# Interaction of 1-hexyl-3 methylimidazolium bromide ionic liquid with methylparaben drug in aqueous solution: Conductometric and molecular dynamics studies

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**Research Article**

**Keywords:** 1-hexyl-3-methylimidazolium bromide, Methylparaben, Fuoss-Onsager, Molecular dynamic simulation, Conductometry

**Posted Date:** September 2nd, 2024

**DOI:** https://doi.org/10.21203/rs.3.rs-4516305/v1



**Version of Record:** A version of this preprint was published at Chemical Papers on February 25th, 2025. See the published version at https://doi.org/10.1007/s11696-025-03946-4.

# Interaction of 1-hexyl-3 methylimidazolium bromide ionic liquid with methylparaben drug in aqueous solution: Conductometric and molecular dynamics studies

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## Abstract

In this research, the thermodynamic properties and molecular interactions of 1-hexyl-3-methylimidazolium bromide + methylparaben + water system were reported using conductometric method and molecular dynamics simulations. The conductometric data were collected for ionic liquid from 0.0012 to 0.1983 mol.kg$^{-1}$ on various molality of methylparaben in aqueous solution ($m_{MP}$ = 0.0000, 0.0005 and 0.0010 mol.kg$^{-1}$) at T = (300.2, 310.2 and 320.2) K and P=0.1 MPa. Fuoss-Onsager equation was applied to get the ion association constants and limiting molar conductivities of ionic liquid and to determine the thermodynamic of ion association. Moreover, molecular dynamics simulations were made to understand the interactions between ionic liquid and methylparaben at the molecular and microscopic level. Radial distribution functions, root mean square deviations, hydrogen bonding and van der Waals and EL interactions were obtained. Furthermore, the diffusion coefficients of ionic liquid in methylparaben and water mixtures were obtained from MD simulation to calculate the molar conductivity of HMIm]Br using Einstein's Nernst equation at T=310.2 K and were in agreement with experimental molar conductivity.

**Keywords**: 1-hexyl-3-methylimidazolium bromide; Methylparaben; Fuoss-Onsager; Molecular dynamic simulation; Conductometry

## 1 Introduction

Conductivity and solubility are the important physicochemical properties which are needed for drug discovery and development. The low solubility of some drugs slows down their dissolution and absorption in the body [1]. The reliable drug solubility data are required to design the suitable pharmaceutical drug delivery [2-3], formulating of drug with low solubility [4], crystallization [5], considering the absorption, and solubilization mechanism [6-7]. Various molecules used as pharmaceutical causes have very poor solubility in water and biological surroundings, so this significantly limits their therapeutic use. Ionic liquids (ILs) were recently used as a new solvent in pharmaceutical processes. Therefore, the ion association performance of ILs in the existence of a drug is a deep insight. ILs are used to effectively dissolve a range of sparingly soluble compounds by means of their ability to interact with solutes [8]. They present the remarkable features such as high electrical conductivity, nonflammability and satisfactory solvating properties for mixtures [9-13]. ILs are also utilized in multi-disciplinary sciences such as electrochemistry, separation processes, synthesis and especially in drug manufacturing [14]. The ILs and drugs interactions would be a requirement influence evaluates the solubility of drugs. To this aim, there are some information regarding the studies of governing on ILs and drug molecular interactions investigated by electrical conductance [15]. Low water solubility of drug nominees is a main challenge in the pharmaceutical manufacturing where 40% of all recently industrialized drugs are generally low soluble or insoluble in water [16-22]. In recent years, ILs were used to increase the solubility of drugs, which can be mentioned in the following works:

Shekaari et al [22] measured the density and electric conductivity for systems containing acetaminophen and 1-octyl-3-methyl imidazolium bromide in aqueous solution at T = (293.15-308.15) K. The limiting molar conductivities ($\Lambda_0$ ) and ion association constants ($K_a$) were determined using low concentration Chemical Model (lcCM). Zafarani-Moattar et al [23] investigated the influence of some ILs on the thermodynamic functions of acetaminophen drug using lcCM. Shekaari et al [15] determined the molar conductivities of 1-alkyl-3-methylimidazolium bromide on various concentrations of aspirin in acetonitrile solutions. They analyzed the obtained data using lcCM. The electrical conductivities the sodium salts of alkyleparabens salts were studied by Apelblat et al [24]. Experimental data were interpreted using the Quint−Viallard conductivity equations. Paluch et al determined the solubility of acetaminophen in water [ 25]. They found it considerable disturbs the obtaned solvation free

energy of acetaminophen. Maginn et al [26] obtained the some ILs properties using the experiment and simulation studies. Dasari et al [27] performed the molecular dynamics simulation of the drug, LASSBio-294, in water and seven ionic liquids (ILs): 1-ethyl-3-methylimidazolium methylphosphonate, 1-ethyl-3-methylimidazolium methylphosphonate imidazolium, 1-ethyl-3-methylimidazolium acetate, 1-butyl-3-methylimidazolium acetate, 1,3-Dimethylimidazolium methylphosphonate, 1-ethyl-3-methylimidazolium glycinate, ethylammonium acetate and calculated the atom-atom radial distribution functions (RDFs). Basouli et al [28] made the molecular dynamics simulation of 1-ethyl-3-methylimidazolium methylsulfate [Emim][MeSO4] at various temperatures and ambient pressure to obtain the relation between counter ions exchange and macroscopic diffusion process.

In this research, in continuation of our previous works [29-30], we investigated the thermodynamic properties of 1-hexyl-3-methylimidazolium bromide ([HMIm]Br) ionic liquid in a solvent mixture of methylparaben (MP) and water at T = (300.2-310.2-320.2) K through experiments and molecular dynamics simulations. Molar conductivity was used to obtain the $K_a$ and $\Lambda_0$ values of the studied ionic liquid using the Fuoss-Onsager equation. Also, we used the $K_a$ values to obtain the standard Gibbs free energy ($\Delta G^\circ$), entropy ($\Delta S^\circ$) and enthalpy ($\Delta H^\circ$). The molecular dynamics simulations were carried out to get more details of the interactions between the HMIm]Br and MP. We determined the RDF, root mean square deviation (RMSD), hydrogen bonds (H-Bonds) and van der Waals (vdw) and electrostatic (EL) interactions. Furthermore, we obtained from MD simulation to determine the molar conductivity of HMIm]Br by Einstein's Nernst equation [30] at T=310K.

## 2 Method

### *2.1 Conductometric measurements*

#### *2.1.1 Materials*

1-Bromohexane(>99%), N-methylimidazole (>99%), ethyl acetate and MP were purchased and completely were of analytical reagent grade. Specification of the material used and chemical companies were illustrated in Table 1. The double distilled and deionized water was used to prepare the stock solutions.

#### *2.1.2. Synthesis of ionic liquid*

The [HMIm]Br was manufactured in according to the previous works [29-30] through direct alkylation of N-methylimidazole. 1-Bromohexane and ethyl acetate was introduced drop by drop to the N-methylimidazole solution that was iced in a bath and in a round bottom. Then, the made solution was reflexed under a nitrogen atmosphere for 72h at T=353.2 K. The obtained mixture was moved apart from reagents and then rinsed triply with ethyl acetate to remove the exceed 1-bromohexane. Trace amount of humidity was eliminated by the high vacuum pumping for at least 24 h. The obtained ionic liquid was verified FTIR spectroscopy. Chemical structure and FTIR spectroscopy of [HMIm]Br were presented in Fig. s1 and Fig.s2 respectively ( see supporting information).

*2.1.3. Apparatus and procedure*

All of conductometric data were get using of a digital conductometer (Proline) with fluctuations of 0.01µs.cm-1. Before the conductometric measurements, conductometer was calibrated with aqueous KCl solution. At first, the 25 ml of pure solvent was put in the conductometric cell and was closed. Then, the [HMIm]Br was introduced to the cell containing solvent with a Hamilton syringes (CH-7402 Bonaduz) based on standard addition method. To keep a constant temperature for the test solution, a GFL circulation water bath was utilized at T = (300.2, 310.2 and 320.2) KK with an accuracy of 0.1 K. The conductivities of [HMIm]Br solutions were generally corrected to regard the conductivity of pure solvent.

