IONIC LIQUIDS AND AMINO ACIDS IN NONLINEAR CHEMICAL SYSTEMS

Murtaza Gani

Abstract

The understanding of molecular level interactions between biomolecules and ionic liquids (ILs) in aqueous media is crucial for the optimization of a number of relevant biotechnological processes. The interactions of imidazolium ionic liquids (ILs), i.e 1-ethyl 3-methyl imidazolium iodide and 1-ethyl 3-methyl imidazolium nitrate with Tyrosine as substrate in nonlinear chemical system were studied by monitoring the potential and spectral behaviours of ionic liquid-amino acid aqueous acid system. The absorbance of tyrosine at 274 nm due to n-π* transition undergoes a bathochromic shift with the addition of the ionic liquids. Also, the absorbance spectra of bromate ion shows two distinct peaks and a broad one less in absorbance in presence of the ionic liquid (emimI), while as in presence of the ionic liquid (emimNO₃), only a broad peak at 300 nm appears due to nitrate ion. The anion moiety of the imidazolium ionic liquid plays an important role in the mechanism by which the amino acids influence the ionic liquid solubility and together they will determine the direction and magnitude of the observed solubility phenomena.

Keywords: Amino acids, Ionic liquids, Imidazolium, Oscillatory reaction

1 Research Scholar, Department of Chemistry, University of Kashmir, Srinagar, 19006.
Introduction

A detailed investigation on tyrosine as the Belousov Zhabotinsky (BZ) oscillator in ferroin [Fe(II)] catalyzed reaction system with inorganic bromate was carried out in aqueous sulfuric acid medium (1.4 M). The aforesaid reagents were mixed with various concentrations to evolve the effective concentrations at which the reaction system exhibited better oscillations. The various oscillatory parameters such as time period ($t_p$), induction period ($t_{in}$), amplitude (A) and number of oscillations (n) were derived and the dependence of concentration of the reacting species on these oscillatory parameters was interpreted on the basis of the Field Koros Noyes (FKN) mechanism.

In the present communication, first of all we have studied the effect of the initial reagent concentrations on the oscillatory behavior of the system containing Tyrosine ($C_9H_{11}NO_3$) as the organic substrate, inorganic bromate as the oxidant and ferroin as catalyst in aqueous sulfuric acid medium. The reason for choosing Ferroin[Fe(II)] as a catalyst is as $E^{0}_{Fe(phen)_3^{3+}/Fe(phen)_3^{2+}}$ (1.06 V) $<$ $E_{p,Tyr}$ (1.14 V), the resulted Fe(phen)$_3^{3+}$ could not react with Tyr. Therefore, the Fe(phen)$_3^{2+}$ acted only as the oscillating catalyst and the catalyst was regenerated through the reduction of Fe(phen)$_3^{3+}$ by the radicals of Tyr and other intermediates. Thus, the presence of Fe(phen)$_3^{2+}$ could retard the consumption of Tyr and inturn, increase the oscillation number. However, as both $E^{0}_{Mn^{3+/Mn^{2+}}}$ (1.50 V) and $E^{0}_{Ce^{4+/Ce^{3+}}}$ (1.47 V) are higher than $E_{p,Tyr}$, the resulted Mn$^{3+}$ or Ce$^{4+}$ could easily oxidize Tyr. Thus, the presence of these metal ions could accelerate the consumption of Tyr, resulting in the decrease of the oscillation number.

