasible for this project to be completed. Application of Chemical Engineering concepts and methods can be applied during the period of project. Work ethics and discipline towards the project schedule is needed to ensure that this project is a success.

CHAPTER 2

LITERATURE REVIEW

2 LITERATURE REVIEW

2.1 Background of Ionic Liquids

Ionic Liquids (ILs) are a promising set of materials with various and astonishing set of properties. According to Wilkes (2002), ILs are molten salts having by definition melting points below 100^0C, evolved from traditional high temperature molten salts. The discovery of ILs can be traced back to the early report by Paul Walden of which the room temperature IL ethylammonium nitrate ($[EtNH_3][NO_3]$; mp 13-14^{o}C), was formaed by the neutralisation of ethylamine with concentrated nitric acid in 1914 (Plechkova and Seddon, 2008). Based on the same literature, it is expected that there may be more than 10^6 possible ILs if all currently known ILs cations and anions were to be paired, and up to 10^{18} if all ternary systems were to be investigated. Ricichert et al. (2006) pointed out that ILs are materials that have been known for over 100 years but renewal of interest arose from a new thinking about these low melting salts as solvents, especially for VOC (Volatile Organic Compound) replacements.

According to Welton (1999), there are many physical properties of ILs that make them interesting as potential solvents for synthesis. Firstly, they are good solvents for a wide range o both inorganic and organic materials, and special combinations of reagents can be brought into the same phase. Besides that, they are usually composed of poorly coordinating ions, so they can be highly polar yet non-coordinating solvents. Moreover, ILs are non-volatile, therefore they can be used in high-vacuum systems and eliminate many containment problems and they do not evaporate as well. ILs with high viscosity values are useful for applications as lubricants or engineering systems. On the other hand, ILs with low viscosity values is generally desired in order to use them as solvents as they would require less pumping costs and increase mass transfer rates.

The viscosity of ILs is relatively high compared to conventional solvents, one to three times of magnitude higher. It has been reported for a variety of ILs to range from 66 to 1110cP at 20-25^{0}C.

2.2 Studies on Viscosity of ILs

The development of prediction methods for viscosities of ILs have been carried out but not in detail. In fact, studies on how the structure of the ions in the IL influences their physical properties such as viscosity and density are rare. Few works have methodically studied the qualitative and quantitative relationships between the structures of ILs. Currently, data and information for many physic-chemical properties of ILs are lacking or still unreliable because its application is relatively new compared to other chemicals in the industry.

An interesting study has been published by Hunt's publication on the viscosity study of 1-Butyl-2,3-dimethyl-imidazolium-based ILs. Substitution for a methyl group at the 2-position of the imidazolium cation was made to form 1-butyl-2,3-dimethyl-imidazolium ($[BDMIM]^+$). This removes the main hydrogen-bonding interaction between the chloride anion and the imidazolium. This loss of hydrogen bonding was expected to reduce the viscosity of the IL but instead, the opposite is observed experimentally as the viscosity has increased.

To give explanation why does a reduction in hydrogen bonding lead to an increase in viscosity of ILs, they performed another study using quantum-chemical methods. The structure of hydrogen bonding of ion pairs of ($[BDMIM]^+$) were compared with those of unsubstituted analogue [BMIM][Cl]. It was explained that the effects due to a loss in hydrogen bonding are outweighed by the loss in entropy. However, this finding is only limited to certain ILs only. This probes further studies on the viscosity of ILs as it interests many researchers and analysts.

Several approaches to estimate and predict physical properties of ILs are known in the literature. Many prediction and estimation methods for properties of pure components and mixtures can be found in current literature, such as journals that has compared correlations between different density prediction methods. However, at the moment there is no literature comparing different correlations in IL viscosity prediction, which is equally important to the density prediction correlations.

2.3 Current IL Viscosity Prediction Methods

In the current chemical engineering industry, the most widely used and commonly accepted viscosity estimation methods for complex molecules are usually based on group contributions for example the Orrick-Erbar method (1974),

$$ln\frac{\mu}{\rho M} = A + B/T \tag{1}$$

and the Sastry-Rao method(1992),

$$\mu = \mu_B P_{vp}^{-N} \tag{2}$$.

The UNIFAC-VISCO (1994) method is predictive but it is limited to the types of ILs which it can be applied. The corresponding states concept such as Przezdziecki and Sridhar (1985), Chatterjee and Vasant (1982), Teja and Rice (1981) are also effective prediction methods of liquids but they require values of parameters(constants) that are not available for ILs yet. The group-contribution (CSGC) method by Yinghua et al(2002) based on temperature difference is also an informative literature. Group contribution methods for viscosity of ILs usually utilizes some variation of temperature dependence stated by de Guzman, and are known as the Andrade equation.

Although the Arrhenious equation,

$$\mu = \mu_0 \exp\left(\frac{E}{RT}\right) \tag{3}$$

is usually accurate in predicting viscosity of liquids, but it is not the case for Ionic Liquids. Therefore, Ghatee et al. (2010) proposed two extensions of the Arrhenius equation namely the Litovitz equation,

$$\mu = \mu_0 exp\left(\frac{B}{T^3}\right) \tag{4}$$

and the Vogel-Fulcher-Tammann(VFT) equation,

$$\mu = \mu_0 exp\left(\frac{K}{T - T_0}\right), \quad (5)$$

Ghatee et al correlation study was based mainly on the change in viscosity of ILs based on two parameters, namely temperature and surface tension. The correlations have been used to proof that a viscous flow is influenced by the nature of the inter-molecular and inter-ionic interactions and also by the structural packing characteristics of the ILs. Although the Litovitz fits viscosity values of some of the ILs with high accuracy, it does not contain parameters that hold on to certain physical meaning. Besides that, VFT does fit the viscosity of the ILs but only with parameters related to the dynamics of glass-forming processes.

Gardas et al. (2007) demonstrated recently the benefits of the group additivity method. However these methods have disadvantage of high computational works in case of molecular dynamics and a limitation in the application of ions that are absent in their data set in the case of common qualitative structure property relationships. Coutinho et al also proposed a method to find viscosity of certain ILs covering range of 293K and 393K and viscosity values of 4 to 21,000cP. The variables considered were molecular weight and temperature.

A study on viscosity of ILs using the Artificial Neural Network (ANN) modeling has been conducted (Rooney, 2010). In this work, the ability of ANN for modeling and prediction of viscosity prediction on ILs mixture has been investigated. Results showed a good agreement between experimental data and the predicted by ANN. It is recommended that the ANN approach could be applied in ILs fields for reduction in error, computational time and cost of overproduction and underproduction. However, the ANN does not rely upon theoretical relations.

CHAPTER 3

METHODOLOGY

3 METHODOLOGY

3.1 Research Methodology

The methodology for conducting this research project is mainly research and calculation. As this project is mainly a quantitative research, the results obtained from this research can be used to compare with other literature results. Besides, the results obtained from this research can be viewed as a summary of the correlations of present literature review regarding the prediction of viscosities of ILs. The results can hence further enhance the research and understanding of the transport properties of ILs.

The project activities in this research are mainly secondary research through journals and online references. After through research has been done, vast amount of calculations are done to compare the predicted viscosity with the experimental viscosity and find the correlations between the different equations. Then, Percentage deviations for the calculated viscosities for all ILs in the form of Average Absolute Deviation (AAD) are compared among all correlations.

3.1.1 Project Activities

The figure below shows the general procedures that will be implemented in this research project.

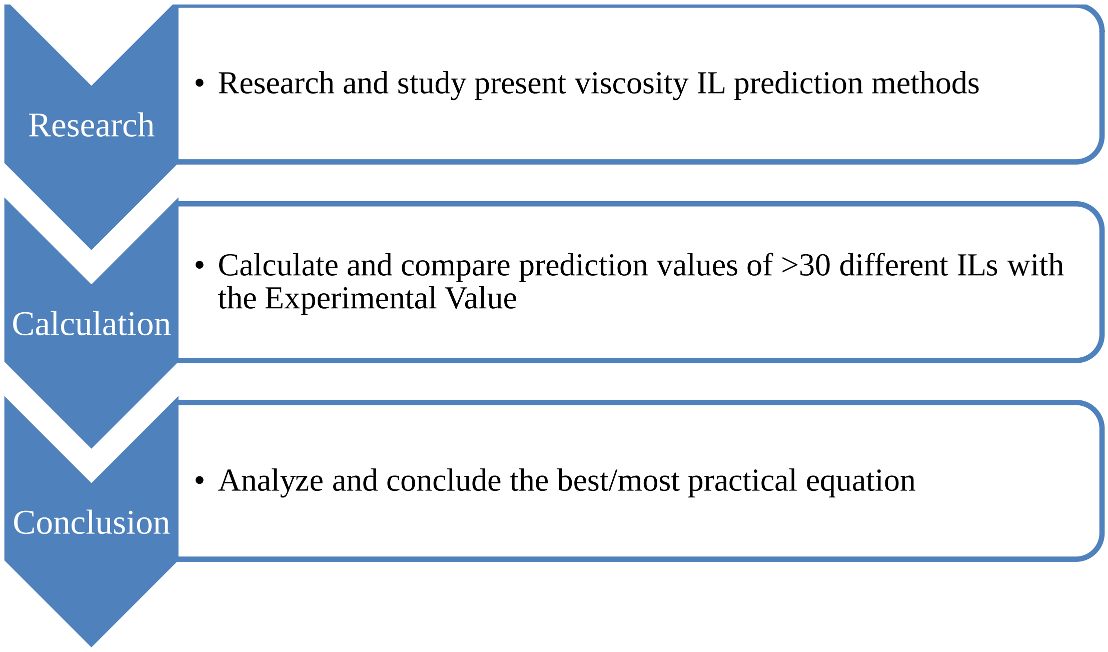


Figure 3.1: General Procedures Implemented In the Research Project

The three main procedures are explained in more detail as below:-

3.1.2 Research

The findings from this research can be summarized as follows:

- ✓ Equations currently used in the market that are specifically designed to predict viscosity of ILs. (usually with A and B constants)
- ✓ Generalized correlations used to estimate pure liquid viscosities (usually with Critical properties as the main parameters)
- ✓ Databases of the selected ILs include:
    - Experimental data of IL viscosity
    - Accentric factors of the studied ILs
    - Critical properties of the studied ILs

3.1.3 Calculation

The calculation part is done in FYP2, based on the data and information that is found from research during FYP1.

The calculation is conducted on 20 different ILs using 5 different equations, namely equation “A,B,C,D, and E”. The viscosity of an IL will be calculated using prediction equations for various data points at different temperature ranges. The calculated viscosity is then compared with the actual experimental viscosity using the %AAD (Average Absolute Deviation) method. This is repeated 30 times (for 30 different ILs) After the %AAD for a specific IL is done, the %AAAD (Average of Average Absolute Deviation) is conducted to determine the average deviation of the particular prediction equation. Finally, the %AAD of each prediction equation is compared to find the most and least effective/accurate prediction equation.

%AAD (Average Absolute Deviation) is calculated using the following formula:

$$\Delta\mu = \frac{100}{n}\sum_{i}^{n}\frac{\left|\mu_i - \mu_i^{exp}\right|}{\mu_i^{exp}}$$

whereas %AAAD (Average of Average Absolute Deviation) is calculated using the following formula:

$$\Delta AAAD\% = \frac{\sum_{i=1}^{N}(\%AAD_i \times n_i)}{N}$$

The planned calculation table is as below:

Table 3.1 Calculation Template for Prediction Methods

Prediction Method (A/B/C/D/E/F/G/H)					
Name of IL	n_i	Temperature Range (K)	Experimental Viscosity (cp)	Calculated Viscosity (cp)	%AAD
IL1					
IL2					
IL3					
IL4					
IL5					
IL6					
IL7					
IL8					
IL9					
IL10					
IL11					
IL12					
IL13					
IL14					
IL15					
IL16					
IL17					
IL18					
IL19					
IL_N					
Overall	N				%AAAD=?

Finally, the results will be compared to find the equation that is the most accurate among the 8 different equations. Analysis of the outcome will also be conducted and explained in detail.

3.2 Key milestones

Several key milestones for this research project must be achieved in order to meet the objective of this project:

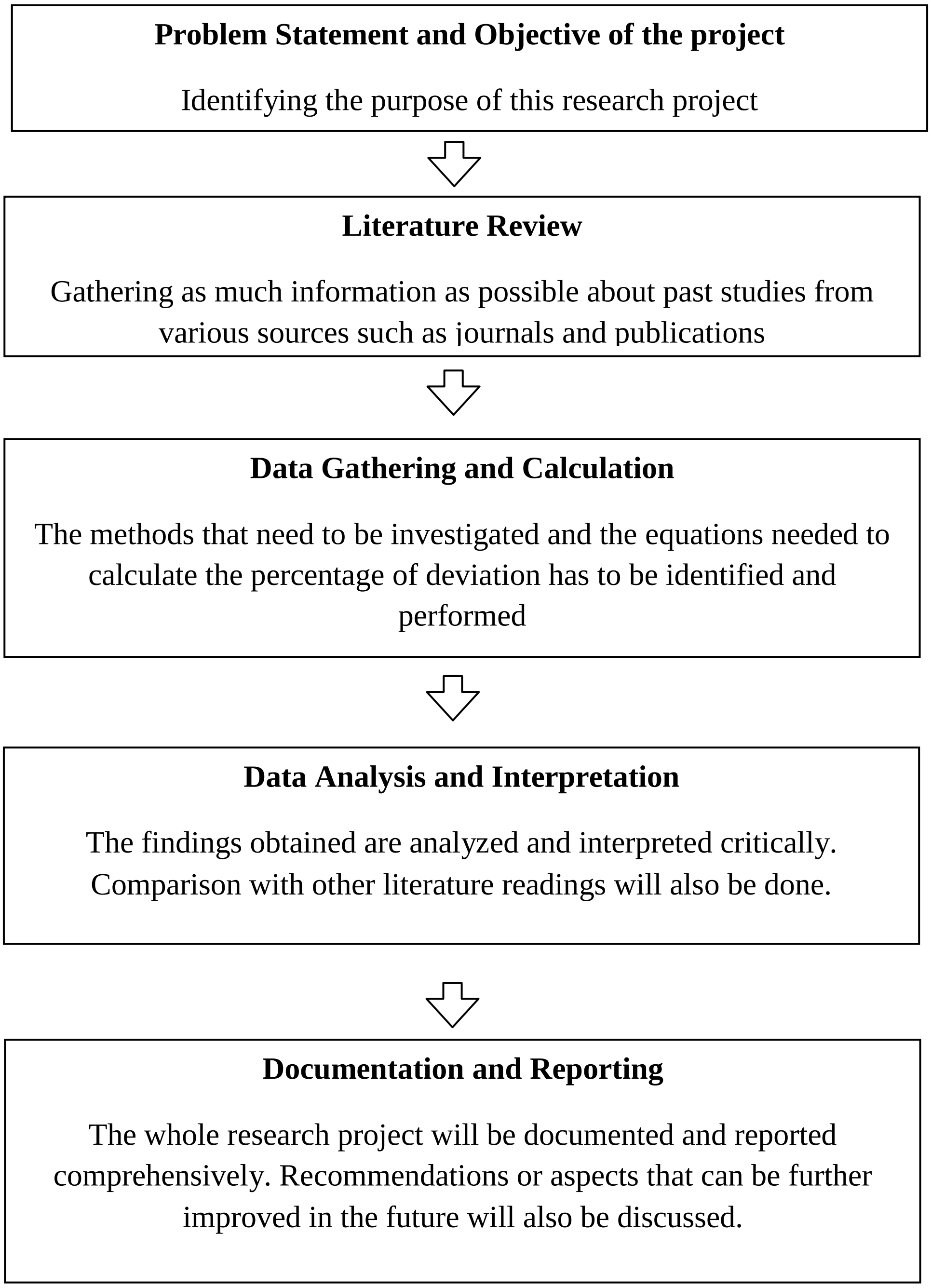


Figure 3.2: Key Milestones

3.3 Gantt Chart & Key Milestones

Table 3.2(a): Gantt Chart & Key Milestones for FYP I

NO	DETAIL / WEEK	1	2	3	4	5	6	7	MID SEM BREAK	8	9	10	11	12	13	14
1	Selection of Project Title															
2	Preliminary Research Work and Literature Review															
3	Submission of Extended Proposal						●									
4	Proposal Defence															
5	Project work continues															
6	Detailed Literature Review															
7	Preparation of Interim Report															
8	Submission of Interim Draft Report														●	
9	Submission of Interim Final Report															●

Suggested milestones ● Process

Table 3.2(b): Gantt Chart & Key Milestones for FYP II

NO	DETAIL / WEEK	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Project Work Continues	■	■	■	■	■	■	■	MID SEM BREAK							
2	Submission of Progress Report							●								
3	Project Work Continues									■	■	■	■	■		
4	Pre-SEDEX											●				
5	Submission of Draft Report												●			
6	Submission of Dissertation (soft bound)													●		
7	Submission of Technical Paper													●		
8	Oral Presentation														●	
9	Submission of Project Dissertation (Hard Bound)															●

Suggested milestones ● Process ■

3.4 Tools

The main tool that is used in this research project is Microsoft Excel 2010 to perform various calculations. Besides, vast journals and publication was obtained from the library bank and also the Information Resource Center (IRC) of University Teknologi Petronas (UTP).

CHAPTER 4

RESULT & DISCUSSION

4 RESULT & DISCUSSION

4.1 Data Gathering

4.1.1 Identified ILs to Be Studied

i. [emim][BF4]
ii. [bmim][BF4]
iii. [bmim][PF6]
iv. [emim][PF6]
v. [dmim][bti]
vi. [dmim][bf4]
vii. [C8mim] [BF4]
viii. [bmim][TFES]
ix. [emim][TFES]
x. [nmim][bti]
xi. [pmim][bti]
xii. [bmim][Cl]
xiii. [C12mim][Cl]
xiv. [dmprim][bti]
xv. [bmpyr][bti]
xvi. [deim][bti]
xvii. [bpy][bti]
xviii. [bdmim][bti]
xix. [emim][ESO4]
xx. [omim][PF6]

4.2 Database of Ionic Liquids

4.2.1 Database of Critical Properties & Acentric Factors of the ILs

The critical properties and acentric factors are unique for every different IL and the viscosity can therefore be predicted using these acentric properties as parameters for the generalized equations that will be discussed later in Section 4.3

The critical properties, the normal boiling temperatures and the acentric factors or ILs have been determined using group contributions based on well-known concepts such as Lydersen(1996) and of Joback and Reid(1987).

The tables below show the data of M, T_b(K) , T_c,(K), P_c(bar), V_c($cm^{3/}$mol), Z_c, and ω of the ILs.

The viscosity data for ILs with respect to temperature can be found in the table below. Most of the data were taken from ILThermo, the IUPAC Ionic Liquids Database. More detailed data can be found in the APPENDIX section.

Table 4.1(a): Critical Properties of ILs *Source: Ind. Eng. Chem. Res., Vol 48, No.14,2009*

Table 3. Critical Properties of Ionic Liquids Calculated by Group Contribution Using the Method Summarized in Table 1 and the Group Contributions Listed in Table 2 of this Article