*2.2. Computational Details*

The NAMD-2.12 package [31] with CHARMM-27 and CHARMM-36 [32] force fields were applied to all simulations. Also, VMD[33] package was used for graphical visualization and analysis. Temperature and pressure was controlled using berendsen thermostat and langevin barostat, respectively [28]. The [HMIm]Br and MP PDB files were taked from Marvin software [34]. Swiss Param[35] and REDDB[36] webservers were utilized to get the topology and charge data, respectively. The TIP3P[37] model was specified for water molecules and the explicit solvent was considered. The periodic boundary conditions were employed to all commands and the simulation time step was fixed to 1 femtoseconds. The made procedure of simulation for considered systems was including “minimization, annealing, and a final 100 nanosecond isothermal-isobaric (NPT) production simulation”[38-39]. The Berendsen thermostat [40] and Langevin barostat was used to control the temperature and pressure during the NPT production

simulation [41]. Lennard-Jones "12-6" was used to recognize the nonbonding interactions between atoms of [HMIm]Br and MP molecules. interactions were considered with particle mesh Ewald with a cut-off of 10nanometers, and vdw cut-off was used with alike value [1]. At the first step, 3 [HMIm]Br molecules were inserted in a box with dimensions of (70.08Å × 70.07Å × 70.14 Å) to equilibrate the system. During heating step the system's temperature brought to a 310 K. The final 100 nanosecond MD simulation were done. The next step, was to equilibrate the MP molecules in a box of (70.08Å × 70.13Å × 70.07 Å) for 100 nanosecond. Finally, to observe the aggregation of HMIM-Br and MP molecules and the effect of their presence on each other's ,a mixed system of these molecules were made in a box dimension of (104.52Å × 101.09Å × 98.12 Å) and a 100 nanosecond MD simulation in NPT ensemble (see Fig. s3 in supporting information).

## 3. Results and discussion

### *3.1. Conductometric study*

#### *3.1.1 Determination of molar conductivity and calibration*

Conductometric data were made for the binary [HMIm]Br + water system. The molar conductivity (Λ) values were determined by using conductometric data. In table2, the Λ values were illustrated as a function of the molal concentration of the ionic liquid ($m_{IL}$) at T = (300.2, 310.2 and 320.2) K. Fig. 1 shows the found data are in good agreement with literature at T = (308.2 and 310.2) K temperatures [43].

#### *3.1.2 Determination of limiting molar conductivity*

The Λ values of HMIm]Br solutions as function of MP molal concentration ( $m_{MP}$=0.000,0.005 and 0.010 mol.kg $^{-1}$) in aqueous system were given in Table 2 at temperature of 300.2, 310.2 and 320.2 K. Moreover, Figs. 2-4 show that the Λ values of HMIm]Br decreases with growing the concentration of [HMIm]Br while it increases with growing the temperature at the similar concentration of MP. The comparable trends have been stated for ILs in the literatures [22,23,29,30,43.45]. It can be explained that the Λ values of HMIm]Br decreases with increasing the concentration of [HMIm]Br as a result of the growth in the ion pair formation[30]. In addition, the ion association and relaxation effect between anion and cation of HMIm]Br

enlarges with a growth in its concentration and consequently the mobility of the charge transporters moderates. The effect of these factors leads to the decrease of Λ values in the concentrated area. Moreover, Figs. 2-4 indicate that the Λ value increases with the increase in temperature. This effect can be mentioned to the mobility increased of free ions with temperature raising. Fig. 5 shows that the Λ value of [HMIm]Br decreases with the increase in MP concentration at T= 300.2 K. The result of MP concentration on the [HMIm]Br Λ values is a consequence of the valuable ions solvation by MP and subsequently the increase in solvent viscosity. However, electrical conductivity decreases with increasing the solvent viscosity [29].

*3.1.3 Correlation of molar conductivity with Fuoss-Onsager equation*

Fuoss_Onsager model was used to correlate the Λ values in according to the following equation:[29]

$$\Lambda = \Lambda_0 - SC^{\frac{1}{2}}\alpha^{\frac{1}{2}} + EC\alpha\log C\alpha + JC\alpha - K_A C\alpha\gamma^2\Lambda \quad (1)$$

$$\mathrm{J} = \sigma_1\Lambda_0 + \sigma_2 \quad (2)$$

$$\mathrm{S} = \alpha\Lambda_0 + \beta_0 \quad (3)$$

$$\alpha = \frac{0.8204 \times 10^6}{(\varepsilon T)^{\frac{3}{2}}} \quad (4)$$

$$\beta = \frac{82.50}{\eta(\varepsilon T^{\,2})^{\frac{1}{2}}} \quad (5)$$

$$\mathrm{E}' = \mathrm{E}_1'\Lambda_0 + \mathrm{E}_2' \quad (6)$$

$$\mathrm{E}_1' = \frac{2.942 \times 10^{12}}{(\varepsilon T)^3} \quad (7)$$

$$\mathrm{E}_2' = \frac{0.4333 \times 10^8}{\eta(\varepsilon T)^2} \quad (8)$$

In above equations, C is the molar concentration (mol.$L^{-1}$) and γ is dissociation degree. The S and E constants can be calculated using dielectric constant ($\varepsilon$ ), kelvin temperature (T) and the viscosity (η). J term, $\sigma_1$ and $\sigma_2$ indicate the ions -solvent interactions and are distance functions [29,44]. The obtained values of $K_A$, $\Lambda_0$, and R for [HMIm]Br on $m_{MP}$ =0.00, 0.005 and 0.010 mol.kg $^{-1}$ on various temperatures were illustrated in table 3. These results indicate that $K_A$ and $\Lambda_0$ values increase with the increase in temperature and MP concentration. In addition, the $\Delta G^o$ values decreases with the increase in temperature and MP concentration. It can be describe that the interactions of the ions of HMIm]Br and MP with increasing MP concentration become stronger [45]. The obtained values of distance parameters (R) decrease as the MP concentrations solutions increase. The small values of (R) for [HMIm]Br is indicated to the strong ionic association.

*3.1.2. Thermodynamics of ion association*

The thermodynamic properties were determined using the ion aggregation constant with the help of the following equations:

$$\Delta G^{\circ} = -RT\ln K_A \tag{9}$$

$$\Delta S^0 = \frac{\Delta H^0 - \Delta G^0}{T} \tag{10}$$

$$\frac{d(\frac{\Delta G}{T})}{dT} = -\frac{\Delta H}{T^2} \tag{11}$$

The values of $\Delta G^{\circ}$, $\Delta H^0$ and $\Delta S^0$ were given in **Table 3.** The results obtained from **Table 3** show that formation of ion pair is spontaneous phenomenon and this process growths with increasing temperature. Here in, this phenomenon has caused the positive entropy in the range of temperature. Due to the unbinding of solvent molecules from solvation layers as association takes place and increasing the freedom degrees number may be attributed the positive values of $\Delta S^0$ to this process. The positive values $\Delta H^0$ show that the process of ion pair formation is endothermic. It can be expected that the ordinary attractions of anions and cations via coulomb forces, vdw forces and H- bonds, may not be adequate to help the ion pair formation.

*3.2 Simulation*

*3.2.1 Calculation of molar Conductivity*

The molar conductivity can be calculated using a direct connection between diffusion coefficients of cations and anions via the Nernst−Einstein (NE) equation [46]:

$$\Lambda_{NE} = \frac{N_A e^2}{k_B T} (z_+^2 D_+ + z_-^2 D_-) \quad (12)$$

where $\Lambda_{NE}$ is the NE molar conductivity, D is the self-diffusion coefficient of ions, and other symbols have usual meaning. [47]. In these calculations, z+=z-=1 was used for [HMIm]Br ionic liquid. The transport of anion and cation were determined by calculation the mean square displacement (MSD) from MD simulation. The Einstein relation was used to calculate the D values in according to the equation 13[48] :

$$D = \frac{1}{6} \lim_{t\to\infty} \frac{d}{dt} \langle [r_i(t) - r_i(0)]^2 \rangle \quad (13)$$

where the $r_i(t)$ and $r_i(0)$ are the position vectors of the mass center of ion i at time t and 0, respectively. The self-diffusion coefficient of cations and anions was computed based on the MSD calculations using the "diffusion coefficient master" of VMD software. The self-diffusion coefficient results were illustrated in table s1. The calculated theoretical and experimental measurements of molar conductivity values of the ionic liquid in the presence and absence of MP drug were calculated using the diffusion coefficient and tabulated in Table 4. In according to the values illustrated in the table 4, the experimental data is in good agreement with the simulation results. Therefore, the simulation results can be used to describe the molecular aggregation between the MP drug and [HMIm]Br at the atomic-level interactions.

