



Sustaining Polymer Extraction and Recovery from Environmental Matrices Using Ionic Liquid

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Abstract

Pollutants in drilling spoils vary; they include petroleum hydrocarbons, additives from the drilling fluid, organics such as aromatic compounds, and, in some cases, naturally occurring radioactive materials. This study investigates the innovative integration of 1-propyl-3-methylimidazolium bromide ionic liquid (propyIMIMBr-IL) in the extraction of two aromatic compounds: anthracene and fluoranthene, as a model that can be replicated to sustain polymer extraction for reuse. The experimental research involved the synthesis of the propyIMIMBr-IL and conducting solubility tests at preset temperatures for fluoranthene (74°C) and anthracene (140°C), respectively. The recovery process involved a two-step extraction for the propyIMIMBr-IL, using methanol and 1-butanol; fluoranthene, using 2-butanol and tetrachloroethylene; and anthracene, using methanol and 2-butanol. The findings revealed a successful recovery of fluoranthene and the propyIMIMBr-IL, which depicts the effectiveness of the research. However, anthracene retrieval remained challenging due to its finer particle size, underscoring the complexity of the study and the need for innovative solutions. Subsequent Fourier Transform Infrared (FTIR) spectroscopy analysis revealed residual anthracene in the recovered propyIMIMBr-IL and fluoranthene. A secondary extraction using 1-butanol and tetrachloroethylene successfully recovered anthracene, though in low yield. Although naturally occurring polymers can be less toxic to the environment, some synthetic polymers biodegrade slowly in the environment and may be harmful for a period, especially in aquatic ecosystems. Thus, this study demonstrates the potential for selective extraction with reduced solvent usage, which can be applied to the selective recovery of synthetic polymers commonly found in drilling spoils.

Keywords: Anthracene, drilling spoil, fluoranthene, ionic liquid, polymers.

Introduction

Polymers are large molecular substances comprising a wide range of properties, characterised by a large molecular mass of repeated structural units, which enables extraction at high temperatures and makes them suitable for use in many applications. These include healthcare (Patil et al., 2018) [18], food packaging, agriculture (Tajeddin & Arabkhedri, 2020) [46] and drilling. Several additives, including polymers such as xanthan gum, carboxymethyl cellulose, guar gum, hydroxyethyl cellulose, and starch, are added to the drilling fluid to enhance its rheological and filtration properties (Odimba, 2023) [32]. Globally, deep drilling has increased significantly, which is crucial for the discovery and exploration of oil and gas by international companies that are highly active in acquisitions and mergers (Wen, 2023) [46]. Drilling spoils, also known as drilling wastes, comprise drilling fluid and drill cuttings, which are regarded as the second-largest waste volume (Peraira et al., 2022) during exploration and production activities. Thus, international conventions and regulations established by host governments restrict disposal (Ismail et al., 2017) [17]. Some compounds in the drilling spoils are not only hazardous but also challenging to degrade in the environment, which can lead to secondary pollution in ecosystems, especially in coastal areas (Zhang et al., 2021) [50]. Thus, novel

technologies are required to explore the possibility of extracting these compounds from the environment for reuse (Mu et al., 2022) [29].

Importance of Polymers

Polymers have been extensively used in the plastic industry, generating waste that requires innovative, sustainable solutions. Ionic liquid is a class of green solvents that act as catalysts in extracting polymers and organics, and have been considered a novel, sustainable route for polymer synthesis (Salas et al., 2025) [43]. The use of polymers in targeted applications has increased tremendously. It is essential to United Nations Sustainable Development Goal 12, which advocates for responsible consumption and production, highlighting the concern for chemical contamination that migrates from additives (de Sousa, 2021) [16]. The use of polymer ingredients in drilling fluids dates back to 1970 due to their hydrophilicity and pseudoplasticity (Davoodi et al., 2024) [14]. There is a possibility of environmental impacts resulting from improper disposal which may be long-term (Osipov et al., 2022 & Murtaza et al., 2021), depending on the type of polymer and the condition of the environment during the period of drilling operation, which may impact soil, water and air, as well as human health (Davoodi et al., 2022) [22].

