frontiers in Chemistry

EDITORIAL
published: 15 December 2020
doi: 10.3389/fchem.2020.627213

Editorial: Properties and Applications of Ionic Liquids in Energy and Environmental Science

Faiz Ullah Shah[1]*, *Rong An*[2]* and *Nawshad Muhammad*[3]*

[1] Chemistry of Interfaces, Luleå University of Technology, Luleå, Sweden, [2] Department of Materials Science and Engineering, Herbert Gleiter Institute of Nanoscience, Nanjing University of Science and Technology, Nanjing, China, [3] Interdisciplinary Research Centre in Biomedical Materials (IRCBM) COMSATS University Islamabad, Islamabad, Pakistan

Keywords: ionic liquids, energy, biomass, lubrication, physical properties

OPEN ACCESS

Edited by:
Vasile I. Parvulescu,
University of Bucharest, Romania

Reviewed by:
Lorenzo Guazzelli,
University of Pisa, Italy
Miguel Angel Centeno,
Instituto de Ciencia de Materiales de Sevilla (ICMS), Spain

Correspondence:
Faiz Ullah Shah
faiz.ullah@ltu.se
Rong An
ran@njust.edu.cn
Nawshad Muhammad
nawshadmuhammad@cuilahore.edu.pk

Specialty section:
This article was submitted to Green and Sustainable Chemistry, a section of the journal Frontiers in Chemistry

Received: *08 November 2020*
Accepted: *23 November 2020*
Published: *15 December 2020*

Citation:
Shah FU, An R and Muhammad N (2020) Editorial: Properties and Applications of Ionic Liquids in Energy and Environmental Science. Front. Chem. 8:627213. doi: 10.3389/fchem.2020.627213

Editorial on the Research Topic

Properties and Applications of Ionic Liquids in Energy and Environmental Science

Ionic liquids (ILs) are salts comprising cations and anions, and usually liquids at or below 100° C. The salts that are liquids at room temperature are generally called as room-temperature ionic liquids (RTILs) (Seddon, 1999; Welton, 2018; Singh and Savoy, 2020). In contrast to inorganic salts, ILs have much lower melting points primarily due to the larger sizes of either the cations or the anion, or both. In addition, their molecular structures possess a high degree of asymmetry which affects the ionic packing and thus decrease the Coulombic attraction between the ions (Welton, 1999). The first IL was prepared by Walden (1914) through a neutralization of ethylamine with a concentrated nitric acid. The resulting ethylammonium nitrate IL $[EtNH_3^+][NO_3^-]$ revealed a melting point of 12°C (Walden, 1914). At that time, ILs did not receive any significant attentions of the scientific community but later on during the 1980s, ILs appeared to be promising in various electrochemical applications (Wilkes et al., 1982; Fannin et al., 1984).

Unlike molecular liquids, ILs exhibit many unique properties making them promising solvents for various industrial applications. Some of the physicochemical properties of ILs include high polarity, negligible volatility, high thermal stability, high ionic conductivity, low melting point, and structural designability (Shah et al., 2013). The latter can be exploited in tuning the physicochemical properties of ILs and making them task specific for challenging applications where molecular liquids cannot be used (Plechkova and Seddon, 2008). Over the past two decades, ILs have been considered as promising solvents with unique abilities in organic synthesis, catalysis, and electrochemistry, separation of metals, gas separation, biomass processing, pharmaceuticals, tribology and energy storage devices such as batteries, supercapacitors, fuel cells, etc. (MacFarlane et al., 2014; Bhattacharyya et al., 2016, 2017; Egorova et al., 2017; Shah et al., 2017, 2020; Clarke et al., 2018; Khan et al., 2018; An et al., 2019; Mezzetta et al., 2019; Khan and Shah, 2020; Nie et al., 2020; Spange et al., 2020).

Deep eutectic solvents (DESs) are emerging as a new class of solvents having many comparable properties with ILs, although these two systems are very different from each other. In contrast to ILs that are composed of cations and anions, DESs are made by mixing Lewis or Brønsted acids and bases, which may contain anionic and/or cationic species (Smith et al., 2014). Compared to ILs, which are extensively studied over the past few decades, the number of publications on DES are very limited. However, a great interest has been recently seen in DES as environmentally benign alternatives for various applications such as synthesis, gas adsorption, biomass processing, electrolytes for energy storage devices, and metal processing applications.

