International Journal of Advanced Research in Science, Engineering and Technology

ISSN: 2350-0328

Vol. 12, Special Issue, December 2025

National Conference on Earth, Elements and Energy: Interdisciplinary Perspectives (NC3EIP–2025)

# Nanocomposite-Engineered Polyurethane Foam for Accurate and Fast Oil-Water Separation

**Manisha M. Kodape, Shivani R. Bhendarkar, Khushbu S. Jaiswal***

Department of Chemistry, Sant Gadge Baba Amravati University, Amravati, Dist. Amravati

**ABSTRACT:** The creation of effective and affordable separation materials is crucial because oil-water contamination poses serious environmental risks. In this study, reduced graphene oxide (rGO), magnetite ($Fe_3O_4$) nanoparticles, and recycled polystyrene (PS) from thermocol waste were combined to create a nanocomposite-modified polyurethane foam (PUF). FTIR and XRD analyses were used to confirm the formation of $Fe_3O_4$and rGO/ $Fe_3O_4$ nanocomposites synthesized by the co-precipitation method. A dip-coating method was used to create the modified PUF, which guaranteed consistent nanomaterial deposition and improved surface hydrophobicity. The PUF structure was successfully coated with rGO/ $Fe_3O_4$ and PS, demonstrating successful surface modification, according to SEM-EDS analysis. Strong superhydrophobic and oleophilic properties of the composite allowed for the quick and selective adsorption of oils and organic solvents, including waste oil, engine oil, toluene, and chloroform. Chloroform showed the best separation efficiency among these.

All things considered, the rGO/ $Fe_3O_4$/PUF/PS composite shows great promise as a recyclable and highly effective material for oil–water separation, industrial wastewater treatment, and oil spill remediation.

**KEY WORDS**: Reduced graphene oxide (rGO), polyurethane foam (PUF), $Fe_3O_4$ nanoparticles, oil-water separation, magnetic adsorbent.

## I. INTRODUCTION

Pollution levels in water bodies are rising as a result of the quick development needed to meet today's high standards of living. The marine environment is being devastated by large-scale oil spills, including those caused by tanker accidents, offshore oil drilling, and operational discharges. By poisoning, suffocating, and destroying habitat, they kill seabirds, marine mammals, and other marine life. The most prevalent pollutants in large aquatic systems, like oceans and seas, are oil spills and other contaminants [1]. Urbanization and the expansion of modern, high-energy industrial businesses are the primary causes of the massive discharge of oily waste into clean water sources. Rivers, lakes, and groundwater in residential areas are tainted by oil and grease from industrial discharges, urban runoff, and illicit used oil disposal. Because it can settle in sediments, contaminate drinking water supplies, and harm freshwater habitats, this contamination presents long-term risks to human and environmental health. Mining, transportation, refining, and oil exploration are the most frequent sources of water pollution [2-3]. Ecosystems and habitats can be destroyed by oil spills, which can have long-term negative effects on the terrestrial and marine environments. Contaminated water exposure is linked to skin irritation, neurological effects, and an increased risk of cancer. Fishing and tourism can be negatively impacted by water pollution, which can result in job losses and financial losses. The World Wildlife Fund for Nature claims that 12% of marine pollution is caused by oil spills [4]. The three main types of oil separation technologies are physical, chemical, and biological [5]. Mechanical oil skimming, chemical dispersion, bioremediation, material adsorption, and in situ burning were the main techniques used in the past to clean up oil spills. Likewise, a variety of physical and chemical processes, including ion exchange, flocculation, coagulation, ultrafiltration, and adsorption membrane filtration, are involved in the treatment of water [6]. In order to produce low-cost, effective, high-removal capacity, stable, and long-lasting materials, researchers concentrate on the physical treatment of oil-water [7]. Because oil is denser than alcohol and less dense than water, its molecules cannot pack as tightly as those of water. They need more space per unit area and are less dense. Recently, it has been discovered that oleophilic porous metals, polymers, and fibers are efficient substitutes for the selective adsorption of dyes, heavy metals, and oil. The widely accessible polyurethane (PU) sponge can be an excellent substrate because of its 3D porous structure, high surface area, high adsorption capacity, high mechanical strength, excellent chemical resistance, ease of fabrication, low density, and high stability [8]. Commercial sponges can adsorb both water and oil at the same time because they are inherently hydrophilic and oleophilic [9]. Polyurethane foam (PUF) is made oleophilic and hydrophobic by loading onto it, which reduces fouling and enhances its performance to develop desired adsorption characteristics [10]. The excellent water oil separation performance of PUF has been enhanced by the use of $Fe_3O_4$, PMMA, $SiO_2$, $MoS_2$, ZnO, $Al_2O_3$, and GO as effective separation materials [11–13]. $Fe_3O_4$ NPs

