E-ISSN: 1116 - 3240 P-ISSN: 3026-9334
MPRI-JAIMR | INTERNATIONAL JOURNAL OF AFRICAN INNOVATION & MULTIDSCIPLINARY RES.
VOL. 03 NO. 2 – JANUARY, 2024

RESOURCE EFFICIENCY AND RECOVERY OF BARITE USING IONIC LIQUID

MORO, OTUAWE (PhD)
Department of Environmental Management, Faculty of Environmental Science, Rivers State University, Nkpolo-Oroworukwo, Port Harcourt, Nigeria.
morootuawe@gmail.com

Keywords: Ionic Liquids, Barite, Resource Efficiency, Recovery, Drilling Fluid

Abstract

Barite is a mineral with high usage in the oil and gas industry. Even though barite is abundant in the earth's crust and can be easily extracted naturally, there is a need to investigate the conservation of barite resources and potential reuse in other processes. The ionic liquid is a green solvent with the potential to recover target minerals for possible reuse in other industries. This study investigates the importance of resource efficiency and recovery of barite using 1-propyl-3-methylimidazolium bromide (propyIMIMBr) ionic liquid. The research methodology includes literature reviews using scientific journals and experimental research for the synthesis of ionic liquids using the microwave technique and characterisation using the Fourier-transform infrared spectroscopy (FTIR) technique. Findings reveal that propyIMIMBr ionic liquid can recover barite, whilst recycling the ionic liquid solution. Hence, the propyIMIMBr ionic liquid can enhance the recovery of value from the drilling waste and has the potential for reuse in other applications. This approach is a drive towards resource efficiency which will help the oil and gas industries meet their sustainable development targets.

Introduction

Barite is a non-metallic mineral (Ebunu et al., 2021) and weighting agent for the preparation of drilling fluid for well operations (Afolayan et al., 2021). It is an oil and gas drilling mud precursor, thus in ever-increasing demand (Baba et al., 2023). Rapid extraction of such mineral resources can negatively impact the exploitation sites' immediate environment (Essalhi et al., 2016). There is evidence of the risk of contamination and human health due to barite mining, as the mining site can become a

EDITOR-IN-CHIEF
Prof. A.I. Mteiye [MALAWI]

hot spot for anthropogenic forces resulting in high concentrations of heavy metals (Adamu et al., 2015). Barite is a primary particulate compound in drilling waste (Fang et al., 2018). This is because barite is a crucial resource to the oil and gas industry and it is a key component in the production of drilling mud to drill oil and gas wells (Johnson et al., 2017). Barite in marine sediments can originate from natural and anthropogenic sources, especially from the oil and gas industry (Haanes et al., 2022). Barite has low solubility and is difficult to dissolve and remove from production equipment (Lu et al., 2019; Geri et al., 2017 & BinMerdhah et al., 2012). Precipitation of the scale in the oil and gas reservoirs, surface and subsurface equipment, and processing and production facilities is a critical problem as it affects petroleum production (Gamal et al., 2021).

Recycling of drilling muds during drilling rig operation, in most cases, leads to the disposal of fine-grained barite containing waste materials (Heinrich, 1989). Though the Environmental Protection Agency identifies barite as a potential source of heavy metals in drilling fluid, mud engineers have been able to manage the concentration of barite in drilled solids by subjecting them to mechanical separation equipment on site, at the rig (Candler et al., 2019). Barite is a key resource to the oil and gas industry, hence green barite supplies must be explored to meet future demands (Penaloza et al., 2023).

Importance of Resource Reuse

Changes in the oil and gas business can impact resource use performance (Shmygol et al., 2023). The recovery and reuse of valuable resources like barite is crucial in achieving a sustainable treatment. Increasing the continuous supply of chemicals, though not expensive eventually, can ameliorate potential impacts on the receiving ecosystem (Chen et al., 2021). Scarce mineral resources are driving up costs for drilling fluids and bits. The gradual depletion of barite, which is a weighting agent, drives costs up dramatically. The world's identified barite reserves will be depleted in over a decade (US Geological Survey, 2006). Significant suppliers are scouring the globe to develop alternative barite sources. Tungsten, a material for hardening drill bits and increasing their durability, was in tight supply in 2008 when rig counts rose rapidly, creating price inflation and bottlenecks. Like barite, the mineral is mainly mined in the interior of China and is vulnerable to supply disruptions from the country's ongoing mining sector reforms. Increasing technological complexity relating to the depletion of petroleum reserves requires fewer and larger suppliers with the capacity, financial resources, and broad technical skills needed to develop the extraordinary innovative technology at the edge of science and support mega projects. Offshore and deep-water projects are unlocking huge reserves but require capital investment many times that of traditional onshore developments (Jacoby, 2012).

