An Overview of Potential Application of Deep Eutectic Solvents in Leather Manufacturing

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An Overview of Potential Application of Deep Eutectic Solvents

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in Leather Manufacturing

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Abstract

Deep eutectic solvents (DES), were first studied during twenty first century. The availability of low-cost raw material and near absence of purification steps have quickly made DES attractive to scientific community. Additionally, the tuneable properties of DES can make it a viable alternative of ionic liquids (ILs) as well as other organic solvents. These solvents, having passed through the lens of green chemistry and sustainability, are novel and versatile in use. Leather manufacturing is an age-old technology and systematic process, it includes intensive use of different chemicals like salts, heavy metals, dyes, fat liquors etc. in pre and post tanning operations. These produce large amounts of

Graphical Abstract

1. Introduction

The world is evolving towards sustainable processes for resource extraction and utilisation, research efforts are

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aqueous waste, making it an ecologically sensitive industry. DESs potentially offer a greener alternative in leather manufacturing by substituting hazardous chemicals. DESs significantly reduce wastewater generation and thus environmental impact. This short review specifically aims to focus on the potential application of DESs at different stages of leather processing and their environmental benefits to overcome the serious environmental challenges which conflict with the sustainable goals. Moreover, the use of DESs provide new opportunities for leather applications as a sustainable solution.

Keywords: Deep eutectic solvent, Green Chemistry, Sustainability, Leather manufacturing, Environmental impact

focused on different approaches to address allied challenges across domains. Green chemistry, often referred as sustainable chemistry, is one of the promising strategies where environment and human health are

prioritised by designing products and processes with less consumption and generation of hazardous compounds [1]. Twelve principles of green chemistry were proposed by Paul Anastas and John Warner [2] with a key emphasis on green solvents. These green chemistry principles stress more on reducing toxicity and refining the chemical processes towards sustainability. Green solvents like ionic liquids (ILs) and Deep Eutectic Solvents (DESs) are playing a pivotal role in promoting sustainable and ecofriendly practices by lessening damage to ecosystems as well as to human health. They are effectively useful because of their properties like low volatility, high stability, tunability, recyclability, suitability across a wide range of temperatures and cost-efficiency [3, 4]. Though ILs and DESs form two different solvent families, both are more desirable than conventional solvents for exhibiting “green” and “designer” properties to a useful level. These solvents have deeply impacted various research fields and process technologies, and gained significant attention with substantial growth in both research and practical applications [5].

Leather and leather-based products remain to be highly appreciated for their intrinsic properties, such as breathability, durability, natural comfort, and aesthetic appeal. The conventional leather manufacturing technology is inherently hazardous, and produce significant amounts of solid and liquid waste, causing potential environmental risks. Several stringent regulations are introduced in processing this biomaterial (hides & skin) due to these substantial environmental impacts of various hazardous chemicals used during the leather making process [6]. Cleaner leather processing, however, becomes crucial to ensure the sustainability of the leather industry. Advance researches have introduced several alternatives for eco-friendly processing stages including

salt-free and phyto-based preservation, greener pretanning, enzymatic and nanoparticle-assisted tanning, biopolymer-based re-tanning and dyeing, and solvent-free or bio-based finishing systems [7]. The application of DESs and ILs in leather production as well as in treatment of chromium containing wastewater are another “green”

approach [8]. Treatment of raw hides and skins with DESs reduces solid waste generation and significantly reduces the effluent load. Being “designer” solvents, DESs and ILs can also improve the physical properties of the finished leather.

In this short review article, an attempt has been made to focus on a short outline on DESs and ILs and their possible applications in leather processing technology and allied areas. The first section of this work particularly emphasises on ILs and DESs, their properties and common types followed by the recent applications of these green solvents in the leather industry. This review highlights the potential of DESs application to make cleaner process technology addressing the existing pollution complications during leather manufacture.

2. Ionic Liquid and Deep Eutectic Solvent

Green chemistry principles lay down the framework for designing chemicals and methods which reduce the use and generation of hazardous substances or make them redundant [2]. These principles have been widely accepted for assessing the “greenness” of chemical paths and comparing the environmental compatibility of different methods. In the field of material science, specifically green chemistry, advancing the preparation of materials with controlled structures and unique functionalities relies on developing new synthetic strategies that minimize the application of reducing agents, solvents, surfactants and cross-linking agents. Both ionic liquids (ILs) and deep eutectic solvents (DESs) are key to green chemistry.

