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# Innovations in residue upgrading for the Niger delta by transforming heavy oil fractions into high-value products: A state of the art review

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## Abstract

This review discusses new innovations in residue upgrading technologies for the conversion of heavy oil fractions into high-value products, especially for Delta and Rivers States of the Niger Delta region. Recent works within the 2020-2024 period show that upgrading methods have been significantly developed; however, no prior work has been done regarding applying those upgrading techniques to the peculiar nature of crude oil from this region. The paper probes the environmental impacts of these technologies, emphasizing the need for localized assessment that would take into consideration the fragile ecosystems of Delta and Rivers States. It further assesses the economic viability of scaling up the implementation of advanced upgrading processes within the current refining infrastructure. The discussion covers variable quality heavy oil in these regions and what that does to upgrading efficiency, how to integrate these technologies into the current refining practices, underlines the potential socio-economic advantages for the local communities through the creation of jobs and enhancing the skills of those communities to underscore the importance of these innovations for sustainable development. The review establishes that in such siamese twin areas, further research is needed to ensure that heavy oil resources in Delta and Rivers States are utilized effectively while ensuring that there is a minimal environmental impact from the extraction process.

**Keywords:** Residue Upgrading; Heavy Crude Fractions; Niger Delta; Environmental Impact; Socio-Economic Development.

## 1. Introduction

The Niger Delta region, which includes Delta and Rivers States, is one of the most important oil-producing regions in Nigeria. It is home to vast reserves of heavy oil, which plays a critical role in the country's economy [1]. However, heavy oil fractions are more difficult to process than lighter crude oils due to their high viscosity, sulfur content, and metal impurities as shown in (Table 1). These challenges necessitate advanced residue upgrading technologies to maximize the value of the region's oil resources.

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**Table 1** Characteristics of Heavy Oil in Delta and Rivers States [2].

| Parameter | Delta State Oil | Rivers State Oil |
|---|---|---|
| API Gravity (°API) | 18-22 | 19 - 23 |
| Sulfur Content (%) | 3.5 - 5.0 | 3.8 - 4.8 |
| Viscosity (cSt) | 100 -120 | 90 - 115 |

Despite the region's significance, research on residue upgrading technologies tailored to the specific properties of the heavy oil found in the Niger Delta is limited. Recent global advancements in upgrading processes, including thermal, catalytic, and bioconversion methods, offer promising opportunities to improve oil quality, reduce environmental impacts, and increase the economic viability of oil production in this area [3]. Residue upgrading technologies are essential for transforming heavy oil fractions into high-value products such as gasoline, diesel, and petrochemical feedstocks [4]. This transformation not only increases the economic value of heavy oil but also helps to reduce the environmental footprint of refining operations [5]. In the Niger Delta, where environmental degradation and pollution have raised concerns, the adoption of cleaner and more efficient residue upgrading processes is crucial. Upgrading technologies present significant advantages, including increased efficiency in converting heavy oil into valuable products, reduced emissions and waste from oil refining, and economic growth through enhanced local industries and job creation [6]. Given the urgent need for sustainable development in the Niger Delta, this review focuses on exploring the application of recent innovations in residue upgrading, specifically in Delta and Rivers States, along with their environmental and economic implications. The primary objective is to critically assess innovations in residue upgrading technologies from 2020 to 2024, identify research gaps regarding their adaptation to the Niger Delta's unique crude oil characteristics, evaluate the environmental impacts and economic feasibility of these technologies, and examine the potential socio-economic benefits, such as job creation and skills development, for local communities.

## 2. Literature Review

Residue upgrading refers to the process of converting heavy oil fractions and residual by-products from petroleum refining into more valuable products, such as lighter fuels (gasoline, diesel) and petrochemical feedstocks [7]. These technologies play a pivotal role in maximizing the value derived from crude oil, especially in regions like the Niger Delta, where heavy oil is predominant [1]. In conventional refining, the residue left after distillation contains high levels of sulfur, metals, and other contaminants, making it unsuitable for direct use in most applications [8]. Without upgrading, this heavy residue has limited economic value, often being used for low-quality products such as fuel oil. Through upgrading technologies, refiners can improve the quality of these fractions, thereby increasing their economic value and reducing the environmental impact of waste products [9].

