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REVIEW

Ionic liquids as green and smart lubricant application: an overview

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Abstract
Ionic liquids due to widespread applications in various fields of science, such as physics, chemistry, and engineering, have been an emerging topic in the field of research in the last few decades. Ionic liquids are mainly used as electrolytes, solvents, and functional materials. Thermal stability, solubility, and liquid nature at a wide temperature range are characteristics of ionic liquids. Researches over the last decades have experienced the use of ionic liquid-based nanomaterial composites since ionic liquids are more stable and more useful with nanoconfined materials. The present review paper describes in detail the physical and chemical properties of ionic liquids as well as their various applications as lubricants.

Keywords Nanoconfined ionic liquids · Lubricants · Viscosity · Thermal stability

Introduction

Lubricants are frequently used in various activities of industries like manufacturing and engineering as metal-working fluids (MWFs). They enhance the stability, workability, and productivity and reduce mechanical deterioration of materials when applied between two interfaces of similar or dissimilar materials such as metals and alloys [1, 2]. Looking at the current demand, there is a need for lubricants that are biodegradable, less toxic, and environment friendly. In terms of green chemistry, it is clear that energy consumption decreases in mechanical applications due to good lubrication properties, which reduce energy loss during friction. Therefore, long life of all materials from friction and wear is protected by using good lubricants, and also excellent lubrication system helps to save the energy, minimize the energy loss, and save the raw materials. Ionic liquids (ILs) had recently been explored as a potential lubricant for various applications. ILs are organic substances in the form of liquid salts that possess some important characteristics such as low melting temperature, high combustible temperature, low vapor pressure, superior thermal stability, low volatility, and easily miscibility with organic substances [3–6]. Many ILs have high thermal stability, so they can potentially be applied for incubation lubrication, in which conventional hydrocarbon oil is unstable. IL-based lubricants have so far been extensively examined as an effectual, sustainable lubricant [7]. Recently, the researchers have produced several brand new IL-based lubricants and their lubrication performance along with desired properties for specific applications has also been systematically evaluated. Several types of IL-based lubricants have now been used in the role of additives, owing to the excellent sustainability, low instability, low hydrothermal burning, and excellent thermal stability

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during high friction and pressure process, and also reliable compatibility of ILs with a base oil (e.g., glycerol, polyethylene glycol, or esters), which make them suitable for future lubricants. Ye et al. reported the first investigation on the use of ILs in the form of lubricants in the year 2001 [8] and since then, the plethora of studies have till now been reported [9]. A variety of ammonium likewise imidazolium ILs have been proven to have more significant stability in comparison to the conventional synthetic oil at 200 °C [10]. Another important advantage of ILs is that different types of ions and diameters can be used; the estimation is in the order of one million combinations, and some are available with their unique property [11]. This means that the ILs can be potentially used for a specific application. However, due to the combination of this large number availability of ILs, it is important for a particular application to systematically check its performance to reduce the number of potential variations [12, 13]. For example, the nature of the elements is likely to react for creating a protective tribofilm from the surface in the case of the metal, and it can be included as a cation and/or ion; these may include P, F, or B, depending on interfacing surfaces. Figure 1 demonstrates the characteristics and major applications of ILs. Overall, the present review article mainly deals with the ionic liquid-based lubricants, their structures and characteristics of ionic liquid-based lubricants, various chemical properties such as biodegradability, thermal stability, and hydrolytic stability, and physical properties such as density, viscosity and viscosity index, lubricity, specific heat capacity, and ionic conductivity of ionic liquids. Also, mechanism and tribological behavior of ionic liquid-based lubricants are discussed in detail.

