https://chemclassjournal.com/
ChemClass Journal Vol. 10 Issue 1 (2026); 35 - 4
e-ISSN:3092-8214 p-ISSN:3092-8206
doi.org/10.33003/chemclass-2026-1001/03

Hydrophobic Deep Eutectic Solvents as Green Chemistry Tools for Remediation of Contaminated Water: A Mini Review

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Abstract

The increasing prevalence of organic and inorganic contaminants in aquatic systems has intensified the global search for efficient, sustainable, and environmentally benign remediation technologies. Hydrophobic deep eutectic solvents (HDESs), a novel subclass of deep eutectic solvents composed of hydrogen bond donors and acceptors with strong intermolecular interactions, have emerged as promising green extractants for the removal of persistent pollutants from water. This review examines the fundamental chemistry underlying HDES formation, their physicochemical properties relevant to environmental applications, and the mechanisms by which they interact with contaminants. Emphasis is placed on their demonstrated capacity to extract hydrophobic organic pollutants, heavy metals, dyes, pharmaceuticals, endocrine disruptors, and emerging contaminants. A critical comparison with conventional treatment methods highlights the advantages of HDESs, including low toxicity, ease of preparation, tunability, reusability, and improved extraction efficiencies. Current research gaps such as challenges in large-scale deployment, viscosity management, phase stability, and environmental fate are discussed. Overall, HDESs represent a versatile and sustainable platform with significant potential for green water purification.

Keywords: Hydrophobic Deep Eutectic Solvents (HDES), water remediation, green solvents, emerging contaminants, sustainable extraction.

1.0 Introduction

Anthropogenic activities and industrial expansion have accelerated the release of toxic chemicals into water bodies, contributing to widespread contamination of freshwater resources. Traditional remediation approaches often rely on harsh or non-biodegradable chemicals that can further degrade the environment, complicating long-term ecological recovery. These contaminants ranging from heavy metals,

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pesticides, and petroleum residues to pharmaceuticals and endocrine disruptors are often persistent, bio-accumulative, and deleterious even at trace concentrations [1, 2]

Access to clean water remains a critical global challenge despite the abundance of water on Earth. Pollution from agricultural runoff, improper waste disposal, oil spill incidents, effluent discharges from wastewater treatment plants, and industrial leaks threaten aquatic ecosystems and human health. Contaminated water impairs agricultural productivity, disrupts ecological balance, and contributes to disease outbreaks and economic losses in affected communities [3, 4]

Understanding the diverse sources of contamination is crucial for designing environmentally sustainable remediation techniques. Naturally occurring chemicals such as uranium, fluoride, and radon can reach harmful concentrations in groundwater. Local land-use practices involving excessive application of fertilizers and pesticides also introduce persistent pollutants. Furthermore, emerging contaminants including pharmaceuticals, nanomaterials, plasticizers, cosmetic residues, and household chemicals pose unique removal challenges due to their complex chemical structures and resistance to conventional treatment processes [5]

Oil spills remain a major environmental concern in various regions, particularly in petroleum-producing nations. The persistence of hydrocarbons and dispersants in aquatic environments has been associated with chronic toxicological effects, ecological degradation, and long-term socioeconomic impact [6].

Given the limitations of traditional remediation methods, the development of green, safe, and efficient alternatives has become imperative. This need has contributed to the rise of ionic liquids (ILs) and, subsequently, deep eutectic solvents (DES), with hydrophobic DES demonstrating distinct advantages for water purification applications.

1.1 Water Decontamination Technologies

A wide range of techniques has been employed to purify water for domestic, agricultural, and industrial uses. These include boiling, chlorination and iodination, distillation, electrodialysis and electro-deionization, reverse osmosis (RO), solar disinfection, activated carbon adsorption, ceramic/clay filtration, and commercially available water purifiers [7]. Each method has proven effective depending on the nature and concentration of contaminants involved.

Activated carbon is widely used due to its porous structure, large surface area, and capability to adsorb organic and inorganic molecules [8, 9]. Reverse osmosis employs pressure-driven membranes to remove up to 99 % of solutes, microorganisms, and dissolved ions, making it one of the most effective technologies for water purification and desalination.