2.1 Ionic Liquid

Ionic liquids are chemical compounds with low melting points consisting of organic cations paired with organic or inorganic anions mainly by ionic bonds. The term ionic liquids are one that has been used to describe a family of organic salts with melting points below 1000C.[1] The cations are commonly bulky organic ammonium or sulfonium cation such as imidazolium or pyridinium. The anions are bulky organic or inorganic anion which leads

to a reduction in lattice energies thus giving rise to low melting points [1]. Ionic liquids are sometimes referred to as ‘designer solvents’ as their respective anions or cations can be modified to elicit a desired reaction.

2.2 Deep Eutectic Solvent

Deep Eutectic Solvents (DES) can be regarded as an extension to the ionic liquids. DESs are mixtures of a hydrogen bond donor (HBD) and acceptor (HBA), whose strong hydrogen bonding interactions significantly lower the melting point compared to their pure components. Abbott et al. initiated DES research in the early 2000s, initially observing that mixtures of quaternary ammonium salts (QAS) and metal chlorides formed liquids with significantly depressed melting points, termed “Lewisacidic ionic liquids”.

2.3 Applications of ILs and DESs

Both ILs and DESs share similar physicochemical properties, such as high density, viscosity, thermal stability, low flammability, and negligible volatility. Their unique advantages and disadvantages allow their properties to be tailored for specific applications, contributing to their widespread use in science, research, and technology. Because of their similar properties, both ILs and DESs are extensively used for similar applications in diverse fields, including electrochemistry, extraction and purification, catalysis and synthesis, biomass processing, gas capture, and other environmental applications [10].

2.4 Environmental impact of deep Eutectic Solvent

The focus of green chemistry is to reduce or eliminate the hazardous materials while designing and processing

Operation

Process name Key features References

name

Beam House Operation

Liming, Deliming, Dehairing and Fibre opening

ILs, specifically imidazolium based one, used as fibre opening agents

chemical products to minimize its environmental impact. There are several environmental analysis tools like EFactor analysis, TOPSIS Analysis, LCA, and Environmental Analysis, used to assess the sustainability and green chemistry performance of DESs. The environmental analysis of DESs involves a balance of factors such as

toxicity, biodegradability, energy consumption, and the overall sustainability of the raw materials [11]. In comparison to traditional solvents, DESs generally present a better alternative, but the specific environmental impact can vary depending on the components involved. This analysis and their respective findings are in line with green chemistry principles and thus DESs become a potential alternative to traditional solvents considering the present environmental consciousness.

3. Uses of DESs in Leather processing

The manufacture of leather is a challenging and complicated process, which converts natural biomaterial to various high-end applications. In leather processing, DESs show notable potential. Abbott et al. applied DES in tanning, where their high ionic strength neutralizes collagen surface charges and disrupts hydrogen bonds, inducing lyotropic swelling and creating channels that enhance penetration of chrome tanning agent [8], Moreover, DES properties such as polarity, viscosity, and ionic strength can be tuned to regulate enzyme conformation [12], activity, and stability, offering new opportunities for leather applications.

This short review focuses on various application of DESs in different operational stages of leather and even in wastewater treatment. A snippet of the various studies is furnished in the given table 1.

Jaykumar et al., 2015 J P Alla et al., 2017 Hui Liu et al., 2022 Ya Xiao et al., 2026

Table 2. Sustainable approaches by using DESs and ILs in various stages of

Process name Key features References

Mineral Tanning Used imidazolium based ILs as tanning agents

leather processing and in waste treatment

Operation

name

Tanning Operation

Mineral (Cr) Tanning, Vegetable Tanning

DES (Ethaline) used as tanning agents

Post tanning Operations

Dyeing, Fat liquoring

DES (Ethaline) and IL(IDP) used to improve thorough penetration and dispersion of dye

DES and ILs are highly effective for removal of Cr (III), dyes etc.

Wastewater Treatment

4. Conclusion

This study demonstrates that DESs and ILs are a promising alternative for cleaner and greener leather processing. They effectively remove inter-fibrillary materials, reduce sludge generation, and improve tanning. DESs delivery system can significantly reduce the amount the chemicals used in post tanning operations with expected outcomes and thus reduce the chemical load in effluent. Usage of DESs in processing of leather maintain the physical and morphological integrity. Even DESs and ILs can help to gain new properties like conductivity, flame resistance etc. Application of DESs in leather processing introduces a sustainable approach to address environmental concerns in the leather industry and longterm industry sustainability.

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