AUCTORES
Globalize your Research
International Journal of BioMed Research
Mohd Farooqh Javvad Ali *
Open Access
Review Article

A Brief Review of Ionic Liquids: Synthesis and Applications

Mohd Farooqh Javvad Ali [1*], Mamidi Praveen [1], Aiman Ghouse [1] and Farhat Fatima [1]
[1] Department of Pharmaceutical Chemistry, G. Pulla Reddy College of Pharmacy, Hyderabad, Telangana, India.
Corresponding Author: Mohd Farooqh Javvad Ali, Department of Pharmaceutical Chemistry, G. Pulla Reddy College of Pharmacy, Hyderabad, Telangana, India.
Received Date: April 02, 2021; **Accepted Date:** April 07, 2021; **Published Date:** April 10, 2021
Citation: Md. Javvad Ali, Praveen M., Ghouse A. and Fatima F. (2021) A brief review of ionic liquids: synthesis and applications. *International J. of Biomed Research*. 1(2); **DOI:** 10.31579/IJBR-2021/011

Abstract

The natural contamination and pollution caused by the chemical industries has expanded in large number for a few decades. The desire of generating environmental friendly materials and less hazardous substances has been increased among the researchers and scientists. This is being fulfilled through the principles of Green chemistry. Ionic liquids (ILs) have emerged as an environmentally friendly alternative to various organic solvents and catalysts with high activity and selectivity. In this review, the history of ionic liquids, its properties, synthesis and applications in various fields have been discussed. The list of commercially available ionic liquids also has been added in this review. The present review is aimed for giving general overview of ionic liquids and processes involved in preparation and development of ionic liquids and also their applications.

Keywords: green chemistry, ionic liquids, organic solvents

Introduction

The Green Chemistry has been a burgeoning topic over last few decades. This has been the driving force for the growth in research on the development of compounds with enhanced health and environmental features [1-3]. In this regard, the industrial and scientific evolution has boosted the production of Ionic Liquids (ILs).

The specific definition of what is an ionic liquid may vary from one person to another, the prevailing definition would be that they are molten analogs of the inorganic salts containing melting point below 100°C, in which asymmetrical ions are held by directional forces.

The interests in ILs emerged because of their many advantageous characteristics, such as low melting point, negligible vapor pressure, high thermal stability, inflammability, wide electro chemical window, recyclability and so on. Since the introduction of ILs in 1914, they are extensively employed in various fields such as organic, inorganic, physical and biological chemistry; however, recently they have been explored as a promising solvent in the extraction and separation of biomolecules, organic compounds, cell organelles and transition and inner-transition metal ions [4-7].

History

There are several beginnings to the history of ionic liquids in which they were discovered independently. It is most commonly dated back to 1914 and the work of Walden on the use of alkylammonium nitrates.

Paul Walden was in search of molten salts which were liquid at temperatures, so that he could use his equipment without any special adaptations. He discovered that [EtNH3][NO3] has a melting point of 12 °C. This was the first example of a protic ionic liquid (PIL), which were later to become an important sub-class of ionic liquids after being rediscovered by Hiroyuki Ohno (Hirao et al. 2000);

The next burst of interest occurred with the discovery of chloroaluminates which were formed by combining the quaternary heterocyclic cations with aluminum chloride. These promised a great deal of potential for use in various different fields, but all failed due to extreme sensitivity to moisture.

Early in 1980s, John Wilkes and group introduced 1, 3-dialkylimidazolium cations into ionic liquids to form the 1-alkyl-3-methylimidazolium chloride aluminium chloride ionic liquids ([CnC1im]Cl-AlCl3, where n = 1– 4), with [C2C1im]+ being preferred because it gave ionic liquids with the best transport properties (Wilkes et al. 1982).

A major step forward was made by Wilkes in the early 1990's, with the report of moisture stable ionic liquids created by replacing the aluminum chloride with other anions, such as tetrafluoroborate or hexafluorophosphate [8].

Since then ionic liquids has seen rapid growth. Starting with imidazolium cations, the cationic components have been varied including ammonium, phosphonium, thiazolium, pyridinium and triazolium species.