*3.2.2 RMSD*

The RMSD of the [HMIm]Br ionic liquid in the presence and absence of MP drug was calculated to show the stability of ionic liquid and drug during the aggregation process. The equation (14) was used to compute the RMSD of ionic liquid and drug [49]:

$$\mathrm{RMSD} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(r_i(t+\Delta t) - r_i(t))^2} \quad (14)$$

Where N is the numbers of atoms and other symbols have usual meaning. Figs. 6 and 7 display the RMSD (Å) variation of ionic liquid atoms in absence and attendance MP drug on aqueous solution, respectively. It can be seen that the configuration of ionic liquid was not changed after relaxation. The RMSD values were demonstrated in table 5. It can be seen, the RMSD (Å) values of ionic liquid in the attendance of MP drug are more than the correspond values in the absence of MP drug. It can be described in terms of the strong interactions between [HMIm]Br and MP drug.

*3.2.3.RDF*

In a system contain particles, the local densities of the particle i all over the place j along the radial direction can be described through RDF [50]. To analyze the HMIMBr-water and HMIMBr-MP-water interactions, the radial distribution functions of these pairs were calculated the 100 ns of time simulation paths ( Fig. 8a-d). The comparison of intensity and position of the first peak in Fig.8c-d the indicate that aggregations of HMIMBr ionic liquid increases in the presence of MP drug. The found results are in agreement with experimental data which $K_A$ values raise with the increase in MP concentration.

*3.2.4. H-Bonds*

The average number of HMIMBr –water and HMIMBr -MP-water molecules H-Bonds was computed in the studied systems by using VMD software all through the last 10 ns of the simulation paths. Fig. 9a-d shows that distribution of H-Bonds in all cases has a normalized distribution. Also, Table 6 gives the obtained results of H-Bonds for studied systems. Fig.10 shows, the average number of normalized H-Bond for HMIMBr and MP drug in mixture are shown an increase compared to alone HMIMBr and MP drug in aqueous system. On the other hand, the strong hydrogen bond happens between HMIMBr ionic liquid and MP drug molecules.

*3.2.5. Interaction energies*

Interaction energies of the system were computed by ‘‘NAMD Energy” of VMD software. The normalized distribution of EL interactions and vdW energies was utilized to assess the forces

between atoms and molecules (see Fig.11 a-d and Fig.s4 in supporting information). The average value of the interaction energies was considered by fitting the distribution function with population data. Fig.12 shows the relationship of EL interactions and vdW energies between MP molecules and HMIMBr ionic liquid in the absence and presence of MP drug. Moreover, the found data were demonstrated in table 7. That observes, the EL interactions contribution between MP drug and ionic liquid are more than the vdw forces in addition to H- bonds. Furthermore, the contribution of EL interactions between HMIMBr ionic liquid in water + MP are more than the EL interactions HMIMBr ionic liquid but the contribution of EL interactions between MP molecules in water + ionic liquid are less than the EL interactions MP molecules in aqueous solution. However, the obtained results show that the ordinary attractions of anions and cations via coulomb forces, vdw forces and H-Bonds are not adequate to help the ion pair formation. Therefore, the EL and H-Bonds interactions play insignificant role on ion pair formation in MP + HMIMBr ionic liquid system. On the other hand, ion pair formation cannot be enthalpy driven.

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## 4. Conclusions

The interactions of HMIMBr ionic liquid with MP drug in water as solvent were investigated by experimental and theoretical studies. The influence of temperature and MP concentration on the interaction of HMIMBr ionic liquid with MP were studied. The $K_a$ and $\Lambda_0$ values of ionic liquid were achieved using Fuoss-Onsager equation and applied to get the standard Gibbs free energy, enthalpy, and entropy variations. MD simulations were made to know the aggregations at the atomic-level interactions. The calculated molar conductivity of HMIMBr ionic liquid were made in the presence and absence of MP drug and found the good agreement between the experimental and simulation results. Also, The RDF results showed that the tendency for aggregation increases in the presence

of MP which is in agreement with changes of KA values. It can be concluded that HMIMBr ion-pair association in water+MP mixtures is endothermic and entropy driven.

**Acknowledgement**

This work has been supported by University of Guilan.

**Declarations**

**Ethical Approval**

This declaration is “not applicable”.

**Competing interests**

The authors declare that they have no known competing financial interests.

**Funding**

This work has been supported by University of Guilan , However, there is no fund number

**Availability of data and materials**

The calculated data can be accessed

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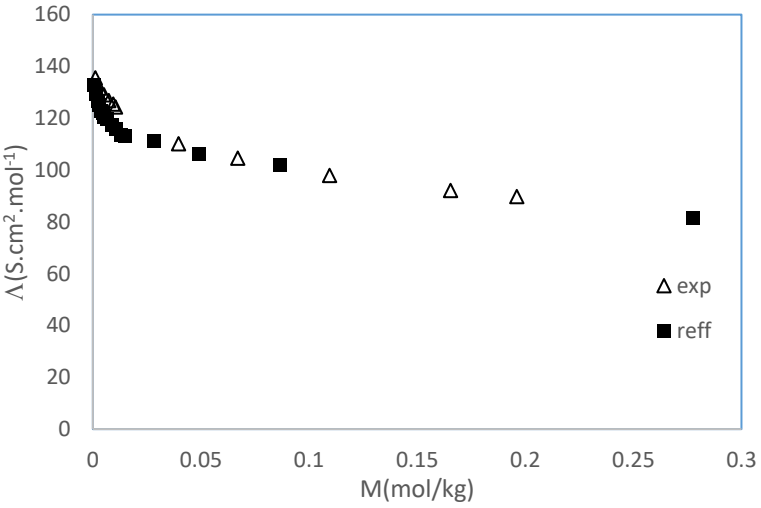



**Fig. 1. Comparison of experimental molar conductivities of IL solutions with the literature data [43] Symbols: [Hmim]Br+water: Δ , this work (310.2 K)., ■ ,Hui Wang et al (308.2)**