No.	ionic liquid	global formula	IUPAC name	M	T_b (K)	T_c (K)	P_c (bar)	V_c (cm^3/mol)	Z_c	ω
IL-1	[P11] [tsac]	C9H14N2F6SO3	1,1-dimethylpyrrolidinium [2,2,2-rifluoro-n-(trifluoromethyl)sulfonyl]acetamide	344.3	638.9	889.7	23.6	836.5	0.2670	0.4956
IL-2	[emim] [tsac]	C9H11N3F6SO3	1-ethyl-3-methylimidazolium [2,2,2-rifluoro-n-(trifluoromethyl)sulfonyl]acetamide	355.3	764.4	1069.9	25.2	833.5	0.2359	0.4981
IL-3	[TEA] [tsac]	C11H20N2F6SO3	tetraethylammonium [2,2,2-trifluoro-n-(trifluoromethyl)sulfonyl]acetamide	374.3	686.1	913.2	19.1	970.2	0.2443	0.6596
IL-4	[TMAlA] [tsac]	C9H14N2F6SO3	trimethylalylammonium [2,2,2-trifluoro-n-(trifluoromethyl)sulfonyl]acetamide	344.3	637.0	875.2	22.5	842.3	0.2609	0.5479
IL-5	[TMEA] [tsac]	C8H14N2F6SO3	trimethylethylammonium [2,2,2-trifluoro-n-(trifluoromethyl)sulfonyl]acetamide	332.3	617.4	854.1	23.3	798.8	0.2622	0.5261
IL-6	[TMiPA] [tsac]	C9H16N2F6SO3	trimethylisopropylammonium [2,2,2-trifluoro-n-(trifluoromethyl)sulfonyl]acetamide	346.3	639.9	876.1	21.9	854.2	0.2569	0.5540
IL-7	[TMPA] [tsac]	C9H16N2F6SO3	trimethylpropylammonium [2,2,2-trifluoro-n-(trifluoromethyl)sulfonyl]acetamide	346.3	640.3	873.7	21.7	855.9	0.2560	0.5705
IL-8	[bmim] [TFES]	C10H16N2F4SO3	1-butyl-3-methylimidazolium 1,1,2,2-tetrafluoroethanosulfonate	320.3	729.4	1030.5	25.7	827.8	0.2480	0.4583
IL-9	[C12mim] [TFES]	C18H32N2F4SO3	1-dodecyl-3-methylimidazolium 1,1,2,2-tetrafluoroethanosulfonate	432.5	912.5	1171.0	15.6	1284.7	0.2059	0.8065
IL-10	[emim] [TFES]	C8H12N2F4SO3	1-ethyl-3-methylimidazolium 1,1,2,2-tetrafluoroethanosulfonate	292.3	683.7	998.2	30.4	713.6	0.2615	0.3743
IL-11	[hpmim] [TFES]	C13H22N2F4SO3	1-hepthyl-3-methylimidazolium 1,1,2,2-tetrafluoroethanosulfonate	362.4	798.1	1080.8	20.7	999.2	0.2304	0.5903
IL-12	[bmim] [HFPS]	C11H16N2F6SO3	1-butyl-3-methylimidazolium 1,1,2,3,3,3-hexafluoropropanesulfonate	370.3	747.6	1032.1	21.3	912.6	0.2266	0.4933
IL-13	[4,4,4,14-P] [HFPS]	C29H57PF6SO3	tributyl(tetradecyl)phosphonium 1,1,2,3,3,3-hexafluoropropanesulfonate	630.8	1058.5	1281.0	8.8	2003.3	0.1662	0.9322
IL-14	[bmim] [TPES]	C12H16N2F8SO4	1-butyl-3-methylimidazolium 1,1,2-trifluoro-2-(perfluoroethoxy)ethanesulfonate	436.3	788.2	1061.3	17.9	1012.9	0.2056	0.5488
IL-15	[6,6,6,14-P] [TPES]	C36H69PF8SO4	tetradecyl(trihexyl)phosphonium 1,1,2-trifluoro-2-(perfluoroethoxy)ethanesulfonate	781.0	1236.4	1520.6	7.1	2446.3	0.1367	0.5812
IL-16	[bmim] [TTES]	C11H16N2F6SO4	1-butyl-3-methylimidazolium 1,1,2-trifluoro-2-(trifluoromethoxy)ethanesulfonate	386.3	770.0	1058.3	20.9	928.2	0.2205	0.5085
IL-17	[bmim] [FS]	C12H16N2F8SO4	1-butyl-3-methylimidazolium 2-(1,2,2,2-tetrafluoroethoxy)-1,1,2,2-tetrafluoroethanesulfonate	436.3	788.2	1061.3	17.9	1012.9	0.2056	0.5488
IL-18	[TMG] [Ac]	C7H17N3O2	1,1,3,3-tetramethylguanidine acetate	175.2	518.1	703.7	28.0	563.0	0.2698	0.7326
IL-19	[bmim] [Ac]	C10H18N2O2	1-butyl-3-methylimidazolium acetate	198.3	624.6	847.3	24.5	658.2	0.2285	0.6681
IL-20	[emim] [Ac]	C8H14N2O2	1-ethyl-3-methylimidazolium acetate	170.2	578.8	807.1	29.2	544.0	0.2367	0.5889
IL-21	[emim] [BEI]	C10H11N3F10S2O4	1-ethyl-3-methylimidazolium bis(pentafluoroethylsulfonyl)imide	491.3	853.1	1231.4	21.9	1045.4	0.2238	0.2895
IL-22	[bmim] [BEI]	C12H15N3F10S2O4	1-butyl-3-methylimidazolium bis(pentafluoroethylsulfonyl)imide	519.4	898.8	1257.1	19.5	1159.6	0.2158	0.3812
IL-23	[4MOPY] [BEI]	C18H24N2F10S2O4	4-methyl-n-octylpyridinium bis(pentafluoroethylsulfonyl)imide	586.5	979.9	1291.4	15.0	1436.7	0.2013	0.5858
IL-24	[NH221] [BEI]	C9H14N2F10S2O4	diethylmethyl(quaternary)ammonium bis(pentafluoroethylsulfonyl)imide	468.3	743.8	1056.3	21.5	1053.3	0.2577	0.3534
IL-25	[NH11(i-3)] [BEI]	C9H14N2F10S2O4	dimethylisopropyl(quaternary)ammonium bis(pentafluoroethylsulfonyl)imide	468.3	743.4	1060.0	21.6	1051.6	0.2581	0.3375
IL-26	[C27guan] [bti]	C29H58N4F6S2O4	[bis(bishexylamine)methylene]dimethylammonium bis[(trifluoromethyl)sulfonyl]imide	704.9	1262.0	1529.0	9.8	2167.1	0.1676	1.0120
IL-27	[dmprim] [bti]	C10H15N3F6S2O4	1,2-dimethyl-3-propylimidazolium bis[(trifluoromethyl)sulfonyl]imide	419.4	867.4	1269.7	27.5	988.6	0.2572	0.3226
IL-28	[dbim] [bti]	C13H21N3F6S2O4	1,3-dibutylimidazolium bis[(trifluoromethyl)sulfonyl]imide	461.5	931.1	1305.0	22.3	1161.5	0.2392	0.4349
IL-29	[E1,3M4I] [bti]	C10H15N3F6S2O4	1,3-diethyl-4-methylimidazolium bis[(trifluoromethyl)sulfonyl]imide	419.4	867.4	1269.7	27.5	988.6	0.2572	0.3226
IL-30	[dmim] [bti]	C7H9N3F6S2O4	1,3-dimethylimidazolium bis[(trifluoromethyl)sulfonyl]imide	377.3	793.8	1239.9	35.8	818.8	0.2845	0.1752
IL-31	[MP4] [bti]	C11H19N2F6S2O4	1-butyl-2-methylpyrrolidinium bis[(trifluoromethyl)sulfonyl]imide	421.4	758.7	1110.0	25.4	1038.9	0.2862	0.2933
IL-32	[bmpy] [bti]	C12H16N2F6S2O4	1-butyl-3-methylpyridinium bis[(trifluoromethyl)sulfonyl]imide	430.4	852.0	1240.5	25.5	1038.8	0.2571	0.3160
IL-33	[C10mim] [bti]	C16H27N3F6S2O4	1-decyl-3-methylimidazolium bis[(trifluoromethyl)sulfonyl]imide	503.5	999.7	1345.1	18.7	1332.8	0.2225	0.5741
IL-34	[N-epy] [bti]	C9H10N2F6S2O4	1-ethylpyridinium bis[(trifluoromethyl)sulfonyl]imide	388.3	778.4	1207.9	32.7	869.0	0.2834	0.1671
IL-35	[hpmim] [bti]	C13H21N3F6S2O4	1-heptyl-3-methylimidazolium bis[(trifluoromethyl)sulfonyl]imide	461.5	931.1	1305.0	22.3	1161.5	0.2392	0.4349
IL-36	[nmim] [bti]	C15H25N3F6S2O4	1-nonyl-3-methylimidazolium bis[(trifluoromethyl)sulfonyl]imide	489.5	976.8	1331.2	19.8	1275.7	0.2277	0.5276
IL-37	[pmim] [bti]	C11H17N3F6S2O4	1-pentyl-3-methylimidazolium bis[(trifluoromethyl)sulfonyl]imide	433.4	885.3	1281.1	25.6	1047.2	0.2521	0.3444
IL-38	[MP3] [bti]	C10H17N2F6S2O4	1-propyl-2-methylpyrrolidinium bis([trifluoromethyl)sulfonyl]imide	407.4	735.8	1096.2	27.4	981.8	0.2953	0.2498
IL-39	[prmim] [bti]	C9H13N3F6S2O4	1-propyl-3-methylimidazolium bis[(trifluoromethyl)sulfonyl]imide	405.3	839.6	1259.3	30.0	933.0	0.2670	0.2575

Table 4.1(b): Critical Properties of ILs (cont.) *Source: Ind. Eng. Chem. Res., Vol 48, No.14,2009*

Table 3. Continued

No.	ionic liquid	global formula	IUPAC name	M	T_b (K)	T_c (K)	P_c (bar)	V_c (cm^3/mol)	Z_c	ω
IL-40	[prmpy] [bti]	C11H14N2F6S2O4	3-methyl-1-propylpyridinium bis[(trifluoromethyl)sulfonyl]imide	416.4	829.1	1228.9	27.5	981.7	0.2645	0.2723
IL-41	[N723'3'] [bti]	C17H34N2F6S2O4	di(iso)propylethylheptylammonium bis[(trifluoromethyl)sulfonyl]imide	508.6	897.6	1176.6	16.1	1408.9	0.2324	0.6653
IL-42	[dmeim] [bti]	C9H13N3F6S2O4	1,2-dimethyl-3-ethylimidazolium bis[(trifluoromethyl)sulfonyl]imide	405.3	844.5	1258.9	29.8	931.5	0.2648	0.2794
IL-43	[BNM2E] [bti]	C10H20N2F6S2O4	dimethylethylbutylammonium bis[(trifluoromethyl)sulfonyl]imide	410.4	738.3	1054.3	24.1	1012.6	0.2779	0.3777
IL-44	[N1123] [bti]	C9H18N2F6S2O4	dimethylethylpropylammonium bis[(trifluoromethyl)sulfonyl]imide	396.4	715.4	1038.7	25.9	955.5	0.2863	0.3334
IL-45	[N1134] [bti]	C11H22N2F6S2O4	dimethylpropylbutylammonium bis[(trifluoromethyl)sulfonyl]imide	424.4	761.2	1070.1	22.5	1069.7	0.2701	0.4228
IL-46	[eomim] [bti]	C9H13N3F6S2O5	ethoxymethyl-3-methylimidazolium bis[(trifluoromethyl)sulfonyl]imide	421.3	862.0	1285.2	29.1	948.6	0.2579	0.2695
IL-47	[prmpyr] [bti]	C10H18N2F6S2O4	n-methyl-n-propylpyrrolidinium bis[(trifluoromethyl)sulfonyl]imide	408.4	736.9	1078.5	26.1	993.2	0.2889	0.3025
IL-48	[tda] [bti]	C42H84N2F6S2O4	tetradecylammonium bis[(trifluoromethyl)sulfonyl]imide	859.3	1470.5	1831.8	7.0	2840.1	0.1310	0.4734
IL-49	[thpa] [bti]	C30H60N2F6S2O4	tetraheptylammonium bis[(trifluoromethyl)sulfonyl]imide	690.9	1195.9	1449.6	9.7	2154.8	0.1726	0.9913
IL-50	[tha] [bti]	C26H52N2F6S2O4	tetrahexylammonium bis[(trifluoromethyl)sulfonyl]imide	634.8	1104.4	1353.0	11.0	1926.4	0.1885	0.9857
IL-51	[tpa] [bti]	C22H44N2F6S2O4	tetramylammonium bis[(trifluoromethyl)sulfonyl]imide	578.7	1012.9	1267.0	12.8	1697.9	0.2060	0.8923
IL-52	[toa] [bti]	C34H68N2F6S2O4	tetraoctylammonium bis[(trifluoromethyl)sulfonyl]imide	747.1	1287.4	1559.2	8.6	2383.2	0.1579	0.8960
IL-53	[S444] [bti]	C14H27NF6S3O4	tributylsulfonium bis[(trifluoromethyl)sulfonyl]imide	483.6	934.9	1269.2	15.6	1389.3	0.2052	0.4263
IL-54	[N7444] [bti]	C21H42N2F6S2O4	tributylheptylammonium bis[(trifluoromethyl)sulfonyl]imide	564.7	990.0	1247.0	13.3	1640.8	0.2108	0.8585
IL-55	[N6444] [bti]	C20H40N2F6S2O4	tributylhexylammonium bis[(trifluoromethyl)sulfonyl]imide	550.7	967.1	1227.4	13.9	1583.7	0.2156	0.8216
IL-56	[N1444] [bti]	C15H30N2F6S2O4	tributylmethylammonium bis[(trifluoromethyl)sulfonyl]imide	480.5	852.7	1136.3	17.7	1298.1	0.2430	0.6068
IL-57	[N8444] [bti]	C22H44N2F6S2O4	tributyloctylammonium bis[(trifluoromethyl)sulfonyl]imide	578.7	1012.9	1267.0	12.8	1697.9	0.2060	0.8923
IL-58	[N7222] [bti]	C15H30N2F6S2O4	triethylheptylammonium bis[(trifluoromethyl)sulfonyl]imide	480.5	852.7	1136.3	17.7	1298.1	0.2430	0.6068
IL-59	[N6222] [bti]	C14H28N2F6S2O4	triethylhexylammonium bis[(trifluoromethyl)sulfonyl]imide	466.5	829.8	1119.2	18.7	1241.0	0.2492	0.5608
IL-60	[N8222] [bti]	C16H32N2F6S2O4	triethyloctylammonium bis[(trifluoromethyl)sulfonyl]imide	494.6	875.6	1153.7	16.8	1355.3	0.2371	0.6523
IL-61	[S222] [bti]	C8H15NF6S3O4	triethylsulfonium bis[(trifluoromethyl)sulfonyl]imide	399.4	797.6	1189.9	21.9	1046.6	0.2317	0.1603
IL-62	[N1114] [bti]	C9H18N2F6S2O4	trimethylbutylammonium bis[(trifluoromethyl)sulfonyl]imide	396.4	715.4	1038.7	25.9	955.5	0.2863	0.3334
IL-63	[N7111] [bti]	C12H24N2F6S2O4	trimethylheptylammonium bis[(trifluoromethyl)sulfonyl]imide	438.5	784.1	1086.1	21.1	1126.8	0.2627	0.4685
IL-64	[N6111] [bti]	C11H22N2F6S2O4	trimethylhexylammonium bis[(trifluoromethyl)sulfonyl]imide	424.4	761.2	1070.1	22.5	1069.7	0.2701	0.4228
IL-65	[N111C2O] [bti]	C7H14N2F6S2O5	trimethylmethoxymethylammonium bis[(trifluoromethyl)sulfonyl]imide	384.3	692.1	1035.7	29.5	856.9	0.2933	0.2599
IL-66	[N8111] [bti]	C13H26N2F6S2O4	trimethyloctylammonium bis[(trifluoromethyl)sulfonyl]imide	452.5	807.0	1102.5	19.8	1183.9	0.2558	0.5146
IL-67	[tmpa] [bti]	C8H16N2F6S2O4	trimethylpropylammonium bis[(trifluoromethyl)sulfonyl]imide	382.4	692.6	1023.4	28.0	898.4	0.2953	0.2900
IL-68	[S111] [bti]	C5H9NF6S3O4	trimethylsulfonium bis[(trifluoromethyl)sulfonyl]imide	357.3	729.0	1156.5	27.3	875.3	0.2481	0.0384
IL-69	[Ph(CH2)mim] [bti]	C13H13N3F6S2O4	1-(1-phenylalkyl)-3-methylimidazolium bis[(trifluoromethyl)sulfonyl]imide	453.4	957.8	1405.9	27.0	1053.1	0.2429	0.3037
IL-70	[Ph(CH2)2mim] [bti]	C14H15N3F6S2O4	1-(2-phenylalkyl)-3-methylimidazolium bis[(trifluoromethyl)sulfonyl]imide	467.4	980.6	1414.8	25.1	1110.2	0.2367	0.3484
IL-71	[Ph(CH2)3mim] [bti]	C15H17N3F6S2O4	1-(3-phenylalkyl)-3-methylimidazolium bis[(trifluoromethyl)sulfonyl]imide	481.4	1003.5	1424.5	23.4	1167.4	0.2309	0.3939
IL-72	[bdmim] [bti]	C11H17N3F6S2O4	1-butyl-2,3-dimethylimidazolium bis[(trifluoromethyl)sulfonyl]imide	433.4	890.3	1281.1	25.5	1045.7	0.2502	0.3669
IL-73	[mbpy] [bti]	C12H16N2F6S2O4	1-butyl-4-methylpyridinium bis[(trifluoromethyl)sulfonyl]imide	430.4	852.0	1240.5	25.5	1038.8	0.2571	0.3160
IL-74	[bmpyr] [bti]	C11H20N2F6S2O4	1-butyl-1-methylpyrrolidinium bis[(trifluoromethyl)sulfonyl]imide	422.4	759.8	1093.1	24.3	1050.3	0.2802	0.3467
IL-75	[bpy] [bti]	C11H14N2F6S2O4	1-butylpyridinium bis[(trifluoromethyl)sulfonyl]imide	416.4	824.2	1229.1	27.7	983.3	0.2666	0.2505
IL-76	[C12mim] [bti]	C18H31N3F6S2O4	1-dodecyl-3-methylimidazolium bis[(trifluoromethyl)sulfonyl]imide	531.6	1045.5	1374.6	16.8	1447.0	0.2126	0.6662
IL-77	[memim] [bti]	C9H13N3F6S2O4	1-methyl-3-ethyl-4-methylimidazolium bis[(trifluoromethyl)sulfonyl]imide	405.3	844.5	1258.9	29.8	931.5	0.2648	0.2794
IL-78	[C2F3mim] [bti]	C8H8N3F9S2O4	1-trifluoroethyl-3-methylimidazolium bis[(trifluoromethyl)sulfonyl]imide	445.3	811.3	1210.5	26.7	925.3	0.2452	0.2338
IL-79	[4MOPY] [bti]	C16H24N2F6S2O4	4-methyl-n-octylpyridinium bis[(trifluoromethyl)sulfonyl]imide	486.5	943.5	1292.0	19.7	1267.2	0.2322	0.4983
IL-80	[C23guan] [bti]	C25H50N4F6S2O4	[bis(bispentylamine)methylene]dimethylammonium bis[(trifluoromethyl)sulfonyl]imide	648.8	1170.5	1432.1	11.2	1938.7	0.1828	1.0159
IL-81	[S224] [bti]	C10H19NF6S3O4	diethylbutylsulfonium bis[(trifluoromethyl)sulfonyl]imide	427.5	843.4	1214.5	19.3	1160.9	0.2221	0.2465
IL-82	[NH221] [bti]	C7H14N2F6S2O4	diethylmethyl(quaternary)ammonium bis[(trifluoromethyl)sulfonyl]imide	368.3	707.4	1061.1	31.9	883.8	0.3199	0.2805
IL-83	[S221] [bti]	C7H13NF6S3O4	diethylmethylsulfonium bis[(trifluoromethyl)sulfonyl]imide	385.4	774.8	1178.3	23.4	989.5	0.2368	0.1186
IL-84	[S225] [bti]	C11H21NF6S3O4	diethylpentylsulfonium bis[(trifluoromethyl)sulfonyl]imide	441.5	866.3	1227.5	18.2	1218.0	0.2177	0.2908
IL-85	[S223] [bti]	C9H17NF6S3O4	diethylpropylsulfonium bis[(trifluoromethyl)sulfonyl]imide	413.4	820.5	1202.0	20.5	1103.8	0.2268	0.2030
IL-86	[NH114] [bti]	C8H16N2F6S2O4	diethylbutyl(quaternary)ammonium bis[(trifluoromethyl)sulfonyl]imide	382.4	730.3	1075.3	29.3	940.9	0.3083	0.3229

Table 4.1(c): Critical Properties of ILs (cont.) *Source: Ind. Eng. Chem. Res., Vol 48, No.14,2009*