Structure

Some of the common cations of ionic liquids:

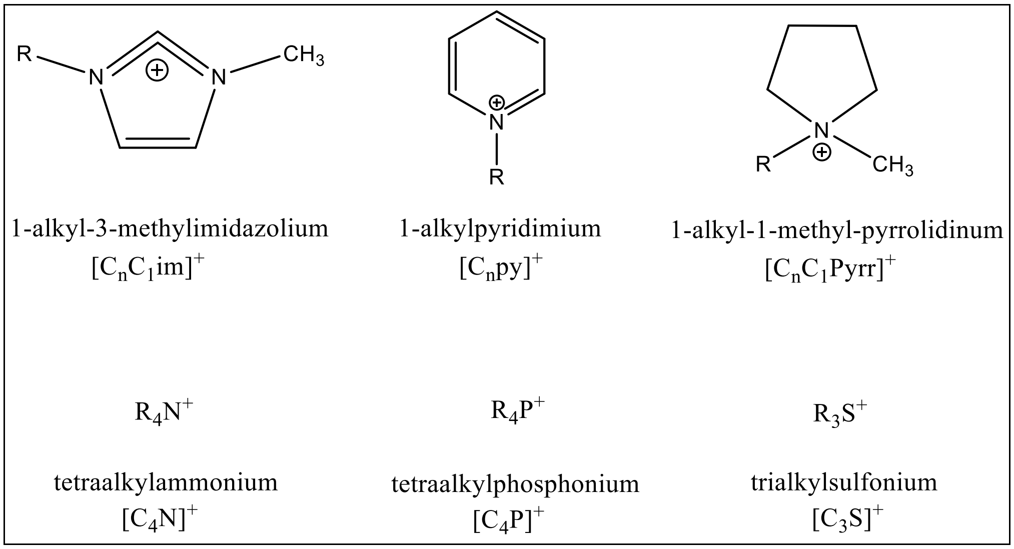


Figure 1: Structures of cations of ionic liquids.

Some of the common anions of ionic liquids:

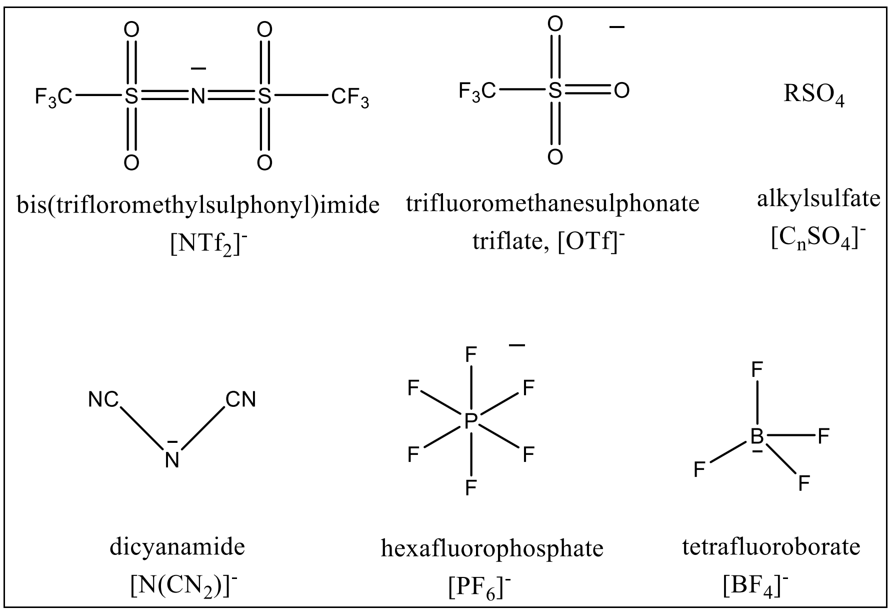


Figure 2: Structures of anions of ionic liquids.

Properties

There are various properties of ionic liquids such as density, viscosity, hydrophobicity, solvation of ionic liquid system. These properties can be influenced by choosing the anion or alkyl chains of the cation [13-17].

Density

The density of the ionic liquids is generally higher than the density of water. But the ionic liquids may also contain traces of water for the purpose of dilution, however such traces do not have much impact and possess relatively very small effect

Viscosity

Viscosity plays a major role in many conditions and it is also one of the most important physical property. The ionic liquids have a broad range of viscosity from 0.035-0.500 Nsm. When compared with the molecular solvents, the ionic liquids are generally viscous. Due to the presence of water in ionic liquids, its viscosity may get effected as similar to the density, they get diluted and become less viscous.

Hydrophobicity

The selection of proper cations and anions will result in the formation of hydrophilic or hydrophobic ionic liquids. The increase in the length of alkyl chain in the cations leads to the development of hydrophobicity in an ionic liquid. The anions such as [PF6]– and (CF3SO2)2N– are responsible for making ionic liquids immiscible in water. Whereas, the nitrates, acetates and trifluoroacetate are responsible for making ionic liquids miscible with water.

Melting Point

The melting point of the ionic liquids is very less. Most of the ionic liquids are in molten form at the room temperature. Some of the ionic liquids have very low boiling point such that at even below –80 °C they will be in liquid state. The melting point of the ionic liquids decreases with the increase in the amount of water molecules available in the ionic liquids. By increasing the substituent chain length, the melting point can be increased.

Vapor Pressure

The vapor pressure of the ionic liquids at room temperature is negligible.

