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Environmental Resource Recovery of Oil-Based Derivatives Using Ionic Liquid

Moro, Otuawe

Department of Environmental Management, Faculty of Environmental Science, Rivers State University, Nkpolo-Oroworukwo, Port Harcourt, Nigeria.

Corresponding Author: moro.otuawe@ust.edu.ng

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Abstract

The surge in the market for commercially valuable materials from waste is a key driver for the novel reuse of drilling wastes, coupled with competitive regulatory requirements to ensure a sustainable approach. This study investigates the environmental resource recovery of oil-based derivatives in a simulated mix comprising barite, phenanthrene, fluoranthene, and anthracene using a room-temperature ionic liquid – 1-propyl-3-methylimidazolium bromide (propyIMIMBr). The mixture was analysed for solubility in ionic liquids. The results revealed the eventual solubility of anthracene in the four-component mix without decomposing the ionic liquid. This finding is significant in recovering valuable materials from a simulated drilling waste mix and separating key

pollutants if optimised as a secondary waste treatment method.

Introduction

The market for drilling waste components includes cuttings, mud and fluids, which has witnessed remarkable attraction in innovative separation, treatment and recycling techniques to ensure sustainable practices during oil and gas operations (Chauvin, 2023). Most countries categorise wastes from drilling as hazardous wastes and propose proactive technical and economic processes for handling them (Lebedev, A., & Cherepovitsyn, 2024). Thus, the oil and gas industry relies on novel technologies to sustain the drilling waste management practice and comply with increasingly stringent regulations (Hossain et al., 2017). Though drilling waste management practices vary according to region, operators still require technologically sound approaches to enable options with more environmental and economic benefits based on the volume of drilling wastes they generate (Ibuchukwu & Nwakaudu, 2012). Drilling waste management comprises different technologies, as no particular method can treat the drilling waste streams to the required standard (Hinden et al., 2020). The major components of the drilling waste streams are the drilling mud and cuttings, which have different chemical compositions due to the various additives added to the mixture. Thus, adequate management is required to reduce harm to the environment (Wang et al., 2012). Also, a closed-loop operation system is required in drilling waste management to enhance sustainability options, improve safety and effective environmental preservation (Alharbi et al., 2024).

RESOURCE RECOVERY AND RECYCLING

A key priority of the oil and gas industry is adopting sustainable and environmentally friendly approaches to eliminate contaminants during operations. Thus, treatment processes are designed to maximise and enhance oil recovery (Massarweh & Abushaikha, 2024). Separating and recovering individual materials that are economically important and beneficial during drilling operations and reuse in other industries proffers a balance between sustainability and environmental impacts. The composition of these materials can be hazardous and a challenge to dispose of. Thus, developing efficient green extraction and material recovery technologies increases the opportunity to use ionic liquids (Inman et al., 2022). In order to achieve sustainable development goal 12, which envisages sustainable consumption and production, it is essential to identify oil derivatives such as phenanthrene, fluoranthene and anthracene, which are aromatic compounds of concern due to their toxicity potential, and barite, which is a weighting agent during drilling operations. Though these chemicals may be less harmful at trace levels, excessive production activities can increase their presence in the environment and safety concerns. Thus, transforming these chemicals into recyclable materials can proffer an effective management solution (UN, 2023).

POTENTIALS OF IONIC LIQUIDS IN MATERIAL RECOVERY

Ionic liquids have a unique potential to dissolve an extensive range of organic compounds, which makes it possible to use them in a mixed organic and inorganic waste stream, where the organic compounds can dissolve in the ionic liquid, leaving the inorganic compounds insoluble for separation and further recovery of the organics from the ionic liquid mixture. The solubility characteristics of ionic liquids promote the selectivity of the target material for extraction and recovery (Shahani et al., 2024). As oil and gas production is critical to economic development, it is imperative to pursue resource recovery technologies to preserve the natural environment from potential harm emanating from exploiting natural resources (Safarli, 2024). Anthropogenic activities like fossil fuels and agriculture are the leading cause of the increase of aromatics in the environment, such as phenanthrene, anthracene and fluoranthene. At the same time, barite, mainly from drilling operations, is a major driver of environmental sustainability as global warming awareness increases. Thus, there is an increase in green technologies to manipulate waste materials to explore their potential reuse options to improve environmental quality in the long run, as petroleum industries can adopt such novel cleaner technology options tailored to their operations (Agboola et al., 2022).