International Journal of Advanced Research in Science, Engineering and Technology

ISSN: 2350-0328

Vol. 12, Special Issue, December 2025

National Conference on Earth, Elements and Energy: Interdisciplinary Perspectives (NC3EIP–2025)

IJARSET IMPACT FACTOR 7.150

enhance polyurethane foam's hydrophobicity, magnetism, and foam stabilization. These nanoparticles give the system magnetic characteristics that enable recovery and recycling in response to an external magnetic field.

## II. METHODS AND MATERIAL

### A. Materials

Ferric chloride hexahydrate ($FeCl_3 \cdot 6H_2O$), ferrous chloride tetrahydrate ($FeCl_2 \cdot 4H_2O$), ammonium hydroxide ($NH_4OH$, 25–30%), graphite powder, hydrazine hydrate, polystyrene (thermocol waste), chloroform, commercial polyurethane (PU) sponge, toluene, engine oil, motorcycle waste oil, methyl red, methyl orange, and distilled water were used exactly as received. After being dissolved in chloroform, thermocol (polystyrene) scrap was utilized as the polymer binder.

### B. General Procedure for PUF Synthesis

**a. $Fe_3O_4$ Nanoparticle Synthesis**

Chemical co-precipitation was used to prepare $Fe_3O_4$ nanoparticles. Solutions of $FeCl_3 \cdot 6H_2O$ (10.4 g in 20 mL DI water) and $FeCl_2 \cdot 4H_2O$ (4 g in 30 mL DI water) were prepared separately and combined at 90°C under nitrogen. A black $Fe_3O_4$ precipitate was formed when ammonium hydroxide was added dropwise until the pH reached approximately 8–9. After separation using magnetic decantation, the product was repeatedly washed with distilled water and dried at 60°C.

**b. Preparation of rGO/$Fe_3O_4$ nanocomposite**

Graphene oxide (GO) was prepared using a modified Hummers method. An ultrasonic bath was used to dissolve GO (150 mg) in 50 ml distilled water. After adding $FeCl_3$ and $FeCl_2$ solutions to dissolve GO while stirring magnetically, $NH_4OH$ was added dropwise until the rGO/$Fe_3O_4$ nanocomposite was completely formed. After cleaning and magnetic separation, the product was dried in an oven.

**c. Production of Modified PUF (rGO/Fe3O4/PUF/PS)**

Cut into 2 × 2 × 1 cm pieces, commercial polyurethane sponge was ultrasonically cleaned with acetone and distilled water before being dried at 50 °C. To create a homogenous PS solution, thermocol waste (polystyrene) was dissolved in chloroform. Ultrasonication was used to disperse Fe3O4 or rGO/Fe3O4 nanoparticles into the PS solution. The samples were dried after the cleaned PU foams were dip-coated in the PS-nanoparticle dispersion for five minutes and any excess solution was removed. To guarantee a consistent coating of the PUF framework, the dipping-drying cycle was repeated three to four times.

