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Solvents and Ionic Liquids used in green synthesis

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Abstract: *Ionic liquids have become very popular in recent years because they are eco-friendly and useful as solvents. This paper explains their properties and how they are used in green chemistry. Ionic liquids have special features like very low vapour pressure, a wide liquid range, and adjustable properties, which make them suitable for many purposes. They are also better for the environment because they do not evaporate easily, are generally non-toxic, and can be reused. These qualities help support sustainable chemical practices. The paper also covers their various uses, such as in catalysis, extraction, energy storage, and making new materials. By reviewing recent progress and real examples, this paper gives a clear overview of how ionic liquids are influencing green chemistry and helping move toward a more sustainable future. Traditional reaction media, especially volatile organic solvents (VOS), cause a lot of air pollution and make separation and recycling difficult. Because of growing environmental concerns, scientists are now searching for safer, eco-friendly alternatives. Ionic liquids (ILs) have become strong candidates for "green" solvents because they have extremely low vapor pressure and high thermal stability. These properties make them easier to contain, reuse, and recover after reactions.*

Keywords: Sustainability, used for green synthesis, importance of green chemistry, Ionic liquids

I. INTRODUCTION

Green chemistry is the approach of designing chemical products and processes in a way that reduces or completely avoids the use and creation of harmful substances. It focuses on making chemistry safer and more environmentally friendly. This concept is applied throughout the entire life cycle of a chemical product—from its design and manufacturing to its use and final disposal. The idea of green chemistry was introduced by scientists who wanted to create cleaner, safer, and more sustainable chemical practices.

Ionic liquids have become popular as green solvents because they have special properties that make them different from traditional organic solvents. These liquids are actually salts that stay in liquid form at or near room temperature. They have very low volatility, can withstand high temperatures, and their physical and chemical properties can be adjusted as needed. Using ionic liquids supports sustainability because they reduce environmental harm and improve efficiency in many processes. They can dissolve many types of substances, both polar and non-polar, and their structure can be customized for specific uses. This makes them useful in many fields, such as pharmaceuticals, biotechnology, and chemical manufacturing. Ionic liquids also support green chemistry by reducing waste and making recycling easier. They are non-flammable and have low vapor pressure, which improves safety in the workplace and lowers the risk of accidents compared to traditional solvents. Although ionic liquids are considered environmentally friendly, researchers are still working to solve challenges like high cost, possible toxicity, and the need for more sustainable methods of production. As research continues, ionic liquids are expected to play an important role in creating cleaner, safer, and more efficient industrial processes.

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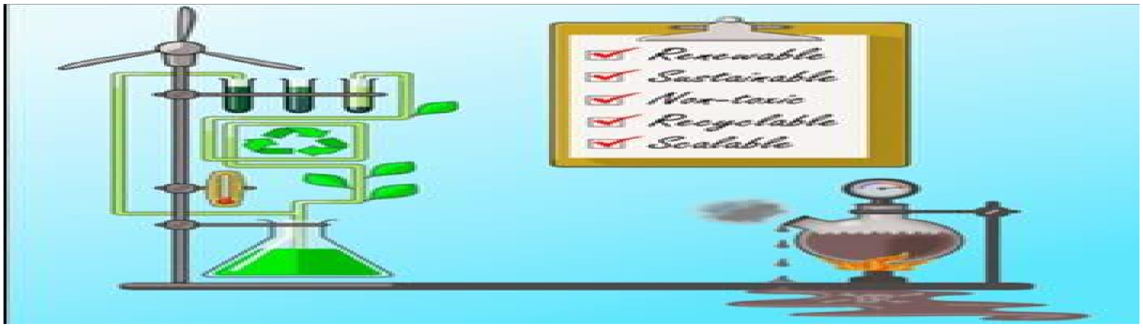

Role of various types of solvents and ionic liquids used in green synthesis:

In the 21st century, our world is facing many environmental challenges, which makes green chemistry very important for the pharmaceutical industry and other chemical fields. Green chemistry helps reduce pollution and protects the environment. The U.S. Environmental Protection Agency (EPA) has recommended new and innovative methods that reduce toxic substances, unwanted waste, and environmental damage. Green chemistry has now grown into a major scientific field. Since the introduction of the EPA's 12 Principles of Green Chemistry, these ideas have received a lot more attention and are being followed more seriously by pharmaceutical companies. Since 1998, solvents and stoichiometric reagents have been considered key factors in creating greener chemical processes, and many companies have studied them in detail. Green solvents are eco-friendly or bio-based solvents, often made from agricultural crops. They are safer for humans and the environment. Green solvents are mainly divided into three types:

- Oxygenated solvents
- Hydrocarbon solvents
- Halogenated solvents

IONIC LIQUIDS:

Ionic liquids (ILs) are made up of a large organic cation that contains nitrogen and a smaller inorganic anion. Normally, ionic compounds are solid at room temperature because the strong attraction between their positive and negative ions holds them tightly together in a crystal structure. However, ionic liquids stay in liquid form at room temperature because their ions are uneven or asymmetrical. This asymmetry lowers the lattice energy, which reduces the melting point of the salt, allowing it to remain liquid.

PHYSICAL PROPERTIES OF IONIC LIQUIDS:

Ionic liquids (ILs) have several unique physical properties that set them apart from traditional solvents, making them very useful in green chemistry and many other fields.

Low Volatility: ILs do not evaporate easily because their positive and negative ions are strongly attracted to each other. This strong bonding keeps them from turning into vapor. As a result, they are ideal for processes where solvent loss must be avoided or where low vapor emissions are important, especially in closed or controlled systems.

High Thermal Stability: Since ILs do not contain easily evaporating molecules, they can remain stable even at high temperatures. They do not break down easily when heated, which makes them perfect for processes that require high heat, such as catalytic reactions or thermal energy storage.

Resistance to Decomposition at High Temperatures: Ionic liquids can tolerate high temperatures without changing their chemical structure or decomposing. This strong heat resistance makes them suitable for energy-intensive applications where other solvents might degrade.

Low Melting Points: Most ionic liquids stay in liquid form at room temperature because they have low melting points. This means they remain liquid across a wide range of temperatures, offering flexibility for processes that involve heating or cooling.

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SYNTHESIS OF IONIC LIQUIDS:

The synthesis of ionic liquids (ILs) is a flexible process that allows scientists to design these liquids for specific uses by choosing the right combination of cations and anions. By doing this, they can control important properties such as solubility, viscosity, thermal stability, and ionic conductivity. Some common methods used to make ionic liquids include:

Neutralization Reaction: This method involves reacting a base with an acid to form an ionic liquid. For example, when imidazole (a base) reacts with hydrochloric acid, it forms imidazolium chloride. The type of acid and base used determines the final ionic liquid and its properties.

Ion Exchange: In this technique, certain ions in a salt are replaced with different ions to create a new ionic liquid. For example, halide-based ILs can be modified by exchanging their anions with tetra fluoroborate or bis (trifluoromethylsulfonyl) imide. This method helps adjust the IL's composition and functionality based on the starting materials.

Metathesis (Double Displacement) Reaction: This method involves mixing two different salts so that their ions swap places, resulting in a new ionic liquid. By choosing salts with specific cations and anions, researchers can design ILs with the properties they want. This approach gives a lot of flexibility in creating customized ILs.

Functionalization: This process involves adding specific chemical groups to an already existing ionic liquid. This changes or improves its properties without altering the main ionic structure. It is especially useful for making task-specific ILs without starting from scratch.

Quaternization: This method involves reacting tertiary amines with alkyl halides to form quaternary ammonium salts. These salts can then be combined with different anions to produce ionic liquids. The resulting cations are stable and adjustable, making this method very common for synthesizing ammonium- and phosphonium-based ILs.

APPLICATIONS OF IONIC LIQUID

Ionic liquids (ILs) are special liquids with unique properties that make them useful in many areas. Some key applications include:

1. Green Solvents in Chemistry:

ILs are environmentally friendly alternatives to traditional volatile organic solvents. They are used in chemical reactions, synthesis, and catalysis, making processes greener and more sustainable.