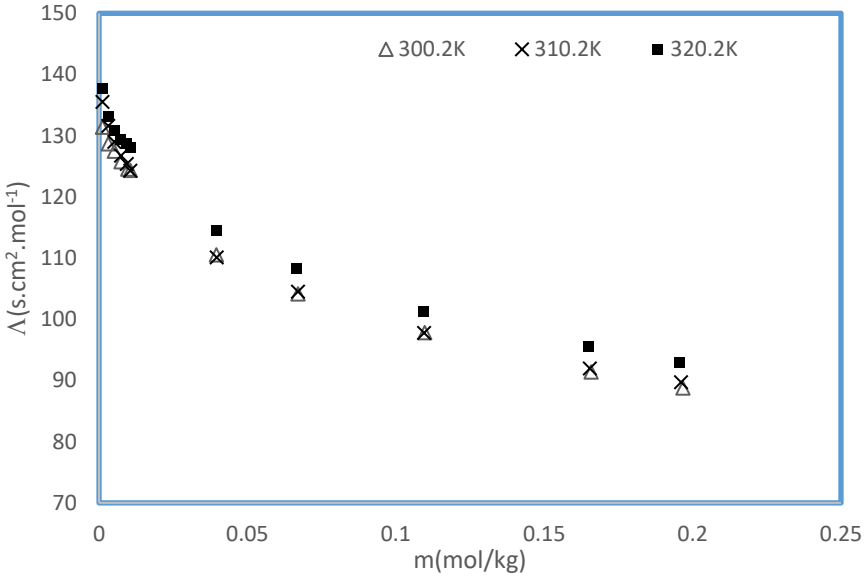



**Figure 2. Molar conductivities of [HMIm]Br as IL molality function on MP 0**

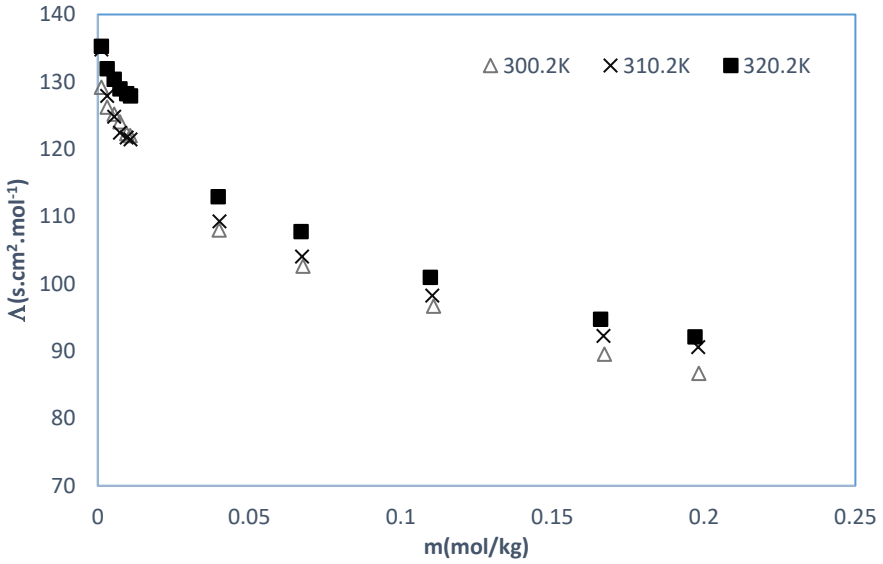



**Figure 3. Molar conductivities of [HMIm]Br as IL molality function on MP 0.005**

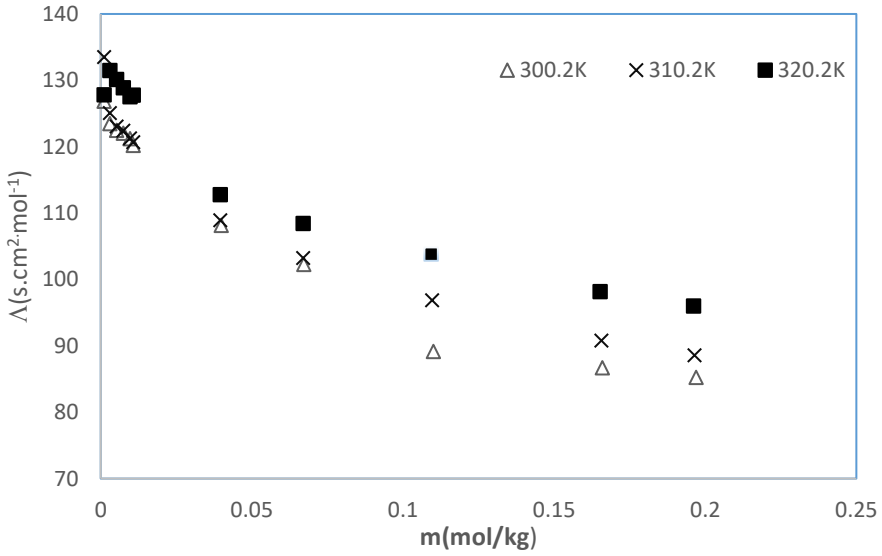


**Figure4. Molar conductivities of [HMIm]Br as IL molality function on MP of 0.01**

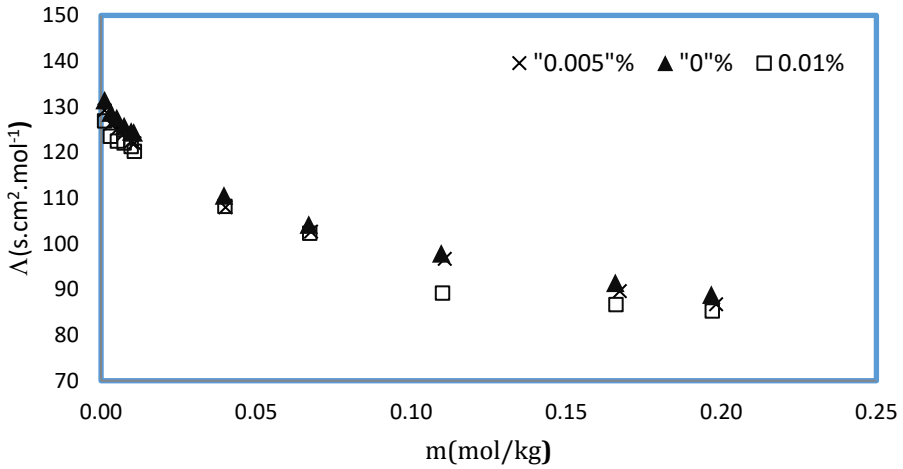



**Figure5. Molar conductivities of [HMIm]Br in MP+ water at T=300.2K**

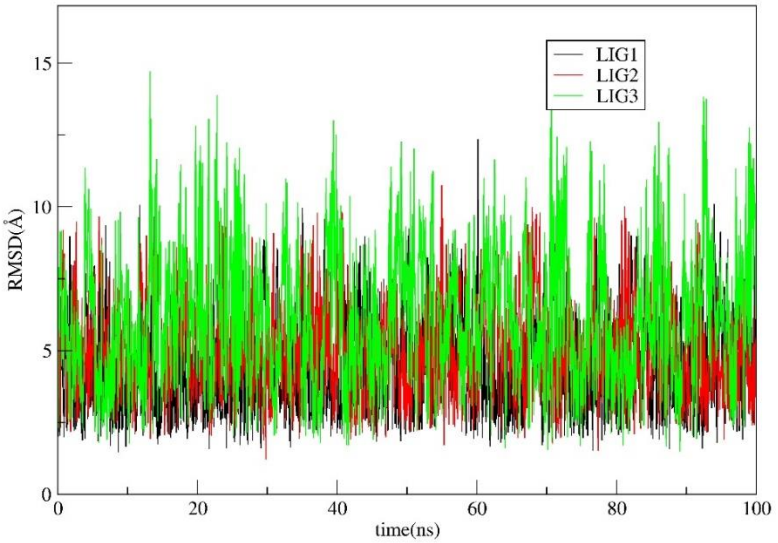