Polarity

The ionic liquids are best suitable for catalytic reactions because number of ionic liquids have high polarity and are non-coordinating. These ionic liquid systems can be designed in such a way that we can obtain desired range of properties, which particularly can be utilized in any required application.

Thermal Conductivity

Thermal conductivity is a crucial parameter for the heat transfer applications. The result of the water contamination on the thermal conductivity is remarkable. For ionic liquids the temperature dependence is very weak and it befits into a straight line with adjustable parameters.

Heat Capacity

The temperature dependence of the ionic liquids is relatively weak. Valkenburg et al. reported the heat capacities of several ionic liquids, and the temperature range of -50 to -300°C is recorded and is also available in the literature.

Heat of Fusion

The hydrophilic ionic liquids have substantial effect on the heat of fusion due to the availability of the water. The water has heat of fusion *times higher than that of the ionic liquids.

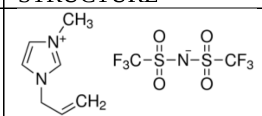
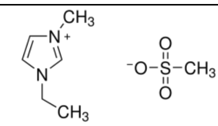
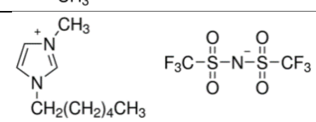
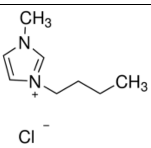
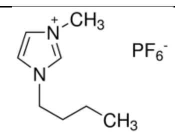
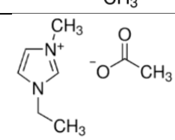
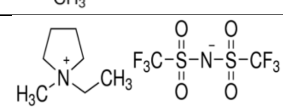
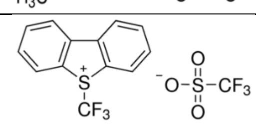
Sensible Heat Storage Density

The heat storage is easily calculated from the density, heat capacity and temperature range chosen. The heat storing capacity of the ionic liquids plays very important role in applications in solar energy production.

Solvation Properties

By changing the constituent ions, the solvating properties of the ionic liquids can be changed. With the help of ethers, hydrocarbons and various organic solvents, the ionic liquids can be made miscible or immiscible. This converts them into a very beneficial solvent when combined with the characteristic of negligible vapor pressure.

1. List of commercially available ionic liquids:

S.No	NAME	CAS-NO.	STRUCTURE
1	1-Allyl-3-methylimidazolium bis(trifluoromethylsulfonyl)imide	655249-87-9	
2	1-Ethyl-3-methylimidazolium methanesulfonate	145022-45-3	
3	1-Hexyl-3-methylimidazolium bis(trifluormethylsulfonyl)imide	382150-50-7	
4	1-Hexyl-3-methylimidazolium bis(trifluormethylsulfonyl)imide	79917-90-1	
5	1-Butyl-3-methylimidazolium hexafluorophosphate	174501-64-5	
6	1-Ethyl-3-methylimidazolium acetate	143314-17-4	
7	1-Ethyl-1-methylpyrrolidinium bis(trifluoromethylsulfonyl)imide	223436-99-5	
8	5-(Trifluoromethyl) dibenzothiophenium trifluoromethanesulfonate	129946-88-9	

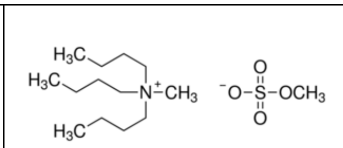
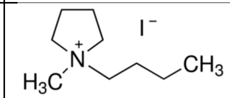
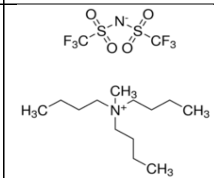
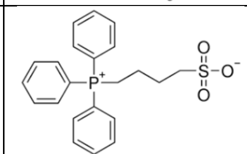
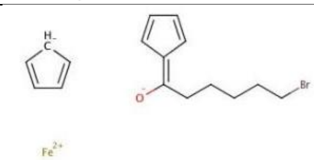
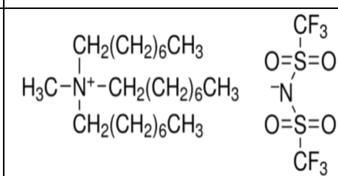
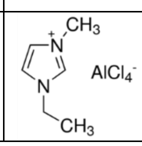
9	Tributylmethylammonium methyl sulfate	13106-24-6	
10	1-Butyl-1-methylpyrrolidinium iodide	56511-17-2	
11	Tributylmethylammonium bis(trifluoromethylsulfonyl)imide	405514-94-5	
12	4-(Triphenylphosphonio)butane-1-sulfonate	164982-05-2	
13	(6-Bromo-1-oxohexyl)ferrocene	57640-76-3	
14	Methyl-trioctylammonium bis(trifluoromethylsulfonyl)imide	375395-33-8	
15	1-Ethyl-3-methylimidazolium tetrachloroaluminate	80432-05-9	

Table 1: List of commercially available ionic liquids.