Distillation remains one of the oldest purification techniques, separating water from non-volatile contaminants through selective vaporization and condensation. Ultraviolet (UV) irradiation is also used to disinfect water by destroying microbial DNA and oxidizing organic molecules [10, 11]
Conventional waste water treatment methods have difficulty removing emerging contaminants such as BTX because the compounds are volatile organic compounds that are chemically stable and poorly biodegradable under standard physical and biological treatment processes.
While these technologies are effective, many are energy-intensive, costly, chemically demanding, or unsuitable for emerging contaminants. Green chemistry principles encourage the adoption of safer solvents and energy-efficient methods to prevent pollution at the source [12]. Deep eutectic solvents align strongly with these principles. Traditional solvents have also been used but with some drawbacks.

1.2 Emerging Green Technologies in Water Remediation

1.2.1 Ionic Liquids (ILs)

Ionic liquids are salts that remain liquid below 100°C and comprise bulky organic cations paired with inorganic or organic anions [13]. Their low vapor pressure, wide liquidus range, chemical stability, and tunability make them attractive alternatives for solvent extraction processes. However, challenges such as poor biodegradability, toxicity concerns, expensive synthesis, and purification complexity limit their widespread environmental application [14].

1.2.2 Deep Eutectic Solvents (DES)

The discovery of deep eutectic solvent began with Abbott and his co-workers looking for liquids that could overcome the moisture sensitivity and high cost of some common ionic liquids [15-17]. In their study, quaternary ammonium salts and metal salts were tested. Choline chloride, zinc in ratio 1:2 presented the lowest freezing point of between 23 ℃ to 25 ℃. They further investigated eutectic mixtures of quaternary ammonium salts and hydrogen bond donors and named them DES [16]. The term eutectic is gotten from the Greek word eutektos which means easily melted. The eutectic point is the temperature and chemical composition at which a mixture of two solids become fully molten at the lowest melting temperature relative to that of either compound.

Deep eutectic solvents represent a newer class of designer solvents created by mixing hydrogen bond acceptors (HBAs) and hydrogen bond donors (HBDs) to produce eutectic mixtures with melting points substantially lower than the individual components. This depression in melting point is as a result of extensive hydrogen bonding networks formed between the electronegative sites of the HBA and the hydrogen atoms of the HBD. These hydrogen bonds weaken the strong ionic interactions and the regular lattice structures that exist in the pure solid components which leads to a reduction of

the overall lattice energy of the mixture [17]. DESs are biodegradable, inexpensive, easy to prepare, and versatile [18, 19].

Their properties including polarity, viscosity, hydrophobicity, and solvating ability—can be tuned simply by altering HBA:HBD combinations or molar ratios [20, 21]. Several DES classes (Types I–V) have been documented based on their chemical constituents, ranging from metal-containing DESs to purely organic formulations [22] as shown in Table 1.

Table 1: Classification of DES Types

Type	Composition	Example	Reference
I	Quaternary ammonium salt + metal chloride	C_2mimCl + $AlCl_3$	[16]
II	Quaternary ammonium salt + hydrated metal chloride	ChCl + $MgCl_2 \cdot 6H_2O$	[17]
III	HBA + HBD	ChCl + Urea (1:2)	[17, 22]
IV	Metal chloride + HBD	$ZnCl_2$ + Urea	[19]
V	HBA + hydroxyl aromatic compound	Thymol + Camphor	[23]

Cat+ = any phosphonium, ammonium or sulfonium cation, X− = a Lewis base, generally a halide anion, MClx = metal chloride, RZ = organic compound.

2.0 Synthesis of Deep Eutectic Solvents

DESs can be synthesized by straightforward procedures that require minimal energy input. Common methods are presented in Table 2:

Table 2: DES Preparation methods

Method	Temperature	Time	Advantages	Scalability	Energy efficiency
Heating and stirring	80 C	1-2 h	Simple, reproducible	High (readily transferable to pilot scale	Moderate (continuous heating required
Evaporation	50 C	Several hrs	Low degradation risk	Moderate (additional solvent recovery step)	Low-moderate (extra energy for solvent removal)
Microwave	60-80 C	20-60 s	Energy-efficient, rapid	Moderate (batch size limitations)	High (short processing time)
Freeze-Drying	-40 to 25 C	12-24 h	Preserves structure, high purity	Low (costly and time-consuming)	Low (energy intensive process)

3.0 Hydrophobic Deep Eutectic Solvents in Extraction and Remediation

Hydrophobic DESs emerged as promising water-immiscible extractants with high selectivity for a wide range of contaminants. Their tunable hydrophobicity, non-volatility, and capacity for reuse enhance their appeal as green alternatives to traditional organic solvents and presented in literature for the first time in 2015 [23, 24].