Ionic Liquids in Material Recovery

Ionic liquids provide opportunities for regenerating and reusing valuable materials and are promising toward a cost-levelized recycling process (Chen, 2023). Continual

investigations on the alternatives to solvent extraction are being explored and advances in separation technologies show the potential use of ionic liquids to enhance the recovery of valuable materials such as inorganics while minimising the environmental impact (Makanyire et al., 2016). There is increasing demand for critical raw materials, as well as a growing need to enhance the industrial process sustainability, highlighting the importance of obtaining them from secondary or alternative sources (Almeida, et al., 2021). Ionic liquids have the potential for advanced chemical recycling due to their regulating catalytic activity, tailorable chemical functionality, low vapour pressures, and thermal stability (Christoff-Tempesta & Epps, 2023). Numerous methods for the recovery of ionic liquids are being considered for industrial use. This includes distillation, extraction, adsorption, membrane separation, aqueous two-phase extraction, and external force field separation (Zhou et al., 2018).

Applications of Ionic Liquids in the Petroleum Industry

The applications of ionic liquids are dependent on their properties, which include the nature of the cation and anion combination and the length of the alkyl chains incorporated in the cation (Kadari et al., 2017). Ionic liquids contain organic cations such as ammonium, imidazolium, pyridinium, piperidinium or pyrrolidinium, as well as halogen, fluorinated or organic anions (Flieger & Flieger, 2019). Hydrophilic liquids such as imidazolium are very good in material recovery processes due to their large chemical structure diversity, with the potential for task-specific extractions, thus enabling solubility in aqueous solutions (Ventura et al., 2017). Waste valorisation using ionic liquids is a useful resource for the waste management and resource recovery industry (Silva et al., 2022). The recyclability of ionic liquids has shown promising recirculation of the solvents for selective extraction and industrial applications provide economic and environmental benefits (Mahandra et al., 2021). A range of ionic liquids are progressively applied in oil fields, with prospects in theoretical and technical support for efficient reservoir development (Sun et al., 2023).

Petroleum production processes require enhanced separation of oil-solid and oil-water which has been successfully achieved using ionic liquids, with enhanced oil recovery and demulsification, due to their physicochemical and thermal characteristics (Song et al., 2023). Some scholars have investigated the effective use of ionic liquid in facilitating the removal and recovery of asphaltene from petroleum (He & Zhiani, 2023), while other researchers provide insight into the operations of the upstream oil and gas industry, identifying the need for stable chemicals like ionic liquids that can be effectively applied in drilling, stimulation and enhancement of oil recovery (Bera et al., 2020). Further, Luo et al (2017) conducted experimental research on the novel use of ionic liquid as an efficient shale inhibitor in water-based drilling fluids to reduce shale hydration (Luo et al., 2017). In the same vein, Ofei et al (2017) proposes the use of ionic liquids as a potential drilling mud additive and demonstrated the use of 1-butyl-3-methylimidazolium chloride ionic liquid in

stabilising the mud viscosity, solid suspension capacity and filtration behaviours of drilling mud (Ofei et al., 2017).

Though barite is an abundant natural resource in the environment and less expensive (Al-Awad & Al-Qasabi, 2000), in line with the Sustainable Development Goal (SDG) 9 which envisages industry, innovation and infrastructure, this study promotes scientific research and innovation of upstream oil and gas processes to facilitate sustainable development. Further, a crucial aspect of SDG 12, envisages responsible consumption and reproduction. This entails environmentally sound management of chemicals and all waste types throughout their lifecycle, thus, reducing adverse impacts on the environment (UNDP, 2023). The waste management hierarchy emphasises reducing, reusing, and recycling as key to sustainable materials management (UNEPA, 2023).

MATERIALS AND METHODS

The extraction of single components from the ionic liquid mixture is carried out using barite. The steps followed in the extraction and recovery of the single component from the ionic liquid mixtures are represented in **Table 1**.