MATERIALS AND METHODS

0.1g of each component - barite, phenanthrene, fluoranthene, and anthracene alongside 1g of 1-propyl-3-methylimidazolium bromide (propyIMIMBr) ionic liquid was weighed using a Sartorius weighing balance. The mix was placed on a preheated hotplate and set to specific temperatures of—140°C. In order to facilitate the solubilisation process, stirring was applied using a device capable of 1000 rpm. The solubilisation was monitored visually, and the duration of each experiment was set to 20 minutes. However, it was observed that anthracene, one of the components of the four-component mix, appeared more challenging to break down compared to the other components. Despite this, anthracene eventually became soluble within 20 minutes without decomposing the ionic liquid.

RESULTS

The result of the solubility of phenanthrene, fluoranthene, and barite in **Figure 1a,** which is a three-component mixture, shows a difference in peak profile, labelled within the high wavenumber regions such as 2800 and 3414^{cm-1} wavenumbers, and the double bond region, around 1650^{cm-1} wavenumber. While the result of the solubility of anthracene, phenanthrene, fluoranthene, and barite in **Figure 1b,** which is a four-component mixture, is comparable to Figure 1a, showing similar difference in peak profile, labelled within the high wavenumber regions (2800-3414^{cm-1} wavenumbers) and the double bond region (1650^{cm-1} wavenumber); though the peak numbers were different.