3.1 Extraction of Volatile Fatty Acids (VFAs)

The first application of HDES (decanoic acid combined with quaternary ammonium salts) demonstrated superior extraction efficiency compared to industrial trioctylamine, with efficiency increasing as VFA chain length increased [24]. The chemical/structural nature of these DES favours the extraction of VFAs, due to the hydrogen bonding ability of both components used to prepare the DESs.

3.2 Removal of Metal Ions

DES-based systems have shown promising results in extracting alkali and transition metals from water. Hydrophobic DESs composed of decanoic acid and lidocaine achieved high extraction efficiencies, requiring only seconds to reach equilibrium and allowing solvent regeneration [25]. In the research organic solvents like dodecane, toluene and kerosene were replaced with hydrophobic deep eutectic solvents consisting of decanoic acid and lidocaine in molar ratios 2:1, 3:1 and 4:1. The main disadvantages of these solvents are their toxicity, volatility and flammability compared to DES. The highlights of this study were, all metals could be extracted with high distribution coefficients, low mass fractions of deep eutectic solvents, attainment of maximum extraction efficiency in a very short time and regeneration of the solvent.

3.3 Extraction of Pesticides

Menthol-based and ammonium-salt-based HDESs have been applied to remove 4 neonicotinoid pesticides from dilute aqueous solutions. Experimental parameters such as HBA:HBD ratio, hydrophobic chain length, and stirring conditions influenced extraction performance, with efficiencies reaching up to 80 %. The DES used were DL Menthol and natural neutral organic acids such as acetic acid, hexanoic acid, octanoic acid, decanoic acid and dodecanoic acid. The other group of DES was quaternary ammonium salts (Tetrabutyl ammonium bromide) and organic acids such as levulinic acid, pyruvic acid, butyric acid. DL Menthol and TBAB formed the HBAs which were dried in a vacuum pump at 40 ℃ for at least 96 h, the carboxylic acids were used without further purification. Stock solutions of the pesticides in Milli-Q water in different concentrations were prepared and used to plot a calibration curve $R^2 \geq 0.997$.

Equal mass of each one of the aqueous solutions of the pesticides and the prepared HDES were put in contact and vigorously stirred for 4 h at room

temperature and left to settle for 24 h to ensure complete separation of phases. A needled syringe was used to take a sample from the water rich phase for easy reading using UV-Vis [26].

3.4 Removal of Pharmaceutical Micropollutants

HDESs exhibit excellent affinity for pharmaceutical residues such as ciprofloxacin, a priority micropollutant in wastewater. DESs containing menthol and fatty acids demonstrated high solubility for the drug in the DES phase and low solubility in water, resulting in effective liquid–liquid extraction. The HDES and water containing the ciprofloxacin were stirred at room temperature and left to settle for a minimum of 12 h to ensure complete phase separation. Using a needled syringe, a sample of the water rich phase was taken and analysed with a UV-Vis spectrophotometer. The results showed C_{12}:C_{10} gave the best extraction efficiency of ciprofloxacin and it also displayed highest solubility value and lowest water solubility value of ciprofloxacin. In conclusion, the research showed excellent extraction efficiencies when cheap, neutral and natural DESs were used.

3.5 Extraction of Endocrine Disruptors

Removal of bisphenol A (BPA) using HDESs has shown promising results. Studies [27-29] attributed high extraction efficiency. Bisphenol A has been used in packaging plastic medical devices and as a plasticizer in food and drink packaging. Ionic and neutral DESs were used for this research. Influential experimental parameters like stirring speed, contact time, initial concentration of Bisphenol A (BPA), DES/water ratio were optimized using Central Composite Design (CCD). All the selected HDES gave good extraction efficiencies due most likely to the hydrophobicity of the DES. It was observed that extraction efficiencies increased with increase in the alkyl chain length in both the fatty acid and quaternary ammonium salt. The best performance for all the studied systems was achieved using the lowest HBA:HBD molar ratio (1:2) and initial concentration of BPA greatly influenced extraction efficiency which decreased as the concentration of BPA decreases to hydrophobic interactions and optimized molar ratios, particularly those using long-chain fatty acids.