Ionic liquids (ILs) are room temperature molten salts and have attracted much attention because of their interesting properties which render them useful for applications in materials science. These properties are a high ion conductivity, non-flammability, (electro)chemical stability and thermal stability. Ionic liquids can be divided generally into two categories; ionic liquids with an ion structure that includes active protons (protic ILs:PILs) and that does not include active protons (aprotic ILs:APILs). An ionic liquid consists of a cation, which is normally a bulk organic structure with low symmetry. The widely used cations in ionic liquids are based on ammonium, sulfonium, phosphonium, imidazolium, pyridinium, picolinium, pyrroloidinium, etc. with different substitutions.
The anion of ionic liquid may be organic or inorganic. For example, anions include \([\text{BF}_4^-, SbF_6^{2-}, PF_6^-, \text{CF}_3\text{SO}_3^-, \text{alkyl sulfates}, \text{etc.}]\). The forces operating between cation and anion of an ionic liquid are overwhelmingly columbic in nature.\(^6\) The ionic liquids reported in this paper are of imidazolium type with same cation but different anions – 1-ethyl 3-methyl imidazolium Iodide and 1-ethyl 3-methyl imidazolium Nitrate. Ionic liquids are gaining extensive attention in protein assays, because ionic liquids not only provide a novel and highly efficient reaction medium but also serve as effective participants in various biological reaction processes. Usually, ionic liquids are employed as neat solvents containing little or no water and emphasis is often placed on protein dynamics and structure due to their relationship to the protein activity, function, and stability.\(^7\) In addition, ionic liquids may be used as co-solvents for water in biphasic systems. The two aqueous phase systems composed of ionic liquids and phosphate are frequently applied for the separation of proteins.\(^8,9\) Investigations on the interactions between ionic liquids and proteins in aqueous solutions are even more important than those in neat ionic liquids phase. The behaviors of proteins in ionic liquid phase have been frequently reported. The impact of various cation/anion pairings on the thermal stability of ribonuclease A in aqueous systems containing a range of imidazolium or bromide-based ionic liquids were systematically elucidated by differential scanning calorimetry.\(^10\) Protein ionic liquid interactions in aqueous media can be interpreted within a Hofmeister framework. Generally, the variations of anionic moiety of ionic liquids appear to have an even more obvious effect on protein properties than the cation variations do.

Tyrosine is one of the most important amino acids which function as precursors of adrenaline, catecholamines, dopamine and melanin. Parkinson’s disease is generally found when tyrosine levels are abnormal.\(^11\) As we know, free iodine reacts with the protein of bacteria (presumably by iodinating tyrosine residues) and thus kills the bacterium organism. Iodine deficiency is currently the most preventable cause of the world’s cretinism, brain damage and thyroid disorders. Biologically, iodine is most essential in the synthesis of thyroid hormones, which serve in the differentiation, growth, metabolism and physiological function of virtually all tissues. The mixtures of amino-acids and ionic liquids could find many applications in these industries. The possibility of various interactions between amino-acids and imidazolium based ionic liquids are electrostatic and hydrophobic interactions. The cationic portion of ionic liquids, i.e. [emim]\(^+\), gets attracted towards the negative charge developed on the carboxylate end of the amino-acids due to electrostatic interactions. Hydrophobic interactions exist between the R-groups of amino-acids and the carbon-chain of ionic liquids. However, these interactions should be pH-dependent due to the zwitterionic structure of amino-acids. Other interactions such as van der Waals and H-bonding are expected to play a significant role in these systems. This area needs further investigation as few
authors have considered this topic. Coutinho et al.\textsuperscript{12} have performed standard molecular dynamics (MD) simulations on mixtures of five amino acids having dissimilar structural properties such as glycine, alanine, valine, isoleucine, and glutamic acid with 1-butyl-3-methylimidazolium bis(trifluoromethyl) sulphonylimide in order to understand the molecular interactions between amino acids and ionic liquids. On the basis of results obtained from MD simulations, the characteristics of the amino acids such as hydrophobicity and force of binding have been linked with ionic liquids in aqueous solutions. The radial distribution functions (RDFs) confirms the presence of significant interactions of nonpolar moieties of hydrophobic amino acids (Val and Ile) with less polar groups of cationic part of ionic liquid, but no interactions have been observed between this cationic part and hydrophilic species (Gly and Ala). All the amino acids showed interactions to ionic liquid cation and the significant interactions take place at the level of the apolar moieties of anion and side chains of the hydrophobic biomolecules. The interactions between Glu and ions of IL/H\textsubscript{2}O are found to be strongest among all other systems which are due to the polar functional group present on the hydrocarbon part of amino acid.

**Experimental**

**Chemicals Required**
All the reagents used were either analytical grade or of high purity. The reagents used were L-Tyrosine LR 98.5\% (SD fine chemicals Mumbai-400025), potassium bromate 99\% (Merck, Mumbai, India), ferroin indicator solution (Merck Limited), sulphuric acid 98\% (Merck; LR), potassium iodide (Merck Limited) and ionic liquids-1-ethyl 3-methyl imidazolium Iodide 97\% (Sigma Aldrich) and 1-ethyl 3-methyl imidazolium Nitrate 99\% (Fluka). All the desired solutions of these reagents were prepared in 2.1 M sulfuric acid except ferroin in aqueous medium as it was reported to undergo dissociation in aqueous acid medium.\textsuperscript{13}