Table 3. Continued

No.	ionic liquid	global formula	IUPAC name	M	T_b (K)	T_c (K)	P_c (bar)	V_c (cm³/mol)	Z_c	ω
IL-87	[S114] [bti]	C8H15NF6S3O4	dimethylbutylsulfonium bis[(trifluoromethyl)sulfonyl]imide	399.4	797.6	1189.9	21.9	1046.6	0.2317	0.1603
IL-88	[S112] [bti]	C6H11NF6S3O4	dimethylethylsulfonium bis[(trifluoromethyl)sulfonyl]imide	371.3	751.9	1167.2	25.2	932.4	0.2423	0.0779
IL-89	[NH11(i-3)] [bti]	C7H14N2F6S2O4	dimethylisopropyl(quaternary)ammonium bis[(trifluoromethyl)sulfonyl]imide	368.3	707.0	1065.7	32.2	882.1	0.3209	0.2648
IL-90	[S115] [bti]	C9H17NF6S3O4	dimethylpentylsulfonium bis[(trifluoromethyl)sulfonyl]imide	413.4	820.5	1202.0	20.5	1103.8	0.2268	0.2030
IL-91	[S113] [bti]	C7H13NF6S3O4	dimethylpropylsulfonium bis[(trifluoromethyl)sulfonyl]imide	385.4	774.8	1178.3	23.4	989.5	0.2368	0.1186
IL-92	[S124] [bti]	C9H17NF6S3O4	methylethylbutylsulfonium bis[(trifluoromethyl)sulfonyl]imide	413.4	820.5	1202.0	20.5	1103.8	0.2268	0.2030
IL-93	[S125] [bti]	C10H19NF6S3O4	methylethylpentylsulfonium bis[(trifluoromethyl)sulfonyl]imide	427.5	843.4	1214.5	19.3	1160.9	0.2221	0.2465
IL-94	[S123] [bti]	C8H15NF6S3O4	methylethylpropylsulfonium bis[(trifluoromethyl)sulfonyl]imide	399.4	797.6	1189.9	21.9	1046.6	0.2317	0.1603
IL-95	[DEME] [bti]	C10H20N2F6S2O5	N,N-diethyl-N-methyl-N-(2-methoxyethyl)ammonium bis[(trifluoromethyl)sulfonyl]imide	426.4	760.7	1080.7	23.5	1028.2	0.2688	0.3915
IL-96	[BMP] [bti]	C12H22N2F6S2O4	N-butyl-N-methylpiperidinium bis[(trifluoromethyl)sulfonyl]imide	436.4	782.7	1108.0	22.6	1107.4	0.2722	0.3917
IL-97	[N222(2O1)] [bti]	C11H22N2F6S2O5	triethyl(2-methoxyethyl)ammonium bis[(trifluoromethyl)sulfonyl]imide	440.4	783.6	1096.3	22.0	1085.3	0.2617	0.4370
IL-98	[P222(2O1)] [bti]	C11H22PNF6S2O5	triethyl(2-methoxyethyl)phosphonium bis[(trifluoromethyl)sulfonyl]imide	457.4	806.7	1134.6	21.4	1125.6	0.2553	0.3980
IL-99	[N222(1O1)] [bti]	C10H20N2F6S2O5	triethyl(2-methoxymethyl)ammonium bis[(trifluoromethyl)sulfonyl]imide	426.4	760.7	1080.7	23.5	1028.2	0.2688	0.3915
IL-100	[P222(1O1)] [bti]	C10H20PNF6S2O5	triethyl(2-methoxymethyl)phosphonium bis[(trifluoromethyl)sulfonyl]imide	443.4	783.9	1119.8	22.8	1068.5	0.2619	0.3525
IL-101	[NH222] [bti]	C8H16N2F6S2O4	triethyl(quaternary)ammonium bis[(trifluoromethyl)sulfonyl]imide	382.4	730.3	1075.3	29.3	940.9	0.3083	0.3229
IL-102	[N222(12)] [bti]	C20H40N2F6S2O4	triethyldodecylammonium bis[(trifluoromethyl)sulfonyl]imide	550.7	967.1	1227.4	13.9	1583.7	0.2156	0.8216
IL-103	[P222(12)] [bti]	C20H40PNF6S2O4	triethyldodecylphosphonium bis[(trifluoromethyl)sulfonyl]imide	567.6	990.2	1260.3	13.7	1624.0	0.2120	0.7861
IL-104	[P2228] [bti]	C16H32PNF6S2O4	triethyloctylphosphonium bis[(trifluoromethyl)sulfonyl]imide	511.5	898.7	1188.7	16.4	1395.6	0.2323	0.6140
IL-105	[N2225] [bti]	C13H26N2F6S2O4	triethylpentylammonium bis[(trifluoromethyl)sulfonyl]imide	452.5	807.0	1102.5	19.8	1183.9	0.2558	0.5146
IL-106	[P2225] [bti]	C13H26PNF6S2O4	triethylpentylphosphonium bis[(trifluoromethyl)sulfonyl]imide	469.5	830.1	1139.5	19.3	1224.2	0.2499	0.4757
IL-107	[bmim] [Br]	C8H15N2Br	1-butyl-3-methylimidazolium bromide	219.1	586.8	834.9	29.8	583.3	0.2506	0.4891
IL-108	[C35guan] [Cl]	C35H74N3Cl	[bis(bisoctylamine)methylene]dimethylammonium chloride	572.5	1140.7	1411.1	7.4	2202.6	0.1385	0.5680
IL-109	[bmim] [Cl]	C8H15N2Cl	1-butyl-3-methylimidazolium chloride	174.7	558.0	789.0	27.8	568.8	0.2415	0.4914
IL-110	[hmim] [Cl]	C10H19N2Cl	1-hexyl-3-methylimidazolium chloride	202.7	603.8	829.2	23.5	683.0	0.2328	0.5725
IL-111	[omim] [Cl]	C12H23N2Cl	1-octyl-3-methylimidazolium chloride	230.8	649.6	869.4	20.3	797.2	0.2240	0.6566
IL-112	[Bemim] [Cl]	C11H13N2Cl	1-benzyl-3-methylimidazolium chloride	208.7	653.4	921.3	28.4	631.8	0.2343	0.5145
IL-113	[C12mim] [Cl]	C16H31N2Cl	1-dodecyl-3-methylimidazolium chloride	286.9	741.1	951.5	16.0	1025.6	0.2072	0.8212
IL-114	[emim] [Cl]	C6H11N2Cl	1-ethyl-3-methylimidazolium chloride	146.6	512.3	748.6	34.2	454.5	0.2495	0.4165
IL-115	[mmim] [Cl]	C5H9N2Cl	1-methyl-3-methylimidazolium chloride	132.6	489.4	728.2	38.5	397.4	0.2530	0.3825
IL-116	[mim] [Cl]	C4H7N2Cl	1-methylimidazolium chloride	118.6	450.5	677.8	48.1	333.1	0.2841	0.4158
IL-117	[ClBenmim] [Cl]	C11H12N2Cl2	1-p-chlorobenzyl-3-methylimidazolium chloride	243.1	695.8	969.6	26.8	682.6	0.2272	0.5521
IL-118	[FBenmim] [Cl]	C11H12N2FCl	1-p-fluorobenzyl-3-methylimidazolium chloride	226.7	657.6	913.1	26.4	652.0	0.2271	0.5660
IL-119	[C23guan] [Cl]	C23H50N3Cl	[bis(bispentylamine)methylene]dimethylammonium chloride	404.1	866.1	1052.1	10.5	1517.3	0.1817	1.0428
IL-120	[dbim] [Cl]	C11H21N2Cl	1,3-dibutylimidazolium chloride	216.8	626.7	849.2	21.8	740.1	0.2284	0.6144
IL-121	[bmim] [dca]	C10H15N5	1-butyl-3-methylimidazolium dicyanamide	205.3	783.0	1035.8	24.4	712.0	0.2017	0.8419
IL-122	[emim] [dca]	C8H11N5	1-ethyl-3-methylimidazolium dicyanamide	177.2	737.2	999.0	29.1	597.8	0.2095	0.7661
IL-123	[omim] [dca]	C14H23N5	1-octyl-3-methylimidazolium dicyanamide	261.4	874.5	1113.1	18.4	940.5	0.1872	0.9908
IL-124	[4MOPY] [dca]	C16H24N4	4-methyl-n-octylpyridinium dicyanamide	272.4	864.1	1094.3	17.2	989.1	0.1872	0.9923
IL-125	[mbpyr] [dca]	C11H20N4	n-methyl-n-butylpyrrolidinium dicyanamide	208.3	680.3	887.2	20.6	772.2	0.2157	0.8555
IL-126	[mhpyr] [dca]	C13H24N4	n-methyl-n-hexylpyrrolidinium dicyanamide	236.4	726.1	929.3	18.1	886.4	0.2078	0.9314
IL-127	[mprpyr] [dca]	C10H18N4	n-methyl-n-propylpyrrolidinium dicyanamide	194.3	657.4	866.5	22.1	715.1	0.2197	0.8161
IL-128	[emim] [DEGlyMSO4]	C11H22N2SO6	1-ethyl-3-methylimidazolium diethyleneglycol monomethylethersulfate	310.4	826.2	1162.9	28.1	862.3	0.2502	0.5176
IL-129	[dmim] [DMPO4]	C7H15N2PO4	1,3-dimethylimidazolium dimethylphosphate	222.2	590.0	816.8	27.2	626.8	0.2509	0.5973
IL-130	[py] [EOESO4]	C9H15NSO5	pyridinium ethoxyethylsulfate	249.3	691.4	1025.9	41.3	644.3	0.3116	0.4224
IL-131	[edmim] [ESO4]	C9H18N2SO4	1-ethyl-2,3-dimethylimidazolium ethylsulfate	250.3	740.5	1082.6	35.8	715.3	0.2842	0.4341
IL-132	[emim] [ESO4]	C8H16N2SO4	1-ethyl-3-methylimidazolium ethylsulfate	236.3	712.7	1067.5	40.5	659.8	0.3008	0.3744
IL-133	[omim] [PF6]	C12H23N2PF6	1-octyl-3-methylimidazolium hexafluorophosphate	340.3	646.1	810.8	14.0	990.9	0.2065	0.9385
IL-134	[bdmim] [PF6]	C9H17N2PF6	1-butyl-2,3-dimethylimidazolium hexafluorophosphate	298.2	582.4	746.3	16.2	818.0	0.2141	0.8526
IL-135	[hpmim] [PF6]	C11H21N2PF6	1-heptyl-3-methylimidazolium hexafluorophosphate	326.3	623.2	787.8	14.7	933.8	0.2101	0.9055

Table 4.1(d): Critical Properties of ILs (cont.) *Source: Ind. Eng. Chem. Res., Vol 48, No.14,20*

Table 3. Continued

No.	ionic liquid	global formula	IUPAC name	M	T_b (K)	T_c (K)	P_c (bar)	V_c (cm³/mol)	Z_c	ω
IL-136	[nmim] [PF6]	C13H25N2PF6	1-nonyl-3-methylimidazolium hexafluorophosphate	354.3	669.0	834.1	13.4	1048.1	0.2028	0.9680
IL-137	[oprim] [PF6]	C14H27N2PF6	1-octyl-3-propylimidazolium hexafluorophosphate	368.3	691.9	857.6	12.8	1105.2	0.1991	0.9937
IL-138	[pmim] [PF6]	C9H17N2PF6	1-pentyl-3-methylimidazolium hexafluorophosphate	298.2	577.5	742.1	16.3	819.6	0.2171	0.8316
IL-139	[eommim] [PF6]	C7H13N2OPF6	ethoxymethyl-3-methylimidazolium hexafluorophosphate	286.2	554.1	723.7	18.2	721.0	0.2177	0.7697
IL-140	[mommim] [PF6]	C6H11N2OPF6	methyloxymethyl-3-methylimidazolium hexafluorophosphate	272.1	531.2	701.2	19.3	663.9	0.2201	0.7277
IL-141	[N-bupy] [PF6]	C9H14NPF6	n-butylpyridinium hexafluorophosphate	281.2	516.3	674.4	17.3	755.6	0.2325	0.7381
IL-142	[Ph(CH2)3mim] [PF6]	C13H17N2PF6	1-(3-phenylalkyl)-3-methylimidazolium hexafluorophosphate	346.3	695.7	885.1	15.7	939.7	0.2007	0.8894
IL-143	[prmim] [PF6]	C7H13N2PF6	1-propyl-3-methylimidazolium hexafluorophosphate	270.2	531.7	696.7	18.3	705.4	0.2232	0.7504
IL-144	[C2C6I] [PF6]	C11H21N2PF6	1-hexyl-3-ethylimidazolium hexafluorophosphate	326.3	623.2	787.8	14.7	933.8	0.2101	0.9055
IL-145	[C2C8I] [PF6]	C13H25N2PF6	1-octyl-3-methylimidazolium hexafluorophosphate	354.3	669.0	834.1	13.4	1048.1	0.2028	0.9680
IL-146	[bmim] [HSO4]	C8H16N2SO4	1-butyl-3-methylimidazolium hydrogensulfate	236.3	782.4	1103.8	43.4	664.9	0.3142	0.7034
IL-147	[emim] [HSO4]	C6H13N2SO4	1-ethyl-3-methylimidazolium hydrogensulfate	208.2	736.7	1073.8	57.6	550.7	0.3553	0.6411
IL-148	[mim] [HSO4]	C4H8N2SO4	1-methylimidazolium hydrogensulfate	180.2	674.9	1012.7	91.9	429.2	0.4684	0.6707
IL-149	[bmim] [I]	C8H15N2I	1-butyl-3-methylimidazolium iodide	266.1	613.7	871.2	28.6	607.5	0.2402	0.4835
IL-150	[TMG] [Lac]	C8H19N3O3	1,1,3,3-tetramethylguanidine lactate	205.3	632.7	816.9	27.2	639.1	0.2557	1.1188
IL-151	[bmim] [mesy]	C9H18N2SO3	1-butyl-3-methylimidazolium methanesulfonate	234.3	713.1	1054.8	37.4	701.3	0.2991	0.3990
IL-152	[emim] [mesy]	C7H14N2SO3	1-ethyl-3-methylimidazolium methanesulfonate	206.3	667.4	1026.0	48.1	587.1	0.3312	0.3307
IL-153	[dmim] [MOESO4]	C8H16N2SO5	1,3-dimethylimidazolium methoxyethylsulfate	252.3	735.1	1094.4	38.9	675.4	0.2887	0.3855
IL-154	[dmim] [MSO4]	C6H12N2SO4	1,3-dimethylimidazolium methylsulfate	208.2	666.9	1040.0	52.9	545.6	0.3339	0.3086
IL-155	[bmim] [MSO4]	C9H18N2SO4	1-butyl-3-methylimidazolium methylsulfate	250.3	735.6	1081.6	36.1	716.9	0.2878	0.4111
IL-156	[MMMPZ] [MSO4]	C7H14N2SO4	1,2,4-trimethylpyrazolium methylsulfate	222.3	694.8	1054.2	45.4	601.1	0.3113	0.3628
IL-157	[MTEOA] [MSO4]	C8H21NSO7	tris(hydroxyethyl)methylammonium methylsulfate	275.3	865.1	1093.4	35.2	744.3	0.2885	1.5198
IL-158	[bmim] [NfO]	C12H15N2F9SO3	1-butyl-3-methylimidazolium nonafluorobutanesulfonate	438.3	762.3	1028.8	17.3	1004.8	0.2030	0.5150
IL-159	[omim] [NfO]	C16H23N2F9SO3	1-octyl-3-methylimidazolium nonafluorobutanesulfonate	494.4	853.8	1103.0	14.2	1233.3	0.1908	0.6926
IL-160	[bmim] [C8S]	C16H32N2SO4	1-butyl-3-methylimidazolium octylsulfate	348.5	895.7	1189.8	20.2	1116.7	0.2286	0.7042
IL-161	[tibmp] [pTSO3]	C20H37PSO3	triisobutylmethylphosphonium p-toluenesulfonate	388.6	894.2	1164.2	16.9	1277.2	0.2236	0.7445
IL-162	[Ch] [Sa]	C12H19NO4	choline salicylate	241.3	762.2	950.5	23.9	726.4	0.2192	1.4009
IL-163	[bdmim] [BF4]	C9H17N2BF4	1-butyl-2,3-dimethylimidazolium tetrafluoroborate	240.1	523.1	671.0	18.9	710.5	0.2413	0.9476
IL-164	[C10mim] [BF4]	C14H27N2BF4	1-decyl-3-methylimidazolium tetrafluoroborate	310.2	632.5	784.6	14.5	997.7	0.2214	1.0818
IL-165	[N-epy] [BF4]	C7H10NBF4	1-ethylpyridinium tetrafluoroborate	195.0	411.2	549.9	23.5	533.9	0.2747	0.7495
IL-166	[moemim] [BF4]	C7H13N2OBF4	ethyloxymethyl-3-methylimidazolium tetrafluoroborate	228.0	494.8	647.0	21.7	613.5	0.2471	0.8692
IL-167	[prmim] [BF4]	C7H13N2BF4	1-propyl-3-methylimidazolium tetrafluoroborate	212.0	472.3	619.7	21.9	597.9	0.2537	0.8485
IL-168	[mommim] [BF4]	C6H11N2OBF4	methyloxymethyl-3-methylimidazolium tetrafluoroborate	214.0	471.9	623.7	23.3	556.4	0.2505	0.8296
IL-169	[bpy] [BF4]	C9H14NBF4	1-butylpyridinium tetrafluoroborate	223.0	456.9	597.6	20.3	648.1	0.2652	0.8307
IL-170	[4MOPY] [BF4]	C14H24NBF4	4-methyl-n-octylpyridinium tetrafluoroborate	293.2	576.3	720.8	15.1	932.1	0.2347	1.0289
IL-171	[C23guan] [BF4]	C23H50N3BF4	[bis(bispentylamine)methylene]dimethylammonium tetrafluoroborate	455.5	803.3	975.1	9.2	1603.5	0.1819	0.9385
IL-172	[DEME] [BF4]	C8H20NOBF4	N,N-diethyl-N-methyl-N-(2-methoxyethyl)ammonium tetrafluoroborate	233.1	393.5	501.4	17.1	693.1	0.2837	0.9465
IL-173	[bmim] [tca]	C9H15N3S	1-butyl-3-methylimidazolium thiocyanate	197.3	763.1	1047.4	19.4	780.7	0.1738	0.4781
IL-174	[emim] [SCN]	C7H11N3S	1-ethyl-3-methylimidazolium thiocyanate	169.3	717.3	1013.6	22.3	666.4	0.1760	0.3931
IL-175	[N-epy] [ta]	C9H10NF3O2	1-ethylpyridinium trifluoroacetate	221.2	535.1	739.9	24.2	586.5	0.2311	0.5483
IL-176	[emim] [ta]	C8H11N2F3O2	1-ethyl-3-methylimidazolium trifluoroacetate	224.2	573.4	785.3	24.3	593.4	0.2206	0.6051
IL-177	[mopmi] [TfO]	C12H13N2F3SO4	1-(4-methoxyphenyl)-3-methylimidazolium trifluoromethanesulfonate	338.3	830.4	1184.7	28.0	827.7	0.2353	0.4481
IL-178	[dbim] [TfO]	C12H21N2F3SO3	1,3-dibutylimidazolium trifluoromethanesulfonate	330.4	776.4	1072.0	23.2	922.0	0.2396	0.5325
IL-179	[N8444] [TfO]	C21H44NF3SO3	tributyloctylammonium trifluoromethanesulfonate	447.7	858.2	1066.7	12.6	1458.4	0.2072	0.9461
IL-180	[Bemim] [TfO]	C12H13N2F3SO3	1-benzyl-3-methylimidazolium trifluoromethanesulfonate	322.3	803.0	1158.0	29.0	813.7	0.2451	0.4118
IL-181	[mbpy] [TfO]	C11H16NF3SO3	1-butyl-4-methylpyridinium trifluoromethanesulfonate	299.3	697.3	997.8	26.9	799.3	0.2587	0.4153
IL-182	[omim] [TfO]	C13H23N2F3SO3	1-octyl-3-methylimidazolium trifluoromethanesulfonate	344.4	799.2	1088.7	21.6	979.1	0.2336	0.5766
IL-183	[4MOPY] [TfO]	C15H24NF3SO3	4-methyl-n-octylpyridinium trifluoromethanesulfonate	355.4	788.8	1065.7	20.1	1027.8	0.2332	0.5898
IL-184	[dmprim] [TMEM]	C12H15N2F9S3O6	1,2-dimethyl-3-propylimidazolium tris(trifluoromethylsulfonyl)methide	550.4	1039.3	1568.6	23.9	1212.0	0.2222	0.1526
IL-185	[bmim] [TMEM]	C12H15N2F9S3O6	1-butyl-3-methilimidazolium tris(trifluoromethylsulfonyl)methide	550.4	1034.4	1571.4	24.0	1213.6	0.2233	0.1322
IL-186	[bmim] [BF4]	C8H15N2BF4	1-butyl-3-methilimidazolium tetrafluoroborate	226.0	495.2	643.2	20.4	655.0	0.2496	0.8877
IL-187	[emim] [BF4]	C6H11N2BF4	1-ethyl-3-methylimidazolium tetrafluoroborate	198.0	449.5	596.2	23.6	540.8	0.2573	0.8087

4.2.2 Experimental Data of Viscosity of ILs

Table 4.2(a): Viscosity (μ) Data of ILs

ID	Cation	ID	Anion	η/cp	t (°C)	Method	Reference
11	C1HI	013	I	1800			22
		031	TFSI	81	25	dv	97
		033	BETI	218	25	dv	97
12	C2HI	014	ClO_4	112	25	dv	97
		021	BF_4	41	25	dv	97
		031	TFSI	54	25	dv	97
		033	BETI	133	25	dv	97
		043	TfO	58	25	dv	97
		051	PF_6	550	25	dv	97
201	C1MI	021	BF_4	67	25	dv	97
		031	TFSI	44	20	dv	18
				100	25	dv	97
		033	BETI	186	25	dv	97
202	DMI	021	BF_4	100	25	dv	97
				154	25		55
				91.4	28		55
		031	TFSI	100	25	dv	97
203	EMI	021	BF_4	43	26±1	dv	39
				37	25	ov	118
				66.5	25		55
				37.7	22		24
				43	28		55
		031	TFSI	34	20	dv	18
					20		98
					25	vc	95
							50 and 67
				32.1	20	pv	112
				28	26±1	pv	39
203	EMI	033	BETI	61	26±1	pv	39
		034	$N(CN)_2$	21(±5%)	25		62
		035	TSAC	24	25	vc	95
		037	MSI	787	20	vc	119
		043	TfO	42.7	25		9
				15	80	pv	39
		061	TA	35	20	dv	18
		062	HB	105	20	dv	18
		063	AcO	162	20	dv	18
203	EMI	082	$F(HF)_{2.3}$	4.9	25		88
				4.8	25		67
		083	NbF6	49	25	vc	94
		084	TaF6	51	25	vc	94
205	C2OMI	021	BF_4	90.9	20	dv	79
				70.9	30	dv	79
				157.6	10	dv	79
205	C2OMI	051	PF_6	148.8	20	dv	79
				82.7	30	dv	79
				279.5	10	dv	79
206	C2F3MI	031	TFSI	248	20	dv	18
207	DEI	031	TFSI	35	20	dv	18
		043	TfO	53	20	dv	18
		061	TA	43	20	dv	18
208	C3MI	021	BF_4	103	25	ov	118
		051	PF_6	312	25		32
				450	25		104
				371	25		39

Source: J. Phys. Chem. Ref. Data, Vol.35, No. 4, 2006

Table 4.2(b): Viscosity (μ) Data of ILs (cont.)

ID	Cation	ID	Anion	η/cp	t (°C)	Method	Reference
				70	25		50
84	P14	034	$N(CN)_2$	509(±5%)	25		62
		037	MSI	1680	20	vc	119
85	P16	034	dca	45(±5%)	25		62
9	PP13	031	TFSI	117	25		121
1001	MP2	031	TFSI	57(±5%)	25	vc	122
		031	TFSI	58(±5%)	25	vc	122
1101	C4-py	031	TFSI	9.9	80		89
1102	C6-py	021	BF_4	240.9	20		89
				15.7	80		89
1102	C6-py	031	TFSI	53.8	20		89
				5.9	80		89
1103	C8-py	031	TFSI	134.4	20		89
				13.5	80		89
1104	C10-py	031	TFSI	160.1	20		89
				15	80		89
1107	C16-py	031	TFSI	29.4	80		89
1109	M4C4-py	021	BF_4	80.85	40	vc	90
				50.22	50	vc	90
1401	S111	031	TFSI	44	45	vc	49
1402	S222	031	TFSI	30	25	vc	98 and 49
		035	TSAC	80	25	vc	95
1403	S444	031	TFSI	75	25		49
1404	S2222	035	TSAC	50	25	vc	95
1502	N1112	035	TSAC	51	25	vc	95
1504	N111C2O	031	TFSI	50	25		50
1505	TMPA	031	TFSI	72	25		51 and 50
				72,69	25	vc	95
1505	TMPA	035	TSAC	45	25	vc	95
1506	N1113'	035	TSAC	108	25	vc	95
1508	N111C3	035	TSAC	42	25	vc	48
1509	N111C3'	035	TSAC	65	25	vc	95
1512	N1123	031	TFSI	83(±5%)	25	vc	44
1513	N1114	031	TFSI	116(±5%)	25	vc	44
1514	N1222	035	TSAC	61	25	vc	95
1519	BNM2E	031	TFSI	110(±5%)	25	vc	44
1520	N1134	031	TFSI	170(±5%)	25	vc	44
1521	N6111	031	TFSI	153(±5%)	25	vc	33 and 44
				132	25	vc	95
1521	N6111	035	TSAC	119	25	vc	95
1524	N7111	031	TFSI	153(±5%)	25	vc	33 and 44
1525	N8111	031	TFSI	181(±5%)	25	vc	33 and 44
				156	25	vc	95
			TSAC	151	25	vc	95
1526	N2225'	035	TSAC	80	25	vc	95
1528	N6222	031	TFSI	167(±5%)	25	vc	33 and 44
1528	N6222	031	TFSI	220	20	pv	112
1529	N7222	031	TFSI	75.5(±5%)	25	vc	33 and 44
1530	N8222	031	TFSI	202(±5%)	25	vc	33 and 44
1531	N723'3'	031	TFSI	362(±5%)	25	vc	33 and 44
1533	N6444	031	TFSI	595(±5%)	25	vc	33 and 44
1534	N7444	031	TFSI	606(±5%)	25	vc	33 and 44
1535	N8444	031	TFSI	574(±5%)	25	vc	33 and 44
		043	TfO	2030(±5%)	25	vc	33 and 44
1536	TPA	031	TFSI	430	25		66

Source: J. Phys. Chem. Ref. Data, Vol.35, No. 4, 2006

Table 4.2(c): Viscosity (μ) Data of ILs (cont.)