3.6 Heavy Metal Removal Using DES-Functionalized Nanomaterials

Functionalizing carbon nanotubes with DESs has enhanced adsorption of Pb^{2+} and Hg^{2+} through improved surface chemistry and binding affinity. Optimal conditions yielded high removal percentages and favourable kinetic behaviour. The presence of lead (Pb) in water has led to a variety of health problems especially in children. The effects can be so bad as it affects the nervous system which causes brain disorders. Lead contamination could be as a result of corrosion of plumbing material of waste disposal associated with certain industries.

DES-based extraction operates through phase partitioning, where contaminants are solubilized into the bulk solvent based on favorable intermolecular interactions and partition coefficients, whereas DES-functionalized adsorption relies on surface binding limited by available active sites.

Extraction is not constrained by surface saturation and is typically faster and more reversible, while adsorption kinetics and capacity are governed by surface area, pore structure, and binding-site availability

AlOmar and his team [30] synthesized DES by combining Choline chloride as hydrogen bond acceptor (HBA) with ethylene glycol (EG), Diethylene glycol (DEG), glycerol (Gly), triethylene glycol (TEG), Urea (U), Malonic acid (MA) all serving as Hydrogen bond donor (HBD) stirring at 400 rpm and 80 ˚C until a DES is formed as a clear liquid without precipitates. At the end of the research, the optimum Pb(II) removal condition were found to be pH 5, adsorbent dosage of 5 mg and contact time of 15 minutes. Pb(II) adsorption system fitted excellently to a pseudo second order kinetics model.

The team went further to remove mercury from water using Ally triphenyl phosphonium bromide based DES- functionalized carbon nanotubes [31]. Several techniques such as extraction, precipitation, ion-exchange, reverse osmosis, coagulation, photo remediation have been used to decrease mercury pollution in water overtime. Carbon nano tubes (CNTs) despite their drawbacks have been successfully utilized in removing cadmium [32], zinc and copper [33] lead [34]

3.7 Removal of organic pollutants from wastewater

Yakubu et al, [35] removed benzene, toluene and xylene from simulated contaminated water using a hydrophobic deep eutectic solvent comprising TBAB and decanoic acid in a 1:2 molar ratio. Using central composite design, the extraction parameters of solvent mass fraction, temperature and contact time were optimized. The design fitted a quadratic model and showed that solvent mass fraction had more effect on extraction efficiency than other parameters.

Adeoye et al [36] synthesized and characterized menthol based hydrophobic deep eutectic solvents for the sono-degradation of phenol and 4-nitrophenol in waste water. The results showed considerably reduction in these pollutants after applying the HDES on synthesized polluted water and refinery waste water.

In an unpublished thesis, Okoduwa et al [37] applied HDES formed from Tetrabutyl ammonium bromide and decanoic acid in a 1:2 ratio at optimum conditions to amine wash water for the removal of benzene, toluene and xylene and recorded extraction efficiencies in the order benzene<toluene<xylene.

Table 3: Comparison between Deep eutectic solvents and traditional organic solvents

Criteria	Deep eutectic solvents	Traditional Organic solvents
Environmental impact	Minimal, biodegradable, reduces hazardous waste	High – contributes to air/water pollution and hazardous waste streams
Cost	Low cost; components (e.g., quaternary ammonium salts, fatty acids, sugars) are cheap and abundant	Can be expensive depending on solvent purity and recovery needs.
Preparation	Simple mixing & heating (no purification required)	Industrial-scale synthesis/purification often energy-intensive
Reusability/ Regeneration	High, can be regenerated with minimal loss of efficiency (e.g., up to 5+ cycles in BTX extraction)	Reuse often limited; solvent recovery via distillation is energy-intensive and costly
Safety	ıermally stable, easy to handle	Many are flammable, hazardous to store/transport

4.0 Conclusion and Future Perspectives

Hydrophobic deep eutectic solvents represent an emerging and environmentally sustainable class of extractants with vast potential in water remediation. Their tunability, ease of synthesis, reusability, and compatibility with green chemistry principles make them strong candidates to replace conventional organic solvents in contaminant extraction. HDESs have demonstrated notable efficiency in removing pesticides, pharmaceuticals, endocrine disruptors, volatile fatty acids, and heavy metals.