2. Synthesis of Ionic Liquids

Ionic liquids can be mainly classified into two main categories, simple salts (these are made up of single cation and single anion) and ionic liquids (these are salts in which equilibrium is involved) [20].

There are two major steps involved in the synthesis of ionic liquids.

- ***Formation of the Desired*** **Cation:** Our desired cation can be achieved by the protonation of amine by an acid or through quaternization reactions of amine with a haloalkane and heating the mixture.
- ***Exchange of Anion:*** By treating the halide salts with Lewis acids to form Lewisacid-based ionic liquids or by anion metathesis, the exchange of anion is carried out.

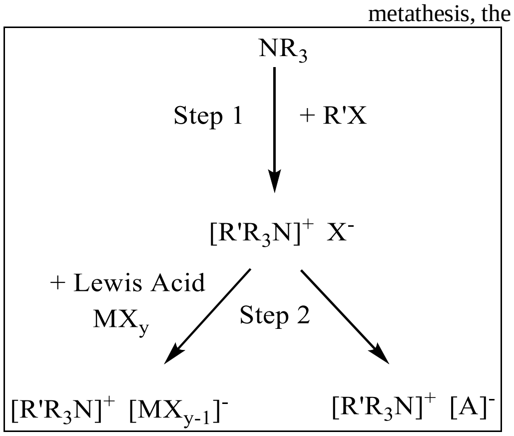


Figure 3: Synthesis of ionic liquids.

3. Applications of Ionic Liquids:

There are various applications of ionic liquids in various sectors and departments, they are used in multiple ways such as described below: [28]

1. Ionic Liquids as Catalysts:

The ionic liquid may act as acidic or basic or organocatalyst based upon the functional group attached to the cation or anion,

a) ***As Acid Catalysts***: the ionic liquids acidic nature is used for many organic transformations like Beckmann rearrangement, synthesis of chalcones, oxidation reactions, Pechmann reaction, Koch carbonylation, asymmetric Aldol condensation, Aza-Michael reaction, Prin's reaction, synthesis of furfural, biodiesel, Hantzsch reaction, and Mannich reaction.

Esterification of alcohols by carboxylic acids is carried out in a halogen-free Bronsted acidic ionic liquid, Nmethyl- 2-pyrrolidinium methyl sulphonate under mild conditions and without additional solvent.

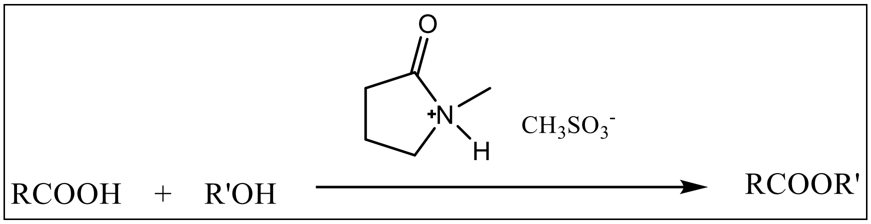


Figure 4: example as acid catalyst.

b) ***As Base Catalyst***: The intrest in the basic functionalized ionic liquids increased due to their high catalytic efficiency than mixture of inorganic base and ionic liquids for base catalyzed processes and also due to convenient recycling.
These basic ionic liquids have been utilized to catalyze many reactions such as
condensation reaction of aldehydes and ketones with hydroxylamine, aza-Michael addition reaction, Michael addition of active methylene compounds, synthesis of quinolines, pyrroles.

Xu et al. developed a green protocol for the Michael addition of N-heterocycles to α,-unsaturated compounds at room temperature by using a basic ionic liquid [bmim]OH as a catalyst and reaction medium.

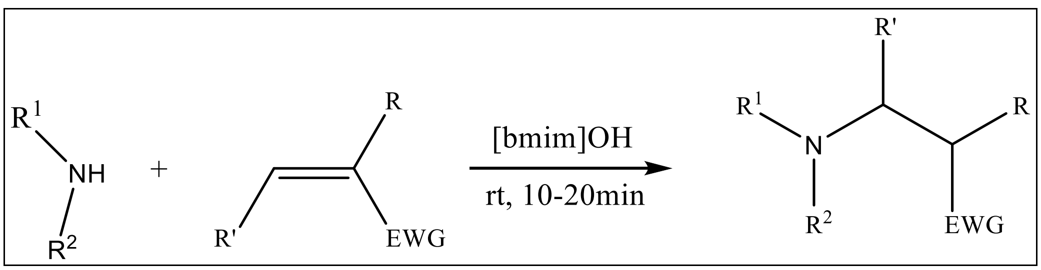


Figure 5: example as base catalyst.

c) ***As Organocatalysts***: Ionic liquids have great potential as catalyst which can be used in many reactions and these act as organocatalysts. One of the best example of ionic liquids as organocatalysts is through hydrogen bonding interactions.