### 2.1. Types of Residue Upgrading Technologies

Several residue upgrading technologies have been developed to address the challenges posed by heavy oil fractions. The most widely used techniques include thermal upgrading, hydrocracking, catalytic upgrading, and emerging technologies like bioconversion and supercritical fluids [10]. Figure 1 illustrates the Integrated solvent deasphalting (SDA), thermal and hydroprocessing processes involved in residue upgrading.

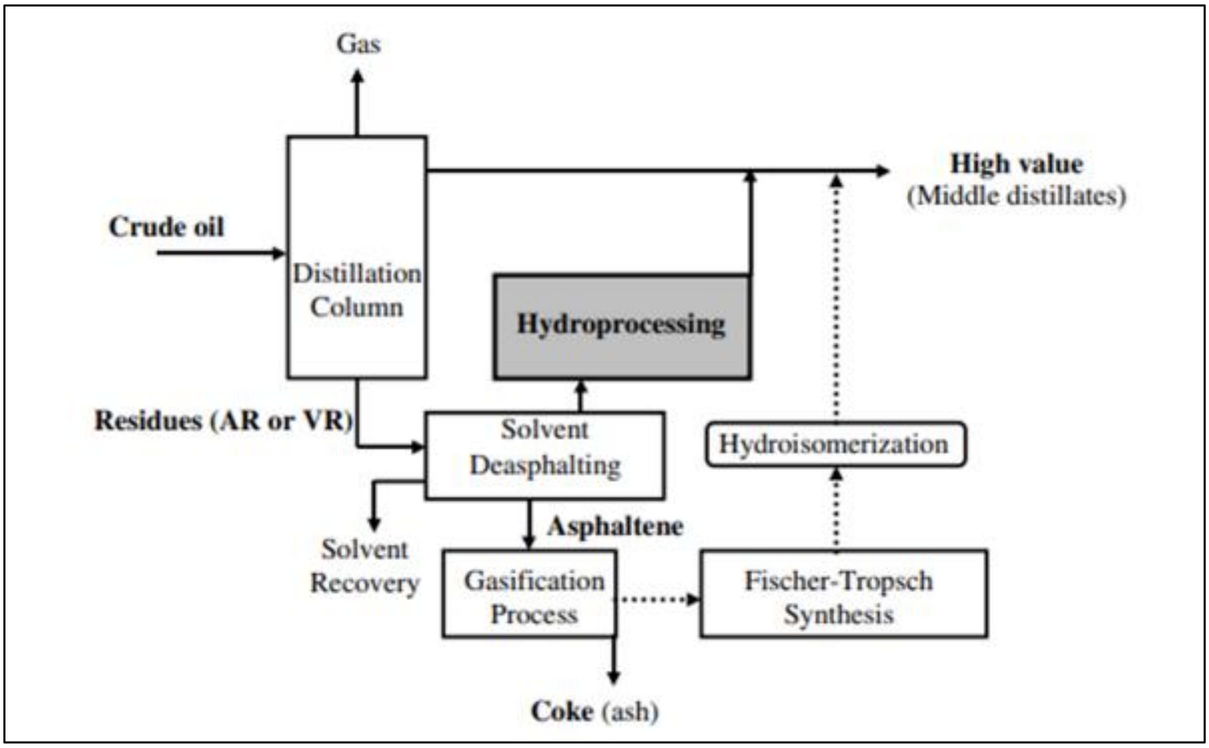


**Figure 1** Integrated solvent deasphalting (SDA), thermal and hydroprocessing processes [11].

*2.1.1. Thermal Upgrading*

Thermal upgrading involves using heat to break down large hydrocarbon molecules in the heavy residue, transforming them into lighter and more valuable fractions [12]. Common thermal upgrading techniques include: Visbreaking: A mild thermal cracking process that reduces the viscosity of heavy oil fractions, producing lighter products suitable for blending into fuels [13]. Coking: A more severe thermal process that cracks long-chain hydrocarbons into lighter molecules, producing coke (a solid carbon by-product), gas oils, and naphtha [14]. From (Table 2) below, it has shown that the coking process gives a higher product yield so can be employed in residue upgrading for the Niger Delta crude oil.