**Fig. 6 Representative plots of RMSD of [HMIm]Br in absence of MP**

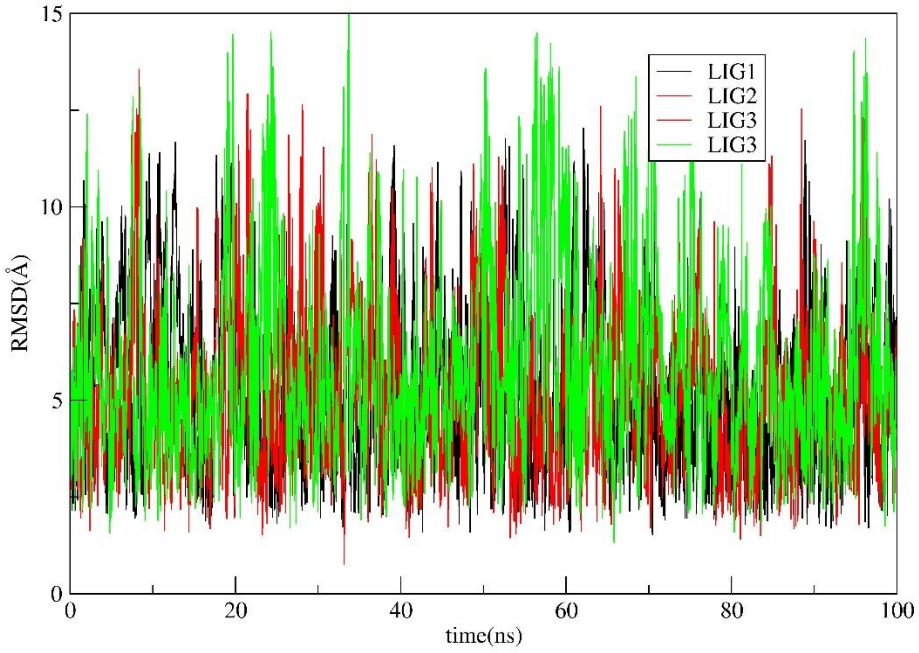
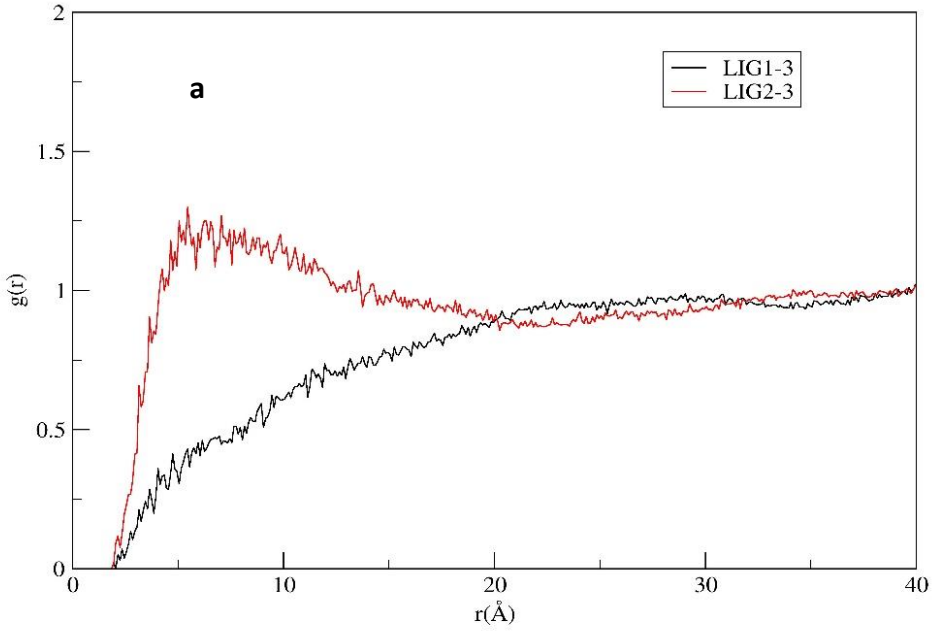
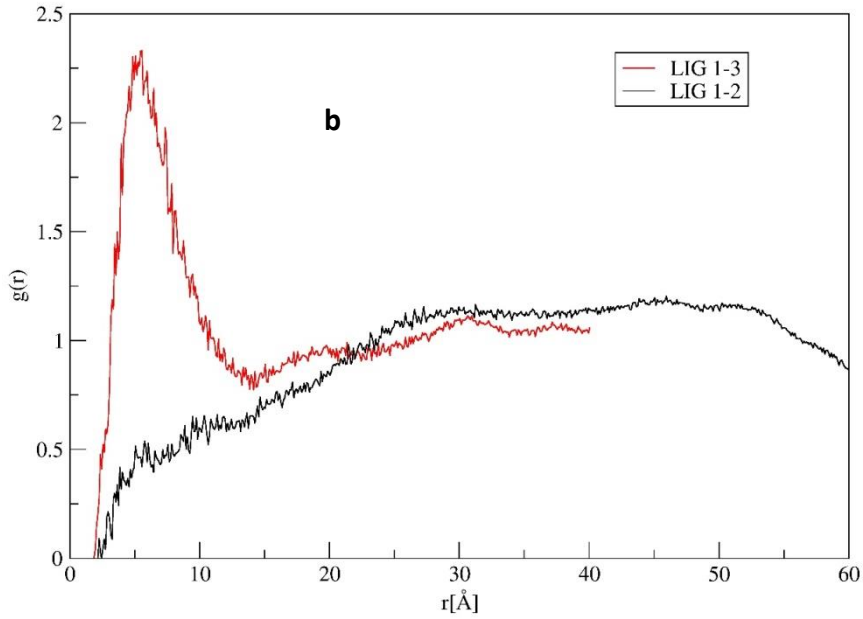


**Fig. 7 Representative plots of RMSD of [HMIm]Br in presence of MP**




b
LIG 1-3
LIG 1-2
g(r)
r[Å]
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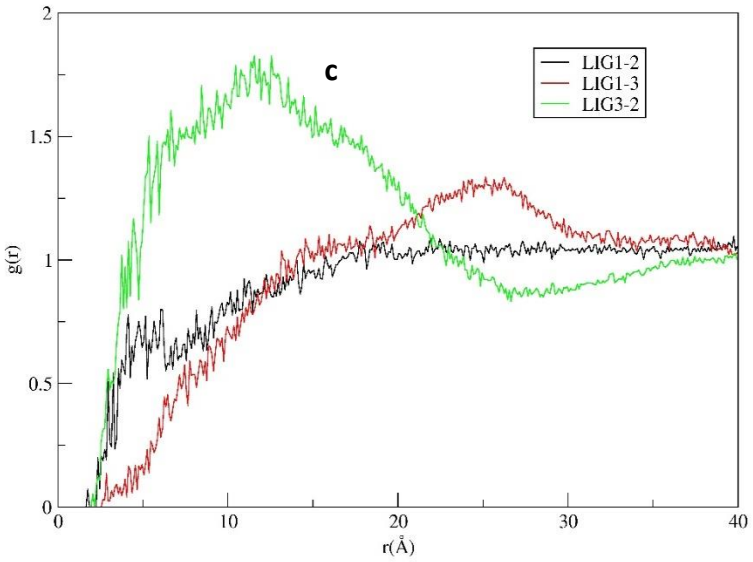
0.5
1
1.5
2
2.5
0
10
20
30
40
50
60



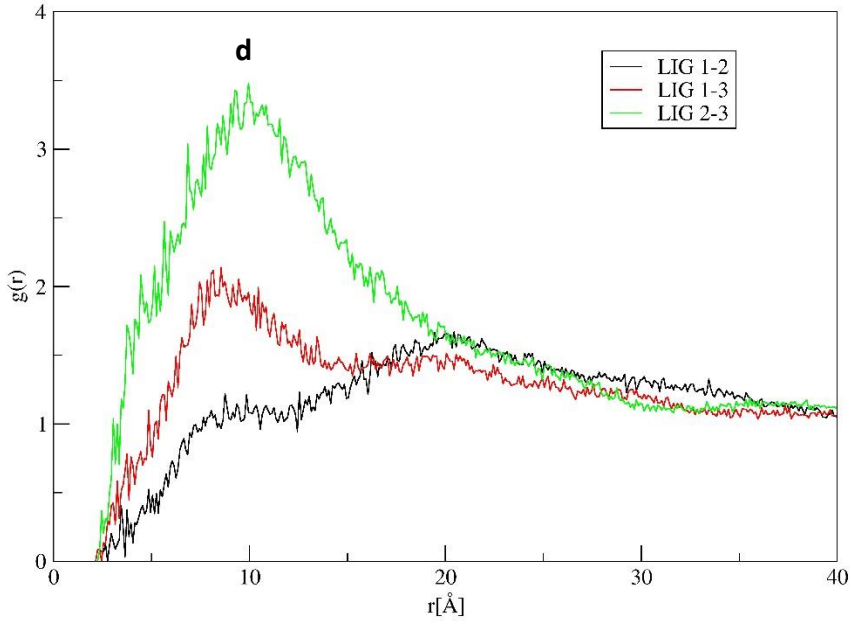
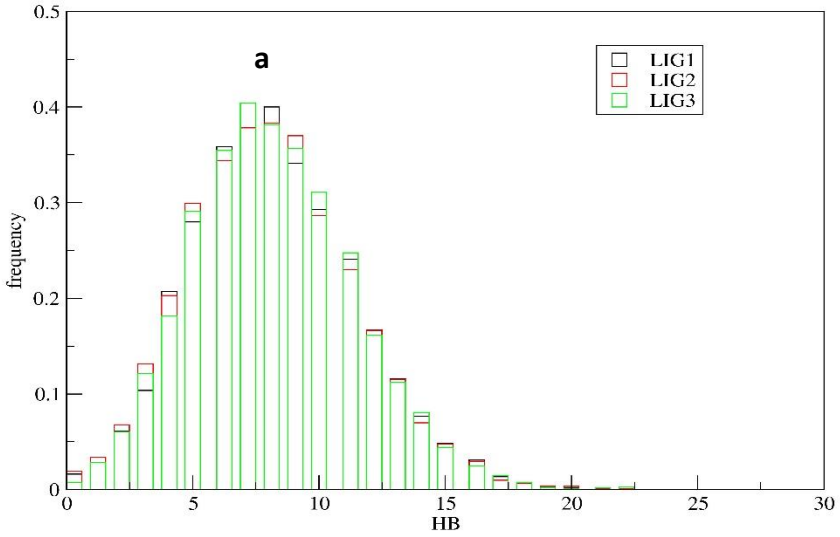