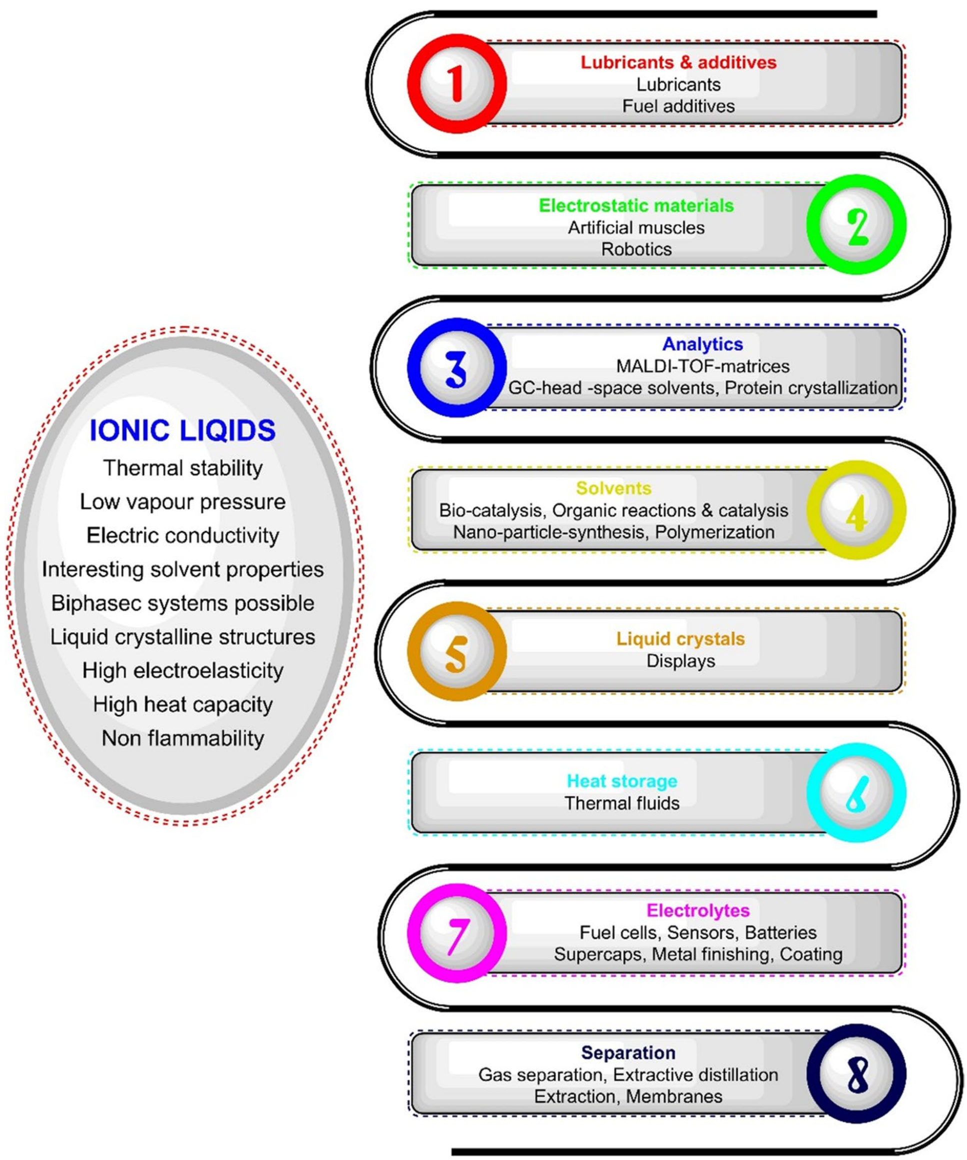

Fig. 1 General characteristics and applications of ionic liquids

Ionic liquid-based lubricants

Some of the most common cations are phosphonium, pyridinium, imidazolium, and ammonium, and CF_3SO_3, PF_6, BF_4, and N-(CF_3 SO_2) are some common anionic ionic liquids. Comprehensive applications of ILs are dependent on the prominent advantages of this superior chemistry and IL is used as a solvent in many machining technology applications [14]. Recent technological advances have helped to tune the properties of traditional lubricants (e.g., perfluoropolyether (PFPE) [15], synthetic ester (SE) [16], polyethylene glycol (PEG) [17], and polyalphaolefin (PAO) [18]) by using ILs.

Structure and characteristics of ionic liquid-based lubricants

Ionic liquids are classified as biological based ionic liquid (organic salt) in addition to those compounds, which are found only in ions and having one or both biological species-based ion. These ions are alternatively incurred positively or negatively charged, and since at least one out of them consists of a delocalized charge, they can act like defective in coordinating their dense structure and protecting against them from forming crystal solid. With those accountable aspects, the ILs hold liquid phase at temperatures below 100 °C or room temperature.