Table 1: Extraction of Single Components from propyIMIMBr Ionic Liquid

Single component mix	Condition	Separation	Recovery
IL and barite mixture	IL- 2g Barite – 0.5g Heating – none Stirring – 800rpm Duration – 20min	a. Membrane filtration: Transfer the mixture quantitatively using a glass rod into the membrane filtration apparatus. b. Rinse the test tube with acetone (to dissolve ionic liquid and quantitatively transfer it into the Buchner funnel which is connected to the membrane filtration apparatus. c. Filter the precipitate (ionic liquid in acetone mixture) using 50 mm-sized filter paper.	a. Vacuum flask containing ionic liquid-methanol mixture. b. Transfer mixture to the rotary evaporator globe and run – temperature 40-60°C; spin – 9rpm; duration 1 hr till a dry residue is obtained c. Residual barite is recovered dry on filter paper

Procedure for Recovering Barite from Ionic Liquid Solution

0.5g of barite is mixed with 2g of ionic liquid at room temperature stirring at 800rpm for 20 minutes. The separation of barite from the mixture is carried out using the membrane

filtration method. After obtaining a dry residue, while the vacuum filtration process is in progress, using a glass rod, the residual barite is washed with acetone to precipitate the ionic liquid from the filter paper into the vacuum beaker, leaving a pure barite residue. The test tube is also rinsed with acetone and poured into the Buchner filtration funnel to dissolve residues of the viscous ionic liquid in the test tube.

RESULTS

The residual barite is recovered dry and produces a calculated yield of 0.5g while the residual ionic liquid in the methanol mixture is transferred to a rotary evaporator to recover propyIMIMBr ionic liquid at 60℃ at 9rpm for about an hour. The recovered ionic liquid produced a calculated yield of 2g at the end of the recovery process. The recovered ionic liquid and barite are characterised using the Fourier-transform infrared spectroscopy (FTIR) technique and the results are represented in **Figure 1.** The FTIR spectra of the recovered ionic liquid and barite were comparable with their pure materials (**Figure 2**).