**d. Oil–Water Separation Testing**

Oil absorption and separation efficiency were evaluated using water dyed with methyl red or methyl orange and various oils (engine oil, motorcycle waste oil, toluene, chloroform). A modified PUF piece was placed on the oil–water mixture, and absorption capacity ($C_t$) and separation efficiency (Eff%) were calculated using:

**Adsorption capacity**

$Ct = Wt - W_0 / W_0$

**Separation efficiency**

$Eff = Mt / Mo \times 100$

where $W_0$ and $W_t$ are initial and final sponge weights, and $M_0$ and $M_t$ are the initial and final masses of oil [21].

**Fig.1. Representation through experimentation. The creation of nanoparticles.**

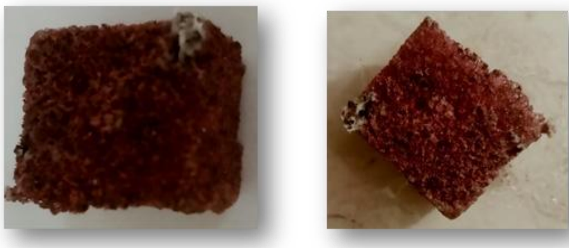


**Fig.2. PUF modification (rGO/Fe3O4/PUF/PS).**

**REACTION**

$$2FeCl3 + FeCl_2 + 8NH_4OH \longrightarrow Fe_3O_4 + 8NH_4Cl + 5H_2O$$

International Journal of Advanced Research in Science, Engineering and Technology
ISSN: 2350-0328
Vol. 12, Special Issue, December 2025
National Conference on Earth, Elements and Energy: Interdisciplinary Perspectives (NC3EIP–2025)
IJARSET IMPACT FACTOR 7.150

## III. RESULTS AND DISCUSSION

$Fe_3O_4$ formation was validated by FTIR spectra that showed Fe–O stretching vibrations below 700 $cm^{-1}$. Remaining surface hydroxyl groups were indicated by broad O–H stretching around 3470 $cm^{-1}$. Characteristic Fe3O4 diffraction peaks were seen in XRD patterns at 30°, 35.5°, 43°, 53°, 57°, and 63°, which corresponded to the (220), (311), (400), (422), (511), and (440) planes. An additional weak peak corresponding to rGO was observed in the rGO/Fe3O4 sample. Successful nanocomposite deposition along the PUF walls was shown by SEM-EDS analysis, with PS forming a thin, continuous layer over some pores. Absorption tests confirmed the composite's hydrophobic and oleophilic properties as well as its recyclability by showing quick and selective oil uptake with high separation efficiencies, especially for chloroform.