ID	Cation	ID	Anion	η/cp	t (°C)	Method	Reference
				204	28		39
210	C3OMI	021	BF_4	262.8	20	dv	79
				138	30	dv	79
				374.3	10	vc	79
		031	TFSI	54	20	dv	18
		043	TfO	74	20	dv	18
		051	PF_6	148.1	30	dv	79
				607.5	10	dv	79
				283.6	20	dv	79
211	C4MI	013	I	1110	25	vc	63 and 100
		021	BF_4	219	25	vc	63 and 100
				180	25	ov	118
				219	25		73
				185.9	10	dv	79
				233	30		98 and 28
				233	20		106
				65.2	30		79
				91.4	30		55
				104.9	20		79
				154.0	20		55
		031	TFSI	52	20	dv	18 and 98
				54.5	25		73
				69	25	vc	63
				57.6	20	pv	112
		031	TFSIw	27	25	vc	63
		043	TfO	90	20	dv	18
				90	20		98
		045	NfO	373	20	dv	18
211	C4MI	048	C8S	874.5	20	vc	102
				207	45	vc	102
				152.3	50	vc	102
		051	PF_6	450	25	vc	63
				312	25		73
				393	25		116
				308.3	20	dv	79
				312	30		32 and 98
				172.8	30	dv	79
				615.0	10	dv	79
				285.83±6.08	20	dv	59
				207±11.12	25	dv	59
				152.67±0.82	31	dv	59
				116.33±5.5	35	dv	59
				94.32±0.29	40	dv	59
				73.35±0.64	45	dv	59
				58.02±1.42	50	dv	59
				45.93±0.72	55	dv	59
				40.4±0.89	60	dv	59
				34.6±0.17	65	dv	59
				28.53±0.81	70	dv	59
			PF_6w	397	25	vc	63 and 100
		061	TA	73	20	dv	18 and 98
		062	HB	182	20	dv	18
212	i-C4MI	031	TFSI	83	20	dv	18
217	C4C2I	031	TFSI	48	20	dv	18
		045	NfO	323	20	dv	18

Source: J. Phys. Chem. Ref. Data, Vol.35, No. 4, 2006

4.3 Equations

4.3.1 Identified Generalized Equations

4.3.1.1. Dutt's Development (1990) (6)

$$\boldsymbol{ln}\left(\frac{\boldsymbol{\mu}}{\boldsymbol{\rho}}\right) = -\mathbf{3.017} + [(\mathbf{442.78} + \mathbf{1.6452}\boldsymbol{t_B})/(\boldsymbol{t} + \{\mathbf{239} - \mathbf{0.19}\boldsymbol{t_B}\})]$$

Where μ = viscosity in cP,

ρ = density in g/ml,

t_B = normal boiling temperature in ^{o}C

4.3.1.2. Letsou & Stiel Method (1964) (7)

$$\boldsymbol{\mu\gamma} = (\boldsymbol{\mu\gamma})^{(\mathbf{0})} + \boldsymbol{\omega}(\boldsymbol{\mu\gamma})^{(\mathbf{1})}$$

$$(\boldsymbol{\mu\gamma})^{(\mathbf{0})} = \mathbf{10^{-4}}\left(\mathbf{151.78} - \mathbf{213.51}\boldsymbol{T_R} + \mathbf{75.03}\boldsymbol{T_R}^{\mathbf{2}}\right)$$

$$(\boldsymbol{\mu\gamma})^{(\mathbf{1})} = \mathbf{10^{-4}}\left(\mathbf{425.59} - \mathbf{767.50}\boldsymbol{T_R} + \mathbf{340.07}\boldsymbol{T_R}^{\mathbf{2}}\right)$$

$$\boldsymbol{\gamma} = \frac{\boldsymbol{T_C}^{\left(\frac{1}{6}\right)}}{\boldsymbol{M}^{\left(\frac{1}{2}\right)}\boldsymbol{P_c}^{\left(\frac{2}{3}\right)}}$$

Where ω = Accentric Factor of IL

T_c = Critical Temperature in K,

T_R = Reduced Temperature T/T_c

P_c = Critical Pressure in atm

M = Molecular weight of IL

4.3.1.3. Golubev Approach (1959) (8)

$$\mu = \mu_c^* T_R^{0.965} \qquad \text{for } T_R < 1$$

$$\mu = \mu_c^* T_R^{[0.71+(0.29/T_R)]} \qquad \text{,otherwise}$$

$$\mu_c^* = 3.5\left[M^{(1/2)} P_c^{(2/3)} T_c^{(1/6)}\right]$$

Where T_R = Reduced Temperature T/T_c,

T_c = Critical Temperature in K

P_c = Critical Pressure in atm

M = Molecular weight of IL

4.3.1.4. Andrade Equation (2011) (9)

$$ln\left[\mu(M)^{1.5}\right] = -10.97 + (1037/T)$$

Where M = Molecular Weight

T = Temperature in K

4.1.3.5. Two Fluid Approach of Teja and Rice (1981) (10)

$$ln(\mu\varepsilon) = ln(\mu\varepsilon)^{(R1)} + \left[ln(\mu\varepsilon)^{(R2)} - ln(\mu\varepsilon)^{(R1)}\right]\frac{\omega-\omega^{(R1)}}{\omega^{(R2)}-\omega^{(R1)}}$$

Where superscripts (R1) and (R2) refer to two reference fluids,

$$\varepsilon = \frac{V_c^{2/3}}{(T_c M)^{1/2}},$$

ω = Acentric Factor

4.3.1.6. Lewis and Squires Method (1934) (11)

$$\mu_L^{-0.2661} = \mu_K^{-0.2661} + \frac{T - T_K}{233}$$

Where μ_L = Liquid viscosity at T, cP

μ_K = Known value of liquid viscosity at T_K, cP

4.3.1.7. Unified equation for the viscosity of pure liquids (2005) (12)

$$\mu = 1.8\left(\frac{M^{1/2}}{Vc^{2/3}}\right)T^{1/2}exp\left(2.34\frac{T_m}{T}\right)$$

Where M_i = atomic mass

V_c = Critical molar volume

T = Temperature in K

M = Molecular Mass

T_m = Melting Temperature in K

4.3.1.8. Uyehara and Watson(1944) (13)

$$\mu = \mu_c \mu_R$$

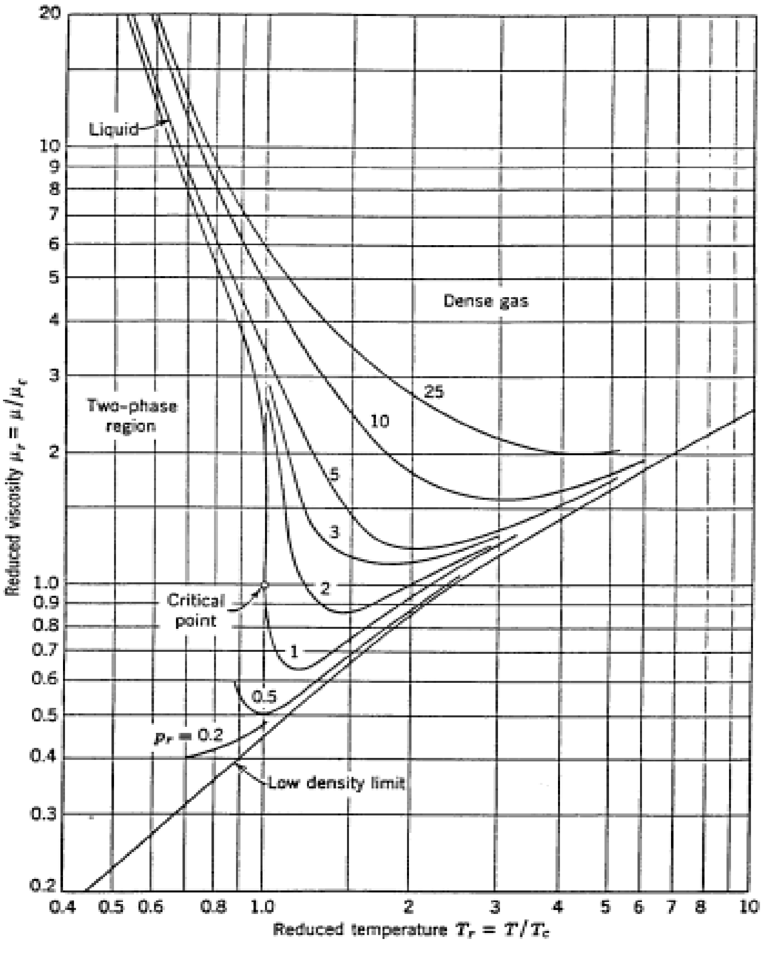
$$\mu_c = 7.7 T_c^{-1/6} M^{1/2} P_c^{2/3}$$

μ_R is determined using Figure 4.1 and Figure 4.2

Where T_c = Critical Temperature

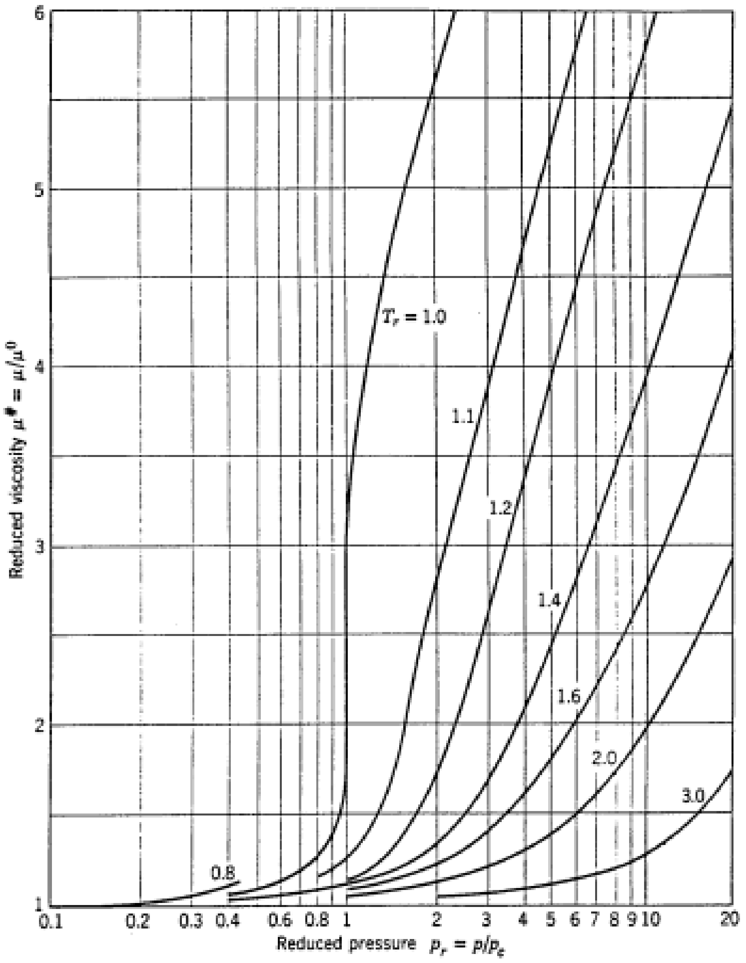
M = Molecular weight

P_c = Critical pressure in atm



Source: Uyehara, O.A., Watson, K.M. (1944)

Figure 4.1: Graph of μ_R against T_R



Source: Uyehara, O.A., Watson, K.M. (1944)

Figure 4.2: Graph of μ_R against P_R

4.3.2 Well-known Non-Generalized Equations for predicting IL viscosity

4.3.2.1. Orrick–Erbar method (1974) (14)

$$\boldsymbol{ln\frac{\mu}{\rho M} = A + \frac{B}{T}}$$

Where ρ = the density,

M = the molecular weight,

T = the temperature in K

A and B are Orrick-Erbar constants

4.3.2.2. Ghatee et al Method (15)

$$\boldsymbol{\left(\frac{1}{\mu}\right)^{\emptyset} = a + bT}$$

Where ϕ, a, and b are constants.

Φ is usually within the range of 0.1< Φ<0.3 for most ILs

Values of constants A,B, Φ, a and b can be found in literature.

4.4 Calculations

Using a detailed Excel Spreadsheet, detailed calculations are done based on the data acquired as mentioned above. As the data calculation is too lengthy and complicated, this segment will show only the main calculations for 64 data points. For detailed excel spreadsheet calculations, please refer to APPENDIX.

4.4.1 Identified ILs and their Critical Properties.

The following table represents the parameters and critical properties of the 20 Ionic Liquids used:

Table 4.3: Parameters and Critical Properties of ILs studied

IL	Data Points	M	Tc(K)	Pc(bar)	Pc(atm)	Ꞷ	Vc(cm^3/mol)
[emim][BF4]	16	198	596.2	23.6	23.91326	0.8087	540.8
[bmim][BF4]	9	226	643.2	20.4	20.67079	0.8877	655
[bmim][PF6]	10	284.2	719.4	17.3	17.52964	0.7917	762.5
[emim][PF6]	3	256.1	508.8	19.5	19.75884	0.7083	648.3
[dmim][bti]	8	377.3	1239.9	35.8	36.27521	0.1752	818.8
[dmim][bf4]	1	310	784.6	14.5	14.69247	1.082	997.7
[C8mim][BF4]	17	282.13	726.1	16	16.21238	0.9954	812.3
[bmim][TFES]	1	320	1030.5	25.7	26.04114	0.4583	827.8
[emim][TFES]	1	433	1171	15.6	15.80707	0.8065	713.6
[nmim][bti]	1	490	1331.2	19.8	20.06282	0.5276	1275.7
[pmim][bti]	1	433	1281.1	25.6	25.93981	0.3442	1161.5
[bmim][Cl]	1	174.7	789	27.8	28.16901	0.491	568.8
[C12mim][Cl]	1	286.9	951.5	16	16.21238	0.821	1025.6
[dmprim][bti]	16	419	1269.7	27.5	27.86503	0.3226	1023.7
[bmpyr][bti]	9	422	1209.2	24.8	25.12919	0.3191	1038.8
[deim][bti]	1	405.34	1254.7	29.9	30.29689	0.2231	950
[bdmim][bti]	1	433.4	1281.1	25.5	25.83848	0.3669	1045.7
[emim][ESO4]	1	126.3	1067.5	40.5	41.03759	0.3744	659.8
[omim][PF6]	1	340.3	810.8	14	14.18583	0.9385	990.9
[bdmim][PF6]	1	298.2	746.3	16.2	16.41504	0.8526	818

4.4.2 Calculations using Excel Spreadsheet

4.4.2.1 Calculation for Letsou & Stiel Method

Table 4.4.1 Calculation for Letsou & Stiel Method

Letsou & Stiel Method											
IL	Data Points	Temp.(K)	Tc(K)	Pc(atm)	Ꞷ	Tr	(μγ)0	(μγ)1	μγ	γ	μ(cP)
[emim][BF4]	16	290.00	596.20	23.91	0.81	0.49	0.01	0.01	0.02	0.02	69.65
		295.00	596.20	23.91	0.81	0.49	0.01	0.01	0.02	0.02	68.00
		300.00	596.20	23.91	0.81	0.50	0.01	0.01	0.02	0.02	66.36
		305.00	596.20	23.91	0.81	0.51	0.01	0.01	0.02	0.02	64.74
		310.00	596.20	23.91	0.81	0.52	0.01	0.01	0.02	0.02	63.15
		315.00	596.20	23.91	0.81	0.53	0.01	0.01	0.02	0.02	61.57
		320.00	596.20	23.91	0.81	0.54	0.01	0.01	0.01	0.02	60.01
		325.00	596.20	23.91	0.81	0.55	0.01	0.01	0.01	0.02	58.47
		330.00	596.20	23.91	0.81	0.55	0.01	0.01	0.01	0.02	56.95
		335.00	596.20	23.91	0.81	0.56	0.01	0.01	0.01	0.02	55.46
		340.00	596.20	23.91	0.81	0.57	0.01	0.01	0.01	0.02	53.98
		345.00	596.20	23.91	0.81	0.58	0.01	0.01	0.01	0.02	52.52
		350.00	596.20	23.91	0.81	0.59	0.01	0.01	0.01	0.02	51.08
		355.00	596.20	23.91	0.81	0.60	0.01	0.01	0.01	0.02	49.66
		360.00	596.20	23.91	0.81	0.60	0.01	0.01	0.01	0.02	48.26
		365.00	596.20	23.91	0.81	0.61	0.00	0.01	0.01	0.02	46.88
[bmim][BF4]	9	323.15	643.20	20.67	0.89	0.50	0.01	0.01	0.02	0.01	119.71
		333.15	643.20	20.67	0.89	0.52	0.01	0.01	0.02	0.01	114.29
		343.15	643.20	20.67	0.89	0.53	0.01	0.01	0.02	0.01	108.99
		353.15	643.20	20.67	0.89	0.55	0.01	0.01	0.02	0.01	103.82

Table 4.4.1 Calculation for Letsou & Stiel Method (cont.)

		363.15	643.20	20.67	0.89	0.56	0.01	0.01	0.01	0.03	55.69
		288.15	643.20	20.67	0.89	0.45	0.01	0.02	0.02	0.03	78.75
		293.15	643.20	20.67	0.89	0.46	0.01	0.01	0.02	0.03	77.09
		296.15	643.20	20.67	0.89	0.46	0.01	0.01	0.02	0.03	76.11
		298.15	643.20	20.67	0.89	0.46	0.01	0.01	0.02	0.03	75.45
[bmim][PF6]	10	288.15	719.40	17.53	0.79	0.40	0.01	0.02	0.02	0.03	74.25
		293.15	719.40	17.53	0.79	0.41	0.01	0.02	0.02	0.03	72.95
		296.15	719.40	17.53	0.79	0.41	0.01	0.02	0.02	0.03	72.17
		298.15	719.40	17.53	0.79	0.41	0.01	0.02	0.02	0.03	71.66
		301.15	719.40	17.53	0.79	0.42	0.01	0.02	0.02	0.03	78.03
		303.15	719.40	17.53	0.79	0.42	0.01	0.02	0.02	0.03	77.46
		305.15	719.40	17.53	0.79	0.42	0.01	0.02	0.02	0.03	76.90
		308.15	719.40	17.53	0.79	0.43	0.01	0.02	0.02	0.03	76.07
		311.15	719.40	17.53	0.79	0.43	0.01	0.02	0.02	0.03	75.24
		313.15	719.40	17.53	0.79	0.44	0.01	0.02	0.02	0.03	74.68
[emim][PF6]	3	343.10	508.80	19.76	0.71	0.67	0.00	0.01	0.01	0.02	35.53
		353.10	508.80	19.76	0.71	0.69	0.00	0.01	0.01	0.02	32.90
		363.10	508.80	19.76	0.71	0.71	0.00	0.01	0.01	0.02	30.37
[dmim][bti]	8	283.15	1239.90	36.28	0.18	0.23	0.01	0.03	0.02	0.02	9.50
		293.15	1239.90	36.28	1.18	0.24	0.01	0.03	0.04	0.02	257.41
		303.15	1239.90	36.28	2.18	0.24	0.01	0.03	0.07	0.02	413.27
		313.15	1239.90	36.28	3.18	0.25	0.01	0.03	0.09	0.02	563.17
		323.15	1239.90	36.28	4.18	0.26	0.01	0.02	0.11	0.02	739.96
		333.15	1239.90	36.28	5.18	0.27	0.01	0.02	0.14	0.02	884.61
		343.15	1239.90	36.28	6.18	0.28	0.01	0.02	0.16	0.02	1023.28
		353.15	1239.90	36.28	7.18	0.28	0.01	0.02	0.18	0.02	1156.07
[dmim][bf4]	1	298.15	784.60	14.69	1.08	0.38	0.01	0.02	0.03	0.03	99.38

Table 4.4.1 Calculation for Letsou & Stiel Method (cont.)

[C8mim] [BF4]	17	283.15	726.10	16.21	1.00	0.39	0.01	0.02	0.03	0.03	92.28
		288.15	726.10	16.21	1.00	0.40	0.01	0.02	0.03	0.03	90.67
		293.15	726.10	16.21	1.00	0.40	0.01	0.02	0.02	0.03	89.07
		298.15	726.10	16.21	1.00	0.41	0.01	0.02	0.02	0.03	87.48
		303.15	726.10	16.21	1.00	0.42	0.01	0.02	0.02	0.03	85.92
		308.15	726.10	16.21	1.00	0.42	0.01	0.02	0.02	0.03	84.36
		313.15	726.10	16.21	1.00	0.43	0.01	0.02	0.02	0.03	82.82
		318.15	726.10	16.21	1.00	0.44	0.01	0.02	0.02	0.03	81.29
		323.15	726.10	16.21	1.00	0.45	0.01	0.02	0.02	0.03	79.78
		328.15	726.10	16.21	1.00	0.45	0.01	0.01	0.02	0.03	78.28
		333.15	726.10	16.21	1.00	0.46	0.01	0.01	0.02	0.03	76.79
		338.15	726.10	16.21	1.00	0.47	0.01	0.01	0.02	0.03	75.32
		343.15	726.10	16.21	1.00	0.47	0.01	0.01	0.02	0.03	73.87
		348.15	726.10	16.21	1.00	0.48	0.01	0.01	0.02	0.03	72.42
		353.15	726.10	16.21	1.00	0.49	0.01	0.01	0.02	0.03	71.00
		358.15	726.10	16.21	1.00	0.49	0.01	0.01	0.02	0.01	131.12
		363.15	726.10	16.21	1.00	0.50	0.01	0.01	0.02	0.01	12.85

For detailed version of excel spreadsheet calculation, kindly refer to APPENDIX.

4.4.2.2 Calculation for Golubev Method

Table 4.4.2 Calculation for Golubev Method

Golubev Approach									
IL	Data Points	Temperature(K)	M	Tc(K)	Pc(bar)	Pc(atm)	Tr	μ*c	μ
[emim][BF4]	16	290	198	596.2	23.6	23.91326	0.486414	118.5929	59.16
		295	198	596.2	23.6	23.91326	0.4948	118.5929	60.14
		300	198	596.2	23.6	23.91326	0.503187	118.5929	61.13
		305	198	596.2	23.6	23.91326	0.511573	118.5929	62.11
		310	198	596.2	23.6	23.91326	0.51996	118.5929	63.09
		315	198	596.2	23.6	23.91326	0.528346	118.5929	64.07
		320	198	596.2	23.6	23.91326	0.536733	118.5929	65.05
		325	198	596.2	23.6	23.91326	0.545119	118.5929	66.03
		330	198	596.2	23.6	23.91326	0.553506	118.5929	67.01
		335	198	596.2	23.6	23.91326	0.561892	118.5929	67.99
		340	198	596.2	23.6	23.91326	0.570278	118.5929	68.97
		345	198	596.2	23.6	23.91326	0.578665	118.5929	69.95
		350	198	596.2	23.6	23.91326	0.587051	118.5929	70.93
		355	198	596.2	23.6	23.91326	0.595438	118.5929	71.91
		360	198	596.2	23.6	23.91326	0.603824	118.5929	72.88
		365	198	596.2	23.6	23.91326	0.612211	118.5929	73.86
[bmim][BF4]	9	283.15	226	643.2	20.4	20.67079	0.440221	116.4353	52.75
		293.15	226	643.2	20.4	20.67079	0.455768	116.4353	54.55
		303.15	226	643.2	20.4	20.67079	0.471315	116.4353	56.34
		313.15	226	643.2	20.4	20.67079	0.486863	116.4353	58.13
		323.15	226	643.2	20.4	20.67079	0.50241	116.4353	59.92
		333.15	226	643.2	20.4	20.67079	0.517957	116.4353	61.71
		343.15	226	643.2	20.4	20.67079	0.533504	116.4353	63.50

Table 4.4.2 Calculation for Golubev Method (cont.)