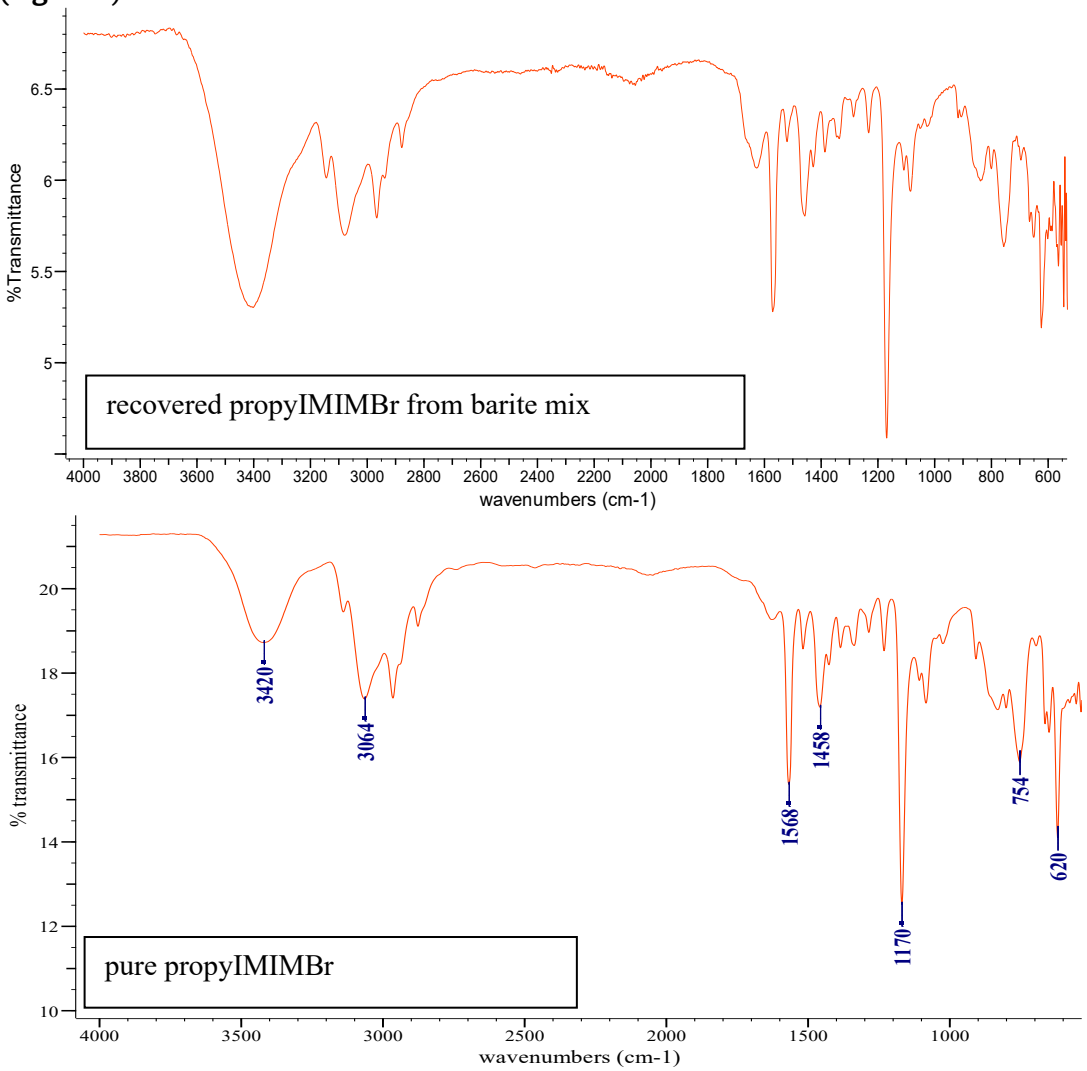

Figure 1: Recovery of propyIMIMBr from barite-propyIMIMBr mixture

EDITOR-IN-CHIEF
Prof. A.I. Mteiye [MALAWI]