**Table 2** Comparison of Major Thermal Upgrading Methods [15].

| Process | Temperature (°C) | Pressure (Bar) | Product Yield (%) | Residue Output (Coke) |
|---|---|---|---|---|
| Visbreaking | 450-500 | 5-10 | 40-50 | Low |
| Coking | 480-520 | 1-5 | 70-80 | High |

*2.1.2. Hydrocracking*

Hydrocracking is a catalytic upgrading process that uses hydrogen gas under high pressure to break large hydrocarbon molecules in the presence of a catalyst [4]. This process is highly effective for converting heavy residues into lighter, higher-value products such as jet fuel, diesel, and naphtha [16]. Hydrocracking also has the advantage of reducing sulfur content, which helps meet environmental regulations [17].

*2.1.3. Catalytic Upgrading*

Catalytic upgrading involves the use of catalysts to accelerate the breakdown of heavy hydrocarbons into lighter fractions [18]. Unlike thermal processes, catalytic methods operate at lower temperatures and produce fewer undesirable by-products such as coke [19]. Some of the most widely used catalytic upgrading techniques include: Fluid Catalytic Cracking (FCC): A process that uses a fluidized catalyst to convert heavy residues into gasoline and other light fractions [20]. Residue Fluid Catalytic Cracking (RFCC): A variant of FCC designed to handle heavier feeds and produce a higher yield of lighter, more valuable products [21].