Cationic structure

The cationic structure provides exceptional characteristics to ILs. ILs is additionally prescribed for intense miscibility with lubricants due to the low melting point, excellent thermal stability (Fig. 2), and their extraordinary molecular structure of ions [19]. Considering the shape, ions possess pretty much spherical shape ion structure and these types of structured molecules are regarded as a symmetrical molecule, although convergence is asymmetric [20]. In the shape of ions, the alkyl chains of molecules, as well as quadrilateral structures, vary on moieties. These properties promote the characteristics and aspect of ILs in the role of a cutting-edge lubrication fluid system and as a reliable entrant for high-performance lubricants, which have exceptional chemical as well as physical properties for use in tribochemical and tribological applications.

Anionic structure

It was observed that the protective films were produced during the production of BF_4 and PF_6 in the built IL, and likewise, subsequent investigators began investigating other fluorine such as periflorodecylphosphate (FAP) amide (NTf_2), triflate (CF_3SO_3, TF), and BIS triphlorom ethylphosnil) [21–23]. Boron in other non-fluorinated ions (e.g., BIS (oculotto) Borate, Bob) and phosphorus (e.g., diabetophosphate, DBP) have also been studied (Fig. 3). In the atmosphere of wear, all these ions were considered to pass through favorable reactions as a result of protective film [24–27].

Non-flammability and low vapor pressure of ILs make them a suitable substance for lubricating purposes. Additionally, most ionic liquids (cationic and anionic) have both tribological and rheological properties and the tendency of cavitation is higher for other materials as compared to ionic liquids. The efficiency of the ILs as lubricating oils depends on the nature of both anion and cation. Ammonium- and sulfonium-based ILs have lower tribological properties than phosphonium-based ILs. Additionally, alkyl substituents with long chains increase the tribological efficiency of cationic and anionic ILs but long alkyl chain substituents decrease the thermal stability of the ILs. Usually, hydrophobic ILs show better tribological performances than hydrophilic ionic ILs [28].

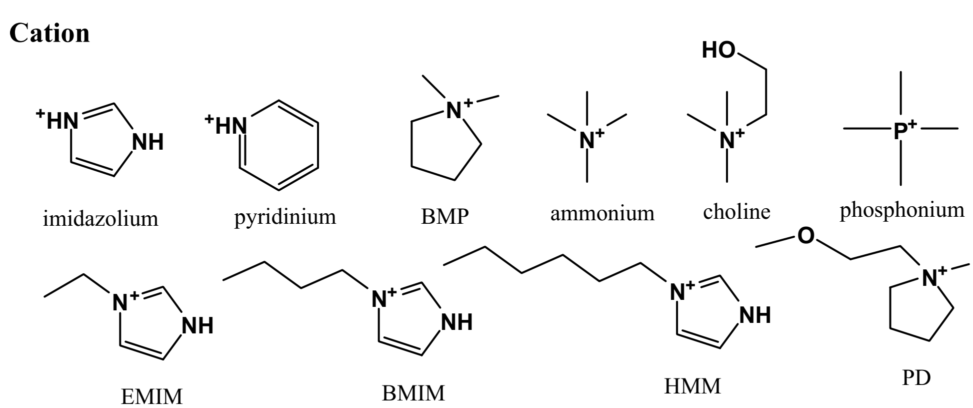

Fig. 2 Structures and abbreviations of cations of the ILs used as lubricating materials in the literature