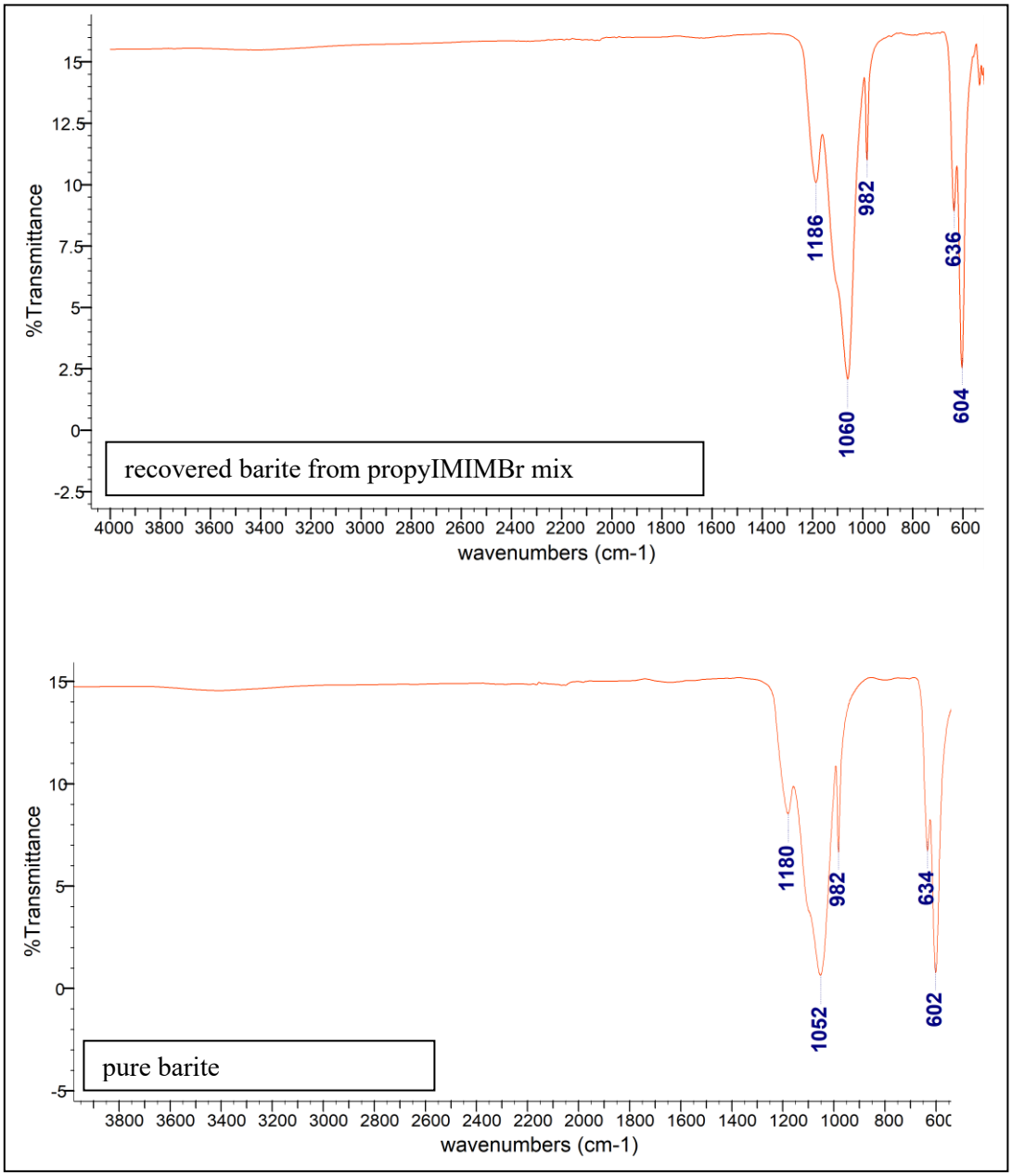

Figure 2: Recovery of barite from barite-propyIMIMBr mixture

DISCUSSION

Due to sustainable development awareness, the oil and gas industry is careful about the use of resources that can lead to the generation of waste materials. The waste management hierarchy envisages the recycling of components for reuse in other processes. Ionic liquids have growing opportunities which have progressively gained attention in the petroleum industry for the separation of valuable materials. As the cost of raw materials gradually increases, this can drive the opportunities for the application of ionic liquids in selective recovery.

CONCLUSION

This study establishes a protocol for the recovery of barite using ionic liquid. The barite recovered in this process can be recycled directly into the drilling fluid formulation to achieve financial and environmental benefits. This approach is a drive towards resource efficiency which will help the oil and gas industries meet their sustainable development targets.

ACKNOWLEDGMENTS

Funded by the Petroleum Technology Development Fund (PTDF) of Nigeria.

REFERENCES

Almeida, J.C., Cardoso, C.E.D., Trindade, T., Freire, M.G., & Pereira, E. (2021). *Relevance on the recovery of high economic value elements and the potential of ionic liquids*. In: Baskar, C., Ramakrishna, S., Baskar, S., Sharma, R., Chinnappan, A., Sehrawat, R. (eds) Handbook of Solid Waste Management. Springer, Singapore. https://doi.org/10.1007/978-981-15-7525-9_98-1

Adamu, C.I., Nganje, T.N., Edet, A. (2015). Heavy metal contamination and health risk assessment associated with abandoned barite mines in Cross River State, southeastern Nigeria. *Environmental Nanotechnology, Monitoring & Management*, *3*, 10–21.

Afolayan, D.O., Adetunji, A.R., Onwualu, A.P. , Ogolo, O., & Amankwah, R.K. (2021).Characterization of barite reserves in Nigeria for use as weighting agent in drilling fluid. *J Petrol Explor Prod Technol 11*, 2157–2178. https://doi.org/10.1007/s13202-021-01164-8

Bera, A., Agarwal, J., Shah, M., Shah, S., & Vij, R. K. (2020). Recent advances in ionic liquids as alternative to surfactants/chemicals for application in the upstream oil industry. *Journal of Industrial and Engineering Chemistry, 82*, 17-30. https://doi.org/10.1016/j.jiec.2019.10.033

Baba, A.A., Akanji, F.T., Agava, R.A., Alabi, A.G.F., Ibrahim, A.S., Ayinla, K.I., Raji, M.A., Adeboye, S.E., & Haruna, M.S. (2023). *Purification of an indigenous barite mineral for sustainability of operation in the Nigerian oil and gas industries*. In: Ouchi, T., *et al.* Rare Metal Technology 2023. TMS 2023. The Minerals, Metals & Materials Series. Springer, Cham. https://doi.org/10.1007/978-3-031-22761-5_22

BinMerdhah AB (2012) Inhibition of barium sulfate scale at high-barium formation water. *J Pet Sci Eng,* 90:124–130. https://doi.org/10.1016/j.petrol.2012.04.005

Candler, J., Tyczynski, P., & Watson, D.E. (2019). Beneficial reuse roadmap for used drilling fluids, pp. 22. https://cese.utulsa.edu