The reaction on which ionic liquids are mostly applied are Diels-Alder cycloadditions and their derivatives.
Luo and coworkers used a functionalized chiral ionic liquid as an efficient reusable organocatalyst for asymmetric Michael addition of ketones/aldehydes with nitroalkenes.

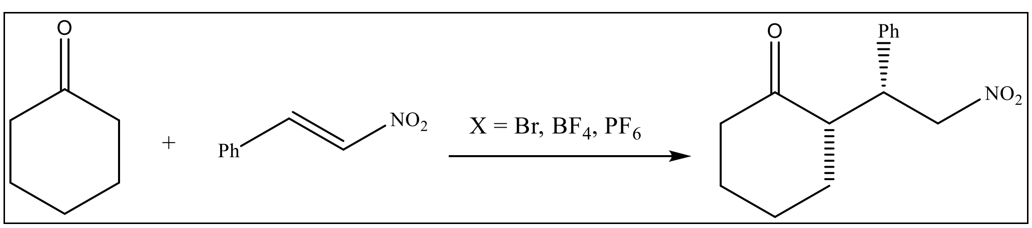


Figure 6: example as organocatalyst.

2. Ionic liquids as Soluble supports:

Ionic liquids have practically nonvolatile nature and have tunable solubility. Due to these characteristics of the ionic liquids, they are being used as soluble supports for catalyst/reagent immobilization.

This has been successfully employed in various organic reactions such as 1,3-cycloadditions, synthesis of thiazolidinones, Knoevengeal reaction , Suzuki coupling, oligosaccharide synthesis , and Grieco's multicomponent synthesis of tetrahydroquinolines.

Xie et al. developed a novel and efficient route for the synthesis of 1,4-benzodiazepine-2,5-dione using ionic liquids as soluble supports.

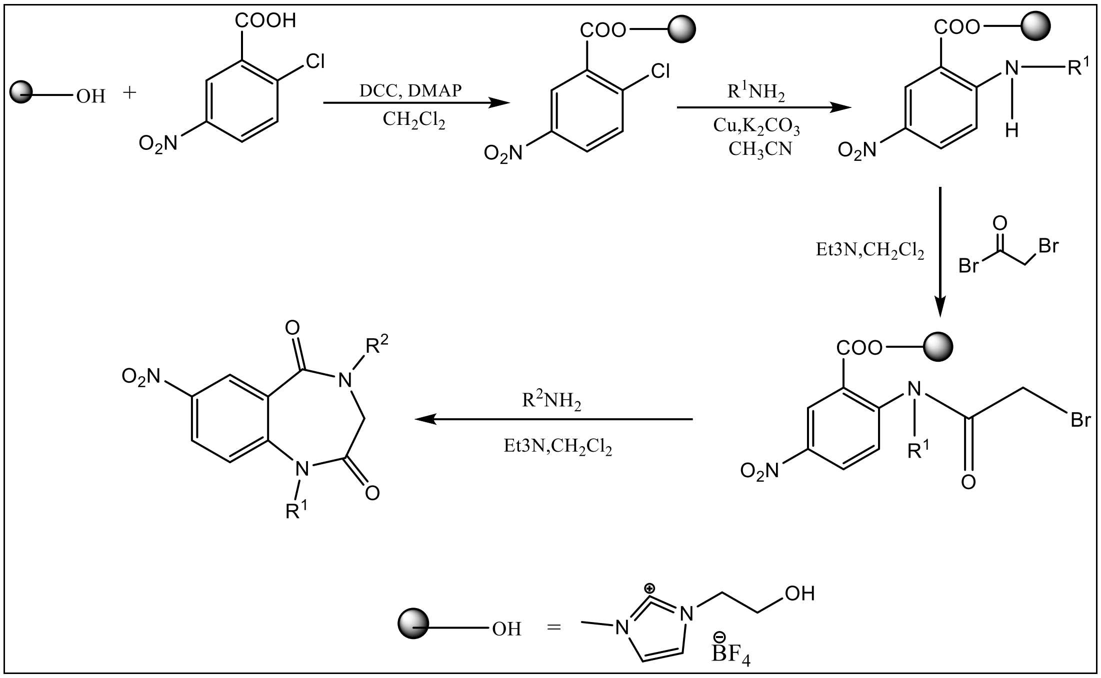


Figure 7: example for soluble supports.