**Procedure**
The ion analyzer (ORION 4 STAR) having pH as well as mV option was calibrated in the oxidation reduction potential (ORP) mode with the standard solutions, using a platinum electrode (EP-89) as the indicator and calomel (SCE) as the reference electrodes. The equipment was hooked to two half cells, one containing any one of the reaction systems under investigation into which the platinum electrode was dipped as an indicator electrode. Another half cell was filled with a 2.5 \times 10^{-4} M solution of potassium chloride, and the calomel electrode was dipped into it as a reference electrode. The two half cells were connected through a salt bridge containing saturated solution of potassium nitrate (Merck) and kept immersed in a high precision water bath (ADVANTEC TBS 451 PA) set up at a temperature of 30 ± 0.1\textdegree C. All the solutions used in the reaction system were first kept under thermostatic conditions at the desired temperature for about 10 minutes to acquire uniform temperature in the system. The reaction was carried out under
stirred conditions with a magnetic stirrer bar (8mm, Cole parmer-04765-55). The reaction started by the addition of a 5 mL 0.053M solution of potassium bromate to a solution containing 5 mL 0.015M tyrosine and 5 mL 0.0015M ferroin. The effects of ionic liquids / liquid electrolytes [(emim) types] were observed by their addition to the above system before bromate addition. Spectrophotometry was also done to monitor the effect of these perturbants by using a spectrophotometer (UV-Vis Shimadzu 3600 Model Tcc-240A). The kinetics of the reaction was monitored at 510 nm- maximum wavelength of ferroin.

Results and Discussion

Potentiometry. Fig. 1 shows the variation in oscillatory parameters at different concentrations of tyrosine, keeping the concentrations of other reagents constant. From the Fig., it is apparent that with increase in the concentration of tyrosine, the induction period decreases. The induction period is observed due to the accumulation of crucial concentration of the organic brominated species prior to the commencement of oscillations. With the increase in the substrate concentration, the rate of formation of bromo-organic derivative increases and hence there is shortening of the induction period. The dependence of the induction period on [tyrosine] fits well with the mechanistic explanations based on the FKN model. The time period becomes shorter with increasing initial substrate concentration. The dependence of the initial substrate concentration on the oscillation period is justified on the basis of the FKN mechanism. According to this mechanism, the overall BZ reaction may be divided into the following three main processes; consumption of bromide ion (process A), autocatalytic reaction of the bromous acid with oxidation of the catalyst (process B), and organic reaction with the reduction of the catalyst (process C)

\[
\begin{align*}
\text{BrO}_3^- + 2\text{Br}^- + 3\text{H}^+ & \rightarrow 3\text{HOBr} \\ 
\text{BrO}_3^- + \text{HBrO}_2 + 2\text{M}_{\text{red}} + 2\text{H}^+ & \rightarrow 2\text{HBrO}_2 + 2\text{M}_{\text{ox}} + \text{H}_2\text{O} \\ 
2\text{M}_{\text{ox}} + \text{Substrate} + \text{Bromoderivative} & \rightarrow f\text{Br}^- + 2\text{M}_{\text{red}} + \text{other products}
\end{align*}
\]

The dependence of the oscillation number and amplitude on [tyrosine] is plotted in Fig.1 and the best oscillatory parameters are observed at [Tyr]= 0.015M.
Fig 1. Showing effect of the initial substrate (tyrosine) concentration on the induction period ($t_{in}$, s), time period ($t_p$, s), amplitude (mV) and number of oscillations (n) while keeping concentrations of other reagents constant.

Fig. 2 depicts the variation of oscillatory parameters with varying $[\text{BrO}_3^-]_0$. With the increase in $[\text{BrO}_3^-]_0$, the induction period undergoes a continuous decrease due to the faster accumulation of the bromoderivative of the substrate while as time period first decreases and then increases as against the number of oscillations which increase first and then decrease. The decrease with respect to time period is due to the reason that bromate causes the bromination of the substrate first giving HBrO$_2$ and HOBr and then Br$_2$ which are responsible for generating critical bromo substrate concentration and also have a direct role in $[\text{M}^{n+}/\text{M}^{(n+1)}]$ redox couple. However, increasing the $[\text{BrO}_3^-]_0$ further from 0.065 mol L$^{-1}$ and onwards substrate becomes limiting and hence no oscillations are seen.