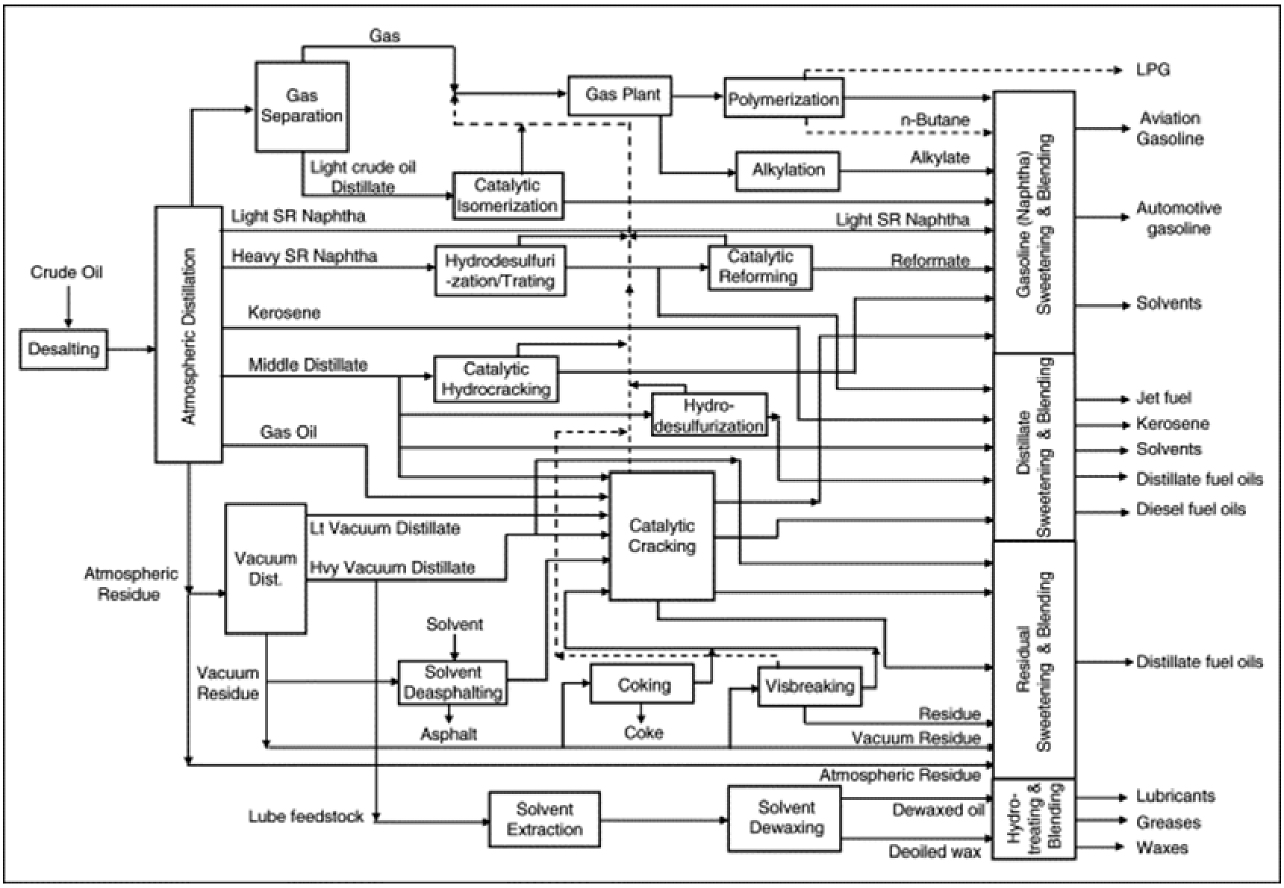


**Figure 2** A schematic diagram of a modern refinery containing most of the processes described above [22].

*2.1.4. Emerging Technologies*

Recent advancements have introduced novel approaches to residue upgrading, particularly for regions with unique crude oil characteristics such as the Niger Delta:

Bioconversion: Uses microorganisms to biologically break down heavy oil into lighter components, offering a more environmentally friendly alternative to traditional upgrading [10]. Supercritical Fluids: This technology uses supercritical fluids (e.g. carbon dioxide) at high pressures and temperatures to dissolve heavy hydrocarbons and facilitate their conversion into lighter fractions [23]. (Table 3) below shows that the use of bioconversion residue upgrading technology has a lower environmental impact compared to supercritical fluid technology in heavy crude oil regions used as case studies below. These technologies can be replicated in the Niger Delta Regions especially in Rivers and Delta States.

**Table 3** Emerging Technologies in Residue Upgrading [24].

| Technology | Region Applied | Environmental Impact | Efficiency (%) |
|---|---|---|---|
| Bioconversion | North America | Low | 70 -75 |
| Supercritical Fluids | Europe | Moderate | 80 -85 |

## 3. Discussions and Analysis

This section critically analyzes the current innovations in residue upgrading technologies, emphasizing their relevance and potential application to the unique context of the Niger Delta. The advancements from 2020 to 2024 are evaluated not only for their technical merits but also for their environmental, economic, and socio-political implications.

**Table 4.** Recent Technological Advancements.

| Technological Advancements | Description | Citations |
|---|---|---|
| Hydrocracking Innovations | Advanced hydrocracking with dual-function catalysts increases the yield of lighter products while reducing by-products like coke. These technologies are essential for heavy oil residues from the Niger Delta due to their high sulfur content. High capital costs are a challenge for local refiners. | [4] |
| Bioconversion Potential | Bioconversion uses microorganisms to degrade heavy hydrocarbons into lighter fractions. It offers environmental benefits and aligns with sustainable development goals. However, its practicality in the Niger Delta depends on adapting the technology to local conditions like temperature and oil types. | [25] |
| Supercritical Fluid Technologies | Supercritical fluid technologies, especially using supercritical $CO_2$, operate at lower temperatures and pressures, reducing environmental risks. However, their economic feasibility and scalability are still under-researched, and initial investment costs may be high. | [26] |

### 3.1. Environmental Considerations

The environmental implications of residue upgrading technologies in the Niger Delta are crucial due to the region's sensitive ecosystems and history of oil spills. Adopting cleaner technologies like bioconversion and supercritical fluid processes can help reduce emissions and mitigate environmental damage, promoting a more sustainable oil and gas industry. However, localized environmental studies are essential to assess the specific impacts of these technologies on the region, ensuring regulatory compliance and fostering public acceptance [27].

### 3.2. Economic Viability and Scalability

The economic feasibility of adopting advanced upgrading technologies in the Niger Delta depends on several factors, including implementation and maintenance costs, which may limit widespread adoption. Market dynamics play a crucial role, as establishing stable demand for high-value products from upgraded heavy oil is necessary to justify investments. Additionally, integrating these technologies into existing refining infrastructure requires significant investments in facility upgrades and workforce training, presenting both challenges and opportunities for local economic development [28].