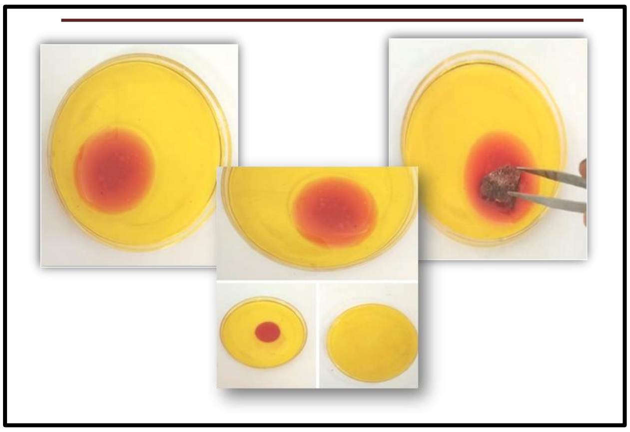


**Fig.3. Absorption of engine oil from water with rGO/$Fe_3O_4$/PUF/PS.**

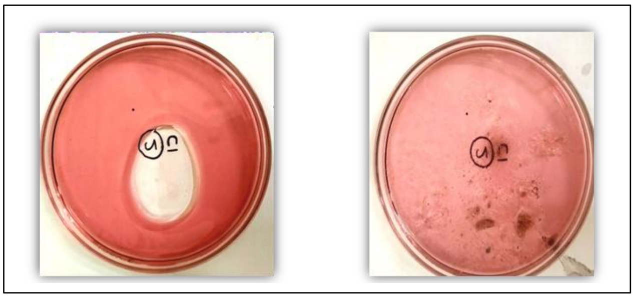


**Fig.4. Absorption of chloroform from water with rGO/$Fe_3O_4$/PUF/PS.**

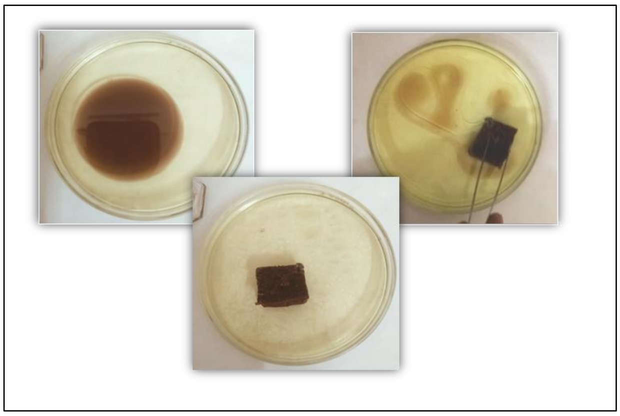


**Fig.5. Absorption of waste engine oil from water using rGO/$Fe_3O_4$/PUF/PS.**

**Fig.6. Absorption of Toluene from water with rGO/$Fe_3O_4$/PUF/PS.**

- **The absorption capacity and separation efficiency of various types of oils were calculated, and the results showed that chloroform has the highest separation efficiency.**

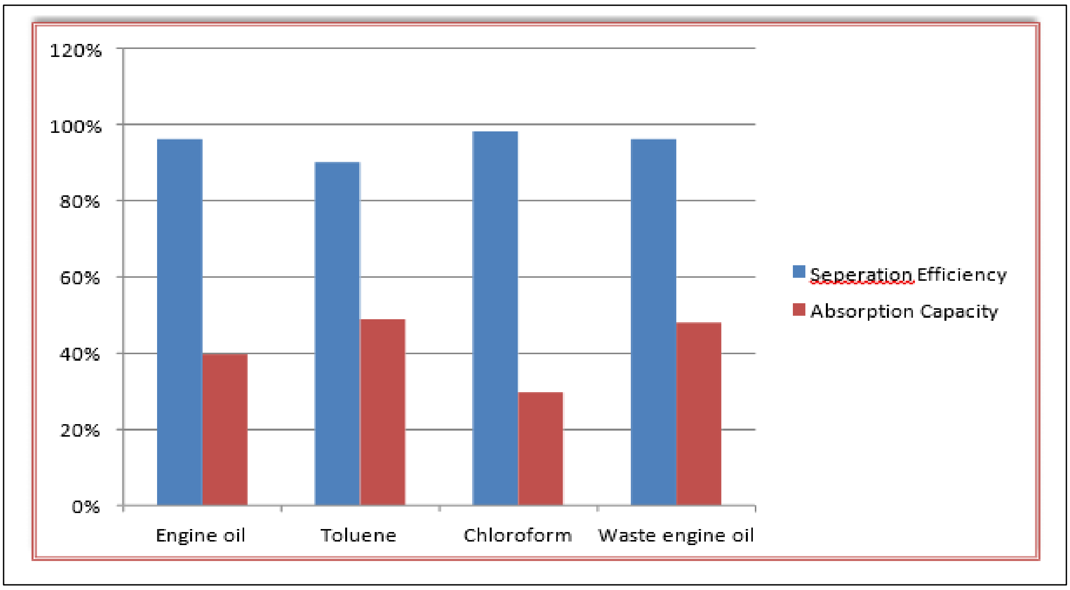
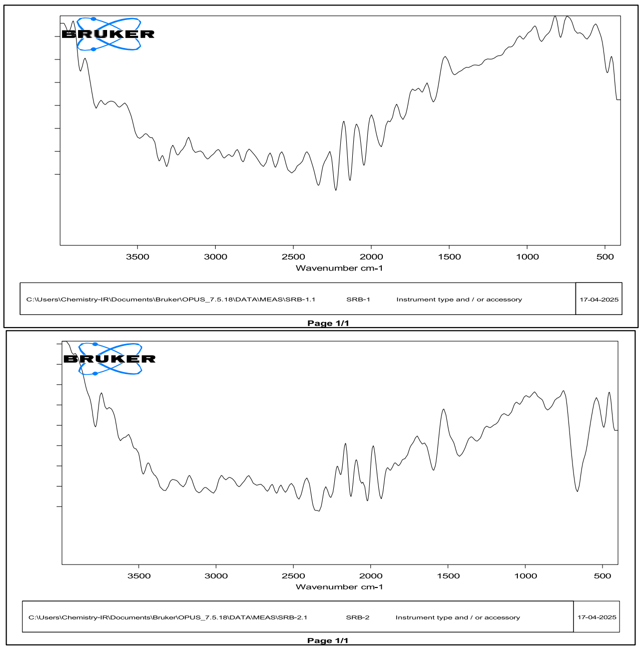