Fig 2. showing effect of the initial bromate concentrations on the induction period ($t_{in}$, s), time period ($t_p$, s), amplitude (mV), and number of oscillations (n) while keeping concentrations of the other reagents constant.
Fig.3 shows the oscillatory parameters for the varying $[\text{Fe(phen)}_3]^{2+}$. With the increase in the concentration of $[\text{Fe(phen)}_3]^{2+}$, the time period decreases following the FKN mechanism, while as the induction period and frequency of oscillations first decrease and then increase. This can be because of the combined effect of the processes B and C, wherein the $[\text{Fe}^{2+}/\text{Fe}^{3+}]$ depends on the autocatalysis process, giving rise to the formation of HBrO$_2$. The amplitude and number of oscillations first increase and then decrease with the increase in $[\text{Fe(phen)}_3]^{2+}$ following the FKN mechanism.

![Graph showing effect of initial $[\text{Fe(phen)}_3]^{2+}$ concentrations on induction period ($t_{in}$, s), time period ($t_p$, s), amplitude (mV), and number of oscillations (n) while keeping concentrations of other reagents constant.]

Fig 3. showing effect of the initial $[\text{Fe(phen)}_3]^{2+}$ concentrations on the induction period ($t_{in}$, s), time period ($t_p$, s), amplitude (mV), and number of oscillations (n) while keeping concentrations of the other reagents constant.

Fig.4 gives the variation of oscillatory parameters with varying $[\text{H}_2\text{SO}_4]_0$, keeping concentrations of other reagents constant. Good results were obtained in 1.4 M $\text{H}_2\text{SO}_4$. The $\text{H}^+$ ions causes the protonation of tyrosine and the reactive protonated intermediate acts as a good nucleophile for bromide ion to form bromotyrosine.

![Graph showing variation of oscillatory parameters with varying $[\text{H}_2\text{SO}_4]_0$.]

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Fig 4 showing effect of the initial $[\text{H}_2\text{SO}_4]_0$ concentration on the induction period ($t_{\text{in}}$, s), time period ($t_p$, s), amplitude (mV), and number of oscillations (n) while keeping concentrations of the other reagents i.e., $[\text{Tyrosine}] = 0.015 \text{ mol L}^{-1}$, $[\text{Fe(phen)}_3]^{2+} = 0.0015 \text{ mol L}^{-1}$ and $[\text{BrO}_3^-] = 0.053 \text{ mol L}^{-1}$ as constant.

The oscillating profiles of the Tyrosine based BZ chemical system with different concentrations of the two ionic liquids (emimI & emimNO$_3$) added before bromate addition are shown in Fig. 5 and 6 and the data corresponding to these oscillating profiles are shown in tables I and II respectively.

**Figure 5.** Potential(mV) versus time(s) plots showing the effect of varying [emimI] concentrations on oscillatory characteristics of the system containing $[\text{Tyrosine}]= 0.015 \text{ mol L}^{-1}$, $[\text{BrO}_3^-] = 0.053 \text{ mol L}^{-1}$, $[\text{Fe(phen)}_3]^{2+} = 0.0015 \text{ mol L}^{-1}$, and $[\text{H}_2\text{SO}_4] = 1.4 \text{ mol L}^{-1}$, at temperatures $30 \pm 0.1^\circ\text{C}$; [emimI] = a) 0.0 molL$^{-1}$; (b) 0.003molL$^{-1}$; (c) 0.013molL$^{-1}$; (d) 0.023molL$^{-1}$; (e) 0.033molL$^{-1}$; (f) 0.043molL$^{-1}$ and (g) 0.053molL$^{-1}$ of the Tyrosine based BZ system.
Figure 6. Potential(mV) versus time(s) plots showing the effect of varying [emimNO$_3$] concentrations on oscillatory characteristics of the system containing [Tyrosine]= 0.015molL$^{-1}$, [BrO$_3$]$^{-}$= 0.053molL$^{-1}$, [Fe(phen)$_3$]$^{2+}$= 0.0015molL$^{-1}$, and [H$_2$SO$_4$] = 1.4molL$^{-1}$, at temperatures 30 ± 0.1°C; [emimNO$_3$] = a) 0.0 molL$^{-1}$; (b) 0.1molL$^{-1}$; (c) 0.2molL$^{-1}$; (d) 0.3molL$^{-1}$; (e) 0.4molL$^{-1}$ and (f) 0.5molL$^{-1}$ of the Tyrosine based BZ system