2. Catalysis and Synthesis:

ILs provide effective media for catalytic and synthetic reactions. Their adjustable properties allow scientists to improve reaction rates, selectivity, and efficiency. They can be used in both homogeneous and heterogeneous catalysis.

3. Extraction and Separation:

ILs dissolve substances well and can selectively extract materials. They are used for extracting metals from ores, purifying chemicals, and separating complex mixtures, offering better efficiency and selectivity than traditional solvents.

4. Electrochemical Applications:

ILs act as electrolytes in batteries and super capacitors. Their thermal stability and low volatility make energy storage devices safer and more reliable. IL-based electrolytes are also being explored for advanced energy technologies.

5. Gas Absorption and Storage:

ILs can absorb and store gases, especially carbon dioxide (CO_2). This makes them useful for carbon capture and storage, helping reduce greenhouse gas emissions.

6. Biocatalysis and Biotechnology:

ILs are compatible with enzymes and other biomolecules. They can improve enzyme stability and activity, making them valuable in biotechnological processes like enzymatic reactions and protein studies.

7. Lubricants and Additives:

ILs are used as lubricants or additives because of their low volatility and high thermal stability. They help improve the performance and lifespan of machinery components.

8. Nanostructure Synthesis:
ILs help create and stabilize nanoparticles and nanostructures. They provide a controlled environment for particle growth, which is useful in nanotechnology and materials science.
9. Drug Delivery:
ILs can dissolve a wide range of compounds and can be tailored for specific applications. This makes them promising for drug delivery systems, improving drug solubility and bioavailability. In summary, the applications of ILs continue to grow as researchers explore new ways to use them. Their versatility makes them essential for developing sustainable, efficient, and innovative processes in science and industry. Ionic liquids (ILs) are special liquids with unique properties that make them useful in many areas. Some key applications include:

TOXICITY ASSESSMENT OF IONIC LIQUIDS:
Evaluating the toxicity of ionic liquids (ILs) is very important to ensure they can be handled safely and used responsibly. In this study, a scale from 1 to 10 was used to measure the toxicity of different ILs, with higher numbers indicating greater toxicity.

Table 2: Toxicity Assessment of Ionic Liquids

Ionic Liquid Type	Toxicity Rating (1-10)
IL-1	**3**
IL-2	**8**
IL-3	**2**
IL-4	**5**

IL-1 had a low toxicity rating of 3, meaning it is quite safe to handle and use. This makes IL-1 a good choice for applications where safety is a priority.
IL-2 had a higher toxicity rating of 8, which means strict safety measures are needed during its use and disposal. While IL-2 may have useful chemical properties, its higher toxicity requires careful handling.
IL-3 scored very low at 2, indicating excellent safety. Its minimal toxicity makes it ideal for situations where both safety and environmental friendliness are important.
IL-4 had a moderate rating of 5, suggesting that careful handling and proper disposal are necessary. While it may be useful in some applications, following safety guidelines is essential.
These results show that choosing ionic liquids with low toxicity is key for protecting human health and the environment. Using safer ILs in chemical processes supports the principles of green chemistry and sustainable development.

II. CONCLUSION

Ionic liquids (ILs) are versatile and environmentally friendly solvents with unique properties, such as low volatility, high thermal stability, tunable physicochemical characteristics, and the ability to dissolve a wide range of substances. These features make them highly valuable in green chemistry, where reducing environmental impact and improving sustainability are key goals. ILs find applications across many fields, including chemical synthesis, catalysis, extraction and separation, energy storage, biotechnology, nanomaterials, lubricants, and drug delivery. Their low toxicity (when carefully selected), recyclability, and non-flammability make them safer alternatives to traditional volatile organic solvents. By enabling cleaner, more efficient, and safer chemical processes, ionic liquids play a crucial role in advancing sustainable industrial practices. Ongoing research into their design, synthesis, and applications continues to expand their potential, making them a cornerstone of green chemistry and environmentally responsible chemical technologies.

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