Polymers in the Environment

Polymers are a major constituent in drilling fluid, improving drilling efficiency. However, the residue left after drilling can be potentially harmful to the environment. Thus, the residual oil recovery from drill cuttings is a critical step towards maximising the sustainable value from drilling waste (Pereira et al., 2019) ^[40]. Several techniques have been developed in the past, highlighting the importance of sustainable treatment of drilling spoils, with the potential recovery of components of economic value (Shahbaz et al., 2023) ^[44] and technical reliability in terms of safety and environmental impact (Almeida et al., 2017) ^[4]. Miikor et al. (2025) ^[28] investigated the environmental performance of three commonly used polymers for drilling operations. This includes starch, hydrolysed polyacrylamide and carboxymethyl cellulose. The study revealed that starch is biodegradable, while hydrolysed polyacrylamide and carboxymethyl cellulose show potential for persistence in the environment. This highlights the importance of considering the environmental impact of chosen polymers in drilling fluid formulation (Miikor et al., 2025) ^[28].

Household Wastes with High Polymer Content

Polymers generated from households that are commonly disposed in wastepaper bins or general wastes have high recyclability potential as chemical feedstocks. Amongst these polymers that are critical to recovery are the low-density polyethylene and polystyrene (Karaduman, 2016) ^[21]. The production of plastics has been projected to increase exponentially, and most of these plastics contains polymetric materials (Rafey & Siddiqui, 2021) ^[41], that are valuable. Plastic waste rarely degrades in the environment and still lacks appropriate management strategies in some developing countries (Eze et al., 2021) ^[17]. While in developing countries about 42% of the plastic waste from packaging is recycled. While there is a target to reduce 55% by 2030 as envisioned in the European Directive 2018/852 (Cerasi et al., 2021) ^[9]. Significant progress has been made in the efforts of developing countries in tackling packaging wastes, this is why in February 2025, the Packaging and Packaging Waste Regulation (PPWR) was established to improve on the requirements of the European Directive 2018/852 to make prevention of waste generation, recycling and producer responsibility schemes achievable, thus fostering circular economy for packaging (Clarity Environmental Limited, 2025) ^[10]. The responsibility of waste management is gradually been extended or shifted to the producer. The Extended Producer Responsibility requires that the producer be held accountable for the management of wastes through the life-cycle of the product, also economic responsibliy like incentives and appropriate environmental considerations like material recovery during the product design (OECD, 2024). A significant challenge of polymer wastes that are common in household is poor decomposition and extensive accumulation which threatens soil and water resources. While introduction of alternative packaging materials are required, novel extraction methods to manage the existing wastes effectively is necessary to minimise adverse effects on the

natural environment (Kabyibekova et al., 2025) ^[20]. Polymer wastes which are commonly littered in the environment contribute about 28% of wastes found not only on streets and public places but also in classrooms (Aderogba, 2013) ^[2] while 80% of wastes found in seas are plastics which have been swept into the ocean (Kibria et al., 2023) ^[22]. Managing the waste components from plastics is a global issue that is achievable by extraction of polymers for recycling (Siskova et al., 2021), as plastic waste continues to increase despite all the environmental limits and policies exploring green chemistry in a lifecycle approach to sustainable consumption (Evode et al., 2021) ^[18]. The implication of this is that the Extended Producer Responsibility now implements the polluter pay principle as Nigeria aims to drastically increase the collection and recycling of plastic wastes by 2029, targeting bottles made from polyethylene terephthalate which is now meant to contain at least 25% recycled materials (UNEP, 2025) ^[47].

Aromatics and Environmental Management

Aromatic compounds commonly found in drilling spoils (Amirdivani et al., 2019) ^[3] are identified as a significant source of their presence in the environment, which has increased over the years through various pathways (Patel et al., 2020) ^[37]. Environmental restoration has driven the development of sustainable solutions, propelling scientists to tackle pollution by exploring processes that integrate clean mechanisms to selectively separate harmful pollutants that can persist in the environment for extended periods (Nazeer et al., 2016) ^[31]. This study, which investigates the selective extraction of anthracene and fluoranthene and the potential to separate them from the environment, is a significant step towards a more sustainable solution in environmental management. As growth in industrialisation drives economic development, it poses a critical environmental threat to sustainable development. Industrial processes require an assessment of process steps at each phase to categorise waste streams that can be isolated and integrated to recover resources of value to the chemical industry (Ogwu, 2022). Drilling spoils are high in aromatic compounds, which have a lethal effect on aquatic life by reducing oxygen and light penetration, with a cumulative impact on food chains (Alaidaroos, 2023) ^[3]. Exposure to pollutants from drilling spoils over an extended period can harm human health, affecting the respiratory, cardiovascular, and nervous systems (Shetty et al., 2023) ^[45]. The findings from this study will provide novel solutions for addressing environmental pollutants, such as polymers and aromatics, commonly found in drilling spoils and other waste materials, including plastics. This will inspire scientists to discover new uses for selective recovery using ionic liquids in polymer science.