Table I shows the variation of oscillatory parameters of tyrosine based BZ system at different concentrations of emimI ionic liquid added. As is evident from the data that a gradual decrease in the induction period and number of oscillations occurs with increase in the concentration of the ionic liquid added. This can be explained in terms of the reaction of iodide ion (anion part of emimI) of ionic liquid and bromate ion leading to the generation of bromide ion and iodine. Br$^{-}$ then as per FKN mechanism leads to the formation of HOBr and HBrO$_2$ in successive steps leading to quicker bromination of the substrate due to which the preoscillatory period and no. of oscillations decrease with increase in ionic liquid concentration and the oscillating profiles corresponding to these concentrations of ionic liquid added are shown in Fig.5.

<table>
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<tr>
<th>[emimI]/mol L$^{-1}$</th>
<th>Induction period $t_{ip}$/s</th>
<th>Time period $t_p$/s</th>
<th>Amplitude/mV</th>
<th>Number of Oscillations/ N</th>
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Table 1. Showing effect of [emimI] on the oscillatory parameters of Tyrosine-Bromate-Ferroin based BZ system

Table 2 depicts the variation of oscillatory parameters of the tyrosine based BZ system with different concentrations of emimNO\(_3\) ionic liquid added. In this case also the induction period and no. of oscillations decrease with increase in ionic liquid concentration. This may be due to the nitration of tyrosine in presence of radical species generated during FKN mechanism due to which the tyrosine concentration becomes limiting and also the sites of tyrosine for the bromination reaction become deficient in number. The nitration of tyrosine in acidic medium is also confirmed by its absorbance peak at 357 nm.

<table>
<thead>
<tr>
<th>[emimNO(_3)] (mol\ L^{-1})</th>
<th>Induction period (t_{in}) /s</th>
<th>Time period (t_p) /s</th>
<th>Amplitude (\mu) /mV</th>
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Table 2. Showing effect of [emimNO\(_3\)] on the oscillatory parameters of Tyrosine-Bromate-Ferroin based BZ system.

**UV-vis Spectrophotometry.**

The interactions of ionic liquids and amino acids in aqueous acid media can be studied by monitoring the spectral changes of the different constituents of the tyrosine based BZ system and...
the two ionic liquids used. The UV-vis spectra of the constituents with the two ionic liquids (EmimI & EmimNO₃) are shown in Fig. 7 and 8 respectively.

**Figure 7.** Effect of emimNO₃ ionic liquid on the absorption spectrum of Tyrosine and Bromate ion
Figure 8. Effect of emimI ionic liquid on the absorption spectrum of Tyrosine and Bromate ion.

From the spectra, it is clear that an additional band in 300-400 region appears in the Tyrosine-IL spectrum. The peak at 274 nm attributed to the n-π* transition of the aromatic amino acid tyrosine (also present in Trp & Phe) undergoes a bathochromic shift due to the addition of ionic liquids. These spectral changes might arise from the disturbance of the microenvironment around the amino acid caused by the binding of ionic liquids with tyrosine molecule. Usually, the amide moieties in the tyrosine expose to a water environment would experience a low-energy π-π* transition under ultraviolet irradiation. In comparison with the electron cloud existing in the ground state, the π* electron cloud has higher polarity because of the formation of an antibonding orbital between C and O in the excited state. As a polar solvent, a water molecule has a stronger ability to
lower the energy of the π* electron cloud rather than π electron cloud, although it lowers the energy levels of both states.\textsuperscript{15} When the microenvironment around the amide moieties of tyrosine is changed, i.e., the surrounding polar water molecules are displaced by the weak-polar ionic liquid moieties, a lower energy is required and the π* transition would undergo a bathochromic shift and thus a hypochromic effect is observed. Considering that the peak at 274 nm is related to the n-π* transition of aromatic amino acid, the subtle variation after addition of ionic liquids further suggests that the microenvironment of the aromatic amino acid is changed due to the interactions between ionic liquids and amino acids.