Despite their promise, challenges remain particularly in understanding large-scale behaviour, long-term environmental fate, biodegradation pathways, viscosity control, and regeneration processes. Future research should prioritize: Expanding the library of biodegradable HBAs and HBDs. Mechanistic studies on extraction pathways. Scale-up modelling and pilot-scale demonstrations. Life-cycle and toxicity assessments and integration with hybrid treatment technologies.

Overall, HDESs are poised to play a transformative role in sustainable water purification and environmental remediation.

References

1] N. Adil *et al.*, "Pesticides, heavy metals and plasticizers: Contamination and risk assessment of drinking-water quality," *Sustainability*, vol. 15, no. 17, p. 13263, 2023.

[2] A. Ismanto *et al.*, "Endocrine disrupting chemicals (EDCs) in environmental matrices: Occurrence, fate, health impact, physio-chemical and bioremediation technology," *Environ. Pollut.*, vol. 302, p. 119061, 2022.

[3] E. McVicker, "Global perspectives on water management: An overview of action steps from the United Nations to local communities," *J. Bus.*, vol. 31, no. 1, 2024.

[4] A. W. Jayawardena, *An Inconvenient Truth About Access to Safe Drinking Water*, 2021.

[5] Y. Luo *et al.*, "A review on the occurrence of micropollutants in the aquatic environment and their fate and removal during wastewater treatment," *Sci. Total Environ.*, vol. 473, pp. 619–641, 2014.

[6] J. Beyer *et al.*, "Environmental effects of the Deepwater Horizon oil spill: A review," *Mar. Pollut. Bull.*, vol. 110, no. 1, pp. 28–51, 2016.

[7] G. Rao *et al.*, "Systematic review of the microbiological performance of household water treatment technologies," *Environ. Sci. Technol.*, 2025.

[8] A. Bhatnagar *et al.*, "An overview of the modification methods of activated carbon for its water treatment applications," *Chem. Eng. J.*, vol. 219, pp. 499–511, 2013.

[9] R. I. Kosheleva, A. C. Mitropoulos, and G. Z. Kyzas, "Synthesis of activated carbon from food waste," *Environ. Chem. Lett.*, vol. 17, no. 1, pp. 429–438, 2019.[10] J. P. Chen *et al.*, "Ultraviolet radiation for disinfection," in *Advanced Physicochemical Treatment Processes*. Berlin, Germany: Springer, 2006, pp. 317–366.

[11] R. James, "Dechlorination by ultraviolet radiation: A suitable alternative to activated carbon in dialysis water systems?" *J. Renal Care*, vol. 35, no. 4, pp. 205–210, 2009.

[12] P. T. Anastas and J. B. Zimmerman, "Design through the 12 principles of green engineering," *Environ. Sci. Technol.*, vol. 37, no. 5, pp. 94A–101A, 2003.

[13] A. Benedetto, "Room-temperature ionic liquids meet bio-membranes: The state-of-the-art," *Biophys. Rev.*, vol. 9, no. 4, pp. 309–320, 2017.

[14] A. El-Hoshoudy *et al.*, "Experimental and theoretical investigation of quaternary ammonium-based deep eutectic solvent for

secondary water flooding," *J. Mol. Liq.*, vol. 294, p. 111621, 2019.

[15] A. P. Abbott *et al.*, "Preparation of novel, moisture-stable, Lewis-acidic ionic liquids containing quaternary ammonium salts with functional side chains," *Chem. Commun.*, no. 19, pp. 2010–2011, 2001.

[16] A. P. Abbott *et al.*, "Novel solvent properties of choline chloride/urea mixtures," *Chem. Commun.*, no. 1, pp. 70–71, 2003.

[17] A. P. Abbott *et al.*, "Deep eutectic solvents formed between choline chloride and carboxylic acids: Versatile alternatives to ionic liquids," *J. Am. Chem. Soc.*, vol. 126, no. 29, pp. 9142–9147, 2004.

[18] C. Florindo, L. C. Branco, and I. M. Marrucho, "Quest for green-solvent design: From hydrophilic to hydrophobic (deep) eutectic solvents," *ChemSusChem*, vol. 12, no. 8, pp. 1549–1559, 2019.