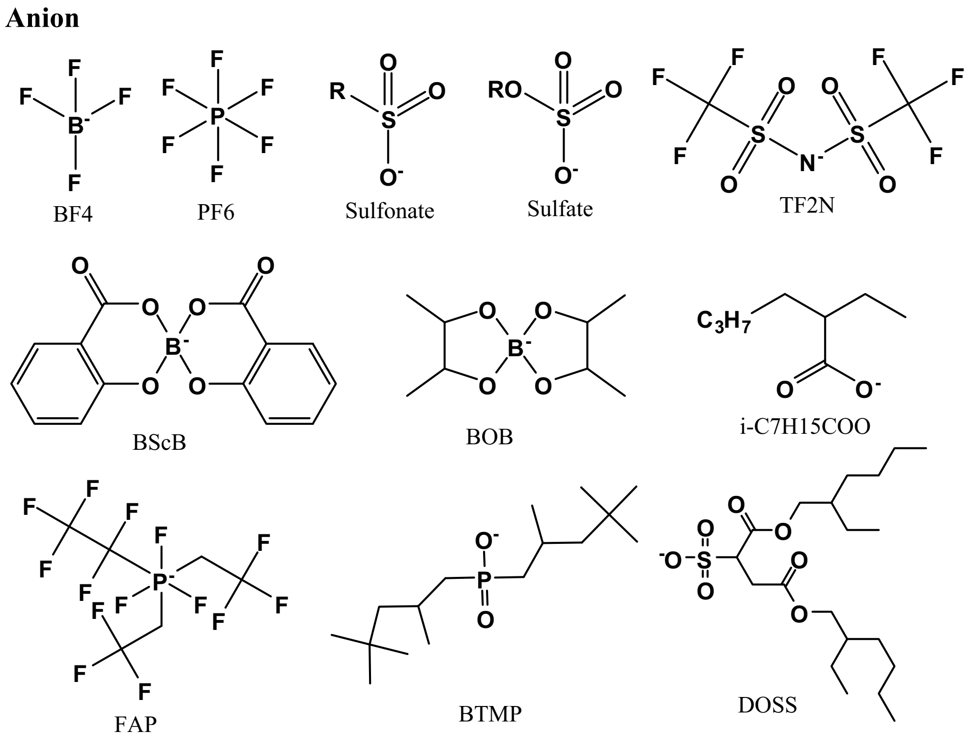

Fig. 3 Structures and abbreviations of anions of the ILs used as lubricating materials in the literature

Chemical properties of ionic liquids

Biodegradability

Biochemical oxidation of lubricants is defined as dissolving chemically lubricant in the environment due to the implementation of live microorganisms. Less ecotoxicity along with rapid biodegradability properties of lubricants are the crucial behavior of an environmentally benign lubricant. The biodegradability and biocompatibility behavior of ionic liquids is dependent on the cationic structures as well as the number of equilibrium molecules. Imidazolium-based ILs are associated with a high level of toxicity along with poor biodegradability and low decomposition stability. Besides, organic materials can also be absorbed by introducing functional polar groups to the alkyl chain. In comparison to water-based or mineral oil-based lubricants, ILs can be recycled and are reusable while maintaining their volume level (non-volatile).Therefore, processing time in addition to the cost of maintenance needs to be minimized [29]. The chemical formulation of ILs helps to determine its physical characteristics. A large number of lengthy carbon chain in ILs increase the viscosity of the ILs because their structure possesses complex branch of the functional groups or alkyl group [30], which correspondingly tends to make them much better with sliding surfaces with high-pressure as well as high-temperature conditions. During the siding, the chemical interaction between the workpiece surfaces along with ILs is achieved by modifying the surface chemistry. Designing biodegradation data as part of the design of safer chemicals is equally important as other parameters and properties of ILs. Key characteristics of ILs such as methods of biodegradation analysis, IL design strategies, and surfactant derivatives, to promote IL biodegradation and theoretical approaches for the prediction of biodegradability of ILs, are the most important parameters to design the lubricating performance of ILs. Also, the importance of metabolite studies as part of biodegradation is equally important to design the lubricants especially based on ILs. Low flammability, negligible vapor pressure, and highly polar solvent behavior of ILs make them a good alternative as safer and green to volatile organic compounds (VOCs). Results of previous research revealed the biodegradation, ecotoxicity, and other toxicity of ILs, but biodegradation data are still comparatively scarce.

Thermal stability

Thermal stability is an important characteristic to resist the decomposition of lubricant within the working temperature range. Under high temperature, the chemical degradation of lubricants is notably high that is responsible for the evaporation of fluid as well as a decrease in viscosity. Thus, ILs, e.g., trihexyltetradecylphosphonium bis(2,4,4-trimethylpentyl) phosphinate [31] and 1-butyl-2,3-dimethylimidazolium hexafluorophosphate [32], do not easily evaporate like mineral oil and water. Therefore, these are considered more eco-friendly than traditional lubricants.

Thermogravimetric analysis (TGA) was used extensively in order to determine the thermal stability of ionic liquids soluble in oils in the presence of dinitrogen. Moreover, the air is the most important and realistic medium for the lubricating performance of ILs where oxidation is inevitable. Usually, ILs is more thermally stable as compared to hydrocarbon oils which decomposed at a temperature around 250 °C. Previous research revealed that phosphonium–carboxylate and ammonium–phosphate ILs exhibited lower thermal stability as compared to phosphonium–phosphate ionic liquids, whereas imidazolium- and pyridinium-based ILs relatively exhibited unaffected in the presence of cationic alkyl chain [33].