Adaptation of Waste Hierarchy in Material Recovery

The waste hierarchy prioritises waste strategies that integrate recovery techniques to acquaint policymakers with viable options for consideration as strategies to drive emission reduction at both local and national levels (Lazarevic et al.,

2010) [25]. The liquid-liquid extraction using ionic liquids is a potential option for sustaining pollutant extraction for reuse in order processes (Lingaitiene & Burinskiene, 2024) [26], which can enhance the the recovery of additives from drilling spoils (Wang & Tester, 2023) [48], and drive an environmentally conscious practice that screens waste streams to determine the hazardous components for possible extraction (Khan & Kaneesamkandi, 2013) [49]. This approach to recovery of hazardous waste components can introduce a new stream of reusable materials for other processes (Ostad-Ali-Askari, 2022) [35].

Policy Implications of Hazardous Wastes in the Environment

Environmental policies and targets aimed at reducing emissions from hazardous waste are crucial in promoting sustainable practices in rapidly growing economies that heavily rely on industrial processes. Initiatives such as the United States' Zero-Waste Initiatives in Nigeria, the United Nations' Sustainable Development Goals, and the European Union's Waste Framework Directive (Dada et al., 2024) [22]. can offer sustainable solutions, especially when integrated with novel recovery processes, such as green chemistry (Berthod & Armstrong, 2021) [21].

Materials and Methods

The experimental steps to synthesise the propy MIMBr-IL, solubility, extraction and recovery are summarised in Table 1 below:

Table 1: Method for Extraction of Organic Contaminants in Drilling Spoil

STEP 1:	Synthesis of propy MIMBr-IL following prescribed conditions
i.	Preparation of propyMIMBr-IL using microwave technology.
ii.	Using the Fourier transform infrared spectroscopy (FTIR) technique to characterise the propyMIMBr-IL and test the purity.
STEP 2:	Solubility Testing
i.	Testing of the solubility of selected pure organic components, representative of those found in drilling spoils, in the prepared propy MIMBr-IL.
ii.	Testing the solubility of the selected pure organic compounds in a range of known solvents such as methanol, ethanol, etc.
iii.	Testing the solubility of propy MIMBr-IL in the same organic solvents to gain an understanding of how the pure component can be separated from propyMIMBr-IL.
iv.	Preparation of a mixture of 2 and 3 components and conduct solubility trials.
STEP 3:	Extraction Trials
i.	Having identified the organic solvents from step 2 that selectively dissolve the propyMIMBr-IL or the pure component but not both, a series of extraction trials can be conducted.
ii.	Conduct extraction trials to recover the pure components from the mixture of ionic liquid and the component phase. Characterise the recovered component, and determine the recovery yield.
iii.	Conduct extraction trials to recover the pure component from the mixture of 2 or more pure components. Characterise the recovered component and record the yields. Conduct further separation trials as required.
iv.	Conduct extraction trials on a simulated mix of components typical of an oil-based mixed stream. Characterise the recovered components and record the yields. Conduct further separation trials as required.
v.	Conduct extraction trials on a real oil-derived mixture (such as aromatics and polymer extraction). Characterise the recovered components and conduct further separation trials as required.
vi.	Assess the extent to which the propyMIMBr-IL can be recovered for recycling.