[19] Q. Zhang *et al.*, "Deep eutectic solvents: Syntheses, properties and applications," *Chem. Soc. Rev.*, vol. 41, no. 21, pp. 7108–7146, 2012.

[20] C. Florindo *et al.*, "Hydrophobic deep eutectic solvents: A circular approach to purify water contaminated with ciprofloxacin," *ACS Sustain. Chem. Eng.*, vol. 7, no. 17, pp. 14739–14746, 2019.

[21] Q. Wen *et al.*, "Assessing the toxicity and biodegradability of deep eutectic solvents," *Chemosphere*, vol. 132, pp. 63–69, 2015.

[22] E. L. Smith, A. P. Abbott, and K. S. Ryder, "Deep eutectic solvents (DESs) and their applications," *Chem. Rev.*, vol. 114, no. 21, pp. 11060–11082, 2014.

[23] D. J. van Osch *et al.*, "The curious case of hydrophobic deep eutectic solvents: Discovery, design, and applications," *ACS Sustain. Chem. Eng.*, vol. 8, no. 29, pp. 10591–10612, 2020.

[24] D. J. van Osch *et al.*, "Hydrophobic deep eutectic solvents as water-immiscible extractants," *Green Chem.*, vol. 17, no. 9, pp. 4518–4521, 2015.

[25] D. J. van Osch *et al.*, "Removal of alkali and transition metal ions from water with hydrophobic deep eutectic solvents," *Chem. Commun.*, vol. 52, no. 80, pp. 11987–11990, 2016.

[26] C. Florindo, L. Branco, and I. Marrucho, "Development of hydrophobic deep eutectic solvents for extraction of pesticides from aqueous environments," *Fluid Phase Equilib.*, vol. 448, pp. 135–142, 2017.

[27] S. A. H. Shah and S. Asman, "Evaluation of deep eutectic solvent as a new monomer for molecularly imprinted polymers for removal of bisphenol A," *J. Polym. Res.*, vol. 30, no. 6, p. 205, 2023.

[28] C. Florindo *et al.*, "Hydrophobic deep eutectic solvents for purification of water contaminated with bisphenol A," *J. Mol. Liq.*, vol. 297, p. 111841, 2020.

[29] Y. An and K. H. Row, "Evaluation of menthol-based hydrophobic deep eutectic solvents for extraction of bisphenol A from environmental water," *Anal. Lett.*, vol. 54, no. 9, pp. 1533–1545, 2021.

[30] M. K. AlOmar *et al.*, "Lead removal from water by choline chloride-based deep eutectic solvent functionalized carbon nanotubes," *J. Mol. Liq.*, vol. 222, pp. 883–894, 2016.

[31] M. K. AlOmar *et al.*, "Allyl triphenyl phosphonium bromide-based DES-functionalized carbon nanotubes for mercury removal from water," *Chemosphere*, vol. 167, pp. 44–52, 2017.

[32] M. Ruthiraan *et al.*, "Comparative kinetic study of functionalized carbon nanotubes and magnetic biochar for removal of Cd^{2+} ions from wastewater," *Korean J. Chem. Eng.*, vol. 32, no. 3, pp. 446–457, 2015.

[33] N. Mubarak *et al.*, "Removal of heavy metals from wastewater using carbon nanotubes," *Sep. Purif. Rev.*, vol. 43, no. 4, pp. 311–338, 2014.

[34] Y.-H. Li *et al.*, "Lead adsorption on carbon nanotubes," *Chem. Phys. Lett.*, vol. 357, nos. 3–4, pp. 263–266, 2002.

[35] A. Yakubu *et al.*, "Application of hydrophobic deep eutectic solvent for extraction of aromatic compounds from contaminated water," *Korean J. Chem. Eng.*, vol. 39, no. 5, pp. 1299–1306, 2022.

[36] D. O. Adeoye *et al.*, "Hydrophobic deep eutectic solvents for sono-degradation of organic pollutants in wastewater," *C. R. Chim.*, vol. 28, no. G1, pp. 327–338, 2025.

[37] U. J. Okoduwa *et al.*, *Preparation of a Hydrophobic Deep Eutectic Solvent and Its Use for the Removal of Benzene, Toluene and Xylene in Refinery Wastewater*, M.Sc. thesis, Ahmadu Bello Univ., Zaria, Nigeria, 2025.