Hua and Shi have proposed a strategy that uses a non-corrosive green lubricant with dissolved lignin in ILs (lignin-[Choline][L-Proline]) to physically adsorb onto steel-DLC contacts. This green IL lubricant exhibits a significant improvement in wear resistance as compared with the commercially available lubricants. Tong et al. have provided an essential molecular insight into understanding the effect of concentration of lithium salt on IL electrolytes using combined experimental and molecular dynamics simulation. The analysis of physicochemical properties, transport properties, and coordination structures of various IL electrolytes in different concentration of lithium salt shed light on the change in structural and physical properties at a micro-scale level. Lethesh et al. have prepared some hydroxyl-containing pyridinium based ILs with different alkyl side chain on cation with Br^- and $[Tf2N]^-$ anions. The different alkyl side chains strongly affected the physiochemical and electrochemical properties of these ILs. The experimental physicochemical properties are in line with the predicted values. The electrochemical window was measured in the range of 3.0–5.4 V. The DFT/COSMO-RS based calculations for the 3-methyl/ethyl ILs with $3Tf_2N$ and $10Tf_2N$ showed the highest conductivity values (0.366–0.383 κ/S m^{-1}) among the synthesized ILs.

Liu et al. have acquired the data of CO_2 solubilities and Henry's constant in Deep Eutectic Solvents (DES) from literature and processed through COSMO-RS-based calculations for improved verification and screening ability. The corrected COSMO-RS with adjustable universal parameters has great reliability to predict the CO_2 solubility in DESs and the ARDs for the logarithmic CO_2 solubility were 6.8, 5.2, 6.6, and 4.7%, in the DESs of different HBA and HBD ratios. Naz et al. have suggested IL-based catalysts containing [BMPy]Cl coupled with a number of different metal chlorides for effective deconstruction of wheat straw biomass. The IL-metal catalytic systems showed up to 86% recovery for $[BMPy]^+CoCl_3^-$ and outstanding recycling abilities. These IL-based catalytic systems were proposed as sustainable solutions for conversion of wheat straw to valuable products.

The Research Topic "Properties and Applications of Ionic Liquids in Energy and Environmental Science" presents research articles that will provide valuable feedback to chemists for designing efficient ILs for various applications in energy and environmental applications.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

FUNDING

FS is grateful for the financial support from the Swedish Research Council (Project No. 2018-04133). RA acknowledges the funding from the Natural Science Foundation of Jiangsu Province (Project No. BK20191289).

REFERENCES

An, R., Wu, M., Li, J., Qiu, X., Shah, F. U., and Li, J. (2019). On the ionic liquid films 'pinned' by core-shell structured Fe_3O_4@carbon nanoparticles and their tribological properties. *Phys. Chem. Chem. Phys.* 21, 281–301. doi: 10.1039/C9CP05905A

Bhattacharyya, S., Filippov, A., and Shah, F. U. (2016). Insights into the effect of CO_2 absorption on the ionic mobility of ionic liquids. *Phys. Chem. Chem. Phys.* 18, 28617–28625. doi: 10.1039/C6CP05804C

Bhattacharyya, S., Filippov, S., and Shah, F. U. (2017). High CO_2 absorption capacity by chemisorption at cations and anions in choline-based ionic liquids. *Phys. Chem. Chem. Phy.* 19, 31216–31226. doi: 10.1039/C7CP07059D

Clarke, C. J., Tu, W. C., Levers, O., Bröhl, A., and Hallett, J. P. (2018). Green and sustainable solvents in chemical processes. *Chem. Rev.* 118, 747–800. doi: 10.1021/acs.chemrev.7b00571

Egorova, K. S., Gordeev, E. G., and Ananikov, V. P. (2017). Biological activity of ionic liquids and their application in pharmaceutics and medicine. *Chem. Rev.* 117, 7132–7189. doi: 10.1021/acs.chemrev.6b00562

Fannin, A. A. Jr., Floreani, D. A., King, L. A., Landers, J. S., Piersma, B. J., Stech, D. J., et al. (1984). Properties of 1,3-dialkylimidazolium chloride-aluminum chloride ionic liquids. 2. Phase transitions, densities, electrical conductivities, and viscosities. *J. Phys. Chem.* 88, 2614–2621. doi: 10.1021/j150656a038