		353.15	226	643.2	20.4	20.67079	0.549052	116.4353	65.28
		363.15	226	643.2	20.4	20.67079	0.564599	116.4353	67.07
[bmim][PF6]	10	288.15	284.2	719.4	17.3	17.52964	0.400542	119.1856	49.29
		293.15	284.2	719.4	17.3	17.52964	0.407492	119.1856	50.12
		296.15	284.2	719.4	17.3	17.52964	0.411662	119.1856	50.61
		298.15	284.2	719.4	17.3	17.52964	0.414443	119.1856	50.94
		301.15	284.2	719.4	17.3	17.52964	0.418613	119.1856	51.44
		303.15	284.2	719.4	17.3	17.52964	0.421393	119.1856	51.77
		305.15	284.2	719.4	17.3	17.52964	0.424173	119.1856	52.10
		308.15	284.2	719.4	17.3	17.52964	0.428343	119.1856	52.59
		311.15	284.2	719.4	17.3	17.52964	0.432513	119.1856	53.08
		313.15	284.2	719.4	17.3	17.52964	0.435293	119.1856	53.41
[emim][PF6]	3	343.1	256.1	508.8	19.5	19.75884	0.674332	115.6658	79.08
		353.1	256.1	508.8	19.5	19.75884	0.693986	115.6658	81.30
		363.1	256.1	508.8	19.5	19.75884	0.71364	115.6658	83.52
[dmim][bti]	8	283.15	377.3	1239.9	35.8	36.27521	0.228365	244.1832	58.72
		293.15	377.3	1239.9	35.8	36.27521	0.23643	244.1832	60.72
		303.15	377.3	1239.9	35.8	36.27521	0.244496	244.1832	62.72
		313.15	377.3	1239.9	35.8	36.27521	0.252561	244.1832	64.71
		323.15	377.3	1239.9	35.8	36.27521	0.260626	244.1832	66.71
		333.15	377.3	1239.9	35.8	36.27521	0.268691	244.1832	68.70
		343.15	377.3	1239.9	35.8	36.27521	0.276756	244.1832	70.69
		353.15	377.3	1239.9	35.8	36.27521	0.284821	244.1832	72.67
[dmim][bf4]	1	298.15	310	784.6	14.5	14.69247	0.380003	112.2674	44.13
[C8mim] [BF4]	17	283.15	282.13	726.1	16	16.21238	0.38996	112.899	45.50
		288.15	282.13	726.1	16	16.21238	0.396846	112.899	46.28
		293.15	282.13	726.1	16	16.21238	0.403732	112.899	47.05

Table 4.4.2 Calculation for Golubev Method (cont.)

		298.15	282.13	726.1	16	16.21238	0.410618	112.899	47.83
		303.15	282.13	726.1	16	16.21238	0.417504	112.899	48.60
		308.15	282.13	726.1	16	16.21238	0.424391	112.899	49.37
		313.15	282.13	726.1	16	16.21238	0.431277	112.899	50.15
		318.15	282.13	726.1	16	16.21238	0.438163	112.899	50.92
		323.15	282.13	726.1	16	16.21238	0.445049	112.899	51.69
		328.15	282.13	726.1	16	16.21238	0.451935	112.899	52.46
		333.15	282.13	726.1	16	16.21238	0.458821	112.899	53.23
		338.15	282.13	726.1	16	16.21238	0.465707	112.899	54.00
		343.15	282.13	726.1	16	16.21238	0.472593	112.899	54.77
		348.15	282.13	726.1	16	16.21238	0.479479	112.899	55.54
		353.15	282.13	726.1	16	16.21238	0.486366	112.899	56.31
		358.15	282.13	726.1	16	16.21238	0.493252	112.899	57.08
		363.15	282.13	726.1	16	16.21238	0.500138	112.899	57.85

For detailed version of excel spreadsheet calculation, kindly refer to APPENDIX.

4.4.2.3 Calculation for Uyehara and Watson Method

Table 4.4.3 Calculation for Uyehara and Watson Method

Uyehara and Watson											
IL	Data Points	Temperature(K)	M	Tc(K)	Pc(bar)	Pc(atm)	Pr	Tr	μC	μR	μ
[emim][BF4]	16	290	198	596.2	23.6	23.91326	0.041818	0.486414	309.9921	0.14	43.40
		295	198	596.2	23.6	23.91326	0.041818	0.4948	309.9921	0.14	43.40
		300	198	596.2	23.6	23.91326	0.041818	0.503187	309.9921	0.14	43.40
		305	198	596.2	23.6	23.91326	0.041818	0.511573	309.9921	0.13	40.30
		310	198	596.2	23.6	23.91326	0.041818	0.51996	309.9921	0.12	37.20
		315	198	596.2	23.6	23.91326	0.041818	0.528346	309.9921	0.12	37.20
		320	198	596.2	23.6	23.91326	0.041818	0.536733	309.9921	0.10	31.00
		325	198	596.2	23.6	23.91326	0.041818	0.545119	309.9921	0.08	24.80
		330	198	596.2	23.6	23.91326	0.041818	0.553506	309.9921	0.08	24.80
		335	198	596.2	23.6	23.91326	0.041818	0.561892	309.9921	0.07	21.70
		340	198	596.2	23.6	23.91326	0.041818	0.570278	309.9921	0.60	186.00
		345	198	596.2	23.6	23.91326	0.041818	0.578665	309.9921	0.05	15.50
		350	198	596.2	23.6	23.91326	0.041818	0.587051	309.9921	0.05	15.50
		355	198	596.2	23.6	23.91326	0.041818	0.595438	309.9921	0.04	12.40
		360	198	596.2	23.6	23.91326	0.041818	0.603824	309.9921	0.03	9.30
		365	198	596.2	23.6	23.91326	0.041818	0.612211	309.9921	0.02	6.20
[bmim][BF4]	9	283.15	226	643.2	20.4	20.67079	0.048377	0.440221	296.7508	0.14	41.55
		293.15	226	643.2	20.4	20.67079	0.048377	0.455768	296.7508	0.14	41.55
		303.15	226	643.2	20.4	20.67079	0.048377	0.471315	296.7508	0.14	41.55
		313.15	226	643.2	20.4	20.67079	0.048377	0.486863	296.7508	0.13	38.58
		323.15	226	643.2	20.4	20.67079	0.048377	0.50241	296.7508	0.12	35.61
		333.15	226	643.2	20.4	20.67079	0.048377	0.517957	296.7508	0.12	35.61
		343.15	226	643.2	20.4	20.67079	0.048377	0.533504	296.7508	0.10	29.68

Table 4.4.3 Calculation for Uyehara and Watson Method (cont.)

		353.15	226	643.2	20.4	20.67079	0.048377	0.549052	296.7508	0.08	23.74
		363.15	226	643.2	20.4	20.67079	0.048377	0.564599	296.7508	0.07	20.77
[bmim][PF6]	10	288.15	284.2	719.4	17.3	17.52964	0.057046	0.400542	292.6328	0.14	40.97
		293.15	284.2	719.4	17.3	17.52964	0.057046	0.407492	292.6328	0.14	40.97
		296.15	284.2	719.4	17.3	17.52964	0.057046	0.411662	292.6328	0.14	40.97
		298.15	284.2	719.4	17.3	17.52964	0.057046	0.414443	292.6328	0.13	38.04
		301.15	284.2	719.4	17.3	17.52964	0.057046	0.418613	292.6328	0.12	35.12
		303.15	284.2	719.4	17.3	17.52964	0.057046	0.421393	292.6328	0.12	35.12
		305.15	284.2	719.4	17.3	17.52964	0.057046	0.424173	292.6328	0.10	29.26
		308.15	284.2	719.4	17.3	17.52964	0.057046	0.428343	292.6328	0.08	23.41
		311.15	284.2	719.4	17.3	17.52964	0.057046	0.432513	292.6328	0.07	20.48
		313.15	284.2	719.4	17.3	17.52964	0.057046	0.435293	292.6328	0.07	20.48
[emim][PF6]	3	343.1	256.1	508.8	19.5	19.75884	0.05061	0.674332	318.7464	0.07	22.31
		353.1	256.1	508.8	19.5	19.75884	0.05061	0.693986	318.7464	0.06	19.12
		363.1	256.1	508.8	19.5	19.75884	0.05061	0.71364	318.7464	0.06	19.12
[dmim][bti]	8	283.15	377.3	1239.9	35.8	36.27521	0.027567	0.228365	500.0456	0.13	65.01
		293.15	377.3	1239.9	35.8	36.27521	0.027567	0.23643	500.0456	0.12	60.01
		303.15	377.3	1239.9	35.8	36.27521	0.027567	0.244496	500.0456	0.10	50.00
		313.15	377.3	1239.9	35.8	36.27521	0.027567	0.252561	500.0456	0.08	40.00
		323.15	377.3	1239.9	35.8	36.27521	0.027567	0.260626	500.0456	0.07	35.00
		333.15	377.3	1239.9	35.8	36.27521	0.027567	0.268691	500.0456	0.07	35.00
		343.15	377.3	1239.9	35.8	36.27521	0.027567	0.276756	500.0456	0.07	35.00
		353.15	377.3	1239.9	35.8	36.27521	0.027567	0.284821	500.0456	0.06	30.00
[dmim][bf4]	1	298.15	310	784.6	14.5	14.69247	0.068062	0.380003	267.7894	0.06	16.07
[C8mim] [BF4]	17	283.15	282.13	726.1	16	16.21238	0.061681	0.38996	276.3422	0.13	35.92
		288.15	282.13	726.1	16	16.21238	0.061681	0.396846	276.3422	0.12	33.16
		293.15	282.13	726.1	16	16.21238	0.061681	0.403732	276.3422	0.12	33.16

Table 4.4.3 Calculation for Uyehara and Watson Method (cont.)

		298.15	282.13	726.1	16	16.21238	0.061681	0.410618	276.3422	0.10	27.63
		303.15	282.13	726.1	16	16.21238	0.061681	0.417504	276.3422	0.08	22.11
		308.15	282.13	726.1	16	16.21238	0.061681	0.424391	276.3422	0.07	19.34
		313.15	282.13	726.1	16	16.21238	0.061681	0.431277	276.3422	0.07	19.34
		318.15	282.13	726.1	16	16.21238	0.061681	0.438163	276.3422	0.07	19.34
		323.15	282.13	726.1	16	16.21238	0.061681	0.445049	276.3422	0.06	16.58
		328.15	282.13	726.1	16	16.21238	0.061681	0.451935	276.3422	0.06	16.58
		333.15	282.13	726.1	16	16.21238	0.061681	0.458821	276.3422	0.13	35.92
		338.15	282.13	726.1	16	16.21238	0.061681	0.465707	276.3422	0.12	33.16
		343.15	282.13	726.1	16	16.21238	0.061681	0.472593	276.3422	0.10	27.63
		348.15	282.13	726.1	16	16.21238	0.061681	0.479479	276.3422	0.08	22.11
		353.15	282.13	726.1	16	16.21238	0.061681	0.486366	276.3422	0.07	19.34
		358.15	282.13	726.1	16	16.21238	0.061681	0.493252	276.3422	0.07	19.34
		363.15	282.13	726.1	16	16.21238	0.061681	0.500138	276.3422	0.07	19.34

For detailed version of excel spreadsheet calculation, kindly refer to APPENDIX.

4.4.2.4 Calculation for Lewis & Squires Method

Table 4.4.4 Calculation for Lewis & Squires Method

Lewis & Squires									
IL	Known Viscosity at T(K)	Data Points	Temperature(K)	M	Tc(K)	Pc(bar)	Pc(atm)	μL^-0.2661	μ
[emim][BF4]	Vk at 290k=46cP	16	290	198	596.2	23.6	23.91326	0.361027	52.74
			295	198	596.2	23.6	23.91326	0.382487	48.00
			300	198	596.2	23.6	23.91326	0.403946	43.90
			305	198	596.2	23.6	23.91326	0.425405	40.35
			310	198	596.2	23.6	23.91326	0.446864	37.23
			315	198	596.2	23.6	23.91326	0.468324	34.49
			320	198	596.2	23.6	23.91326	0.489783	32.06
			325	198	596.2	23.6	23.91326	0.511242	29.89
			330	198	596.2	23.6	23.91326	0.532701	27.95
			335	198	596.2	23.6	23.91326	0.55416	26.21
			340	198	596.2	23.6	23.91326	0.57562	24.63
			345	198	596.2	23.6	23.91326	0.597079	23.20
			350	198	596.2	23.6	23.91326	0.618538	21.90
			355	198	596.2	23.6	23.91326	0.639997	20.72
			360	198	596.2	23.6	23.91326	0.661457	19.63
			365	198	596.2	23.6	23.91326	0.682916	18.63
[bmim][BF4]	Vk at 283.15k=277cP	9	283.15	226	643.2	20.4	20.67079	0.223901	115.02
			293.15	226	643.2	20.4	20.67079	0.26682	86.39
			303.15	226	643.2	20.4	20.67079	0.309738	67.72
			313.15	226	643.2	20.4	20.67079	0.352656	54.80
			323.15	226	643.2	20.4	20.67079	0.395575	45.43
			333.15	226	643.2	20.4	20.67079	0.438493	38.40
			343.15	226	643.2	20.4	20.67079	0.481412	32.97

Table 4.4.4 Calculation for Lewis & Squires Method (cont.)

			353.15	226	643.2	20.4	20.67079	0.52433	28.68
			363.15	226	643.2	20.4	20.67079	0.567249	25.23
[bmim][PF6]	Vk at 288.15k=400.2cP	10	288.15	284.2	719.4	17.3	17.52964	0.203018	134.94
			293.15	284.2	719.4	17.3	17.52964	0.224477	114.53
			296.15	284.2	719.4	17.3	17.52964	0.237353	104.57
			298.15	284.2	719.4	17.3	17.52964	0.245936	98.68
			301.15	284.2	719.4	17.3	17.52964	0.258812	90.79
			303.15	284.2	719.4	17.3	17.52964	0.267395	86.08
			305.15	284.2	719.4	17.3	17.52964	0.275979	81.76
			308.15	284.2	719.4	17.3	17.52964	0.288855	75.89
			311.15	284.2	719.4	17.3	17.52964	0.30173	70.68
			313.15	284.2	719.4	17.3	17.52964	0.310314	67.52
[emim][PF6]	Vk at 343.1k=23.4cP	3	343.1	256.1	508.8	19.5	19.75884	0.432167	39.32
			353.1	256.1	508.8	19.5	19.75884	0.475086	33.69
			363.1	256.1	508.8	19.5	19.75884	0.518004	29.26
[dmim][bti]	Vk at 283k=77.06cP	8	283.15	377.3	1239.9	35.8	36.27521	0.315357	65.76
			293.15	377.3	1239.9	35.8	36.27521	0.358275	53.40
			303.15	377.3	1239.9	35.8	36.27521	0.401194	44.40
			313.15	377.3	1239.9	35.8	36.27521	0.444112	37.61
			323.15	377.3	1239.9	35.8	36.27521	0.487031	32.35
			333.15	377.3	1239.9	35.8	36.27521	0.529949	28.19
			343.15	377.3	1239.9	35.8	36.27521	0.572868	24.82
			353.15	377.3	1239.9	35.8	36.27521	0.615786	22.06
[C8mim] [BF4]	Vk at 283.15k = 1036.98cP	17	283.15	282.13	726.1	16	16.21238	0.157581	204.05
			288.15	282.13	726.1	16	16.21238	0.17904	165.67
			293.15	282.13	726.1	16	16.21238	0.200499	137.72
			298.15	282.13	726.1	16	16.21238	0.221959	116.66

Table 4.4.4 Calculation for Lewis & Squires Method (cont.)

			303.15	282.13	726.1	16	16.21238	0.243418	100.35
			308.15	282.13	726.1	16	16.21238	0.264877	87.42
			313.15	282.13	726.1	16	16.21238	0.286336	76.99
			318.15	282.13	726.1	16	16.21238	0.307795	68.42
			323.15	282.13	726.1	16	16.21238	0.329255	61.29
			328.15	282.13	726.1	16	16.21238	0.350714	55.29
			333.15	282.13	726.1	16	16.21238	0.372173	50.19
			338.15	282.13	726.1	16	16.21238	0.393632	45.80
			343.15	282.13	726.1	16	16.21238	0.415092	42.00
			348.15	282.13	726.1	16	16.21238	0.436551	38.68
			353.15	282.13	726.1	16	16.21238	0.45801	35.77
			358.15	282.13	726.1	16	16.21238	0.479469	33.19
			363.15	282.13	726.1	16	16.21238	0.500929	30.90

For detailed version of excel spreadsheet calculation, kindly refer to APPENDIX.

4.4.2.5 Calculation for Unified Equation for the Viscosity of Pure Liquids

Table 4.4.5 Calculation for Unified Equation for the Viscosity of Pure Liquids

Unified Equation for the Viscosity of Pure Liquids											
IL	Data Points	Temperature(K)	M	Vc	Tm	Tc(K)	Pc(bar)	Pc(atm)	Ꞷ	Tr	µ
[emim][BF4]	16	290	198	540.8	240	596.2	23.6	23.91326	0.8087	0.486414	44.13
		295	198	540.8	240	596.2	23.6	23.91326	0.8087	0.4948	43.07
		300	198	540.8	240	596.2	23.6	23.91326	0.8087	0.503187	42.08
		305	198	540.8	240	596.2	23.6	23.91326	0.8087	0.511573	41.14
		310	198	540.8	240	596.2	23.6	23.91326	0.8087	0.51996	40.26
		315	198	540.8	240	596.2	23.6	23.91326	0.8087	0.528346	39.44
		320	198	540.8	240	596.2	23.6	23.91326	0.8087	0.536733	38.66
		325	198	540.8	240	596.2	23.6	23.91326	0.8087	0.545119	37.92
		330	198	540.8	240	596.2	23.6	23.91326	0.8087	0.553506	37.22
		335	198	540.8	240	596.2	23.6	23.91326	0.8087	0.561892	36.56
		340	198	540.8	240	596.2	23.6	23.91326	0.8087	0.570278	35.94
		345	198	540.8	240	596.2	23.6	23.91326	0.8087	0.578665	35.35
		350	198	540.8	240	596.2	23.6	23.91326	0.8087	0.587051	34.78
		355	198	540.8	240	596.2	23.6	23.91326	0.8087	0.595438	34.25
		360	198	540.8	240	596.2	23.6	23.91326	0.8087	0.603824	33.74
		365	198	540.8	240	596.2	23.6	23.91326	0.8087	0.612211	33.25
[bmim][BF4]	9	323.15	226	655	200	643.2	20.4	20.67079	0.8877	0.50241	268.60
		333.15	226	655	200	643.2	20.4	20.67079	0.8877	0.517957	261.13
		343.15	226	655	200	643.2	20.4	20.67079	0.8877	0.533504	25.44
		353.15	226	655	200	643.2	20.4	20.67079	0.8877	0.549052	24.83
		363.15	226	655	200	643.2	20.4	20.67079	0.8877	0.564599	24.28
		288.15	226	655	200	643.2	20.4	20.67079	0.8877	0.447994	30.24
		293.15	226	655	200	643.2	20.4	20.67079	0.8877	0.455768	29.67

Table 4.4.5 Calculation for Unified Equation for the Viscosity of Pure Liquids (cont.)

		296.15	226	655	200	643.2	20.4	20.67079	0.8877	0.460432	29.34
		298.15	226	655	200	643.2	20.4	20.67079	0.8877	0.463542	29.13
[bmim][PF6]	10	288.15	284.2	762.5	198.54	719.4	17.3	17.52964	0.7917	0.400542	302.69
		293.15	284.2	762.5	198.54	719.4	17.3	17.52964	0.7917	0.407492	297.03
		296.15	284.2	762.5	198.54	719.4	17.3	17.52964	0.7917	0.411662	293.79
		298.15	284.2	762.5	198.54	719.4	17.3	17.52964	0.7917	0.414443	291.69
		301.15	284.2	762.5	198.54	719.4	17.3	17.52964	0.7917	0.418613	288.64
		303.15	284.2	762.5	198.54	719.4	17.3	17.52964	0.7917	0.421393	286.67
		305.15	284.2	762.5	198.54	719.4	17.3	17.52964	0.7917	0.424173	284.74
		308.15	284.2	762.5	198.54	719.4	17.3	17.52964	0.7917	0.428343	281.92
		311.15	284.2	762.5	198.54	719.4	17.3	17.52964	0.7917	0.432513	279.20
		313.15	284.2	762.5	198.54	719.4	17.3	17.52964	0.7917	0.435293	277.44
[emim][PF6]	3	343.1	256.1	648.3	154.6	508.8	19.5	19.75884	0.7083	0.674332	20.01
		353.1	256.1	648.3	154.6	508.8	19.5	19.75884	0.7083	0.693986	19.70
		363.1	256.1	648.3	154.6	508.8	19.5	19.75884	0.7083	0.71364	19.42
[dmim][bti]	8	283.15	377.3	818.8	154.6	1239.9	35.8	36.27521	0.1752	0.228365	23.59
		293.15	377.3	818.8	154.6	1239.9	35.8	36.27521	1.1752	0.23643	22.98
		303.15	377.3	818.8	154.6	1239.9	35.8	36.27521	2.1752	0.244496	22.43
		313.15	377.3	818.8	154.6	1239.9	35.8	36.27521	3.1752	0.252561	21.95
		323.15	377.3	818.8	154.6	1239.9	35.8	36.27521	4.1752	0.260626	21.51
		333.15	377.3	818.8	154.6	1239.9	35.8	36.27521	5.1752	0.268691	21.12
		343.15	377.3	818.8	154.6	1239.9	35.8	36.27521	6.1752	0.276756	20.77
		353.15	377.3	818.8	154.6	1239.9	35.8	36.27521	7.1752	0.284821	20.45
[dmim][bf4]	1	298.15	310	997.7	203.12	784.6	14.5	14.69247	1.082	0.380003	26.37
[C8mim] [BF4]	17	283.15	282.13	812.3	263.88	726.1	16	16.21238	0.9954	0.38996	50.59
		288.15	282.13	812.3	263.88	726.1	16	16.21238	0.9954	0.396846	49.14
		293.15	282.13	812.3	263.88	726.1	16	16.21238	0.9954	0.403732	47.79

Table 4.4.5 Calculation for Unified Equation for the Viscosity of Pure Liquids (cont.)