Synthesis of 1-propyl-3-methylimidazolium Ionic Liquid

1-propyl-3-methylimidazolium ionic liquid (propyMIMBr-IL) was synthesised using 5.0g, 0.06mol of 1-methylimidazole and 10.2g, 0.08mol of 1-bromopropane (from Arcos organics). The mixture was heated first using a Baumatic open stainless steel microwave (model number: BTM 17.3SS) set at 20% for a duration of 4 seconds. This process was repeated four times (i.e., 20% for 4 seconds x 4). Afterwards, the duration was extended to 10 seconds and repeated once (i.e. 20%, 10 seconds x 1). The reactant mixture was washed with 20 ml of diethyl ether four times. The residual ether was evaporated under

vacuum using a Buchi Rotary RII and CVC 3000 Vacuubrand PC 3001 Vario at 40–60°C, with a rotation speed of 10rpm, for a duration of 1 hour and 30 minutes. The resultant yield of 90% was characterised using FTIR.

Solubility of Drilling Spoil Components in propyMIMBr-IL and Organic Solvents

The solubility of typical aromatics found in drilling spoils (anthracene and fluoranthene) was tested in the propyMIMBr-IL using 0.2 g of anthracene and 0.2 g of fluoranthene, respectively, in 2 g of IL. It was discovered that fluoranthene

dissolved in solution at 74°C, while anthracene was soluble at 140°C after a duration of 20 minutes at 1000rpm. Furthermore, solubility tests were carried out on the same selected aromatic compounds using a range of organic solvents. It was discovered that 5ml of 2-butanol and tetrachloroethylene solvents, respectively, dissolved more than 1g of fluoranthene, which was stirred at 600-1000rpm at room temperature for a duration of 20 minutes. None of the range of organic compounds tested could dissolve anthracene.

Selection of Organic Solvent for Extraction of propyIMIMBr-IL

Additionally, propyIMIMBr-IL was tested for solubility in a range of organic solvents to identify the solvent that can be used in recovering propyIMIMBr-IL for recycling. 5 mL of solvent was diffused into 2g of propyIMIMBr-IL. 1-Butanol and methanol were selected as suitable solvents for extraction, as they successfully dissolved the IL at room temperature within a 20-minute duration of stirring at 600-1000rpm. Based on the findings from the solubility mixtures, a 2-3 component mixture comprising anthracene, fluoranthene, and IL was prepared. Hence, 2g of propyIMIMBr-IL was dissolved in the test tube containing 0.2g of an anthracene and fluoranthene mixture, and stirred for a duration of 20 minutes at 1000rpm at a set temperature of 74°C. Methanol was added to the test tube containing propyIMIMBr-IL, anthracene and fluoranthene mixture since methanol dissolves propyIMIMBr-IL and not anthracene or fluoranthene. Hence, the methanol-

propyIMIMBr-IL mixture was decanted into a 0.22µm membrane filter apparatus to remove traces of anthracene and fluoranthene. In contrast, the residual anthracene and fluoranthene mixture remained at the base of the test tube. The residue (anthracene and fluoranthene mixture) on the filter paper was quantitatively transferred to the test tube and washed with 2-butanol to dissolve fluoranthene while anthracene remained insoluble. For the recovery of propyIMIMBr-IL, the methanol-propyIMIMBr-IL mixture was transferred to a rotary evaporator, which was set at 40°C and ramped up to 60°C at a speed of 9rpm for a duration of 1 hour and 30 minutes. A visible dry residue was obtained and weighed to determine the effectiveness of the recovery process. For the recovery of fluoranthene from the 2-butanol-fluoranthene mixture, the mixture was quantitatively transferred to a rotary evaporator using the same recovery protocol for propyIMIMBr-IL.

It was discovered that 1-butanol, an organic solvent that also dissolves propyIMIMBr-IL, was a good substitute for methanol, as propyIMIMBr-IL is also soluble in 1-butanol and thus produced similar results. While fluoranthene is also soluble in tetrachloroethylene, an organic solvent, this makes it another option that can replace 2-butanol during the extraction of fluoranthene; however, using a filter paper of a different size (0.45µm) is recommended. The recovered propyIMIMBr-IL, fluoranthene, and anthracene, using the two sets of organic solvents, were characterised using FTIR spectroscopy, and the spectra were matched with the original for comparison (**Figure 1**).