Khan, A. S., Man, Z., Bustam, M. A., Nasrullah, A., Ullah, Z., Sarwono, A., et al. (2018). Efficient conversion of lignocellulosic biomass to levulinic acid using acidic ionic liquids. *Carbohydr. Polym.* 181, 208–214. doi: 10.1016/j.carbpol.2017.10.064

Khan, I. A., and Shah, F. U. (2020). Fluorine-free Ionic liquid-based electrolyte for supercapacitors operating at elevated temperatures. *ACS Sust. Chem. Eng.* 8, 10212–10221. doi: 10.1021/acssuschemeng.0c02568

MacFarlane, D. R., Tachikawa, N., Forsyth, M., Pringle, J. M., Howlett, P. C., Elliott, G. D., et al. (2014). Energy applications of ionic liquids. *Energy Environ. Sci.* 7, 232–250. doi: 10.1039/C3EE42099J

Mezzetta, A., Perillo, V., Guazzelli, L., and Chiappe, C. (2019). Thermal behavior analysis as a valuable tool for comparing ionic liquids of different classes. *J. Therm. Anal. Calorim.* 138, 3335–3345. doi: 10.1007/s10973-019-08951-w

Nie, H., Schauser, N. S., Dolinski, N. D., Hu, J., Hawker, C. J., Segalman, R. A., et al. (2020). Light-controllable ionic conductivity in a polymeric ionic liquid. *Angew. Chem. Int. Ed.* 59, 5123–5128. doi: 10.1002/anie.201912921

Plechkova, N., and Seddon, K. (2008). Applications of ionic liquids in the chemical industry. *Chem. Soc. Rev.* 37, 123–150. doi: 10.1039/B006677J

Seddon, K. (1999). Ionic liquids: designer solvents for green synthesis. *Chem. Eng.* 730, 33–35.

Shah, F. U., Glavatskih, S., and Antzutkin, O. N. (2013). Boron in tribology: from borates to ionic liquids. *Tribol. Lett.* 51, 26387–26398. doi: 10.1007/s11249-013-0181-3

Shah, F. U., Gnezdilov, O., and Filippov, A. (2017). Ion dynamics in halogen-free phosphonium bis(salicylato)borate ionic liquid electrolytes for lithium-ion batteries. *Phys. Chem. Chem. Phys.* 19, 16721–16730. doi: 10.1039/C7CP02722B

Shah, F. U., Gnezdilov, O. I., Khan, I., Filippov, A., Slad, N. A., and Johansson, P. (2020). Structural and ion dynamics in fluorine-free oligoether carboxylate ionic liquid-based electrolytes. *J. Phys. Chem. B* 124, 9690–9700. doi: 10.1021/acs.jpcb.0c04749

Singh, S. K., and Savoy, A. W. (2020). Ionic liquids synthesis and applications: an overview. *J. Mol. Liq.* 297:112038. doi: 10.1016/j.molliq.2019.112038

Smith, E. L., Abbott, A. P., and Ryder, K. S. (2014). Deep eutectic solvents (DESs) and their applications. *Chem. Rev.* 114, 11060–11082. doi: 10.1021/cr300162p

Spange, S., Lienert, C., Friebe, N., and Schreiter, K. (2020). Complementary interpretation of ET(30) polarity parameters of ionic liquids. *Phys. Chem. Chem. Phys.* 22, 9954–9966. doi: 10.1039/D0CP01480J

Walden, P. (1914). Molecular weights and electrical conductivity of several fused salts. *Bull. Acad. Impér. Sci. St. Petersbourg* 8:405.

Welton, T. (1999). Room-temperature ionic liquids. Solvents for synthesis and catalysis. *Chem. Rev.* 99, 2071–2084. doi: 10.1021/cr980032t

Welton, T. (2018). Ionic liquids: a brief history, *Biophys. Rev.* 10, 691–706. doi: 10.1007/s12551-018-0419-2

Wilkes, J. S., Levisky, J. A., Wilson, R. A., and Hussey, C. L. (1982). Dialkylimidazolium chloroaluminate melts: a new class of room-temperature ionic liquids for electrochemistry, spectroscopy, and synthesis. *Inorg. Chem.* 21, 1263–1264. doi: 10.1021/ic00133a078

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.