3. Separation of solutes from ionic liquids by distillation/stripping:

As the ionic liquids have negligible vapour pressure, the ionic liquids can be recovered using distillation from the compounds having low boiling points. Before the adaption of ionic liquids as solvents for the production of nitroaromatics, Dal and Lancaster studied two different ionic liquids, [bmpy][OTf] and [bmpy][N(Tf)2], and developed a regime by which the solvent may be recovered and reused.

The recycling of the IL was achieved by dissolving the post-reaction mixture into dichloromethane and adding water. It was then possible to extract any unreacted nitric acid, plus the acetic acid (HOAc) generated by the reaction with water. After removing the dichloromethane, the organics were removed from the IL by steam distillation.

The samples of the ionic liquids are withdrawn after each run, and analyzed before being reused and it revealed that there was no difference between the recovered and the original Ionic liquid [Dal & Lancaster, 2005].

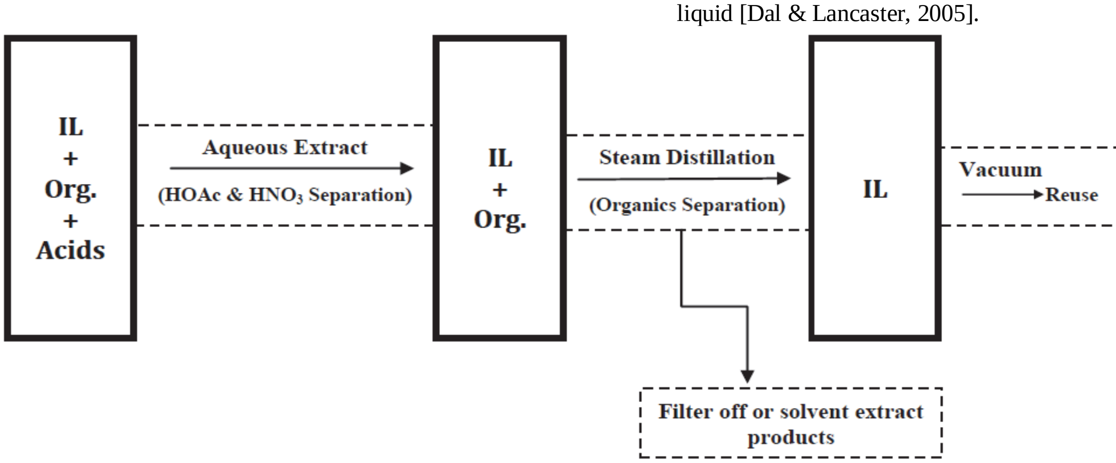


Figure 8: Separation of solutes from ionic liquids by distillation/stripping.

4. **Ionic liquids as Lubricants:**
Ionic liquids get readily adsorbed onto metal surfaces, which typically have some form of charging and form layers. The surface adsorption and long alkyl chains typically present in the cation are thought to result in the formation of relatively thick, low friction layers that lead to a reduction in friction and wear, particularly in the boundary lubrication wear. Ionic liquid lubricants have been shown to outperform commercially available lubricants, such as fully formulated engine oils.
5. **Ionic liquids as heat storages:**
Wu, B. & Reddy, Ramana & Rogers, Robin. (2001). Novel ionic liquid thermal storage for solar thermal electric power systems. International Solar Energy Conference. 445-451.
Feasibility of ionic liquids as liquid thermal storage media and heat transfer fluids in a solar thermal power plant was investigated. Many ionic liquids such as [C 4min][PF 6], [C 8mim][PF 6], [C 4min][bistrifluromethane sulflonimide], [C 4min][BF 4], [C 8mim][BF 4], and [C 4min][bistrifluromethane sulflonimide] were synthesized and characterized using thermogravimetric analysis (TGA), differential scanning calorimeter (DSC), nuclear magnetic resonance (NMR), viscometry, and some other methods. Properties such as decomposition temperature, melting point, viscosity, density, heat capacity, and thermal expansion coefficient were measured. The calculated storage density for [C 8mim][PF 6] is 378 MJ/m 3 when the inlet and outlet field temperatures are 210°C and 390°C. For a single ionic liquid, [C 4mim][BF 4], the liquid temperature range is from -75°C to 459°C. It is found that ionic liquids have advantages of high density, wide liquid temperature range, low viscosity, high chemical stability, non-volatility, high heat capacity, and high storage density. Based on our experimental results, it is concluded that ionic liquids could be excellent liquid thermal storage media and heat transfer fluids in solar thermal power plant.
6. **Ionic liquids in Protein Crystallization:**
Cryst. Growth Des. 2009, 9, 8, 3463-3469
Publication Date: May 4, 2009.
https://doi.org/10.1021/cg900140b

Crystals grown using ionic liquids as precipitating agents or as additives provided X-ray diffraction resolution similar to or better than that obtained without ionic liquids. The ionic liquids improved the crystallization behavior and provided improved diffraction resulting in the determination of the structure. Ionic liquids should be considered as useful additives for the crystallization of other proteins [38].