Although emimI and emimNO\textsubscript{3} have identical cationic imidazolium cation moiety, their interactions with Tyrosine result in very different UV-vis spectra due to the variation of anion moiety in the two ionic liquids. A significant decrease of absorbance at 310 nm is observed for the emimNO\textsubscript{3}-Tyr mixture with respect to that of emimI- Tyr mixture in which a slight red shift at 350 nm is observed. Ionic liquid anion exhibits an appreciable affinity for the nonpolar groups of the amino acid, this interaction of the ionic liquid anion with the amino acid has been proved by RDF’s of different molecular regions of valine and selected atoms of the ionic liquid anion. As far as the binding of the ionic liquid cation to the amino acid is concerned, the RDF’s shows the preference of the cation for the least polar moieties of the amino acid. The imidazolium cationic moiety enters the subdomains of proteins and interact with the hydrophobic residues\textsuperscript{15}. It further illustrates that the anion moieties of the imidazolium ionic liquids play a very important role in the interactions of ionic liquids with proteins.

The molecular mechanism behind the solubility effect of ions and amino acids in aqueous acid ionic liquid solutions is the role of the ionic liquid anion and the interactions that take place there with. There are actually interactions not only with the ionic liquid cation but also with the anion. The anion, unlike the cation establishes interactions with all the amino acids.

**Comparison of simple electrolytes with Liquid electrolytes.**

Table 3 shows the effect of varying concentrations of the simple electrolyte KI on the oscillatory parameters of Tyrosine based BZ system. The decrease in induction period with increase in concentration of KI concentration is due to the iodination of tyrosine leading to the iodo derivatives of tyrosine as formed in biological systems in the thyroid gland. The oscillating profiles showing the effect of varying concentrations of KI are shown in Fig. 9.
<table>
<thead>
<tr>
<th>[KI]/ mol L(^{-1})</th>
<th>Induction period (t_{\text{ind}})/s</th>
<th>Time period (t_{p})/s</th>
<th>Amplitude/ mV</th>
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**Table 3.** Showing effect of [KI] on the oscillatory parameters of Tyrosine-Bromate-Ferroin based BZ system

**Figure 9.** Potential(mV) versus time(s) plot showing the effect of varying KI concentrations on oscillatory characteristics of the system containing [Tyrosine]= 0.015molL\(^{-1}\), [BrO\(_3^-\)]= 0.053molL\(^{-1}\), [Fe(phen)]\(^3+\) = 0.0015molL\(^{-1}\), and [H\(_2\)SO\(_4\)]= 1.4molL\(^{-1}\), at temperatures 30 ± 0.1°C; [KI] = (a) 0.0molL\(^{-1}\); (b) 0.00165mol L\(^{-1}\); (c) 0.0033molL\(^{-1}\); (d) 0.0066molL\(^{-1}\); (e) 0.0132molL\(^{-1}\) and (f) 0.0265molL\(^{-1}\) of the Tyrosine based BZ system.
Table 4 and 5 show the comparison of the simple electrolytes KI/KNO₃ with the liquid electrolytes emimI/emimNO₃ bearing the same anion moiety but different cationic part, it is concluded that the variation in oscillatory parameters is more drastic in case of simple electrolytes as compared to that of liquid electrolytes because of strong columbic forces of attraction present in liquid electrolytes.

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Table 4. Showing comparison of effect of KI and emimI on the oscillatory parameters of Tyrosine based BZ system

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<td>8</td>
<td>875</td>
<td>135</td>
<td>154</td>
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Table 5. Showing comparison of effect of KNO₃ and emimNO₃ on the oscillatory parameters of Tyrosine based BZ system.

Conclusions
The systematic study performed at various concentration ranges has revealed the effective concentrations of the reagents at which better oscillations were exhibited by the reaction system. Furthermore, tyrosine being essential in thyroid hormone formation, so the interaction of various electrolytes bearing the iodide ion (I⁻) can be helpful in understanding the iodination of tyrosine as observed in vivo conditions. Since amino acids can be taken as model systems, the molecular...
mechanism reported here can be helpful to understand the solubility and stability behavior of other more complex biomolecules, in particular drugs and proteins in aqueous solutions with ILs and thus be relevant to develop and improve ionic liquid based biotechnological processes.

In practical terms, the information on the factors and molecular-level phenomena that govern the interactions between biomolecules and ionic liquids gathered in this work will help to establish optimal conditions for biomolecule extractions in environmentally friendly standards and will contribute to the improvement of other crucial processes in biotechnology, such as the stabilization of enzymes and their activities in ionic liquids, constituting thus profitable knowledge susceptible of being appropriated in biochemistry, biology, and biotechnology, with possible economical impact.

References.