Fig.7. Separation efficiency and absorption capacity are used to separate different types of oil.

## IV.CHARACTERIZATION

**FTIR :**




The FTIR spectra were recorded from 3500 to 400 cm-1.
The FTIR 3470 cm-1 is associated with the stretching vibration of the OH groups. The peak below 700 cm-1 corresponds to the stretching vibration of Fe-O, which confirms the presence of $Fe_3O_4$.

**International Journal of Advanced Research in Science, Engineering and Technology**

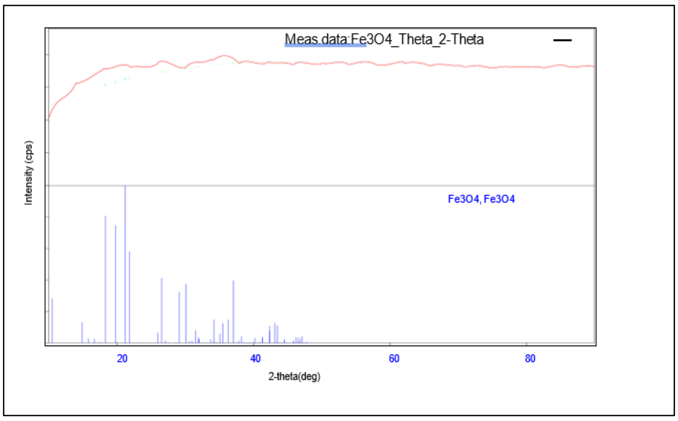
ISSN: 2350-0328

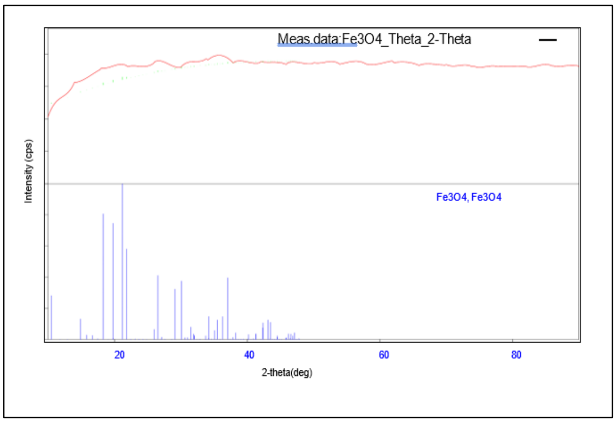
**Vol. 12, Special Issue, December 2025**