Conclusion

Over the past few years, ionic liquids have been kept on utilization altogether as a medium and catalyst for numerous reactions. The potential of ionic liquids is huge but still there are reports that appears in few cases where ionic liquids responds with the reactants and thus they cannot be considered as idle solvents. There is still development and research going on in these aspects of ionic liquids.

We have discussed about the origin of ionic liquids, their properties and processes involve in synthesis. The applications in various fields like catalysis, in providing soluble supports, separation of solutes, in protein crystallization and also as lubricants and heat storages have been explained. There is still requirement of more infinitesimal understanding and research to be carried out of ionic liquids.

Acknowledgement

All the authors are grateful to Asst. Prof. Dr. K. Naresh, and all the faculty of Department of Pharmaceutical Chemistry, G. Pulla Reddy College of Pharmacy for providing the necessary facilities to carry out this study.

Conflict of Interest

All the authors declare that they have no conflict of Interest.

Reference

1. P. J. Dunn (2012) The Importance of Green Chemistry in Process Research and Development. *Chemical Society Reviews*, Vol. 41(4). pp. 1452-1461.
2. R. A. Sheldon (2012) Fundamentals of Green Chemistry: Efficiency in Reaction Design. *Chemical Society Reviews*, Vol. 41(4), pp. 1437-1451.
3. D. J. C. C. Concepción Jiménez-González, (2011) Green Chemistry and Engineering—A Practical Design Approach. *John Wiley & Sons Inc., Hoboken*. pp. 3-39.
4. N. V. Plechkova, R. D. Rogers and K. R. Seddon, Eds., (2009) Ionic Liquids: From Knowledge to Application. *American Chemical Society*, Vol. 1030, p. 472.
5. F. Karadas, M. Atilhan and S. Aparicio (2010) Review on the Use of Ionic Liquids (ILs) as Alternative Fluids for CO_2 Capture and Natural Gas Sweetening. *Energy & Fuels*, Vol. 24(11), pp. 5817-5828.
6. Thomas Welton (1999) Room-Temperature Ionic Liquids. *Chem. Rev.* 99 (8): 2071–2084.
7. Freemantle, Michael (2009) An Introduction to Ionic Liquids. Royal Society of Chemistry.
8. Welton T. (2018) Ionic liquids: a brief history. *Biophys Rev*. 10(3):691-706.
9. C. J. Bradaric, A. Downard, C. Kennedy, A. J. Robertson and Y. Zhou (2003) Industrial Preparation of Phosphonium Ionic Liquids. *Green Chemistry*, Vol. 5(2), pp. 143-152.
10. J. S. Wilkes; M. J. Zaworotko (1992) Air and water stable 1-ethyl-3-methylimidazolium based ionic liquids. *Chemical Communications* (13): 965–967.
11. Gordon W. Driver (2015) Aqueous Brønsted-Lowry Chemistry of Ionic Liquid Ions. Chem Phys Chem. 16 (11): 2432–2439.
12. K. J. Fraser; D. R. MacFarlane (2009) Phosphonium-Based Ionic Liquids: An Overview. *Aust. J. Chem.* 62 (4): 309–321. doi:10.1071/ch08558
13. S. Nazari, K. Ghandi, S. B. Cameron and M. B. Johonson (2013) Physicochemical Properties of Imidazo Pyridine Protic Ionic Liquids. *Journal of Materials Chemistry* A, Vol. 1(38), pp. 11570-11579.
14. Greaves, Tamar L.; Drummond, Calum J. (2008) Protic Ionic Liquids: Properties and Applications. *Chemical Reviews*. 108 (1): 206–237.
15. Ngo, H. L., LeCompte, K., Hargens, L. and McEwen, A. B., (2000) Thermal Properties of Imidazolium Ionic Liquids. *Thermochim. Acta*, 357–358, 97.
16. C. F. Poole, (2004) Chromatographic and Spectroscopic Methods for the Determination of Solvent Properties of Room Temperature Ionic Liquids. *Journal of Chromatography A*, Vol. 1037, No. 1-2, pp. 49-82.
17. Anthony, J. L., Maginn, E. J. and Brennecke, J. F., (2001) Solution Thermodynamics of Imidazolium Based Ionic Liquids and Water. *J. Phys. Chem. B*, 105, 10942.
18. Chen, Jin; Xie, Fengwei; Li, Xiaoxi; Chen, Ling (2018) Ionic liquids for the preparation of biopolymer materials for drug/gene delivery: a review. *Green Chemistry*. 20 (18): 4169–4200.