**Fig.8 . The RDF plot of MP- MP in water (a) MP- MP in HMIm]Br + water (b) [HMIm]Br-[HMIm]Br in water (c) [[HMIm]Br- [HMIm]Br in MP+water (d )during the last 10 ns of the 100 ns simulation time.**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LIG1
LIG2
LIG3
frequency
HB
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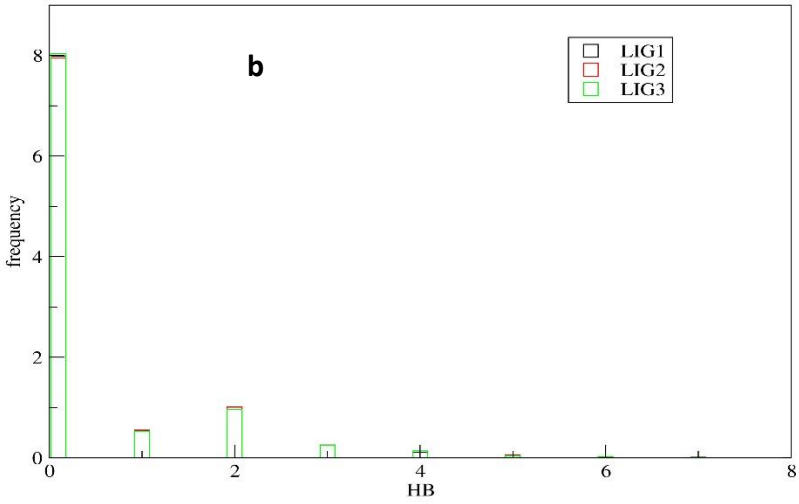
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
30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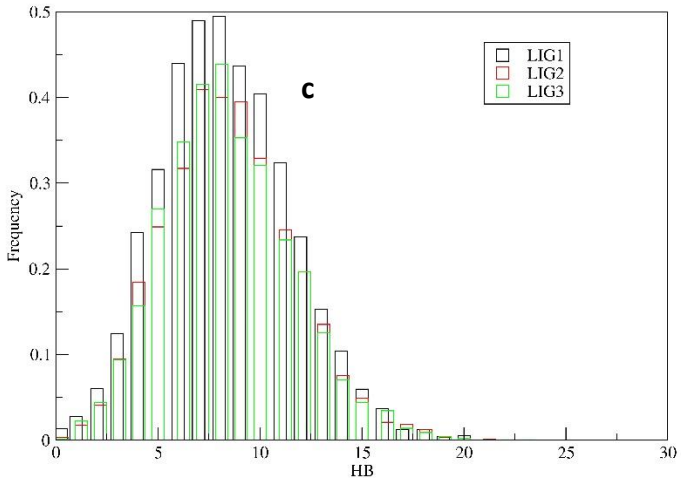
LIG1
LIG2
LIG3
frequency
HB
8
6
4
2
0
0
2
4
6
8



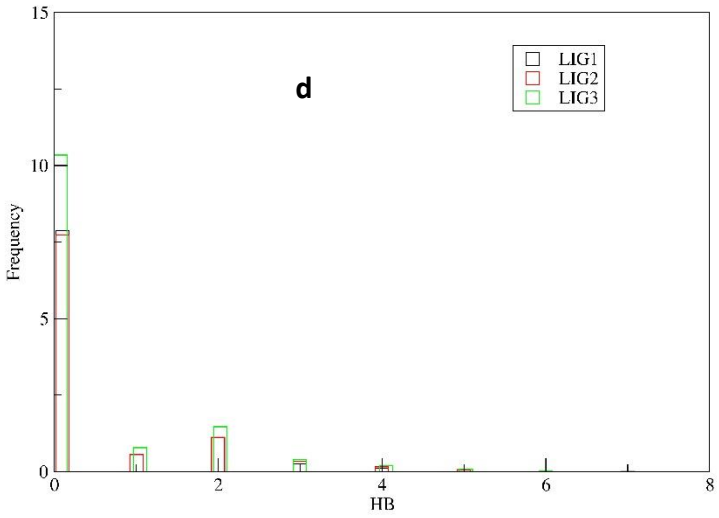
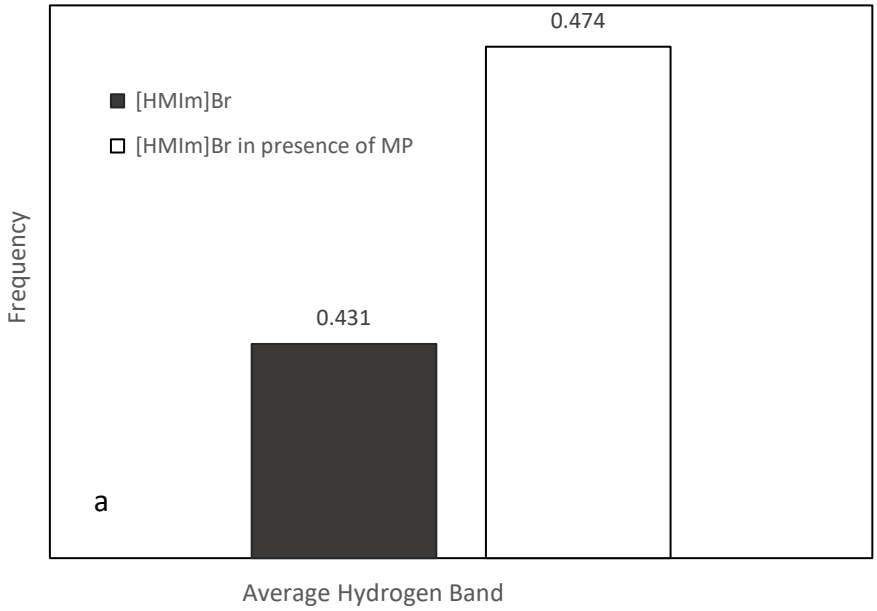




**Fig. 9. Normalized distribution of HB of MP in water(a) [HMIm]Br in water, (b) MP in HMIm]Br +water(c), and MP in HMIm]Br +water(d)**



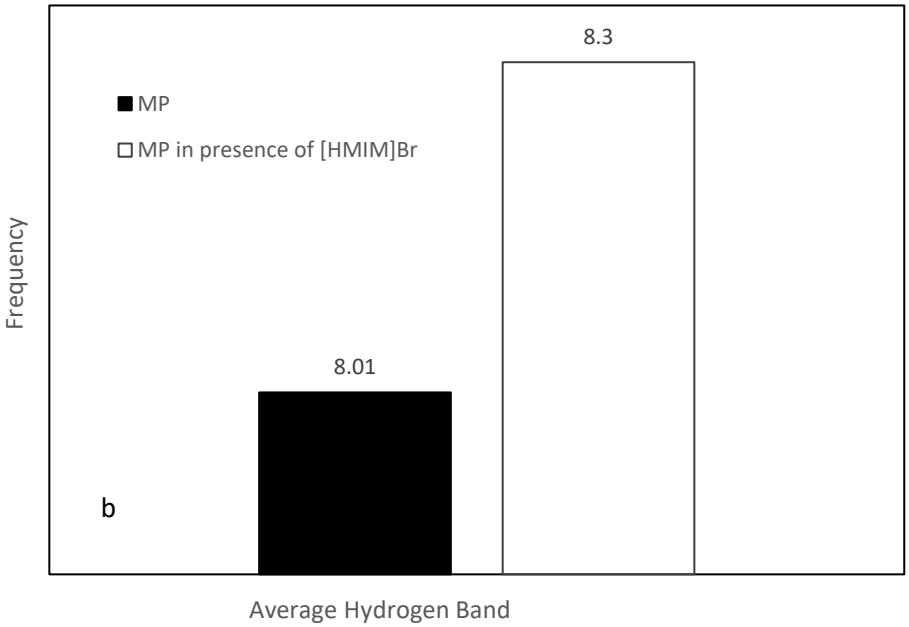




**Fig. 10 The comparison of HB average values of [HMIm]Br in water and [HMIm]Br iMP+ water (a) MP in water and MP in [HMIm]Br + water (b)**