**National Conference on Earth, Elements and Energy: Interdisciplinary Perspectives (NC3EIP–2025)**

IJARSET IMPACT FACTOR 7.150

- **XRD patterns for $Fe_3O_4$ and rGO/$Fe_3O_4$.**



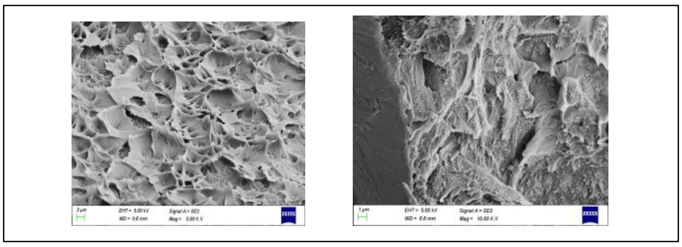




1) $Fe_3O_4$ (top graph) has standard peaks with strong reflection at ~300, ~35.50, ~430, ~530, ~570, and ~630, corresponding to the diffraction planes 220, 311, 400, 422, 511, and 440.

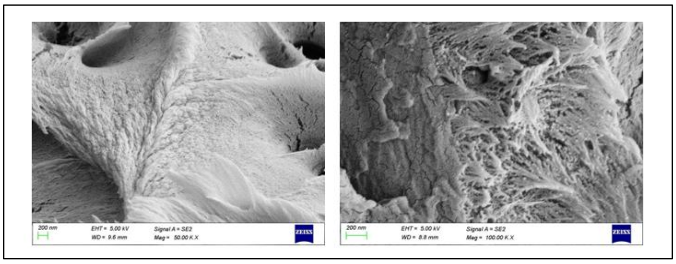
2) The estimated peak position for rGO/$Fe_3O_4$ (Bottom Graph) has standard peaks with strong reflection at ~180, ~300, ~35.50, ~430, ~530, ~570, ~630, and ~10-120 with possible phase of Fe3O4, 220, 311, 400, 422, 511, 440, and weak intensity peak of GO/rGO.

## MODIFIED PUF CHARACTERIZATION

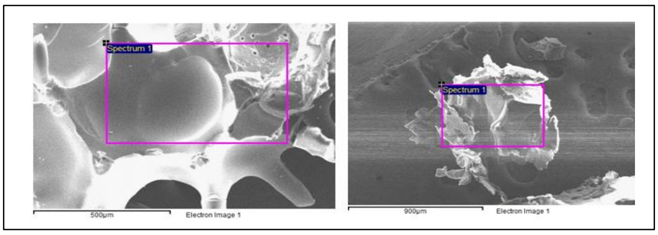
- **EDS-SEM of modified PUF containing magnetic $Fe_3O_4$ nanoparticles and rGO/$Fe_3O_4$ nanocomposite.**

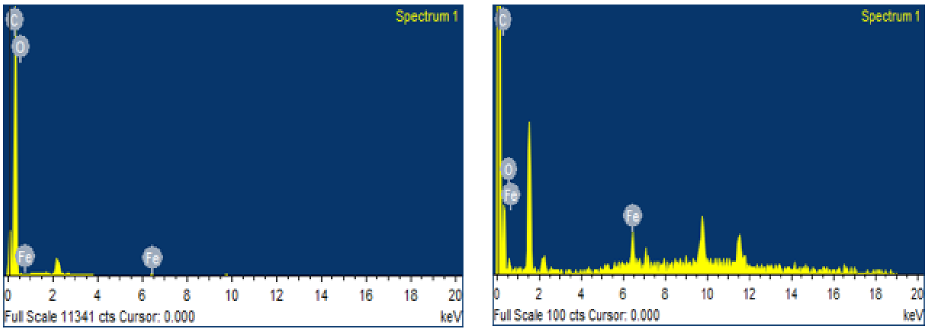


- **EDS-SEM analysis of modified PUF after oil- water separation using magnetic $Fe_3O_4$ nanoparticles and rGO/$Fe_3O_4$ nanocomposite.**



- **EDS-SEM of rGO/Fe3O4 nanocomposite and modified PUF loaded with magnetic Fe3O4 nanoparticles.**