19. Zhou, Feng; Liang, Yongmin; Liu, Weimin (2009) Ionic liquid lubricants: designed chemistry for engineering applications. *Chemical Society Reviews*. 38 (9): 2590–9.
20. Han, H.-Y., Geng, X., Zhang, B.-X., Meng, J., Liu, X., He, X.-M., Hu, X.-M. (2019) Synthesis of novel functional ionic liquids and their application in biomass. *RSC Advances,* 9(51), 29652–29658.
21. J Ranke; S Stolte; R Störmann; J Arning & B Jastorff (2007) Design of sustainable chemical products – the example of ionic liquids. *Chem. Rev.* 107 (6): 2183–2206.
22. N. Meine, F. Benedito and R. Rinaldi (2010) Thermal Stability of Ionic Liquids Assessed by Potentiometric Titration. *Green Chemistry*, Vol. 12(10), pp. 1711-1714.
23. M. Armand, F. Endres, D. R. MacFarlane, H. Ohno and B. Scrosati (2009) Ionic-Liquid Materials for the Electrochemical Challenges of the Future. *Nature Materials*, Vol. 8(8), 8, 621-629.
24. C. Wang, H. Luo, X. Luo, H. Li and S. Dai, (2010) Equimolar CO_2 Capture by Imidazolium-Based Ionic Liquids and Superbase Systems. *Green Chemistry*, Vol. 12(11), pp. 2019-2023.
25. L. Magna, Y. Chauvin, G. P. Niccolai and J.-M. Basset (2003) The Importance of Imidazolium Substituents in the Use of Imidazolium-Based Room-Temperature Ionic Liquids as Solvents for Palladium-Catalyzed Telomerization of Butadiene with Methanol. *Organometallics,* Vol. 22, No. 22, pp. 4418-4425.
26. M. J. A. Shiddiky and A. A. J. Torriero (2011) Application of Ionic Liquids in Electrochemical Sensing Systems. *Biosensors and Bioelectronics*, Vol. 26(5), pp. 1775-1787.
27. K. E. Johnson, R. M. Pagni and J. Bartmess (2007) Brønsted Acids in Ionic Liquids: Fundamentals, Organic Reactions, and Comparisons. *Monatshefte für Chemie*, Vol. 138(11), pp. 1077-1101.
28. Plechkova NV, Seddon KR (2008) Applications of ionic liquids in the chemical industry. *Chemical Society Reviews*. 37: 123-150.
29. W. Wang, L. Shao, W. Cheng, J. Yang and M. He (2008) Brønsted Acidic Ionic Liquids as Novel Catalysts for Prins Reaction. *Catalysis Communications*, Vol. 9(3), pp. 337-341.
30. H. Nakamoto and M. Watanabe (2007) Bronsted Acid-Base Ionic Liquids for Fuel Cell Electrolytes. *Chemical Communications*, 24, pp. 2539-2541.
31. Smiglak M.; Pringle J. M.; Lu X.; Han L.; Zhang S.; et al. (2014) Chemical Communications (Cambridge, United Kingdom) 50(66), 9228-9250.
32. Blanchard, L. A. and Brennecke, J. F. (2001) Recovery of Organic Products from Ionic Liquids using Supercritical Carbon Dioxide. *Ind. Eng. Chem. Res.*, 40, 287.
33. Brennecke, J. F. and Maginn, E. J., (2001) Ionic Liquids: Innovative Fluids for Chemical Processing. *AIChE J.*, 47, 2384.
34. Wasserscheid, P. and Keim, W., (2000) Ionic Liquids-New ‘Solutions’ for Transition Metal Catalysis. *Agnew. Chem. Int. Ed*, 39, 3772.
35. Marsh, K.N., Deev, A., Wu, A.CT. *et al.* (2002) Room temperature ionic liquids as replacements for conventional solvents – A review. *Korean J. Chem. Eng.* 19, 357–362.
36. Aghabarari B, Dorostkar N, Ghiaci M, Amini SG, Rahimi E, et al. (2014) Esterification of fatty acids by new ionic liquids as acid catalysts. *Journal of the Taiwan Institute of Chemical Engineers*. 45: 431-435.
37. Amendola SC, Sharp-Goldman SL, Janjua MS, Spencer NC, Kelly MT, et al. (2000) A safe, portable, hydrogen gas generator using aqueous borohydride solution and Ru catalyst. *International Journal of Hydrogen Energy*. 25: 969-975.
38. Judge, R. A., Takahashi, S., Longenecker, K. L., Fry, E. H., Abad-Zapatero, C., & Chiu, M. L. (2009) The Effect of Ionic Liquids on Protein Crystallization and X-ray Diffraction Resolution. *Crystal Growth & Design*, 9(8), 3463–3469.