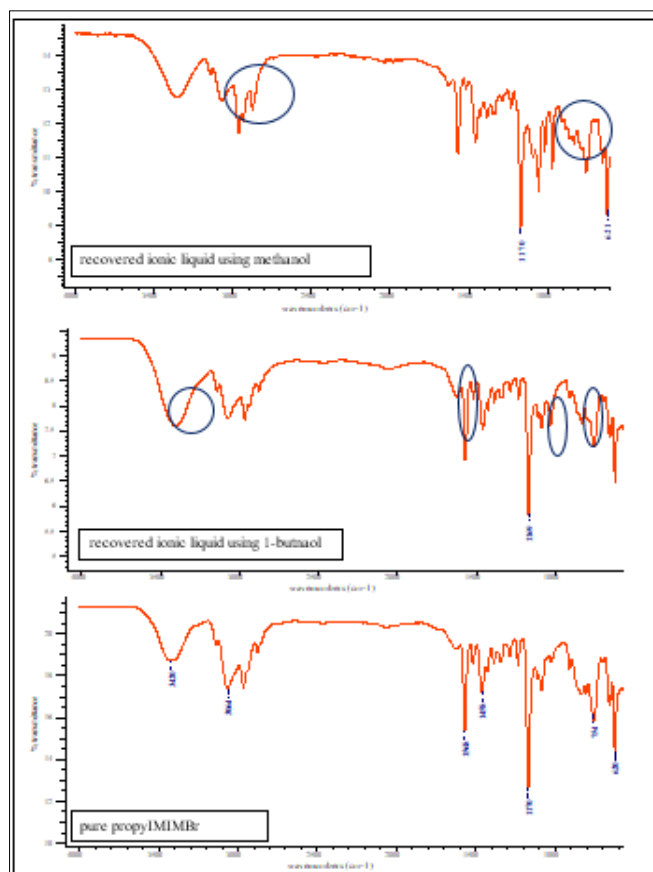


Fig 1: Recovery of ionic liquid from anthracene and fluoranthene using methanol and 1-butanol