Hygroscopicity

Any oil lubricates, water acts as a destructive pollutant, and water can degrade the molecules of oil through hydrolysis. The issue of hygroscopic stability in a lubricant is crucial, as it can affect the physical as well as chemical properties of lubricants. Toxic by-products may be produced crushing the surface of the lubricant hydrolysis process which can cause permanent degradation of a lubricant and a decline in quality. For example, ILs containing halogen ions when passing through thermal decomposition through hydro-electric process produce toxic by-products boric acid (H_3BO_3), (phosphoric acid (H_3PO_4), and hydrogen fluoride (HF) which can disrupt the metal surface [34]. ILs such as 1-n-butyl-3-methylimidazolium hexafluorophosphate [C_4mm][PF_6] and ethyl imidazolium tetrafluoroborate [C_4emem][BF_4] are rich in fluorine and are also sensitive to wet conditions. They undergo hydrolysis and degradation of ions produces highly toxic and very corrosive products of HF. $[TFO]^-$, $[NTF_2]^-$, $[(RO_2PO_2)]^-$, and [CH_3SO_3] are examples of the formation of non-toxic organic reactions of ILs, which are hydrolysis-stable ions. Many studies reported that ILs when it's in contact with water has a physical properties. The physical characteristics of fluids are the essential properties of lubricants that affect the cooling behavior of the fluids. The capability of coolant minimize temperature is fervently dependent on the heat transfer properties such as convective heat transfer coefficient, specific heat capacity, thermal conductivity, and specific heat of evaporation. Numerous types of formulations and the physical properties of ILs have been explored by several researchers. Table 1 demonstrates the evaluation of physical as well as thermal properties of ILs, water, and mineral oil. Interestingly, the specific description of data comparability from Table 1 suggests that ILs offer a wide range of physical and thermal properties in comparison with two other normal water-based as well as mineral oil-based coolants.

Physical properties of ionic liquids

Density, viscosity, and viscosity index

The density of ILs is found to be higher than mineral oil as well as water, owing to the higher size and symmetrical shape of their molecular structures. Viscosity (microscopy friction force) in a fluid serves as a resistance to the molecule movements in relative motion under share stress condition [35] and viscosity index (VI) is employed to calculate it using the standard of ASTM D2270 at 40 °C as well as at 100 °C.The applications of IL lubricants offer appropriate liquid ranges for wide applications primarily in the engineering as well as manufacturing. ILs are a group of molecular solvents which shows highly viscous nature. The viscosity of ILs relies on the combination of anions as well as cations viz. by varying the content of their ions. The size and shape, as well as molar mass of the anions, have already been suggested to be the possible contributors to the physical appearance, i.e., viscosity and density as well as thermal stability of ILs [36]. Lighter, smaller, and highly symmetrical structures of the anion molecules contribute extra viscosity in IL systems. Additionally, the thermophysical characteristics including melting point and hydrophobicity, as well as the viscosity of ILs, have been relatively modified by using lengthening the alkyl chain length of the cations. The viscosities of ILs are controlled primarily by van der Waals interactions as well as hydrogen-bonded structures.

Table 1 Physical properties of mineral oils, water, and ionic liquids at 1 bar

S. No	Parameters	Unit	Mineral oil	Water	Ionic liquids	Ref
1	Specific heat capacity, *cp* at 25 °C	$J\ g^{-1}\ K^{-1}$	1.9	4.2	1.0–1.70	41, 42
		$J\ mol^{-1}\ K^{-1}$	-	75.6	227–1366	43
2	Thermal conductivity, λ	$W\ m^{-1}\ K^{-1}$	0.1	0.6	0.1–0.2	44
3	Specific heat of vaporization, *r*	$J\ g^{-1}$	210	2260	-	-
		$KJ\ mol^{-1}$	-	40.7	115–201	45
4	Kinematic viscosity, ν (at 40 °C)	$mm^2\ s^{-1}$	05.20	0.66	20–3333	46
5	Density, ρ at 25 °C	$g\ ml^{-1}$	0.9–1.0	0.99	1.0–2.2	-
6	Dynamic viscosity, η (at 40 °C)	mPa s	04–17	0.65	28–3400	46
7	Flash point	°C	< 200	-	> 200	47