The micrograph of rGO/Fe3O4/PUF/PS with oil after absorption is displayed in the EDS-SEM.
The PS aims to produce a dark, continuous layer that blocks some of the pores in the PUF skeleton.
The surface of the PU foam is covered by PS, but the inner pores of the rGO sheet are visible because it is transparent.
The side wall and a few open PU foam pores were successfully coated with rGO/Fe3O4, according to the EDS-SEM.
In order to achieve effective oil-water separation, the study successfully demonstrated the synthesis and characterization of a modified polyurethane foam (PUF) nanocomposite made of reduced graphene oxide (rGO), Fe3O4 nanoparticles, and thermocol (polystyrene, PS). Fe3O4 and rGO/Fe3O4 nanocomposites were successfully synthesized, according to FTIR and XRD analyses, with distinctive peaks confirming the existence of functional groups and crystalline structures related to these materials. EDS-SEM imaging showed that the addition of thermocol and the rGO/Fe3O4 nanocomposite to the PUF matrix produced a hierarchically porous structure. The uniform distribution of rGO and Fe3O4 on the foam surface was further verified by elemental mapping. The modified PUF composite shows promise for effective and reusable oil-water separation applications due to its combined superhydrophobicity, oleophilicity, and magnetic responsiveness.

## V. CONCLUSION

This study's modified PUF shows great promise for oil-water separation. The rGO/$Fe_3O_4$/PUF/PS composite possessed strong hydrophobicity, oleophilicity, magnetic responsiveness, and structural stability. Successful nanoparticle synthesis, incorporation, and homogeneous surface coating were verified by characterization. High efficiency toward various oils and organic solvents was demonstrated by absorption and separation measurements, establishing this material as a viable, affordable, and eco-friendly option for wastewater treatment and oil spill cleanup.

## REFERENCES

1) H. Zhang, X. Ding, S. Wang, Y. Huang, X.F. Zeng, S. Maganti, Q.Jiang, M. Huang, Z. Guo, D. Cao, Eng. Sci. 2022, 320
2) T.A. Abdullah, T. Juzsakova, R.T. Rasheed, M.A. Mallah, A.D. Salman, L.P. Cuong, M. Jakab, B. Zsirka, K. Kulacz, V. Sebestyen, Nanomaterials , 2022, 12, 189
3) W.F. Elmobarak, F. Almomani, Chemospere, 2021, 129054
4) J. Meng, F. Li, T. Li, W.Cao, Appl. Surf. Sci. 2023, 614, 156183.
5) J. Wang, J. Xu, Z. Lian, J. Wang, G. Chen, Y. Li, H. Yu, Colloids Surf. A 2022, 128703.
6) Abraham O. Ekperusi, Amarachi P. Onyena, Marvellous Y. Akpudo, Chibuike C. Peter, Christiana O. Akpoduado, Omesiri H. Experusi, SPE Nigeria Annual International Conference and Exibition, 2019, SPE-198777
7) M. Nueraji, Z. Toktarba, A. Ardakkyzy, D. Sridhar, H. Algadi, B. Bin Xu, J.T. Althakafy, A.K. Alanazi, H.M. Abo-Dief, S. Adilov, Z. Guo, Environ. 2023, 115212.
8) Mona Alinejad, Christian Henry, Saeid Nikafsar, Akash Gondaliya, Sajad Bagheri, Nusheng Chen, Sandip K. Singh, David B. Hodge, Mojgan Nejad, polyme s, 2019, 11(7)
9) P. Wang, Q. Cui, Q. Zeng, Q. Jiang, Q. Ren, Sol. Energy, 2023, 59-69
10)M. Dong, G. Wang, X. Zhang, D.Tan, D.J.P. Kumar, J. Ren, H. Colorado, H. Hou, Z. Toktarbay, Z. Guo, Adv. Compos. Hybrid Mater, 2023, 6, 207
11)S. Sui, H. Quan, Y. Hu, M. Hou, S. Guo, J. Colloid Interface Sci. 2021, 589, 275
12)X. Zhang, Z. Mao, J. Ding, H. Chen, Mater. Chem. Phys., 2024, 312, 128688
13)S. Wu, Y. Xiang, T. Cai, j. Environ. Sci., 2024, 139, 160
14)Hengchang Bi, Xiao Xie, Kuibo Yin, Yilong Zhou, Shu Wan, Longbing He, Feng Xu, Florian Banhart, Litao Sun, Rodney S. Ruoff, Advanced Functional material 2012, 4421- 4425