		298.15	282.13	812.3	263.88	726.1	16	16.21238	0.9954	0.410618	46.52
		303.15	282.13	812.3	263.88	726.1	16	16.21238	0.9954	0.417504	45.33
		308.15	282.13	812.3	263.88	726.1	16	16.21238	0.9954	0.424391	44.22
		313.15	282.13	812.3	263.88	726.1	16	16.21238	0.9954	0.431277	43.17
		318.15	282.13	812.3	263.88	726.1	16	16.21238	0.9954	0.438163	42.19
		323.15	282.13	812.3	263.88	726.1	16	16.21238	0.9954	0.445049	41.26
		328.15	282.13	812.3	263.88	726.1	16	16.21238	0.9954	0.451935	40.39
		333.15	282.13	812.3	263.88	726.1	16	16.21238	0.9954	0.458821	39.56
		338.15	282.13	812.3	263.88	726.1	16	16.21238	0.9954	0.465707	38.78
		343.15	282.13	812.3	263.88	726.1	16	16.21238	0.9954	0.472593	38.04
		348.15	282.13	812.3	263.88	726.1	16	16.21238	0.9954	0.479479	37.34
		353.15	282.13	812.3	263.88	726.1	16	16.21238	0.9954	0.486366	36.67
		358.15	282.13	812.3	263.88	726.1	16	16.21238	0.9954	0.493252	36.04
		363.15	282.13	812.3	263.88	726.1	16	16.21238	0.9954	0.500138	35.44

For the complete calculation excel spreadsheet, kindly refer to APPENDIX.

4.5 Master Table

Table 4.5 Master Calculation Table

Methods				Letsou & Stiel		Golubev		Uyehara and Watson		Lewis & Squires		Unified Equation for Pure Liquids	
IL name	Data Points	Temp. (K)	Exp. Visc. (cP)	Calc. visc.	%AAD	Calc. visc.	%AAD	Calc. visc.	%AAD	Calc. visc.	%AAD	Calc. visc.	%AAD
[emim][BF4]	16	290.00	46.00	69.65	33.96	46.26	0.57	43.40	5.65	52.74	12.78	44.13	4.24
		295.00	41.00	68.00	39.70	47.64	16.21	43.40	5.85	48.00	14.58	43.07	4.80
		300.00	32.00	66.36	51.78	49.02	53.19	43.40	35.62	43.90	27.11	42.08	23.95
		305.00	31.00	64.74	52.12	50.39	62.56	40.30	30.00	40.35	23.17	41.14	24.65
		310.00	27.00	63.15	57.24	51.76	91.70	37.20	37.77	37.23	27.49	40.26	32.94
		315.00	24.00	37.17	35.43	42.12	75.49	37.20	55.00	34.49	30.41	39.44	39.14
		320.00	22.00	38.33	42.61	29.47	33.96	31.00	40.91	32.06	31.37	38.66	43.09
		325.00	21.00	37.12	43.43	31.82	51.52	24.80	18.09	29.89	29.75	37.92	44.62
		330.00	19.00	56.95	66.64	32.16	69.26	24.80	30.52	27.95	32.02	37.22	48.96
		335.00	18.00	55.46	67.54	24.49	36.07	21.70	20.55	26.21	31.31	36.56	50.77
		340.00	18.00	53.98	66.65	19.82	10.11	19.00	5.53	24.63	26.92	35.94	49.91
		345.00	16.00	52.52	69.53	31.14	94.62	15.50	3.13	23.20	31.04	35.35	54.73
		350.00	15.00	51.08	70.63	32.45	116.35	15.50	3.33	21.90	31.52	34.78	56.87
		355.00	15.00	49.66	69.80	23.76	58.38	12.40	17.34	20.72	27.60	34.25	56.20
		360.00	15.00	48.26	68.92	23.06	53.70	9.30	38.00	19.63	23.59	33.74	55.54
		365.00	13.00	46.88	72.27	18.35	41.12	6.20	52.31	18.63	30.24	33.25	60.91
[bmim][BF4]	9	283.15	277.00	119.71	131.39	37.88	86.33	141.55	48.90	115.02	140.84	268.60	3.13
		293.15	154.00	114.29	34.74	40.43	73.75	141.55	8.09	86.39	78.27	261.13	41.02
		303.15	91.40	108.99	16.14	42.97	52.99	71.55	21.72	67.72	34.96	25.44	259.0

Table 4.5 Master Calculation Table (cont.)

		313.15	59.10	103.82	43.07	45.49	23.02	38.58	34.72	54.80	7.85	24.83	138.0
		323.15	39.60	55.69	28.90	48.00	21.22	35.61	10.08	45.43	12.83	24.28	63.13
		333.15	28.00	78.75	64.45	50.50	80.35	35.61	27.18	38.40	27.09	30.24	7.41
		343.15	20.40	77.09	73.54	36.14	77.16	29.68	45.47	32.97	38.13	29.67	31.24
		353.15	15.50	76.11	79.63	20.52	32.39	23.74	53.16	28.68	45.96	29.34	47.18
		363.15	11.90	75.45	84.23	17.54	47.39	20.77	74.56	25.23	52.83	29.13	59.15
[bmim][PF6]	10	288.15	400.20	74.25	438.96	32.09	91.98	40.97	89.76	204.94	95.27	302.69	32.21
		293.15	294.00	102.96	185.55	33.26	88.69	40.97	86.07	184.53	59.32	297.03	1.02
		296.15	245.80	155.66	57.91	33.96	86.18	40.97	83.33	160.57	53.08	293.79	16.33
		298.15	217.90	157.24	38.58	34.43	84.20	38.04	82.54	145.68	49.58	291.69	25.30
		301.15	182.70	172.59	5.86	35.13	80.77	35.12	80.78	104.79	74.34	288.64	36.70
		303.15	162.90	204.51	20.35	35.60	78.15	35.12	78.44	86.08	89.23	286.67	43.17
		305.15	145.10	76.90	88.68	36.07	75.14	29.26	79.83	81.76	77.47	284.74	49.04
		308.15	123.20	76.07	61.96	36.77	70.15	23.41	81.00	75.89	62.33	281.92	56.30
		311.15	104.00	75.24	38.23	37.47	63.97	20.48	80.30	70.68	47.14	98.20	5.90
		313.15	95.00	74.68	27.20	37.94	60.06	20.48	78.44	67.52	40.70	77.44	22.67
[emim][PF6]	3	343.10	23.40	35.53	34.14	73.81	215.42	22.31	4.65	39.32	40.49	20.01	16.95
		353.10	17.10	32.90	48.03	76.61	347.99	19.12	11.84	33.69	49.25	19.70	13.20
		363.10	13.30	30.37	56.21	79.37	496.74	19.12	43.80	29.26	54.54	19.42	31.52
[dmim][bti]	8	283.15	77.06	94.98	18.87	13.12	82.98	65.01	15.64	65.76	17.18	73.25	5.20
		293.15	47.46	257.41	81.56	14.96	68.49	60.01	26.43	53.40	11.13	42.51	11.64
		303.15	31.58	413.27	92.36	16.90	46.49	50.00	58.34	44.40	28.87	22.43	40.78
		313.15	22.32	563.17	96.04	18.93	15.18	40.00	79.23	37.61	40.66	21.95	1.70
		323.15	16.55	739.96	97.76	21.05	27.20	25.00	51.08	32.35	48.85	21.51	23.07
		333.15	12.75	884.61	98.56	23.25	82.37	15.00	17.67	28.19	54.77	21.12	39.63
		343.15	10.14	1023.2	99.01	25.53	151.75	15.00	47.93	24.82	59.15	8.47	19.72
		353.15	8.28	1156.0	99.28	27.87	236.58	10.04	21.22	22.06	62.47	6.99	18.45

Table 4.5 Master Calculation Table (cont.)

[dmim][bf4]	1	298.15	34.00	99.38	65.79	29.94	11.94	16.07	52.74	-	-	26.37	28.91
[C8mim][Bf4]	17	283.15	132.40	92.28	43.48	28.72	78.31	35.92	72.87	204.05	35.11	150.59	12.08
		288.15	187.50	90.67	106.80	29.81	84.10	33.16	82.31	165.67	13.18	149.14	25.72
		293.15	162.90	89.07	82.89	30.91	81.03	33.16	79.64	137.72	18.28	147.79	10.23
		298.15	224.17	198.44	12.97	32.01	85.72	27.63	87.67	216.66	3.47	146.52	53.00
		303.15	246.18	188.25	30.77	33.10	86.55	246.11	0.03	200.35	22.87	145.33	69.39
		308.15	191.95	174.92	9.74	34.20	82.18	19.34	89.92	187.42	2.41	144.22	33.10
		313.15	147.92	133.92	10.45	35.30	76.14	19.34	86.92	76.99	92.14	143.17	3.32
		318.15	116.38	110.67	5.16	36.40	68.73	19.34	83.38	68.42	70.09	142.19	18.15
		323.15	91.95	79.78	15.26	37.49	59.22	16.58	81.97	61.29	50.01	141.26	34.91
		328.15	74.79	78.28	4.46	38.59	48.40	16.58	77.83	55.29	35.26	40.39	85.19
		333.15	60.95	76.79	20.63	39.68	34.89	35.92	41.06	50.19	21.45	39.56	54.07
		338.15	50.88	75.32	32.45	40.77	19.86	33.16	34.82	45.80	11.10	38.78	31.21
		343.15	42.06	73.87	43.06	41.86	0.47	27.63	34.30	42.00	0.15	38.04	10.57
		348.15	35.78	72.42	50.60	42.95	20.04	22.11	38.21	38.68	7.50	37.34	4.17
		353.15	30.11	71.00	57.59	44.03	46.24	19.34	35.76	35.77	15.82	36.67	17.89
		358.15	25.87	131.12	80.27	45.11	74.39	19.34	25.23	33.19	22.06	36.04	28.22
		363.15	21.57	128.49	83.21	46.19	114.15	19.34	10.32	30.90	30.20	35.44	39.13
[bmim][TFES]	1	298.15	23.00	18.50	24.35	20.88	9.23	31.98	39.06	-	-	29.92	23.14
[emim][TFES]	1	298.15	17.24	25.29	31.83	11.85	31.27	26.22	52.11	-	-	49.82	65.39
[nmim][bti]	1	298.15	28.90	24.84	16.32	9.43	67.37	32.15	11.24	-	-	17.04	69.64
[pmim][bti]	1	298.15	20.00	20.93	4.45	12.12	39.39	36.25	81.26	-	-	27.74	27.90
[bmim][Cl]	1	298.15	25.00	12.08	106.93	30.88	23.52	26.49	5.95	-	-	28.46	12.15
[C12mim][Cl]	1	298.15	29.90	18.52	61.41	17.83	40.38	22.86	23.54	-	-	24.33	22.90
[dmprim][bti]	16	290.00	131.00	110.57	18.48	11.65	91.11	31.47	75.98	103.35	26.75	149.44	12.34
		295.00	106.00	494.39	78.56	12.43	88.27	30.40	71.32	98.77	7.32	98.72	7.37
		300.00	85.00	77.46	9.73	13.24	84.42	29.33	65.49	72.35	17.48	50.39	68.69

Table 4.5 Master Calculation Table (cont.)

		305.00	69.00	104.98	34.27	14.07	79.61	28.27	59.03	58.98	16.99	49.08	40.57
		310.00	58.00	131.98	56.05	14.92	74.28	27.20	53.10	53.33	8.76	47.86	21.19
		315.00	49.00	158.47	69.08	15.79	67.78	26.14	46.66	48.50	1.02	46.71	4.90
		320.00	42.00	184.46	77.23	16.68	60.29	25.07	40.30	44.34	5.29	45.63	7.95
		325.00	37.00	209.95	82.38	17.58	52.47	24.01	35.12	40.73	9.16	44.61	17.05
		330.00	33.00	234.95	85.95	18.51	43.91	22.94	30.48	37.57	12.17	43.64	24.39
		335.00	29.00	1372.8	97.89	19.45	32.92	21.88	24.57	34.79	16.64	42.74	32.14
		340.00	27.00	2834.6	99.05	20.41	24.41	20.81	22.93	32.32	16.47	41.88	35.52
		345.00	24.00	306.99	92.18	21.38	10.90	19.74	17.73	30.13	20.34	41.06	41.55
		350.00	23.00	330.04	93.03	22.37	2.72	18.68	18.79	28.16	18.33	40.29	42.92
		355.00	21.00	352.60	94.04	23.38	11.32	17.61	16.13	26.40	20.45	39.56	46.92
		360.00	20.00	374.69	94.66	24.39	21.97	16.55	17.26	24.80	19.37	38.87	48.54
		365.00	19.00	396.30	95.21	25.42	33.81	15.48	18.52	23.36	18.66	38.21	50.27
[bmpyr][bti]	9	283.10	167.80	196.00	14.39	11.89	92.91	123.42	26.45	135.29	24.03	148.32	13.13
		293.10	96.20	86.21	11.59	13.51	85.96	88.32	8.19	71.91	33.77	88.70	8.46
		298.10	74.90	146.92	49.02	14.35	80.84	59.20	20.96	64.21	16.65	51.89	44.33
		303.10	59.50	976.16	93.90	15.21	74.44	80.33	35.01	57.76	3.02	50.51	17.80
		313.10	39.40	121.50	67.57	16.98	56.89	9.59	75.66	47.61	17.24	47.99	17.90
		323.10	28.40	144.39	80.33	18.83	33.69	8.58	69.78	40.06	29.10	45.77	37.95
		333.10	20.90	166.32	87.43	20.75	0.74	7.58	63.75	34.26	39.00	43.79	52.27
		343.10	15.90	187.28	91.51	22.72	42.88	6.57	58.68	19.71	19.33	42.03	62.17
		353.10	13.10	207.31	93.68	24.74	88.87	5.56	57.53	16.06	18.43	40.44	67.61
%AAAD				63.34		68.75		43.99		32.64		35.96	

4.6 Summary of Calculation Results

Table 4.6: Summary of Calculation Results

Prediction Method	ILs Calculated	Data Points	Temperature Range(K)	%AAAD
Letsou & Stiel	20	100	283.15-363.15	63.34
Golubev	20	100	283.15-363.15	68.75
Uyehara and Watson	20	100	283.15-363.15	43.99
Lewis & Squires	16	88	283.15-363.15	32.64
Unified Equation for Pure Liquids	20	100	283.15-363.15	35.96

4.7 Discussion

The above results and tables clearly show that all the required data and information has been successfully obtained through detailed research. Besides that, calculation for around 100 data points for each method has been performed with the help of Microsoft Excel software. The figure below summarizes the research results and the comparison of %AAAD between the 5 identified methods, which are the Letsou & Stiel method, Golubev method, Uyehara and Watson method, Lewis & Squires method, and the Unified Equation for Pure Liquids method.

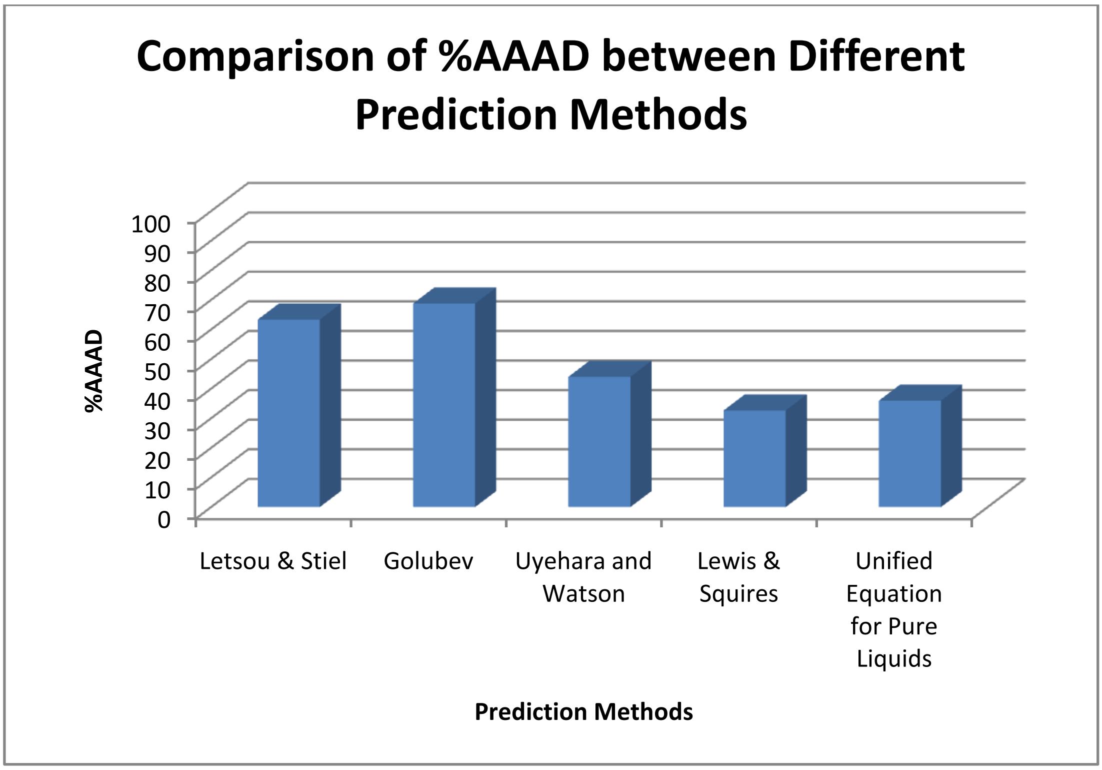


Figure 4.3: Comparison of % AAAD between Different Prediction Methods

The graph above indicates that the Lewis & Squires method, with an Average of Absolute Average Deviation (%AAAD) of 32.64% is the best correlation for the prediction of liquid viscosity of Ionic Liquids. The Unified Equation for Pure Liquids is not far behind as it gives a %AAAD of 35.96%. Uyehara and Watson method performed fair results, with a %AAAD of around 40%. Letsou & Stiel and Golubev method, on the other hand, performed mediocre-ly with error deviation with less than 50% accuracy. The 5 correlations considered in the study gave varying results and none of them can be claimed to give the most accurate representation for all ILs at all temperatures. Therefore, the averages of the deviations were used to determine their accuracy in predicting the IL viscosities.

As we can see, although the prediction results may not be pin-point accurate, but that is to be expected as these equations are not proven to be accurate for ILs. It should also be mentioned that most generalized correlations were derived for organic fluids and no applications to ILs had been done. This could explain the greater deviations found in some particular cases.

Even though as of now, the estimation of viscosity of ILs cannot give a true representation of the actual viscosity, but by performing this research, we can know roughly the viscosity of ILs and this will benefit the industry in a great manner. For instance, just by applying the Lewis & Squires method, we can know what range the viscosity of IL is in, and thus, we can easily identify the suitable applications for the ILs, be it in the lubricant industry, or in the solvents industry. This will definitely save cost and time because this method is by far more cost-effective and time-saving as viscosity of ILs can be determined by just applying the Lewis & Squires method(which is basically cost-less) instead of identifying the viscosity of ILs through Experimental methods, such as using a viscometer.

CHAPTER 5

CONCLUSIONS & RECOMMENDATIONS

5 CONCLUSIONS & RECOMMENDATIONS

5.1 Conclusions

In conclusion, all the objectives set during the planning of the project were achieved successfully. As a recap, the objectives of the project were:

- To review current literature to find the equations that are used to predict viscosity of liquids using their critical properties
- To compare different prediction methods of viscosity of ILs with the actual viscosity and compare their accuracy.
- To determine the best and most accurate generalized correlation in estimating the viscosities of Ionic Liquids.

For this project, 5 different equations namely the Letsou & Stiel method, Golubev method, Uyehara and Watson method, Lewis & Squires method, and the Unified Equation for Pure Liquids method were successfully identified. Besides, their accuracy was identified and compared against each other using Chemical Engineering knowledge and calculations that involve the critical properties of ILs as the parameters of the equations. To wrap up, after months of hard work, the ultimate objective of the project which is to come up with the best prediction method was met successfully and the prediction method that performed the best was the Lewis & Squires method.

This research is definitely an asset to the Ionic Liquid industry, which is rapidly blooming due to the “green” or environmental friendly nature of Ionic Liquids compared to other VOC chemicals.

5.2 Recommendations

This project is a new specific area of research as far as the chemical engineering community is concerned, as ILs are relatively new compared to other chemicals and this may serve as a starting point for further related researches. As more researches related to the physical and chemical properties of ILs are done, the potential of ILs as substitutes for non-environmental friendly chemicals especially solvents can be fulfilled. For now, research regarding the viscosity of ILs are far from sufficient and is lacking behind compared to researches done regarding especially the density and other properties of Ionic Liquids.

Although this project has served its purpose by identifying the best method for viscosity prediction of ILs so that we can identify their potential applications, there is still much to be desired from the accuracy of the prediction methods. Therefore, further research on the prediction of viscosity of Ionic Liquids can be continued, using this research project as a basis or reference, since this is the first research project done to compare the viscosity prediction methods of Ionic Liquids using only their critical properties and basic properties.

In a nutshell, more and more research of this nature has to be done in order to ensure that the potential of ILs in replacing current non-environmental friendly chemicals can be fulfilled as Ionic Liquids might just be the answer to the pollution and sustainability issues that all of us are facing currently and also in the future.