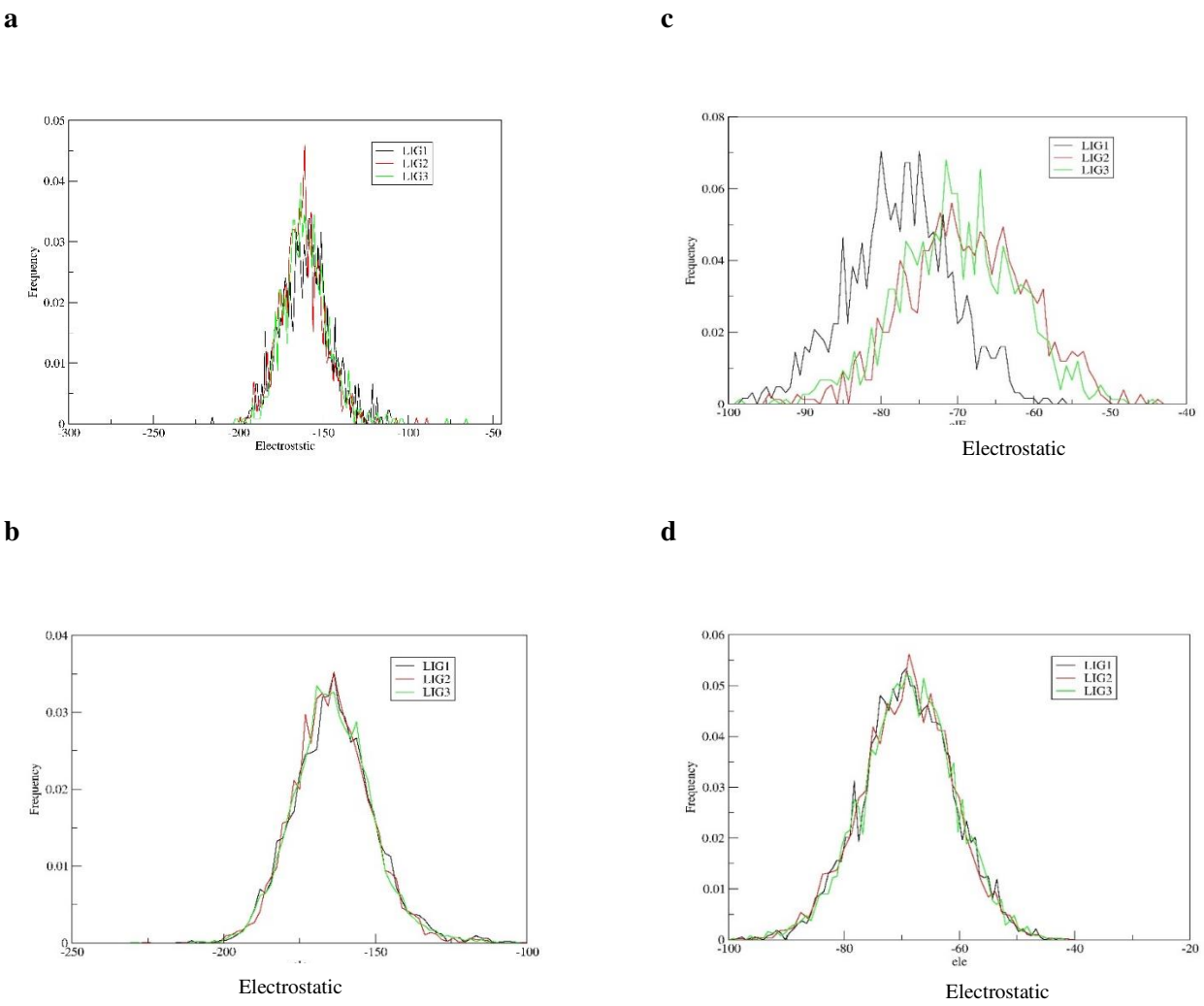



**Fig. 11. Normalized distribution of electrostatic of MP in water(a) [HMIm]Br in water, (a) HMIm]Br in MP + water (b), MP in water(c) and MP in HMIm]Br +water(d)**

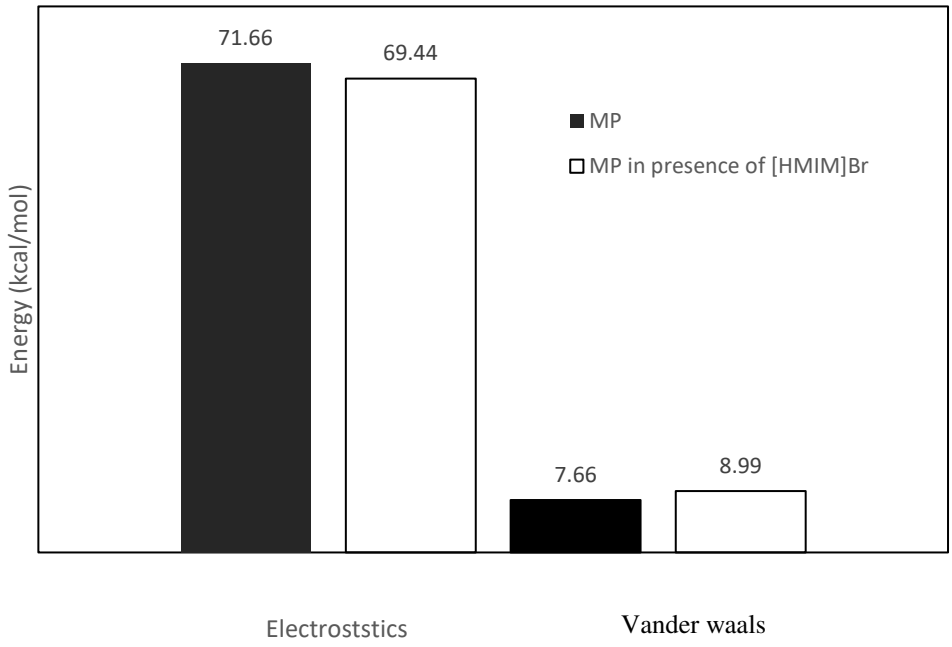



**Fig. 12 The comparison of electrostatic and vander waals energies of MP in water and MP in [HMIm]Br + water**

**Table 1. Specification of the used component**

| Chemical Name | Source | Initial Massfraction Purity | Purification Method |
|---|---|---|---|
| N-methyl imidazole | Merck | >0.99 | None |
| 1-Bromohexane | Merck | >0.99 | None |
| Ethyl acetate | Merck | >0.998 | None |
| 1 - hexyl - 3 - Methyimidazolium bromide | Senthesized | >0.99 | Distillation |
| Methyl paraben (MP) | Sigma-Aldrich | >0.98 | None |

**Table 2. Molar conductivities $\Lambda_m$ of [HMIm]Br in different mixtures as a function of ILs molality ($m_{IL}$) on different**