15)Serrano-Lujan L, Victor-Roman S, Toledo C, Environmental impact of the production of graphene oxide and reduced graphene oxide, 2019, 1:179
16)Bala Anegbe, Ikhazuagbe H. Ifijen, Muniratu Maliki, Ita E. Uwidia, Aireguamen I. Aigbodion, Environmental Sciences Europe, 2024, 36:15
17)Xiaodong Chen, Zhan Qu, Zhe Liu, Guoyu Ren, ACS Omega, 2022, 23503-23510, 7, 27
18)Dongdong Ge, Yuz Zhang, Zhenshan,Cui, Guilong Wang, Jun Liu, xiaomeng Lv,J. Coat. Trchnol. Res., 2023, 661-670
19)E.A. Moawed, M.S. Eissa, S.A. Al-Tantawy, International journal of Environmental Science and Technology, 2023, 7767-7774
20)A.A. Alazab, T.A Saleh, j. Water Proc. Eng,. 2022, 103125
21)Ayman Madbouly, Mohamed Morsy. Amir Elzwawy, Journal of Inorganic and Organometallic Polymers and materials, 2024, 2292-2305.
22)Tiago Mari, Matheus V. G. Zimmermann, Bruna Rossi Fenner, Francisco Maciel Monticell, Heitor Luiz Ornaghi Junior, Camila Baldasso, Ademir J. Zattera, polymers, 2025, 1127.
23)M.S. Manojkumar, K. Jeyajothi, A. Jagadeesan, V. Jeevanantham, j. Indian Chem Soc., 2022, 100559
24)Prateekshya Suman Sahu, Ravi Prakash Verma, Chetna Tewari, Nanda Gopal Sahoo, Biswajit Saha, Environmental Science and Pollution Reasearch, 2023, 93054-93069
25)R. Suriyaprabha, S.H. Khan, B. Pathak, M.H. Fulekar, J. Phys. Conf. Ser. 2017, 169
26)Proteekshya Suman Sahu, Ravi Prakash Verma, Ajinkya Hariran Dabhade, Chetna Tewari, Nanda Gopal Sahoo, Biswajit Saha, Environmental Pollution, 2023, 121201
27)Neeru Sharma, Vikas Sharma, Yachana Jain, Mitlesh Kumari, Ragini Gupta, S. K. Shrma, K. Sachdev,Macromolecular Symposia, 1/1700006
28)R. Dawn, m. Zzaman, F. Faizal, C. Kiran, A. Kumari, R. Shahid, C. Panatarani,I.M. Joni, V.K. Verma, S.K. Sahoo, K. Amemiya, V.R. Singh, Braz. J. Phys., 2022, 99

## AUTHOR'S BIOGRAPHY

| Full name | Dr. Manisha M. Kodape |
|---|---|
| Science degree | M.Sc.,M. Phil, Ph.D |
| Academic rank | Professor |
| Institution | Sant Gadge Baba Amravati University, Amravati |

| Full name | Ms. Shivani R. Bhendarkar |
|---|---|
| Science degree | M.Sc. Chemistry |
| Academic rank | Student |
| Institution | Sant Gadge Baba Amravati University, Amravati |

| Full name | Ms. Khushbu S. Jaiswal |
|---|---|
| Science degree | M.Sc. Chemistry |
| Academic rank | Research Scholar |
| Institution | Sant Gadge Baba Amravati University, Amravati |