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APPENDIX

From Excel File,

Letsou & Stiel Method

IL	Temperature(K)	M	Pc(bar)	Pc(atm)	Ꞷ	Tr	(μγ)0	(μγ)1	μγ	γ	μ(cP)
[emim][BF4]	290.00	198.00	23.60	23.91	0.81	0.49	0.01	0.01	0.02	0.02	69.65
	295.00	198.00	23.60	23.91	0.81	0.49	0.01	0.01	0.02	0.02	68.00
	300.00	198.00	23.60	23.91	0.81	0.50	0.01	0.01	0.02	0.02	66.36
	305.00	198.00	23.60	23.91	0.81	0.51	0.01	0.01	0.02	0.02	64.74
	310.00	198.00	23.60	23.91	0.81	0.52	0.01	0.01	0.02	0.02	63.15
	315.00	198.00	23.60	23.91	0.81	0.53	0.01	0.01	0.02	0.02	61.57
	320.00	198.00	23.60	23.91	0.81	0.54	0.01	0.01	0.01	0.02	60.01
	325.00	198.00	23.60	23.91	0.81	0.55	0.01	0.01	0.01	0.02	58.47
	330.00	198.00	23.60	23.91	0.81	0.55	0.01	0.01	0.01	0.02	56.95
	335.00	198.00	23.60	23.91	0.81	0.56	0.01	0.01	0.01	0.02	55.46
	340.00	198.00	23.60	23.91	0.81	0.57	0.01	0.01	0.01	0.02	53.98
	345.00	198.00	23.60	23.91	0.81	0.58	0.01	0.01	0.01	0.02	52.52
	350.00	198.00	23.60	23.91	0.81	0.59	0.01	0.01	0.01	0.02	51.08
	355.00	198.00	23.60	23.91	0.81	0.60	0.01	0.01	0.01	0.02	49.66
	360.00	198.00	23.60	23.91	0.81	0.60	0.01	0.01	0.01	0.02	48.26
	365.00	198.00	23.60	23.91	0.81	0.61	0.00	0.01	0.01	0.02	46.88
[bmim][BF4]	323.15	226.00	20.40	20.67	0.89	0.50	0.01	0.01	0.02	0.01	119.71
	333.15	226.00	20.40	20.67	0.89	0.52	0.01	0.01	0.02	0.01	114.29
	343.15	226.00	20.40	20.67	0.89	0.53	0.01	0.01	0.02	0.01	108.99
	353.15	226.00	20.40	20.67	0.89	0.55	0.01	0.01	0.02	0.01	103.82
	363.15	226.00	20.40	20.67	0.89	0.56	0.01	0.01	0.01	0.03	55.69
	288.15	226.00	20.40	20.67	0.89	0.45	0.01	0.02	0.02	0.03	78.75
	293.15	226.00	20.40	20.67	0.89	0.46	0.01	0.01	0.02	0.03	77.09
	296.15	226.00	20.40	20.67	0.89	0.46	0.01	0.01	0.02	0.03	76.11
	298.15	226.00	20.40	20.67	0.89	0.46	0.01	0.01	0.02	0.03	75.45
[bmim][PF6]	288.15	284.20	17.30	17.53	0.79	0.40	0.01	0.02	0.02	0.03	74.25
	293.15	284.20	17.30	17.53	0.79	0.41	0.01	0.02	0.02	0.03	72.95

	296.15	284.20	17.30	17.53	0.79	0.41	0.01	0.02	0.02	0.03	72.17
	298.15	284.20	17.30	17.53	0.79	0.41	0.01	0.02	0.02	0.03	71.66
	301.15	284.20	17.30	17.53	0.79	0.42	0.01	0.02	0.02	0.03	78.03
	303.15	284.20	17.30	17.53	0.79	0.42	0.01	0.02	0.02	0.03	77.46
	305.15	284.20	17.30	17.53	0.79	0.42	0.01	0.02	0.02	0.03	76.90
	308.15	284.20	17.30	17.53	0.79	0.43	0.01	0.02	0.02	0.03	76.07
	311.15	284.20	17.30	17.53	0.79	0.43	0.01	0.02	0.02	0.03	75.24
	313.15	284.20	17.30	17.53	0.79	0.44	0.01	0.02	0.02	0.03	74.68
[emim][PF6]	343.10	256.10	19.50	19.76	0.71	0.67	0.00	0.01	0.01	0.02	35.53
	353.10	256.10	19.50	19.76	0.71	0.69	0.00	0.01	0.01	0.02	32.90
	363.10	256.10	19.50	19.76	0.71	0.71	0.00	0.01	0.01	0.02	30.37
[dmim][bti]	283.15	377.30	35.80	36.28	0.18	0.23	0.01	0.03	0.02	0.02	9.50
	293.15	377.30	35.80	36.28	1.18	0.24	0.01	0.03	0.04	0.02	257.41
	303.15	377.30	35.80	36.28	2.18	0.24	0.01	0.03	0.07	0.02	413.27
	313.15	377.30	35.80	36.28	3.18	0.25	0.01	0.03	0.09	0.02	563.17
	323.15	377.30	35.80	36.28	4.18	0.26	0.01	0.02	0.11	0.02	739.96
	333.15	377.30	35.80	36.28	5.18	0.27	0.01	0.02	0.14	0.02	884.61
	343.15	377.30	35.80	36.28	6.18	0.28	0.01	0.02	0.16	0.02	1023.28
	353.15	377.30	35.80	36.28	7.18	0.28	0.01	0.02	0.18	0.02	1156.07
[dmim][bf4]	298.15	310.00	14.50	14.69	1.08	0.38	0.01	0.02	0.03	0.03	99.38
[C8mim] [BF4]	283.15	282.13	16.00	16.21	1.00	0.39	0.01	0.02	0.03	0.03	92.28
	288.15	282.13	16.00	16.21	1.00	0.40	0.01	0.02	0.03	0.03	90.67
	293.15	282.13	16.00	16.21	1.00	0.40	0.01	0.02	0.02	0.03	89.07
	298.15	282.13	16.00	16.21	1.00	0.41	0.01	0.02	0.02	0.03	87.48
	303.15	282.13	16.00	16.21	1.00	0.42	0.01	0.02	0.02	0.03	85.92
	308.15	282.13	16.00	16.21	1.00	0.42	0.01	0.02	0.02	0.03	84.36
	313.15	282.13	16.00	16.21	1.00	0.43	0.01	0.02	0.02	0.03	82.82
	318.15	282.13	16.00	16.21	1.00	0.44	0.01	0.02	0.02	0.03	81.29
	323.15	282.13	16.00	16.21	1.00	0.45	0.01	0.02	0.02	0.03	79.78
	328.15	282.13	16.00	16.21	1.00	0.45	0.01	0.01	0.02	0.03	78.28

	333.15	282.13	16.00	16.21	1.00	0.46	0.01	0.01	0.02	0.03	76.79
	338.15	282.13	16.00	16.21	1.00	0.47	0.01	0.01	0.02	0.03	75.32
	343.15	282.13	16.00	16.21	1.00	0.47	0.01	0.01	0.02	0.03	73.87
	348.15	282.13	16.00	16.21	1.00	0.48	0.01	0.01	0.02	0.03	72.42
	353.15	282.13	16.00	16.21	1.00	0.49	0.01	0.01	0.02	0.03	71.00
	358.15	282.13	16.00	16.21	1.00	0.49	0.01	0.01	0.02	0.01	131.12
	363.15	282.13	16.00	16.21	1.00	0.50	0.01	0.01	0.02	0.01	12.85
[bmim][TFES]	298.15	320.00	25.70	26.04	0.46	0.29	0.01	0.02	0.02	0.01	18.50
[emim][TFES]	298.15	433.00	15.60	15.81	0.81	0.25	0.01	0.03	0.03	0.01	25.29
[nmim][bti]	298.15	490.00	19.80	20.06	0.53	0.22	0.01	0.03	0.03	0.01	24.84
[pmim][bti]	298.15	433.00	25.60	25.94	0.34	0.23	0.01	0.03	0.02	0.01	20.93
[bmim][Cl]	298.15	174.70	27.80	28.17	0.49	0.38	0.01	0.02	0.02	0.01	12.08
[C12mim][Cl]	298.15	286.90	16.00	16.21	0.82	0.31	0.01	0.02	0.03	0.01	18.52
[dmprim][bti]	290.00	419.00	27.50	27.87	0.32	0.23	0.01	0.03	0.02	0.02	110.57
	295.00	419.00	27.50	27.87	1.32	0.23	0.01	0.03	0.05	0.01	494.39
	300.00	419.00	27.50	27.87	2.32	0.24	0.01	0.03	0.07	0.01	77.46
	305.00	419.00	27.50	27.87	3.32	0.24	0.01	0.03	0.10	0.01	104.98
	310.00	419.00	27.50	27.87	4.32	0.24	0.01	0.03	0.12	0.01	131.98
	315.00	419.00	27.50	27.87	5.32	0.25	0.01	0.03	0.15	0.01	158.47
	320.00	419.00	27.50	27.87	6.32	0.25	0.01	0.03	0.17	0.01	184.46
	325.00	419.00	27.50	27.87	7.32	0.26	0.01	0.03	0.19	0.01	209.95
	330.00	419.00	27.50	27.87	8.32	0.26	0.01	0.02	0.22	0.01	234.95
	335.00	419.00	27.50	27.87	9.32	0.26	0.01	0.02	0.24	0.02	1372.83
	340.00	419.00	27.50	27.87	10.32	0.27	0.01	0.02	0.26	0.01	2834.65
	345.00	419.00	27.50	27.87	11.32	0.27	0.01	0.02	0.28	0.01	306.99
	350.00	419.00	27.50	27.87	12.32	0.28	0.01	0.02	0.31	0.01	330.04
	355.00	419.00	27.50	27.87	13.32	0.28	0.01	0.02	0.33	0.01	352.60
	360.00	419.00	27.50	27.87	14.32	0.28	0.01	0.02	0.35	0.01	374.69
	365.00	419.00	27.50	27.87	15.32	0.29	0.01	0.02	0.37	0.01	396.30
[bmpyr][bti]	283.10	422.00	24.80	25.13	0.32	0.23	0.01	0.03	0.02	0.01	19.60
	293.10	422.00	24.80	25.13	1.32	0.24	0.01	0.03	0.04	0.01	46.01

298.10	422.00	24.80	25.13	2.32	0.25	0.01	0.03	0.07	0.02	377.88
303.10	422.00	24.80	25.13	3.32	0.25	0.01	0.03	0.09	0.01	976.16
313.10	422.00	24.80	25.13	4.32	0.26	0.01	0.02	0.12	0.01	121.50
323.10	422.00	24.80	25.13	5.32	0.27	0.01	0.02	0.14	0.01	144.39
333.10	422.00	24.80	25.13	6.32	0.28	0.01	0.02	0.16	0.01	166.32
343.10	422.00	24.80	25.13	7.32	0.28	0.01	0.02	0.18	0.01	187.28
353.10	422.00	24.80	25.13	8.32	0.29	0.01	0.02	0.20	0.01	207.31

Golubev Approach

IL	Data Points	Temperature(K)	M	Tc(K)	Pc(bar)	Pc(atm)	Tr	μ*c	μ
		290	198	596.2	23.6	23.91326	0.486414	118.5929	59.16
		295	198	596.2	23.6	23.91326	0.4948	118.5929	60.14
		300	198	596.2	23.6	23.91326	0.503187	118.5929	61.13
		305	198	596.2	23.6	23.91326	0.511573	118.5929	62.11
		310	198	596.2	23.6	23.91326	0.51996	118.5929	63.09
		315	198	596.2	23.6	23.91326	0.528346	118.5929	64.07
		320	198	596.2	23.6	23.91326	0.536733	118.5929	65.05
[emim][BF4]	16	325	198	596.2	23.6	23.91326	0.545119	118.5929	66.03
		330	198	596.2	23.6	23.91326	0.553506	118.5929	67.01
		335	198	596.2	23.6	23.91326	0.561892	118.5929	67.99
		340	198	596.2	23.6	23.91326	0.570278	118.5929	68.97
		345	198	596.2	23.6	23.91326	0.578665	118.5929	69.95
		350	198	596.2	23.6	23.91326	0.587051	118.5929	70.93
		355	198	596.2	23.6	23.91326	0.595438	118.5929	71.91
		360	198	596.2	23.6	23.91326	0.603824	118.5929	72.88
		365	198	596.2	23.6	23.91326	0.612211	118.5929	73.86
		283.15	226	643.2	20.4	20.67079	0.440221	116.4353	52.75
		293.15	226	643.2	20.4	20.67079	0.455768	116.4353	54.55
		303.15	226	643.2	20.4	20.67079	0.471315	116.4353	56.34
		313.15	226	643.2	20.4	20.67079	0.486863	116.4353	58.13
[bmim][BF4]	9	323.15	226	643.2	20.4	20.67079	0.50241	116.4353	59.92
		333.15	226	643.2	20.4	20.67079	0.517957	116.4353	61.71
		343.15	226	643.2	20.4	20.67079	0.533504	116.4353	63.50
		353.15	226	643.2	20.4	20.67079	0.549052	116.4353	65.28
		363.15	226	643.2	20.4	20.67079	0.564599	116.4353	67.07
		288.15	284.2	719.4	17.3	17.52964	0.400542	119.1856	49.29
[bmim][PF6]	10	293.15	284.2	719.4	17.3	17.52964	0.407492	119.1856	50.12
		296.15	284.2	719.4	17.3	17.52964	0.411662	119.1856	50.61

		298.15	284.2	719.4	17.3	17.52964	0.414443	119.1856	50.94
		301.15	284.2	719.4	17.3	17.52964	0.418613	119.1856	51.44
		303.15	284.2	719.4	17.3	17.52964	0.421393	119.1856	51.77
		305.15	284.2	719.4	17.3	17.52964	0.424173	119.1856	52.10
		308.15	284.2	719.4	17.3	17.52964	0.428343	119.1856	52.59
		311.15	284.2	719.4	17.3	17.52964	0.432513	119.1856	53.08
		313.15	284.2	719.4	17.3	17.52964	0.435293	119.1856	53.41
		343.1	256.1	508.8	19.5	19.75884	0.674332	115.6658	79.08
[emim][PF6]	3	353.1	256.1	508.8	19.5	19.75884	0.693986	115.6658	81.30
		363.1	256.1	508.8	19.5	19.75884	0.71364	115.6658	83.52
		283.15	377.3	1239.9	35.8	36.27521	0.228365	244.1832	58.72
		293.15	377.3	1239.9	35.8	36.27521	0.23643	244.1832	60.72
		303.15	377.3	1239.9	35.8	36.27521	0.244496	244.1832	62.72
[dmim][bti]	8	313.15	377.3	1239.9	35.8	36.27521	0.252561	244.1832	64.71
		323.15	377.3	1239.9	35.8	36.27521	0.260626	244.1832	66.71
		333.15	377.3	1239.9	35.8	36.27521	0.268691	244.1832	68.70
		343.15	377.3	1239.9	35.8	36.27521	0.276756	244.1832	70.69
		353.15	377.3	1239.9	35.8	36.27521	0.284821	244.1832	72.67
[dmim][bf4]	1	298.15	310	784.6	14.5	14.69247	0.380003	112.2674	44.13
		283.15	282.13	726.1	16	16.21238	0.38996	112.899	45.50
		288.15	282.13	726.1	16	16.21238	0.396846	112.899	46.28
		293.15	282.13	726.1	16	16.21238	0.403732	112.899	47.05
		298.15	282.13	726.1	16	16.21238	0.410618	112.899	47.83
		303.15	282.13	726.1	16	16.21238	0.417504	112.899	48.60
[C8mim] [BF4]	17	308.15	282.13	726.1	16	16.21238	0.424391	112.899	49.37
		313.15	282.13	726.1	16	16.21238	0.431277	112.899	50.15
		318.15	282.13	726.1	16	16.21238	0.438163	112.899	50.92
		323.15	282.13	726.1	16	16.21238	0.445049	112.899	51.69
		328.15	282.13	726.1	16	16.21238	0.451935	112.899	52.46
		333.15	282.13	726.1	16	16.21238	0.458821	112.899	53.23
		338.15	282.13	726.1	16	16.21238	0.465707	112.899	54.00

		343.15	282.13	726.1	16	16.21238	0.472593	112.899	54.77
		348.15	282.13	726.1	16	16.21238	0.479479	112.899	55.54
		353.15	282.13	726.1	16	16.21238	0.486366	112.899	56.31
		358.15	282.13	726.1	16	16.21238	0.493252	112.899	57.08
		363.15	282.13	726.1	16	16.21238	0.500138	112.899	57.85
[bmim][TFES]	1	298	320	1030.5	25.7	26.04114	0.28918	174.82	52.80
[emim][TFES]	1	298	433	1171	15.6	15.80707	0.254483	148.9267	39.76
[nmim][bti]	1	298	490	1331.2	19.8	20.06282	0.223858	189.7294	44.76
[pmim][bti]	1	298	433	1281.1	25.6	25.93981	0.232613	210.3231	51.49
[bmim][Cl]	1	298	174.7	789	27.8	28.16901	0.377693	130.1892	50.88
[C12mim][Cl]	1	298	286.9	951.5	16	16.21238	0.31319	119.0966	38.85
[dmprim][bti]	16	290	419	1269.7	27.5	27.86503	0.2284	216.6864	52.12
		295	419	1269.7	27.5	27.86503	0.232338	216.6864	52.98
		300	419	1269.7	27.5	27.86503	0.236276	216.6864	53.85
		305	419	1269.7	27.5	27.86503	0.240214	216.6864	54.72
		310	419	1269.7	27.5	27.86503	0.244152	216.6864	55.58
		315	419	1269.7	27.5	27.86503	0.24809	216.6864	56.45
		320	419	1269.7	27.5	27.86503	0.252028	216.6864	57.31
		325	419	1269.7	27.5	27.86503	0.255966	216.6864	58.17
		330	419	1269.7	27.5	27.86503	0.259904	216.6864	59.04
		335	419	1269.7	27.5	27.86503	0.263842	216.6864	59.90
		340	419	1269.7	27.5	27.86503	0.26778	216.6864	60.76
		345	419	1269.7	27.5	27.86503	0.271718	216.6864	61.62
		350	419	1269.7	27.5	27.86503	0.275656	216.6864	62.49
		355	419	1269.7	27.5	27.86503	0.279594	216.6864	63.35
		360	419	1269.7	27.5	27.86503	0.283532	216.6864	64.21
		365	419	1269.7	27.5	27.86503	0.287469	216.6864	65.07
[bmpyr][bti]	9	283.1	422	1209.2	24.8	25.12919	0.234122	201.3383	49.59
		293.1	422	1209.2	24.8	25.12919	0.242392	201.3383	51.28
		298.1	422	1209.2	24.8	25.12919	0.246527	201.3383	52.13
		303.1	422	1209.2	24.8	25.12919	0.250662	201.3383	52.97

313.1	422	1209.2	24.8	25.12919	0.258932	201.3383	54.66
323.1	422	1209.2	24.8	25.12919	0.267201	201.3383	56.34
333.1	422	1209.2	24.8	25.12919	0.275471	201.3383	58.02
343.1	422	1209.2	24.8	25.12919	0.283741	201.3383	59.70
353.1	422	1209.2	24.8	25.12919	0.292011	201.3383	61.38

Uyehara and Watson

IL	Data Points	Temperature(K)	M	Tc(K)	Pc(bar)	Pc(atm)	Pr	Tr	µC	µR	µ
[emim][BF4]	16	290	198	596.2	23.6	23.91326	0.041818	0.486414	309.9921	0.14	43.40
		295	198	596.2	23.6	23.91326	0.041818	0.4948	309.9921	0.14	43.40
		300	198	596.2	23.6	23.91326	0.041818	0.503187	309.9921	0.14	43.40
		305	198	596.2	23.6	23.91326	0.041818	0.511573	309.9921	0.13	40.30
		310	198	596.2	23.6	23.91326	0.041818	0.51996	309.9921	0.12	37.20
		315	198	596.2	23.6	23.91326	0.041818	0.528346	309.9921	0.12	37.20
		320	198	596.2	23.6	23.91326	0.041818	0.536733	309.9921	0.10	31.00
		325	198	596.2	23.6	23.91326	0.041818	0.545119	309.9921	0.08	24.80
		330	198	596.2	23.6	23.91326	0.041818	0.553506	309.9921	0.08	24.80
		335	198	596.2	23.6	23.91326	0.041818	0.561892	309.9921	0.07	21.70
		340	198	596.2	23.6	23.91326	0.041818	0.570278	309.9921	0.60	186.00
		345	198	596.2	23.6	23.91326	0.041818	0.578665	309.9921	0.05	15.50
		350	198	596.2	23.6	23.91326	0.041818	0.587051	309.9921	0.05	15.50
		355	198	596.2	23.6	23.91326	0.041818	0.595438	309.9921	0.04	12.40
		360	198	596.2	23.6	23.91326	0.041818	0.603824	309.9921	0.03	9.30
		365	198	596.2	23.6	23.91326	0.041818	0.612211	309.9921	0.02	6.20
[bmim][BF4]	9	283.15	226	643.2	20.4	20.67079	0.048377	0.440221	296.7508	0.14	41.55
		293.15	226	643.2	20.4	20.67079	0.048377	0.455768	296.7508	0.14	41.55
		303.15	226	643.2	20.4	20.67079	0.048377	0.471315	296.7508	0.14	41.55
		313.15	226	643.2	20.4	20.67079	0.048377	0.486863	296.7508	0.13	38.58
		323.15	226	643.2	20.4	20.67079	0.048377	0.50241	296.7508	0.12	35.61
		333.15	226	643.2	20.4	20.67079	0.048377	0.517957	296.7508	0.12	35.61
		343.15	226	643.2	20.4	20.67079	0.048377	0.533504	296.7508	0.10	29.68
		353.15	226	643.2	20.4	20.67079	0.048377	0.549052	296.7508	0.08	23.74
		363.15	226	643.2	20.4	20.67079	0.048377	0.564599	296.7508	0.07	20.77
[bmim][PF6]	10	288.15	284.2	719.4	17.3	17.52964	0.057046	0.400542	292.6328	0.14	40.97
		293.15	284.2	719.4	17.3	17.52964	0.057046	0.407492	292.6328	0.14	40.97