**MP concentration ($m_{MP}$) at T = (300.2 -310.2-320.2)K and P = 0.1 MPa.**

| $m_{IL}$(mol.kg$^{-1}$) | $\Lambda^a$(S.cm$^2$.mol$^{-1}$) | $m_{IL}$(mol.kg$^{-1}$) | $\Lambda$(S.cm$^2$.mol$^{-1}$) | $m_{IL}$(mol.kg$^{-1}$) | $\Lambda$(S.cm$^2$.mol$^{-1}$) |
|---|---|---|---|---|---|
| ***T* = 300.2 K** | | ***T* = 310.2 K** | | ***T* = 320.2 K** | |
| $m_{MP}$ = 0.000(mol.kg$^{-1}$) | | | | | |
| 0.0012 | 131.43 | 0.0012 | 135.53 | 0.0012 | 137.63 |
| 0.0031 | 128.70 | 0.0031 | 131.63 | 0.0031 | 133.07 |
| 0.0051 | 127.47 | 0.0051 | 128.98 | 0.0051 | 130.89 |
| 0.0074 | 125.74 | 0.0074 | 126.75 | 0.0074 | 129.31 |
| 0.0097 | 124.57 | 0.0094 | 125.40 | 0.0094 | 128.71 |
| 0.0105 | 124.37 | 0.0105 | 124.28 | 0.0105 | 128.12 |
| 0.0396 | 110.55 | 0.0397 | 110.13 | 0.0397 | 114.48 |
| 0.0670 | 104.19 | 0.0670 | 104.53 | 0.0667 | 108.23 |
| 0.1097 | 97.84 | 0.1095 | 97.80 | 0.1093 | 101.36 |
| 0.1658 | 91.42 | 0.1654 | 91.99 | 0.1650 | 95.52 |
| 0.1968 | 88.80 | 0.1961 | 89.72 | 0.1958 | 92.94 |
| $m_{MP}$ = 0.005 | | | | | |
| 0.0012 | 129.17 | 0.0012 | 134.80 | 0.0012 | 135.25 |
| 0.0031 | 126.23 | 0.0031 | 127.92 | 0.0031 | 131.96 |
| 0.0054 | 125.20 | 0.0054 | 124.83 | 0.0054 | 130.39 |
| 0.0073 | 124.06 | 0.0073 | 122.43 | 0.0073 | 128.95 |
| 0.0096 | 122.29 | 0.0096 | 121.71 | 0.0096 | 128.22 |
| 0.0107 | 121.99 | 0.0108 | 121.45 | 0.0108 | 127.90 |
| 0.0401 | 107.97 | 0.0402 | 109.27 | 0.0398 | 112.93 |

| | | | | | |
|---|---|---|---|---|---|
| **0.0677** | **102.61** | **0.0674** | **104.05** | **0.0671** | **107.76** |
| **0.1108** | **96.69** | **0.1104** | **98.23** | **0.1098** | **100.97** |
| **0.1672** | **89.55** | **0.1669** | **92.27** | **0.1659** | **94.71** |
| **0.1983** | **86.70** | **0.1981** | **90.61** | **0.1971** | **92.13** |
| **$m_{MP}$ = 0.010** | | | | | |
| **0.0011** | **126.86** | **0.0011** | **133.53** | **0.0011** | **133.60** |
| **0.0030** | **123.48** | **0.0030** | **125.06** | **0.0030** | **131.49** |
| **0.0052** | **122.45** | **0.0052** | **123.06** | **0.0052** | **130.15** |
| **0.0075** | **122.03** | **0.0075** | **122.43** | **0.0075** | **128.89** |
| **0.0097** | **121.24** | **0.0097** | **121.25** | **0.0097** | **127.52** |
| **0.0108** | **120.20** | **0.0108** | **120.70** | **0.0108** | **127.79** |
| **0.0399** | **108.13** | **0.0396** | **108.91** | **0.0396** | **112.77** |
| **0.0672** | **102.27** | **0.0670** | **103.25** | **0.0670** | **108.43** |
| **0.1101** | **89.16** | **0.1096** | **96.87** | **0.1094** | **103.79** |
| **0.1660** | **86.68** | **0.1656** | **90.81** | **0.1652** | **98.15** |
| **0.1970** | **85.25** | **0.1965** | **88.60** | **0.1961** | **95.99** |

**[a] The average standard uncertainty of molar conductivity values were u(Λ)= 0.18, 0.20 and 0.21 S $cm^2$ $mol^{-1}$ at *T* = 300.2, 310.2 and 320.2 K, respectively, u(m)= 0.0001and u(T)= 0.1K**

**Table 3. Ion association constant ($K_A$), limiting molar conductivity ($\Lambda_0$) and thermodynamic functions ($\Delta G_A^\circ$, $\Delta H_A^\circ$ and $\Delta S_A^\circ$) at T = (300.2, 310.2 and 320.2) K and P = 0.1 MPa.**

| T/K | $K_A$ ($dm^3.mol^{-1}$) | $\Lambda_0$ ($S.cm^2.mol^{-1}$) | $\Delta G_A^\circ$ ($kJ.mol^{-1}$) | $\Delta S_A^\circ$ ($J.mol^{-1}.K^{-1}$) | $\Delta H_A^\circ$ ($kJ.mol^{-1}$) | R ($A^0$) |
|---|---|---|---|---|---|---|
| **$m_{MP}$ =0.000 ($mol.kg^{-1}$)** | | | | | | |
| **300.2** | **12.43** | **136.42** | **-6.28** | **58.42** | **11.26** | **12.24** |

| | | | | | | |
|---|---|---|---|---|---|---|
| **310.2** | **13.48** | **139.28** | **-6.70** | **60.34** | **12.02** | **11.30** |
| **320.2** | **16.81** | **142.83** | **-7.51** | **63.46** | **12.81** | **10.38** |
| **$m_{MP}$ =0.005(mol.kg$^{-1}$)** | | | | | | |
| **300.2** | **12.59** | **134.13** | **-6.32** | **59.16** | **11.44** | **12.12** |
| **310.2** | **13.87** | **135.51** | **-6.78** | **61.25** | **12.22** | **11.15** |
| **320.2** | **17.09** | **142.02** | **-7.55** | **64.24** | **13.02** | **10.28** |
| **$m_{MP}$ = 0.010(mol.kg$^{-1}$)** | | | | | | |
| **300.2** | **13.24** | **132.32** | **-6.44** | **55.36** | **10.18** | **12.03** |
| **310.2** | **14.14** | **134.37** | **-6.82** | **57.05** | **10.87** | **11.11** |
| **320.2** | **17.37** | **138.93** | **-7.55** | **59.86** | **11.58** | **10.27** |

**Table 4. Comparison of calculated molar conductivities ($\Lambda_{NE}$) with experimental data ($\Lambda_m$) at T=310.2K**

| | **$m_{MP}$(mol.kg$^{-1}$)** | | |
|---|---|---|---|
| **$m_{[HMIm]Br}$ (mol.kg$^{-1}$)** | | **$\Lambda_{NE}$ $\left(s.cm^2.mol^{-1}\right)$** | **$\Lambda_m$ $\left(s.cm^2.mol^{-1}\right)$** |

| | | | |
|---|---|---|---|
| **0.0105** | **0.000** | **122.4** | **124.28** |
| | **0.010** | | |
| **0.0108** | | **113.8** | **120.7** |

**Table 5. Calculated average of RMSD for MP and [HMIm]Br on different MP concentration ($m_{MP}$ =0.000 and 0.010 mol.kg$^{-1}$) at T=310.2K**

| **RMSD [Å]** | | | |
|---|---|---|---|
| **$m_{MP}$ =0.000 (mol.kg$^{-1}$)** | | **$m_{MP}$ =0.010 (mol.kg$^{-1}$)** | |
| **MP** | **[HMIm]Br** | **MP** | **[HMIm]Br** |
| **0.71** | **5.22** | **0.88** | **5.42** |

**Table 6. Calculated average of H-Bondd for MP and [HMIm]Br on different MP concentration ($m_{MP}$ =0.000 and 0.010 mol.kg$^{-1}$) at T=310.2K**

| Number of H-bonds | | | |
|---|---|---|---|
| $m_{MP}$ =0.000 (mol.kg-1) | | $m_{MP}$ =0.010 (mol.kg$^{-1}$) | |
| **MP** | **[HMIm]Br** | **MP** | **[HMIm]Br** |
| **8.01** | **0.431** | **8.30** | **0.474** |

**Table 7. Calculated average of EL and vdw energies at T=310.2K**

| El [kcal.mol$^{-1}$] | | vdw [kcal.mol$^{-1}$] | |
|---|---|---|---|
| | $m_{MP}$ =0.000 (mol.kg$^{-1}$) [HMIm]Br | | |
| **MP** | | **MP** | **[HMIm]Br** |
| **-71.66** | **-146.66** | **-7.66** | **-18.00** |
| | $m_{MP}$=0.010 (mol.kg$^{-1}$) | | |
| **-69.44** | **-164.83** | **-8.99** | **-18.82** |

## Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Suportinginformation.docx