Lubricity

The fluid lubricity refers to the capability of lubricating or the ability of lubrication through a lubricant or lubricant ingredients and fluid lubricity are determined by the application of lubricants in minimizing friction as well as wear of the metal sliding pairs. Ionic liquids came into existence as emerging lubricating materials two decades before. Some previous studies suggested the superior performance of ILs over pre-available lubricating fluids on their various properties such as friction coefficient under environmental friendliness, elastohydrodynamic lubrication conditions, thermal oxidation stability, low-temperature fluidity, incompressibility, electrical conductivity, ultralow volatility, viscosity-temperature properties, antiwear performance, and friction reduction under boundary lubrication conditions. Also, the superior behavior of ILs as lubricants over other lubricants in terms of hydraulic fluids, oxygen compressor lubricating fluids, metalworking fluids, micro/nano electromechanical system applications, electrical conductive lubricants, and space lubricants. ILs have potential lubricating oils as well as boundary lubricants on several metal surfaces such as distinctive material pairs [37]. Greater numbers of hydrophobic anions amplify the lubricity effect as well as thermo-oxidative stability [38].

Specific heat capacity

Specific heat capacity of a substance refers to the magnitude of energy needed to raise the temperature of 1 mol by 1 K. The heat capacity of ILs is usually higher compared to water as their unit is inscribed on the molar basis, as mentioned in Table 1 [39–41]. Larger molecular weight is taken into account for these values, which means that suitable amount of heat is required for heating the liquid or is absorbed by the liquid; thereby, the heating, as well as cooling, behavior of the ILs, is considered better than water and mineral oil. The heat capacity of ILs is based on the form of ion chosen instead of its cation in its formulations [42]. An overall trend of escalating heat capacity of ILs suggests that the size of the ion or the molecular weight provides the greater value of heat capacity [43]. ILs having remarkable specific heat capacity as well as comparative thermal conductivity offer more useful cooling features in comparison with water as well as mineral oil.

Ionic conductivity

Ionic conductivities (ICs) were calculated from the Nernst–Einstein relationship using calculated diffusion coefficients and the following equation (Eq. 1) [44].

$$\text{Ionicconductivity} = \sigma_{NE} = \frac{N_I q^2}{V k_B T}(D^+ + D^-) \quad (1)$$

where q is the charge of the cation or anion; N_I is the number of ion pairs; D^- and D^+ are the diffusion coefficients of the anion and cation, respectively; kB is the Boltzmann constant; V is the molar volume; and T is the absolute temperature. Reddy et al. had reported that experimental ICs of MAF, EAF, and EAP at room temperature are 43.80, 12.16, and 0.87 mS cm^{-1}, respectively as depicted in Fig. 3 [45]. The sequence of experimental ICs for the first triad is EAP for MAF > EAF > PAF and EAF > EAA > second quarter. The IC is calculated from the study of simulation for the first and second triads in the same order. From the simulation study, the IC is 40.62, 7.67, 1.68, 2.28, and 1.35 mS cm^{-1} respectively for MAF, EAF, PAF, EAA, and EAP. For example, the value of IC for EAF and PAF is 7.67 and 1.68 mS cm^{-1} respectively. The ionic conductivity of ionic liquids is dependent upon the chain length of alkaline molecules. The increase in the length of the alkaline molecules reduces the conductivity; essentially, the trend effectively arises from the variation of the transmission coefficient of cation and ions. Sunda et al. calculated the ICs of four quaternary ammonium-based ILs and reported similar behavior from their simulations [46].

Mechanism of ionic liquids

It must be mentioned that ionic liquids are not ions in solution; however, ionic liquids are pure compounds like Na + Cl − (l). These pure ionic liquids behave like electrolytic solutions or polar organic solvents. The Coulomb interactions in-between anions and cations are generally stronger; therefore, these types of compounds show higher melting points. The first-order description of ionic liquids is normal charged species in a liquid state [47]. Dipole, hydrogen bonding, and dispersive forces are the main factors for the interactions of IL constituents. The protic ionic liquids are obtained by using strong acid into N-alkylimidazole. The melting points of protic ionic liquids change with symmetry and asymmetry of nitrogen cations, and the lowest melting points are observed asymmetric nitrogen cations [48]. A complexing agent is included, the endothermic move to lower temperature, and melting point can be moved to lower room temperature by using complexing agent. In other words, it leads to enhance the chemical stability for the liquid. The thermodynamic stability of anion complexes is enhanced by holding strong chemical bonds [49].