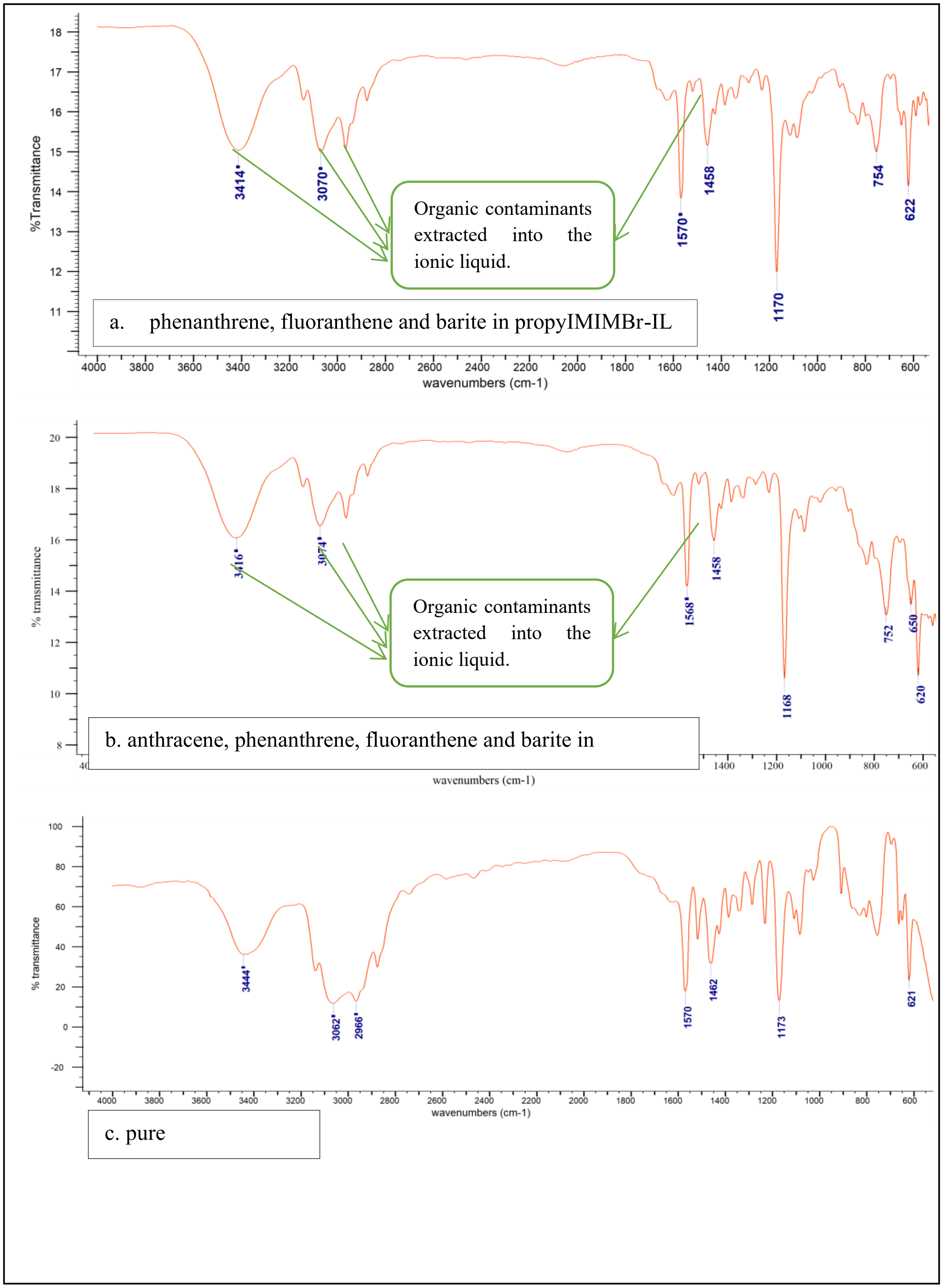

Figure 1: Solubility of anthracene, phenanthrene, fluoranthene and barite in propyIMIMBr - ionic liquid mixture

Phenanthrene and fluoranthene are three-ringed aromatic compounds soluble in most organic solvents, enabling separation and recovery when extracted into the ionic liquid. While anthracene is also a three-ringed aromatic compound, it is insoluble in most organic solvents, making recovery possible. The spectra in **Figure 1c** show the pure ionic liquid and demonstrated potential in extracting organic compounds at set temperatures to get the target material into a solution to separate multiple contaminates, which are potential materials for recycling.

DISCUSSION

Improper hazardous waste management is a global issue (Akpan & Olukanni, 2020). Emerging technologies are being deployed to treat wastes consisting of polyaromatic hydrocarbons, which are potentially toxic (Patel et al., 2020). The rapid solubilisation of the four-component mixtures within the designated timeframe underscores the inherent solvating power of ionic liquids. The ability of ionic liquids to dissolve diverse chemical species, including inorganic compounds like barite and organic polycyclic aromatic hydrocarbons (PAHs) such as phenanthrene, fluoranthene, and anthracene, highlights their versatility as solvent systems.

Of particular interest is the behaviour of anthracene, which initially displayed resistance to dissolution but eventually became soluble within the ionic liquids. This phenomenon suggests a dynamic interplay between temperature, agitation, and molecular interactions governing solubility kinetics. The observed solubility enhancement of anthracene over time implies overcoming potential kinetic barriers to dissolution, possibly attributed to increased thermal energy and improved molecular dispersion within the ionic liquid matrix.

Furthermore, the absence of ionic liquid decomposition during anthracene solubilisation indicates the robustness and stability of the ionic liquid solvent system under the applied experimental conditions. This resilience is essential for maintaining the integrity of ionic liquids in practical applications, ensuring their sustainability and effectiveness as green solvents.

Overall, the findings shed light on the intricate solubility dynamics of complex mixtures in ionic liquid environments, emphasising the importance of understanding molecular interactions and kinetic processes. Further investigations into the thermodynamic and structural aspects of solvation in ionic liquids are warranted to unravel the underlying mechanisms driving solubility phenomena. Such insights are significant for designing and optimising ionic liquid-based chemical synthesis, separation, and environmental remediation processes.

CONCLUSION

The investigation elucidated the solubility behaviour of barite, phenanthrene, fluoranthene, and anthracene in ionic liquids, revealing rapid solubilisation of the components within the designated time frame. Initially resistant to dissolution, anthracene eventually became soluble without causing decomposition of the ionic liquid, highlighting the dynamic nature of solubility processes in ionic liquid mixtures.

RECOMMENDATION

This study recommends further investigation of the extraction of resistant compounds such as anthracene and other complex waste mixtures to optimise the use of liquid-liquid extraction in an ionic liquid-based application. Also, the recyclability of ionic liquids after extraction is crucial thus additional practicable steps to explore purification methods for widespread industrial applications are recommended.

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