### 3.3. Socio-Economic Implications

Adopting advanced upgrading technologies in the Niger Delta could have significant socio-economic benefits, including job creation and skills development. The implementation of these technologies would generate skilled positions in operation and maintenance, while training programs for local communities would equip the workforce to manage these innovations. Additionally, involving local communities in decision-making processes is crucial to foster trust and ensure that the initiatives align with their needs and interests, ultimately promoting more sustainable and inclusive growth in the region [29].

## 4. Current and Emerging Trends

The residue upgrading industry is witnessing significant shifts towards sustainability, driven by stringent environmental regulations and the need for greener processes. Key trends include the adoption of carbon capture and storage (CCS) technologies, which aim to minimize greenhouse gas emissions, and the implementation of circular economy principles that focus on resource recovery and waste reduction. Additionally, the integration of digital technologies, such as artificial intelligence (AI) and machine learning, is optimizing upgrading operations through real-time data analysis and predictive maintenance, ultimately enhancing efficiency and reducing operational costs [30]. Emerging innovations are also shaping the future of residue upgrading. Biotechnological advancements, particularly in genetic engineering, are enabling the development of tailored microorganisms that can efficiently degrade heavy hydrocarbons [31].

This approach not only improves bioconversion rates but also aligns with sustainable practices. Moreover, nanotechnology is being explored to enhance catalytic processes and thermal upgrading techniques, while the integration of renewable energy sources is gaining traction, promoting hybrid systems that reduce reliance on fossil fuels and lower overall emissions [32]. For the Niger Delta, these trends present both opportunities and challenges. Adapting current and emerging technologies to local conditions is crucial, given the region's unique heavy oil characteristics and environmental context. By fostering collaboration among industry stakeholders, academia, and government, the Niger Delta can leverage these advancements to enhance residue upgrading processes. Supportive policies and investment in research and development will be vital in positioning the region as a leader in sustainable energy practices, ultimately contributing to both economic growth and environmental protection.

## 5. Limitations of the Study

While this review provides valuable insights into innovations in residue upgrading technologies for the Niger Delta, several limitations should be acknowledged. First, the scope of the review primarily focuses on advancements in residue upgrading from 2020 to 2024. This narrow time frame may overlook earlier foundational research and technologies that continue to influence current practices. Future studies should encompass a broader historical perspective to fully understand the evolution of residue upgrading technologies and their applicability to the Niger Delta. Secondly, the review emphasizes the importance of localized adaptations of global technologies; however, it does not delve deeply into specific case studies from the Niger Delta itself. The lack of region-specific data limits the ability to draw definitive conclusions about the feasibility and effectiveness of certain technologies in local contexts. Future research should prioritize empirical studies that evaluate the performance of these technologies directly within the Niger Delta, considering the unique characteristics of its heavy oil and environmental conditions. Lastly, the socio-economic aspects discussed in the review, including job creation and community engagement, require more comprehensive exploration. While the potential benefits are highlighted, detailed assessments of how these technologies can be integrated into local economies and the specific barriers to adoption were not fully addressed. Further research should include stakeholder analysis, community perspectives, and economic impact assessments to provide a holistic understanding of the implications of residue upgrading technologies in the Niger Delta.

## 6. Conclusion

In summary, innovations in residue upgrading technologies offer promising opportunities for the Niger Delta, blending technological advancement with environmental and socio-economic benefits. The region’s unique heavy oil characteristics require tailored approaches, but emerging technologies such as bioconversion show potential for transforming heavy oil into high-value products with minimal environmental impact. Closing the existing knowledge gaps and fostering community involvement will be crucial to ensure that these innovations not only improve local employment but also contribute to sustainable development. Ultimately, this study highlights that by embracing residue upgrading advancements, the Niger Delta can lead the way in sustainable oil and gas practices. This study will benefit society by promoting environmental conservation, boosting economic growth, and fostering local development through technological innovations. The way forward involves continued research, stakeholder engagement, and scalable implementation.