Additionally, the lubricating behavior of ILs has shown a good correlation with the IL compatibility, concentration, and chemical property, with other material compositions, oil additives and rubbing conditions and contact surfaces. Phosphorus-containing ILs exhibited efficient wear reductions and friction over the other ionic liquids and base oils. Three different groups of phosphonium-mediated ionic liquids were blended into a PAO base oil at the known content in order to understand the impact of anions [38] and tested at the steel-steel ball on flat sliding contact at high temperature (100 °C). The study suggested the outperformance of all three groups regarding the wear reduction.

The efficient behavior from low to high was observed in the order of phosphonium–sulfonate, phosphonium–carboxylate, and phosphonium–phosphate [38]. Previous research revealed that $[P_{6,6,6,14}]$-[BTMPP], $[N_{8,8,8,H}]$[DEHP], and $[P_{8,8,8,8}]$[DEHP] exhibited equal to or higher surface protection for both steel-iron and steel-steel contacts as compared to ZDDP [50].

Tribological behavior of ionic lubricants

ILs have been employed as an ingredient or neat lubricant for various lubrication systems. Researchers have illustrated the excellent results from IL-based lubricants because of their exceptional properties and the capability to customize or substitution for the standard lubricant, which is the simple way to achieve an excellent result or better output performance. Additionally, the opportunity of varying the combination of anions and cations provides a considerable advantage and formulations of ILs for particular manufacturing as well as engineering applications. Many studies have shown the potential of the ILs, as well as their physical properties. These parameters are frequently used in antiwear as well as lubrication properties of ILs though these are well known for providing specific aims and objectives. The overall performance of ionic liquids confirms that when ionic liquid mixed with bio-based oil provides the minimum coefficient of frictions, improved tribological performance of oil in the presence of ionic liquid is the result of dipolar structure ionic liquids that leads to absorb on the interacting surfaces and produce the lubrication film [51].

The major concerns included thermal oxidation, toxicity, corrosion, oil miscibility, and cost for the ionic liquids to be used as lubricating agent. The recent development of ionic liquids as thermally stable, noncorrosive, and oil solubility has been largely discussed by some previous researchers. The mainstream research of ionic liquids involved lubrication has been shifted from using ionic liquids as both lubricant additives and as neat or base lubricants. The focus is on developing the halogen- and phosphorus-free ionic liquids as energy efficient and environment-friendly lubricant additives for the steel-based engineering surfaces, and to establish the correlation between structure of anion and tribo-physical properties of ionic liquids. Halogen-free ionic liquids such as borate-based ionic liquids are more important for application as lubricant in the present and future.

1onic Liquids as a neat lubricant

There have been a good number of research studies on ionic liquids as neat lubricants [52]. Investigation of neat ionic liquids (e.g., [BMIM] BPH4) has been mentioned, which has not been well known during the past few years. Since the crystal structure of the IL is monopolized by the C-H-P interactions between the lubricants and the ions, the question occurred whether or not it would be transferred even in the ideal liquid phase structure. By implementing 1D NOSEY NMR and measuring $13CT_1$ relaxation data, almost identical methods of interaction in liquid phase compared to crystal structure can be found. Lyn et al. studied various types of alkyl chain components and $Br^{-}BF_4^{-}$, and BF^{-6} ions [53] have studied diversity in chemical changes for various types of methylimidazolium salt. They observed high sensitivity in the imidazolium ring for a 2-proton chemical shift (mainly based on the length of the alkyl series, among other factors). The effect was most apparent for bromide salts. Also, they noticed the unexpected H/D exchange for 2-protons. Today, these results can be interpreted as the H-bonding effect, and of course, there is no surprise in the acidity of H_2 in it [54, 55].

Ionic liquids as an additive

Apart from the lubricant applications, the use of ILs as lubricant additives and corrosion inhibition proves to reduce friction effectively and to wear different sliding content study suggested the ability to make ILs electric double layer in water [56]. Thus, it is useful for the adsorption of additives in the case of silicon nitride ceramic surface, which is beneficial to the tribology properties of lubricant and reduces the frictional force. Nonetheless, uses of water-based lubricants are primarily constricted under elevated test temperature because of their high volatile characteristic as well as the cooling point. Moreover, the development of tribofilm on ceramic substrates in the course of the lubrication process based on water-based lubricants is very thin. High coefficient of friction and major attached surface clean alkyl phosphate is anticipated in contrast to ILs [57].