Christoff-Tempesta, T., & Epps, T.H. (2023). Ionic-Liquid-Mediated Deconstruction of Polymers for Advanced Recycling and Upcycling. *ACS Macro Letters* 12(8), 1058-1070 DOI: 10.1021/acsmacrolett.3c00276

Chen, R. (2023). Ionic liquids-mediated recovery of metals from spent batteries. *Journal of Ionic Liquids, 3*(2), 100070. https://doi.org/10.1016/j.jil.2023.100070

Chen, G., Ye, Y., Yao, N., Hu, N., Zhang, J., & Huang, Y. (2021). A critical review of prevention, treatment, reuse, and resource recovery from acid mine drainage. *Journal of Cleaner Production*, *329*, 129666. https://doi.org/10.1016/j.jclepro.2021.129666

Ebunu, A.I., Olanrewaju, Y.A., Ogolo, O., Adetunji, A.R., & Onwualu, A.P. (2021). Barite as an industrial mineral in Nigeria: occurrence, utilization, challenges and future prospects, *Heliyon*, *7*(6)1-12.

Essalhi, A., Essalhi, M., & Toummite, A. (2016). Environmental impact of mining exploitation: A case study of some mines of barite in the Eastern Anti-Atlas of Morocco. *Journal of Environmental Protection, 7*, 1473-1482. doi: 10.4236/jep.2016.711124.

Flieger, J., & Flieger, M. (2019). Ionic liquids toxicity—Benefits and threats. *International Journal of Molecular Sciences*, *21*(17), 6267. https://doi.org/10.3390/ijms21176267

Fang, J.K.H., Rooks, C.A., Krogness, C.M., Kutti, T., Hoffmann, F., Bannister, R.J. (2018). Impact of particulate sediment, bentonite and barite (oil-drilling waste) on net fluxes of oxygen and nitrogen in Arctic-boreal sponges. *Environmental Pollution, 238*, 948-958, https://doi.org/10.1016/j.envpol.2017.11.092

Gamal, H., Al-Afnan, S., Elkatatny, S., Bahgat, M. (2021). "Barium sulfate scale removal at low-temperature," *Geofluids,* pp. 12. https://doi.org/10.1155/2021/5527818

EDITOR-IN-CHIEF
Prof. A.I. Mteiye [MALAWI]

Geri, B.S., Mahmoud, M.A., Shawabkeh, R.A., Abdulraheem, A. (2017) Evaluation of barium sulfate (barite) solubility using different chelating agents at a high temperature. *J Pet Sci Technol 7*(1), 42–56. https://doi.org/10.22078/JPST.2017.707

Haanes, H., Jensen, H.K., Lepland, A., & Heldal, H.E. (2022). Increased barium levels in recent marine sediments from the Norwegian and Barents Seas suggest impact of hydrocarbon drilling and production. *Marine Pollution Bulletin*, *186*, 114478. https://doi.org/10.1016/j.marpolbul.2022.114478

Heinrich, G. (1989). Process for recovering barite from drilling muds. United States Patent. Patent No. 4,804,461. https://patentimages.storage.googleapis.com

He, X., & Zhiani, R. (2023). Synthesis of Ruthenium (II) trisbipyridine complex containing ionic liquids immobilized on fibrous CoMn2O4 for isolation of asphaltene from petroleum. *Arabian Journal of Chemistry*, *16*(11), 105289. https://doi.org/10.1016/j.arabjc.2023.105289

Jacoby, D. (2012). *Optimal Supply Chain Management in Oil, Gas and Power Generation. PennWell Corporation*, USA. ISBN-13: 978-1-59370-292-2.

Johnson, C.A., Piatak, N.M., and Miller, M.M. (2017). *Barite (Barium)*, chap. D *of* Schulz, K.J., DeYoung, J.H., Jr., Seal, R.R., & Bradley, D.C., eds., Critical mineral resources of the United States—Economic and environmental geology and prospects for future supply: U.S. Geological Survey Professional Paper 1802, p. D1–D18, https://doi.org/10.3133/pp1802D.