		296.15	284.2	719.4	17.3	17.52964	0.057046	0.411662	292.6328	0.14	40.97
		298.15	284.2	719.4	17.3	17.52964	0.057046	0.414443	292.6328	0.13	38.04
		301.15	284.2	719.4	17.3	17.52964	0.057046	0.418613	292.6328	0.12	35.12
		303.15	284.2	719.4	17.3	17.52964	0.057046	0.421393	292.6328	0.12	35.12
		305.15	284.2	719.4	17.3	17.52964	0.057046	0.424173	292.6328	0.10	29.26
		308.15	284.2	719.4	17.3	17.52964	0.057046	0.428343	292.6328	0.08	23.41
		311.15	284.2	719.4	17.3	17.52964	0.057046	0.432513	292.6328	0.07	20.48
		313.15	284.2	719.4	17.3	17.52964	0.057046	0.435293	292.6328	0.07	20.48
		343.1	256.1	508.8	19.5	19.75884	0.05061	0.674332	318.7464	0.07	22.31
[emim][PF6]	3	353.1	256.1	508.8	19.5	19.75884	0.05061	0.693986	318.7464	0.06	19.12
		363.1	256.1	508.8	19.5	19.75884	0.05061	0.71364	318.7464	0.06	19.12
		283.15	377.3	1239.9	35.8	36.27521	0.027567	0.228365	500.0456	0.13	65.01
		293.15	377.3	1239.9	35.8	36.27521	0.027567	0.23643	500.0456	0.12	60.01
		303.15	377.3	1239.9	35.8	36.27521	0.027567	0.244496	500.0456	0.10	50.00
[dmim][bti]	8	313.15	377.3	1239.9	35.8	36.27521	0.027567	0.252561	500.0456	0.08	40.00
		323.15	377.3	1239.9	35.8	36.27521	0.027567	0.260626	500.0456	0.07	35.00
		333.15	377.3	1239.9	35.8	36.27521	0.027567	0.268691	500.0456	0.07	35.00
		343.15	377.3	1239.9	35.8	36.27521	0.027567	0.276756	500.0456	0.07	35.00
		353.15	377.3	1239.9	35.8	36.27521	0.027567	0.284821	500.0456	0.06	30.00
[dmim][bf4]	1	298.15	310	784.6	14.5	14.69247	0.068062	0.380003	267.7894	0.06	16.07
		283.15	282.13	726.1	16	16.21238	0.061681	0.38996	276.3422	0.13	35.92
		288.15	282.13	726.1	16	16.21238	0.061681	0.396846	276.3422	0.12	33.16
		293.15	282.13	726.1	16	16.21238	0.061681	0.403732	276.3422	0.12	33.16
		298.15	282.13	726.1	16	16.21238	0.061681	0.410618	276.3422	0.10	27.63
		303.15	282.13	726.1	16	16.21238	0.061681	0.417504	276.3422	0.08	22.11
[C8mim] [BF4]	17	308.15	282.13	726.1	16	16.21238	0.061681	0.424391	276.3422	0.07	19.34
		313.15	282.13	726.1	16	16.21238	0.061681	0.431277	276.3422	0.07	19.34
		318.15	282.13	726.1	16	16.21238	0.061681	0.438163	276.3422	0.07	19.34
		323.15	282.13	726.1	16	16.21238	0.061681	0.445049	276.3422	0.06	16.58
		328.15	282.13	726.1	16	16.21238	0.061681	0.451935	276.3422	0.06	16.58
		333.15	282.13	726.1	16	16.21238	0.061681	0.458821	276.3422	0.13	35.92

		338.15	282.13	726.1	16	16.21238	0.061681	0.465707	276.3422	0.12	33.16
		343.15	282.13	726.1	16	16.21238	0.061681	0.472593	276.3422	0.10	27.63
		348.15	282.13	726.1	16	16.21238	0.061681	0.479479	276.3422	0.08	22.11
		353.15	282.13	726.1	16	16.21238	0.061681	0.486366	276.3422	0.07	19.34
		358.15	282.13	726.1	16	16.21238	0.061681	0.493252	276.3422	0.07	19.34
		363.15	282.13	726.1	16	16.21238	0.061681	0.500138	276.3422	0.07	19.34
[bmim][TFES]	1	298	320	1030.5	25.7	26.04114	0.038401	0.28918	380.7714	0.08	31.98
[emim][TFES]	1	298	433	1171	15.6	15.80707	0.063263	0.254483	310.8442	0.08	26.22
[nmim][bti]	1	298	490	1331.2	19.8	20.06282	0.049843	0.223858	379.4398	0.08	32.15
[pmim][bti]	1	298	433	1281.1	25.6	25.93981	0.038551	0.232613	426.0384	0.09	36.25
[bmim][Cl]	1	298	174.7	789	27.8	28.16901	0.0355	0.377693	309.9598	0.09	26.49
[C12mim][Cl]	1	298	286.9	951.5	16	16.21238	0.061681	0.31319	266.3907	0.09	22.86
[dmprim][bti]	16	290	419	1269.7	27.5	27.86503	0.035887	0.2284	440.2377	0.07	31.47
		295	419	1269.7	27.5	27.86503	0.035887	0.232338	440.2377	0.07	30.40
		300	419	1269.7	27.5	27.86503	0.035887	0.236276	440.2377	0.07	29.33
		305	419	1269.7	27.5	27.86503	0.035887	0.240214	440.2377	0.06	28.27
		310	419	1269.7	27.5	27.86503	0.035887	0.244152	440.2377	0.06	27.20
		315	419	1269.7	27.5	27.86503	0.035887	0.24809	440.2377	0.06	26.14
		320	419	1269.7	27.5	27.86503	0.035887	0.252028	440.2377	0.06	25.07
		325	419	1269.7	27.5	27.86503	0.035887	0.255966	440.2377	0.05	24.01
		330	419	1269.7	27.5	27.86503	0.035887	0.259904	440.2377	0.05	22.94
		335	419	1269.7	27.5	27.86503	0.035887	0.263842	440.2377	0.05	21.88
		340	419	1269.7	27.5	27.86503	0.035887	0.26778	440.2377	0.05	20.81
		345	419	1269.7	27.5	27.86503	0.035887	0.271718	440.2377	0.04	19.74
		350	419	1269.7	27.5	27.86503	0.035887	0.275656	440.2377	0.04	18.68
		355	419	1269.7	27.5	27.86503	0.035887	0.279594	440.2377	0.04	17.61
		360	419	1269.7	27.5	27.86503	0.035887	0.283532	440.2377	0.04	16.55
		365	419	1269.7	27.5	27.86503	0.035887	0.287469	440.2377	0.04	15.48
[bmpyr][bti]	9	283.1	422	1209.2	24.8	25.12919	0.039794	0.234122	415.7666	0.03	13.61
		293.1	422	1209.2	24.8	25.12919	0.039794	0.242392	415.7666	0.03	12.61
		298.1	422	1209.2	24.8	25.12919	0.039794	0.246527	415.7666	0.03	11.60

303.1	422	1209.2	24.8	25.12919	0.039794	0.250662	415.7666	0.03	10.60
313.1	422	1209.2	24.8	25.12919	0.039794	0.258932	415.7666	0.02	9.59
323.1	422	1209.2	24.8	25.12919	0.039794	0.267201	415.7666	0.02	8.58
333.1	422	1209.2	24.8	25.12919	0.039794	0.275471	415.7666	0.02	7.58
343.1	422	1209.2	24.8	25.12919	0.039794	0.283741	415.7666	0.02	6.57
353.1	422	1209.2	24.8	25.12919	0.039794	0.292011	415.7666	0.01	5.56

Lewis & Squires Method

IL	Known Viscosity at T(K)	Data Points	Temperature(K)	M	Tc(K)	Pc(bar)	Pc(atm)	µL^-0.2661	µ
[emim][BF4]	Vk at 290k=46cP	16	290	198	596.2	23.6	23.91326376	0.3610274	52.74
			295	198	596.2	23.6	23.91326376	0.3824866	48.00
			300	198	596.2	23.6	23.91326376	0.4039458	43.90
			305	198	596.2	23.6	23.91326376	0.4254051	40.35
			310	198	596.2	23.6	23.91326376	0.4468643	37.23
			315	198	596.2	23.6	23.91326376	0.4683235	34.49
			320	198	596.2	23.6	23.91326376	0.4897827	32.06
			325	198	596.2	23.6	23.91326376	0.511242	29.89
			330	198	596.2	23.6	23.91326376	0.5327012	27.95
			335	198	596.2	23.6	23.91326376	0.5541604	26.21
			340	198	596.2	23.6	23.91326376	0.5756197	24.63
			345	198	596.2	23.6	23.91326376	0.5970789	23.20
			350	198	596.2	23.6	23.91326376	0.6185381	21.90
			355	198	596.2	23.6	23.91326376	0.6399973	20.72
			360	198	596.2	23.6	23.91326376	0.6614566	19.63
			365	198	596.2	23.6	23.91326376	0.6829158	18.63
[bmim][BF4]	Vk at 283.15k=277cP	9	283.15	226	643.2	20.4	20.67078731	0.2239011	115.02
			293.15	226	643.2	20.4	20.67078731	0.2668195	86.39
			303.15	226	643.2	20.4	20.67078731	0.309738	67.72
			313.15	226	643.2	20.4	20.67078731	0.3526564	54.80
			323.15	226	643.2	20.4	20.67078731	0.3955749	45.43
			333.15	226	643.2	20.4	20.67078731	0.4384933	38.40
			343.15	226	643.2	20.4	20.67078731	0.4814118	32.97
			353.15	226	643.2	20.4	20.67078731	0.5243302	28.68
			363.15	226	643.2	20.4	20.67078731	0.5672487	25.23
[bmim][PF6]	Vk at 288.15k=400.2cP	10	288.15	284.2	719.4	17.3	17.52963826	0.2030178	134.94

			293.15	284.2	719.4	17.3	17.52963826	0.224477	114.53
			296.15	284.2	719.4	17.3	17.52963826	0.2373525	104.57
			298.15	284.2	719.4	17.3	17.52963826	0.2459362	98.68
			301.15	284.2	719.4	17.3	17.52963826	0.2588118	90.79
			303.15	284.2	719.4	17.3	17.52963826	0.2673955	86.08
			305.15	284.2	719.4	17.3	17.52963826	0.2759792	81.76
			308.15	284.2	719.4	17.3	17.52963826	0.2888547	75.89
			311.15	284.2	719.4	17.3	17.52963826	0.3017302	70.68
			313.15	284.2	719.4	17.3	17.52963826	0.3103139	67.52
			343.1	256.1	508.8	19.5	19.75884081	0.4321671	39.32
[emim][PF6]	Vk at 343.1k=23.4cP	3	353.1	256.1	508.8	19.5	19.75884081	0.4750855	33.69
			363.1	256.1	508.8	19.5	19.75884081	0.518004	29.26
			283.15	377.3	1239.9	35.8	36.27520519	0.3153569	65.76
			293.15	377.3	1239.9	35.8	36.27520519	0.3582753	53.40
			303.15	377.3	1239.9	35.8	36.27520519	0.4011938	44.40
			313.15	377.3	1239.9	35.8	36.27520519	0.4441122	37.61
[dmim][bti]	Vk at 283k=77.06cP	8	323.15	377.3	1239.9	35.8	36.27520519	0.4870307	32.35
			333.15	377.3	1239.9	35.8	36.27520519	0.5299491	28.19
			343.15	377.3	1239.9	35.8	36.27520519	0.5728676	24.82
			353.15	377.3	1239.9	35.8	36.27520519	0.615786	22.06
			283.15	282.13	726.1	16	16.21238221	0.1575809	204.05
			288.15	282.13	726.1	16	16.21238221	0.1790401	165.67
			293.15	282.13	726.1	16	16.21238221	0.2004993	137.72
			298.15	282.13	726.1	16	16.21238221	0.2219586	116.66
			303.15	282.13	726.1	16	16.21238221	0.2434178	100.35
[C8mim] [BF4]	Vk at 283.15k = 1036.98cP	17	308.15	282.13	726.1	16	16.21238221	0.264877	87.42
			313.15	282.13	726.1	16	16.21238221	0.2863362	76.99
			318.15	282.13	726.1	16	16.21238221	0.3077955	68.42
			323.15	282.13	726.1	16	16.21238221	0.3292547	61.29
			328.15	282.13	726.1	16	16.21238221	0.3507139	55.29
			333.15	282.13	726.1	16	16.21238221	0.3721731	50.19

			338.15	282.13	726.1	16	16.21238221	0.3936324	45.80
			343.15	282.13	726.1	16	16.21238221	0.4150916	42.00
			348.15	282.13	726.1	16	16.21238221	0.4365508	38.68
			353.15	282.13	726.1	16	16.21238221	0.4580101	35.77
			358.15	282.13	726.1	16	16.21238221	0.4794693	33.19
			363.15	282.13	726.1	16	16.21238221	0.5009285	30.90
[dmprim][bti]	Vk at 290 = 131 cP	16	290	419	1269.7	27.5	27.86503192	0.2727299	83.35
			295	419	1269.7	27.5	27.86503192	0.2941891	73.66
			300	419	1269.7	27.5	27.86503192	0.3156484	65.67
			305	419	1269.7	27.5	27.86503192	0.3371076	58.98
			310	419	1269.7	27.5	27.86503192	0.3585668	53.33
			315	419	1269.7	27.5	27.86503192	0.3800261	48.50
			320	419	1269.7	27.5	27.86503192	0.4014853	44.34
			325	419	1269.7	27.5	27.86503192	0.4229445	40.73
			330	419	1269.7	27.5	27.86503192	0.4444037	37.57
			335	419	1269.7	27.5	27.86503192	0.465863	34.79
			340	419	1269.7	27.5	27.86503192	0.4873222	32.32
			345	419	1269.7	27.5	27.86503192	0.5087814	30.13
			350	419	1269.7	27.5	27.86503192	0.5302407	28.16
			355	419	1269.7	27.5	27.86503192	0.5516999	26.40
			360	419	1269.7	27.5	27.86503192	0.5731591	24.80
			365	419	1269.7	27.5	27.86503192	0.5946183	23.36
[bmpyr][bti]	Vk at 283.15= 167.8 cP	10	283.1	282.13	726.1	16	16.21238221	0.2556339	92.64
			293.1	282.13	726.1	16	16.21238221	0.2985524	71.91
			298.1	282.13	726.1	16	16.21238221	0.3200116	64.21
			303.1	282.13	726.1	16	16.21238221	0.3414708	57.76
			313.1	282.13	726.1	16	16.21238221	0.3843893	47.61
			323.1	282.13	726.1	16	16.21238221	0.4273077	40.06
			333.1	282.13	726.1	16	16.21238221	0.4702262	34.26
			343.1	282.13	726.1	16	16.21238221	0.5131446	29.71
			353.1	282.13	726.1	16	16.21238221	0.5560631	26.06

Unified Equation for the Viscosity of Pure Liquids

IL	Temperature(K)	M	Vc	Tm	Tc(K)	Pc(atm)	ω	Tr	μ
	290.00	198.00	540.80	240.00	596.20	23.91	0.81	0.49	44.13
	295.00	198.00	540.80	240.00	596.20	23.91	0.81	0.49	43.07
	300.00	198.00	540.80	240.00	596.20	23.91	0.81	0.50	42.08
	305.00	198.00	540.80	240.00	596.20	23.91	0.81	0.51	41.14
	310.00	198.00	540.80	240.00	596.20	23.91	0.81	0.52	40.26
	315.00	198.00	540.80	240.00	596.20	23.91	0.81	0.53	39.44
	320.00	198.00	540.80	240.00	596.20	23.91	0.81	0.54	38.66
[emim][BF4]	325.00	198.00	540.80	240.00	596.20	23.91	0.81	0.55	37.92
	330.00	198.00	540.80	240.00	596.20	23.91	0.81	0.55	37.22
	335.00	198.00	540.80	240.00	596.20	23.91	0.81	0.56	36.56
	340.00	198.00	540.80	240.00	596.20	23.91	0.81	0.57	35.94
	345.00	198.00	540.80	240.00	596.20	23.91	0.81	0.58	35.35
	350.00	198.00	540.80	240.00	596.20	23.91	0.81	0.59	34.78
	355.00	198.00	540.80	240.00	596.20	23.91	0.81	0.60	34.25
	360.00	198.00	540.80	240.00	596.20	23.91	0.81	0.60	33.74
	365.00	198.00	540.80	240.00	596.20	23.91	0.81	0.61	33.25
	323.15	226.00	655.00	200.00	643.20	20.67	0.89	0.50	268.60
	333.15	226.00	655.00	200.00	643.20	20.67	0.89	0.52	261.13
	343.15	226.00	655.00	200.00	643.20	20.67	0.89	0.53	25.44
	353.15	226.00	655.00	200.00	643.20	20.67	0.89	0.55	24.83
[bmim][BF4]	363.15	226.00	655.00	200.00	643.20	20.67	0.89	0.56	24.28
	288.15	226.00	655.00	200.00	643.20	20.67	0.89	0.45	30.24
	293.15	226.00	655.00	200.00	643.20	20.67	0.89	0.46	29.67
	296.15	226.00	655.00	200.00	643.20	20.67	0.89	0.46	29.34
	298.15	226.00	655.00	200.00	643.20	20.67	0.89	0.46	29.13
	288.15	284.20	762.50	198.54	719.40	17.53	0.79	0.40	302.69
[bmim][PF6]	293.15	284.20	762.50	198.54	719.40	17.53	0.79	0.41	297.03
	296.15	284.20	762.50	198.54	719.40	17.53	0.79	0.41	293.79

	298.15	284.20	762.50	198.54	719.40	17.53	0.79	0.41	291.69
	301.15	284.20	762.50	198.54	719.40	17.53	0.79	0.42	288.64
	303.15	284.20	762.50	198.54	719.40	17.53	0.79	0.42	286.67
	305.15	284.20	762.50	198.54	719.40	17.53	0.79	0.42	284.74
	308.15	284.20	762.50	198.54	719.40	17.53	0.79	0.43	281.92
	311.15	284.20	762.50	198.54	719.40	17.53	0.79	0.43	279.20
	313.15	284.20	762.50	198.54	719.40	17.53	0.79	0.44	277.44
	343.10	256.10	648.30	154.60	508.80	19.76	0.71	0.67	20.01
[emim][PF6]	353.10	256.10	648.30	154.60	508.80	19.76	0.71	0.69	19.70
	363.10	256.10	648.30	154.60	508.80	19.76	0.71	0.71	19.42
	283.15	377.30	818.80	154.60	1239.90	36.28	0.18	0.23	23.59
	293.15	377.30	818.80	154.60	1239.90	36.28	1.18	0.24	22.98
	303.15	377.30	818.80	154.60	1239.90	36.28	2.18	0.24	22.43
[dmim][bti]	313.15	377.30	818.80	154.60	1239.90	36.28	3.18	0.25	21.95
	323.15	377.30	818.80	154.60	1239.90	36.28	4.18	0.26	21.51
	333.15	377.30	818.80	154.60	1239.90	36.28	5.18	0.27	21.12
	343.15	377.30	818.80	154.60	1239.90	36.28	6.18	0.28	20.77
	353.15	377.30	818.80	154.60	1239.90	36.28	7.18	0.28	20.45
[dmim][bf4]	298.15	310.00	997.70	203.12	784.60	14.69	1.08	0.38	26.37
	283.15	282.13	812.30	263.88	726.10	16.21	1.00	0.39	50.59
	288.15	282.13	812.30	263.88	726.10	16.21	1.00	0.40	49.14
	293.15	282.13	812.30	263.88	726.10	16.21	1.00	0.40	47.79
	298.15	282.13	812.30	263.88	726.10	16.21	1.00	0.41	46.52
	303.15	282.13	812.30	263.88	726.10	16.21	1.00	0.42	45.33
	308.15	282.13	812.30	263.88	726.10	16.21	1.00	0.42	44.22
[C8mim] [BF4]	313.15	282.13	812.30	263.88	726.10	16.21	1.00	0.43	43.17
	318.15	282.13	812.30	263.88	726.10	16.21	1.00	0.44	42.19
	323.15	282.13	812.30	263.88	726.10	16.21	1.00	0.45	41.26
	328.15	282.13	812.30	263.88	726.10	16.21	1.00	0.45	40.39
	333.15	282.13	812.30	263.88	726.10	16.21	1.00	0.46	39.56
	338.15	282.13	812.30	263.88	726.10	16.21	1.00	0.47	38.78

	343.15	282.13	812.30	263.88	726.10	16.21	1.00	0.47	38.04
	348.15	282.13	812.30	263.88	726.10	16.21	1.00	0.48	37.34
	353.15	282.13	812.30	263.88	726.10	16.21	1.00	0.49	36.67
	358.15	282.13	812.30	263.88	726.10	16.21	1.00	0.49	36.04
	363.15	282.13	812.30	263.88	726.10	16.21	1.00	0.50	35.44
[bmim][TFES]	298.15	320.00	827.80	201.25	1030.50	26.04	0.46	0.29	29.92
[emim][TFES]	298.15	433.00	713.60	234.25	1171.00	15.81	0.81	0.25	49.82
[nmim][bti]	298.15	490.00	1275.70	139.25	1331.20	20.06	0.53	0.22	17.04
[pmim][bti]	298.15	433.00	1161.50	201.24	1281.10	25.94	0.34	0.23	27.74
[bmim][Cl]	298.15	174.70	568.80	201.37	789.00	28.17	0.49	0.38	28.46
[C12mim][Cl]	298.15	286.90	1025.60	200.12	951.50	16.21	0.82	0.31	24.33
[dmprim][bti]	290.00	419.00	1023.70	259.88	1269.70	27.87	0.32	0.23	49.14
	295.00	419.00	1023.70	269.88	1269.70	27.87	1.32	0.23	51.78
	300.00	419.00	1023.70	269.88	1269.70	27.87	2.32	0.24	50.39
	305.00	419.00	1023.70	269.88	1269.70	27.87	3.32	0.24	49.08
	310.00	419.00	1023.70	269.88	1269.70	27.87	4.32	0.24	47.86
	315.00	419.00	1023.70	269.88	1269.70	27.87	5.32	0.25	46.71
	320.00	419.00	1023.70	269.88	1269.70	27.87	6.32	0.25	45.63
	325.00	419.00	1023.70	269.88	1269.70	27.87	7.32	0.26	44.61
	330.00	419.00	1023.70	269.88	1269.70	27.87	8.32	0.26	43.64
	335.00	419.00	1023.70	269.88	1269.70	27.87	9.32	0.26	42.74
	340.00	419.00	1023.70	269.88	1269.70	27.87	10.32	0.27	41.88
	345.00	419.00	1023.70	269.88	1269.70	27.87	11.32	0.27	41.06
	350.00	419.00	1023.70	269.88	1269.70	27.87	12.32	0.28	40.29
	355.00	419.00	1023.70	269.88	1269.70	27.87	13.32	0.28	39.56
	360.00	419.00	1023.70	269.88	1269.70	27.87	14.32	0.28	38.87
	365.00	419.00	1023.70	269.88	1269.70	27.87	15.32	0.29	38.21
[bmpyr][bti]	283.10	422.00	1038.80	273.12	1209.20	25.13	0.32	0.23	56.66
	293.10	422.00	1038.80	273.12	1209.20	25.13	1.32	0.24	53.37
	298.10	422.00	1038.80	273.12	1209.20	25.13	2.32	0.25	51.89
	303.10	422.00	1038.80	273.12	1209.20	25.13	3.32	0.25	50.51

313.10	422.00	1038.80	273.12	1209.20	25.13	4.32	0.26	47.99
323.10	422.00	1038.80	273.12	1209.20	25.13	5.32	0.27	45.77
333.10	422.00	1038.80	273.12	1209.20	25.13	6.32	0.28	43.79
343.10	422.00	1038.80	273.12	1209.20	25.13	7.32	0.28	42.03
353.10	422.00	1038.80	273.12	1209.20	25.13	8.32	0.29	40.44