Tribochemical reaction properties

As a result of their low vapor pressure, ILs serve as a lubricant inside the vacuum condition. Researchers have carried out substantially high vacuum pin-on-disk sliding analysis to understand the consequences of sliding material (Fe, Cu, AI, Ti, etc.) on the decomposition of tribal characteristics of ILs [58]. ILs offer low friction coefficient for every metal. Some partial pressures occurred throughout the sliding; however, the degree of decomposition and the form of discharge gas depend on types of metals. Physical selection turns into a key component of regulating gas discharge, owing to the

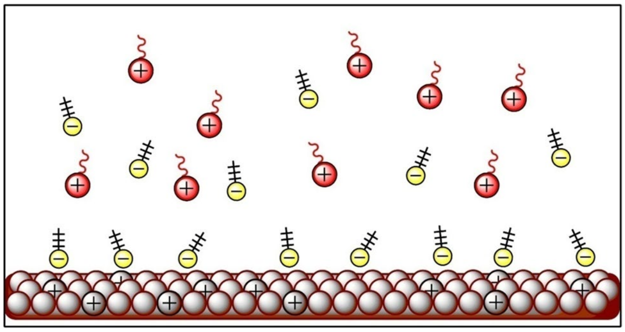

Fig. 4 A schematic representation of layers of ILs adsorbed on a metal surface

triangle decomposition of ionic fluid. Adsorption, chemisorption, and tribochemical reactions are all chemical reactions, which typically show a vital role for developing boundary layer from surface-active substances. In the course of the sliding process, a positive charge is built on the surface of the small convex volume on the metal surface by the energy emitting electron which shows significantly less under the convex number of the contact. Whereas ions are unquestionably interacted with rubbing surfaces, adsorption often occurs on the surface because of the strong electrostatic interaction, even when they are infrequently seen as shown in Fig. 4 [59]. In case, the intense electrostaticinteraction of metal surfaces and ILs allows to development of adsorbed, and plays a role to reduce wear andfriction.

Ionic liquids as extreme temperature lubricants

The surface properties of IL-lubricant metal during sliding contact at room temperature of 300 °C have been examined by Phillips et al. Before treatment of IL, a few iron samples have been oxidized in Fe_2O_3 as well as Fe_3O4 form. After that, metallic as well as oxidized samples have been reacted along with ionic fluid at high temperatures. Chemical analysis pronounced the rusting on the surface as a consequence of reactions between ILs as well as steel/iron substrates. A sequence of recent polyethylene glycol has been developed along with functionalized dicationic [60], with alkyl or polyfluoroalkyl substitute. These ILs exhibit excellent thermal stability as well as a reliable lubricant. Imidazolium-based dynamic liquids have much higher degradation temperatures ($T_d > 400$ °C) in comparison with their triazolium alternatives. The attachment of polyfluoroalkyl groups increases antiviral properties; at the same time, a reduction in decomposition temperature is also found. These types of ILs additionally display impressive tribal behavior at 300 °C, which implies their capability of high-temperature lubricants. A different range of decalic ionic fluid, such as polyacylater, polyifluoracillil, and 1,4-bismithlebenzene, is referred to among the many rings of alkyl-substituted imidazolium [61], which has bridging moieties. The characteristics and properties of these materials have been tailored by the linker series and/or alkaline compounds in the imidazolium ring. Lubrication capability related to ILs is dependent upon the polarity of molecules, thermal stability, orderly layers, and their ability to build tricorrosion processes at the interface.

Conclusion and outlook

This review paper outlines the characteristics of ionic liquids, which are incomparable to several engineering and manufacturing applications especially in the field of lubricating and oils. The viscosity value of the ILs is 3000 mm greater than 20 mm at 2 °C to 40 °C, which is the ability to produce enough lubricant layer, which renders outstanding load carrying capacity on the metal bearing, different lubricant system (hydrodynamic, elastohydrodynamic, and so forth), and the ability to accommodate a wider temperature range for the cooling action, which is found lager in the case of other traditional lubricants. Many current research works have conferred the comprehensive findings of ILs, which clearly classified ILs as suitable advanced lubricants in widespread engineering as well as manufacturing applications. ILs are still moving ahead in the form of lubricants as well as lubricant additives for various common lubricants. It has been demonstrated that ILs have notable abilities which are more reliable than natural cooling (water) and conventional fossil fuel-based lubricants.

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Declarations

Conflict of interest The authors declare no competing interests.

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