Kadari, M., Belarbi, E. H., Moumene, T., Bresson, S., Haddad, B., Abbas, O., & Khelifa, B. (2017). Comparative study between 1-propyl-3-methylimidazolium bromide and trimethylene bis-methylimidazolium bromide ionic liquids by FTIR/ATR and FT-RAMAN spectroscopies. *Journal of Molecular Structure*, *1143*, 91-99. https://doi.org/10.1016/j.molstruc.2017.04.076

Luo, Z., Wang, L., Yu, P., & Chen, Z. (2017). Experimental study on the application of an ionic liquid as a shale inhibitor and inhibitive mechanism. *Applied Clay Science*, *150*, 267-274. https://doi.org/10.1016/j.clay.2017.09.038

Lu A.Y.T., Shi W., Wang J. Venkatesan, R., Harouaka, K., Paudyal, S., Ko, S., Dai., C., Gao, S., Deng, G., Zhao, Y., Wang, X., Kan, A.T. & Tomson, M. (2019) The mechanism of barium sulfate deposition inhibition and the prediction of inhibitor dosage. *J Chem Eng Data* 64(11), 4968–4976. https://doi.org/10.1021/acs.jced.9b00799

Mahandra, H., Faraji, F., & Ghahreman, A., (2021). Novel Extraction Process for Gold Recovery from Thiosulfate Solution Using Phosphonium Ionic Liquids. *ACS Sustainable Chemistry & Engineering, 9*(24), 8179-8185. DOI: 10.1021/acssuschemeng.1c01705

Makanyire, T., Sanchez-Segado, S. & Jha, A. Separation and recovery of critical metal ions using ionic liquids. *Adv. Manuf.* 4, 33–46. https://doi.org/10.1007/s40436-015-0132-3

Ofei, T. N., Bavoh, C. B., & Rashidi, A. B. (2017). Insight into ionic liquid as potential drilling mud additive for high-temperature wells. *Journal of Molecular Liquids*, *242*, 931-939. https://doi.org/10.1016/j.molliq.2017.07.113

Penaloza, I., Tita, A., McNew, E., & Chu, P. (2023). Barite resources, production and recovery using froth flotation: A review. *Minerals Engineering*, *203*, 108327. https://doi.org/10.1016/j.mineng.2023.108327

Song, F., Zhou, J., Jia, Z., He, L., Sui, H., & Li, X. (2023). Interfacial behaviors of ionic liquids in petroleum Production: A review. *Journal of Molecular Liquids*, *382*, 121864. https://doi.org/10.1016/j.molliq.2023.121864

Silva, F.E., Sousa, A., Freire, M., & Coutinho, J. (2022). *Waste valorisation using ionic liquids*. Green Chemistry Series, DOI: https://doi.org/10.1039/9781839164682

Shmygol, N., Łuczka, W., Khvostina, I., Chyba, Z., & Galtsova, O. (2023). Resource efficiency and pricing policy of industries the sustainable development context, *IOP Conf. Series: Earth and Environmental Science 1150*, 1-11. doi:10.1088/1755-1315/1150/1/012003

Shmygol, N., Luczka, W., Trokhymets, O., Pawliszczy, D., & Zavgorodniy, R. (2020). Model of diagnostics of resource efficiency in oil and gas sector of economy of Ukraine. E3S Web of Conferences 166(4):13005. DOI:10.1051/e3sconf/202016613005

Sun, J., Xiu, Z., Li, L., Lv, K., Zhang, X., Wang, Z., Dai, Z., Xu, Z., Huang, N., & Liu, J. (2023). Application status and prospect of ionic liquids in oilfield chemistry. *Petroleum*. https://doi.org/10.1016/j.petlm.2023.08.001

US Geological Survey. (2006). Mineral Commodity Summaries. Based on an Extrapolation of Data.

United Nations Environmental Protection Agency (2023). Sustainable Materials Management: Non-Hazardous Materials and Waste Management Hierarchy. https://www.epa.gov

United Nations Development Programme (UNDP) (2023). What are the sustainable development goals? https://www.undp.org

EDITOR-IN-CHIEF
Prof. A.I. Mteiye [MALAWI]

Ventura, S.P.M., Quental, M.V., Mondal, D., Freire, M.G., & Coutinho, J.A.P. (2017). Ionic-Liquid-mediated extraction and separation processes for bioactive compounds: past, present, and future trends. *Chemical Reviews*, *117*(10), 6984-7052. https://doi.org/10.1021/acs.chemrev.6b00550

Zhou, J., Sui, H., Jia, Z., Yang, Z., He, L., & Li, X. (2018). Recovery and purification of ionic liquids from solutions: A review. *RSC Advances, 8*(57), 32832-32864. https://doi.org/10.1039/c8ra06384b

EDITOR-IN-CHIEF
Prof. A.I. Mteiye [MALAWI]