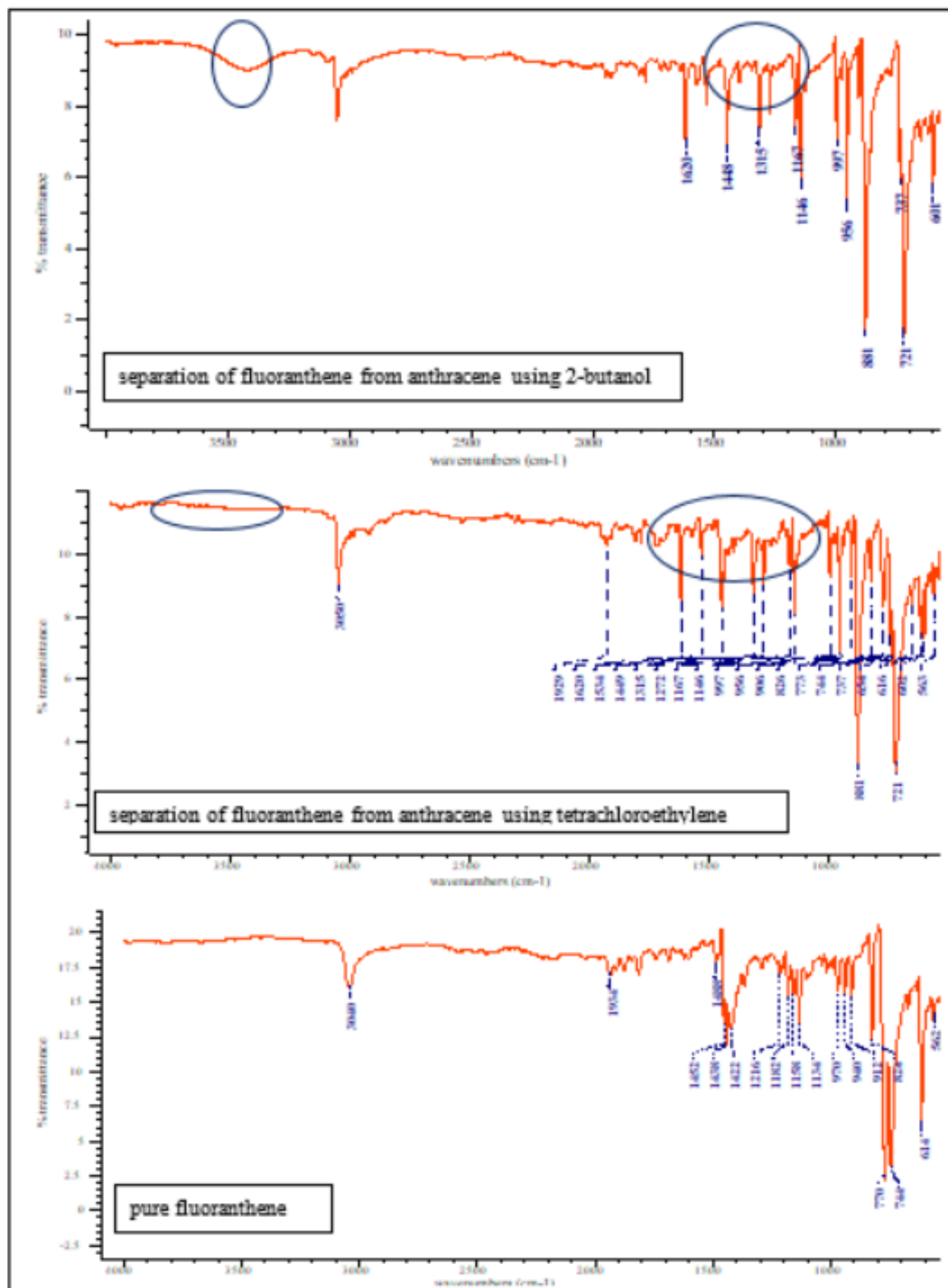


Fig 2: Recovery of anthracene from a fluoranthene mixture using tetrachloroethylene