## Compliance with ethical standards

### *Disclosure of conflict of interest*

No conflict of interest to be disclosed.

## References

[1] Aa, I., Op, A., Ujj, I., & Mt, B. (2022). A critical review of oil spills in the Niger Delta aquatic environment: causes, impacts, and bioremediation assessment. Environmental Monitoring and Assessment, 194(11), 816.

[2] Ofodile, S. E., Boisa, N., Obunwo, C. C., & Frank, O. M. (2018). Characterisation of oil properties from Niger Delta crude. J Environ Anal Toxicol, 8(2), 1-7.

[3] Ismail, W. A., Raheem, A. S. A., & Bahzad, D. (2022). Biotechnological approaches for upgrading of unconventional crude oil. In Microbial Syntrophy-Mediated Eco-enterprising (pp. 125-175). Academic Press.

[4] Prajapati, R., Kohli, K., & Maity, S. K. (2021). Slurry phase hydrocracking of heavy oil and residue to produce lighter fuels: An experimental review. Fuel, 288, 119686.

[5] Awasthi, M. K., Sarsaiya, S., Patel, A., Juneja, A., Singh, R. P., Yan, B., ... & Taherzadeh, M. J. (2020). Refining biomass residues for sustainable energy and bio-products: An assessment of technology, its importance, and strategic applications in circular bio-economy. Renewable and Sustainable Energy Reviews, 127, 109876.

[6] Wang, S., Zhao, S., Uzoejinwa, B. B., Zheng, A., Wang, Q., Huang, J., & Abomohra, A. E. F. (2020). A state-of-the-art review on dual purpose seaweeds utilization for wastewater treatment and crude bio-oil production. Energy Conversion and Management, 222, 113253.

[7] Yatimi, Y., Mendil, J., Marafi, M., Alalou, A., & Al-Dahhan, M. H. (2024). Advancement in heavy oil upgrading and sustainable exploration emerging technologies. Arabian Journal of Chemistry, 105610.

[8] Kaya, D., & Hung, Y. T. (2021). Advances in treatment of vegetable oil refining wastes. Environmental and natural resources engineering, 325-375.

[9] Xu, H., Song, Y., Zhang, Y., & Song, H. (2022). Catalytic vacuum residue upgrading under methane: Evaluation of process feasibility, stability and versatility. Fuel, 309, 122155.

[10] Muh, E., Tabet, F., & Amara, S. (2021). Biomass conversion to fuels and value-added chemicals: a comprehensive review of the thermochemical processes. Current Alternative Energy, 4(1), 3-25.

[11] Rana, M. S., Sámano, V., Ancheyta, J., & Diaz, J. A. I. (2007). A review of recent advances on process technologies for upgrading of heavy oils and residua. Fuel, 86(9), 1216-1231.

[12] Silveira, E. A., Santanna, M. S., Barbosa Souto, N. P., Lamas, G. C., Galvão, L. G. O., Luz, S. M., & Caldeira-Pires, A. (2023). Urban lignocellulosic waste as biofuel: thermal improvement and torrefaction kinetics. Journal of Thermal Analysis and Calorimetry, 148(1), 197-212.

[13] Robinson, P. R. (2024). Coking and Visbreaking. In Petroleum Science and Technology: Downstream (pp. 131-140). Cham: Springer Nature Switzerland.

[14] Subhashini, & Mondal, T. (2021). Non-conventional Catalytic Materials for Refining and Petrochemicals. Catalysis for Clean Energy and Environmental Sustainability: Petrochemicals and Refining Processes-Volume 2, 377-399.

[15] Nguyen, T. H., Nguyen, Q. A., Cao, A. N. T., Ernest, T., Nguyen, T. B., Pham, P. T., & Nguyen, T. M. (2022). Hydrodemetallization of heavy oil: Recent progress, challenge, and future prospects. Journal of Petroleum Science and Engineering, 216, 110762.

[16] Speight, J. G. (2023). Hydrotreating and Hydrocracking Processes in Refining Technology. CRC Press.

[17] Vedachalam, S., Baquerizo, N., & Dalai, A. K. (2022). Review on impacts of low sulfur regulations on marine fuels and compliance options. Fuel, 310, 122243.