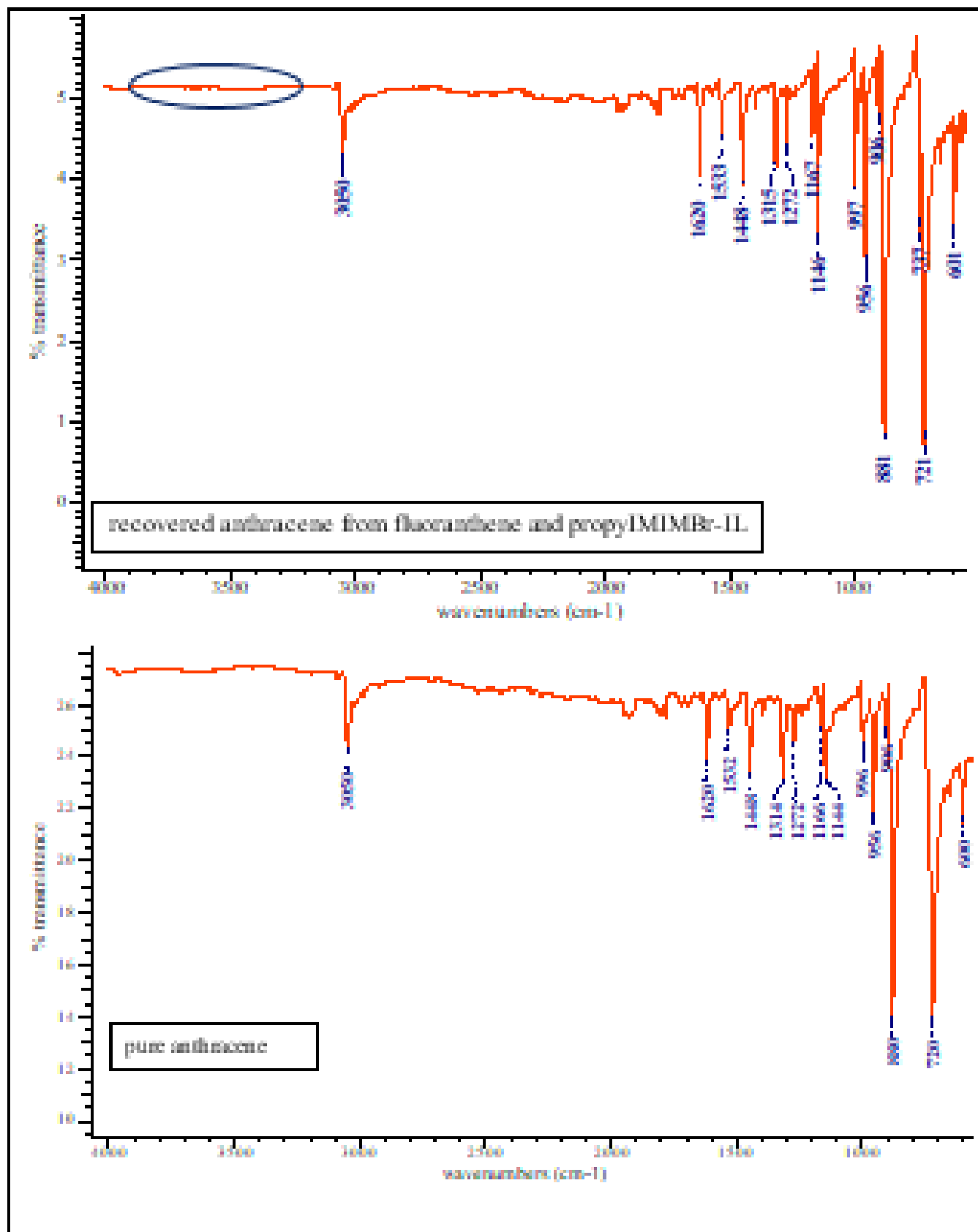


Fig 3: Separation of fluoranthene from anthracene using 2-butanol and tetrachloroethylene

Results

Fluoranthene solubility was observed at 74°C, while anthracene required 140°C in propylMIMBr. The first extraction method yielded the recovery of ionic liquid and fluoranthene (Figure 1) in high yields; however, anthracene could not be recovered due to its fine particle size. FTIR

analysis revealed the presence of residual anthracene in the recovered ionic liquid and fluoranthene mixture (Figure 2). A second extraction method using 1-butanol and tetrachloroethylene successfully recovered anthracene, albeit in low yield, with spectral characteristics matching the reference spectrum (Figure 3). The ionic liquid recovered in

high yield using 1-butanol is consistent with the reference spectrum shown in Figure 1.

Discussion

The solvent selection was critical in the chosen extraction route for the synthesised green solvent, propyIMIMBr-IL, and the selected drilling spoil components, anthracene and fluoranthene (Moro, 2024). As the drive to minimise hazardous waste disposal (such as drilling spoils) continually grows globally, the overview of material reuse and solvent recovery from this study can be extended to polymer extraction, which requires a complete recovery cycle where the conventional solvents used can also be recycled in the same process. While filtration and evaporation seem reliable (Lau & Koenig, 2001; Blaney, 1986), other solvent recovery techniques, such as those using machine learning, screen cleaning, and dry cleaning, which have been achieved in a chemical waste treatment centre in Hong Kong, can be adapted. Solvent compatibility aids in separation and recovery and is regarded as highly efficient. However, their sustainable reuse, such as ionic liquids, will reduce environmental impacts compared to conventional solvents. Hence, if they play a key role in the extraction or recovery process, additional measures for their reuse must be considered. Waste streams can be more complex than the simulated mix, as is the case with waste solvent reuse and recovery (Aboagye et al., 2021).

Furthermore, in this study, the fine particle size hindered anthracene recovery during the extraction process using the first method, necessitating the use of alternative solvents. The FTIR analysis confirmed the presence of residual components in the recovered substances, especially around the fingerprint region (1500-720cm⁻¹), emphasising the need for thorough purification procedures. The study demonstrates the potential of propyIMIMBr-IL for selective extraction of aromatics prevalent in drilling spoils, which can be extended to polymer recovery as the United Nations Sustainable Development Goal 2 and 12 envisions a close loop of organic wastes to enhance responsible consumption of raw materials, reduce waste and which will ensure a cleaner environment for agriculture and improved wellbeing (Otte et al., 2022).

Conclusion

Selective extraction methods using propyIMIMBr-IL facilitated the successful recovery of anthracene, with the second method yielding satisfactory results. Solvent compatibility and particle size emerged as crucial factors influencing extraction efficiency. Further optimisation of extraction conditions may enhance anthracene recovery yields and contribute to the development of more efficient extraction protocols for toxins commonly found in drilling spoils, which can also be applied to synthetic polymers.

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