[18] Wang, L., Guo, J., Li, C., Xiong, R., Chen, X., & Zhang, X. (2024). Advancements and future prospects in in-situ catalytic technology for heavy oil reservoirs in China: A review. Fuel, 374, 132376.

[19] Jahangiri, H., Santos, J., Hornung, A., & Ouadi, M. (2021). Thermochemical conversion of biomass and upgrading of bio-products to produce fuels and chemicals. Catalysis for Clean Energy and Environmental Sustainability: Biomass Conversion and Green Chemistry-Volume 1, 1-47.

[20] Oloruntoba, A., Zhang, Y., & Hsu, C. S. (2022). State-of-the-art review of fluid catalytic cracking (FCC) catalyst regeneration intensification technologies. Energies, 15(6), 2061.

[21] Adanenche, D. E., Aliyu, A., Atta, A. Y., & El-Yakubu, B. J. (2023). Residue fluid catalytic cracking: A review on the mitigation strategies of metal poisoning of RFCC catalyst using metal passivators/traps. Fuel, 343, 127894.

[22] Fink, J. (2021). Petroleum engineer's guide to oil field chemicals and fluids. Gulf Professional Publishing.

[23] Montesantos, N., & Maschietti, M. (2020). Supercritical carbon dioxide extraction of lignocellulosic bio-oils: The potential of fuel upgrading and chemical recovery. Energies, 13(7), 1600.

[24] Solarte-Toro, J. C., Laghezza, M., Fiore, S., Berruti, F., Moustakas, K., & Alzate, C. A. C. (2022). Review of the impact of socio-economic conditions on the development and implementation of biorefineries. Fuel, 328, 125169.

[25] Rose, P. K. (2022). Bioconversion of agricultural residue into biofuel and high-value biochemicals: Recent advancement. In Zero waste biorefinery (pp. 233-268). Singapore: Springer Nature Singapore.

[26] Pavlova, P. L., Minakov, A. V., Platonov, D. V., Zhigarev, V. A., & Guzei, D. V. (2022). Supercritical fluid application in the oil and gas industry: a comprehensive review. Sustainability, 14(2), 698.

[27] Hansen, S., Mirkouei, A., & Diaz, L. A. (2020). A comprehensive state-of-technology review for upgrading bio-oil to renewable or blended hydrocarbon fuels. Renewable and Sustainable Energy Reviews, 118, 109548.

[28] Rahmatpour, A., & Ghasemi Meymandi, M. (2021). Large-scale production of C9 aromatic hydrocarbon resin from the cracked-petroleum-derived C9 fraction: chemistry, scalability, and techno-economic analysis. Organic Process Research & Development, 25(1), 120-135.

[29] Adeola, A. O., Akingboye, A. S., Ore, O. T., Oluwajana, O. A., Adewole, A. H., Olawade, D. B., & Ogunyele, A. C. (2022). Crude oil exploration in Africa: socio-economic implications, environmental impacts, and mitigation strategies. Environment Systems and Decisions, 42(1), 26-50.

[30] Shelare, S. D., Belkhode, P. N., Nikam, K. C., Jathar, L. D., Shahapurkar, K., Soudagar, M. E. M., ... & Rehan, M. (2023). Biofuels for a sustainable future: Examining the role of nano-additives, economics, policy, internet of things, artificial intelligence and machine learning technology in biodiesel production. Energy, 128874.

[31] Sharma, P., Bano, A., Singh, S. P., Sharma, S., Xia, C., Nadda, A. K., ... & Tong, Y. W. (2022). Engineered microbes as effective tools for the remediation of polyaromatic aromatic hydrocarbons and heavy metals. Chemosphere, 306, 135538.

[32] Contreras-Mateus, M., Hethnawi, A., Mheibesh, Y., Montoya, T., Hashlamoun, K., Bakir, M., ... & Nassar, N. N. (2022). Applications of Nanoparticles in Energy and the Environment: Enhanced Oil Upgrading and Recovery and Cleaning up Energy Effluents. In Energy Transition: Climate Action and Circularity (pp. 169-267). American Chemical Society.