Chapter

7

Conclusion and future perspective

Contents

This chapter discuss overall summary of the thesis. The future perspective of this work is also discussed.

7.1 Conclusions

Nanotechnological advancements in different sectors, such as agriculture, textiles, health, and electronics, have improved our living standards. However, most of these developments come at the cost of various environmental issues and energy crises. Pollution is one of the biggest problems because it has worsened living conditions at several ecological levels. The rapid pace of industrialization and urbanization, the exploitation of natural resources, industrial and domestic discharges, emissions from power plants, transportation, and industrial activities are primarily responsible for environmental deterioration. Industrial effluents, agricultural run-off, use of plastics, vehicle emissions, and domestic discharges enriched with organic, inorganic, and biological contaminants are major sources of water, air, and soil pollution. Especially considering their hazardous effects, it is imperative to find solutions for environmental and energy issues, achieve sustainable development, switch to renewable energy, and promote global research for developing new materials and approaches to reduce water, soil, and air pollution.

The primary objective of this research was to synthesize graphene oxide (GO) and advance the field of composite materials by integrating metal oxides. This integration is a crucial step toward developing versatile materials with diverse applications. The incorporation of surfactants and deep eutectic solvents (DESs) into these nanocomposites (NCs) adds complexity, promising enhanced properties and improved environmental compatibility. These unique features position them as promising candidates for applications such as wastewater treatment, gas separation/purification, fluorescent sensors, green hydrogen production, antimicrobial surfaces, photocatalysis, energy storage, and adsorption.

The outcomes of this research suggest that graphene-based composites of metal oxides functionalized by surfactants and DESs NCs exhibit significant potential for a range of environmental, energy, and sensor applications. This chapter presents key findings derived from experimental work, offering insights into the synthesis, surface modification, morphological features, and potential applications of various graphene-based composites of metal oxide functionalized by surfactant and DES NCs. The study outlines future prospects emerging from a comprehensive analysis of these innovative materials. Also, covers the way for more sustainable and environmentally friendly practices in the field of graphene based NCs.

In conclusion, this thesis encompasses a thorough investigation of graphene-based composites with metal oxide functionalization by surfactant and DES throughout multiple chapters. Each chapter contributes distinct insights and innovative approaches to the overall exploration.

Chapter 1 serves as an introduction to the realm of nanotechnology and nanocomposites, with a specific focus on the prominent carbon-based two-dimensional material, GO. This chapter provides a concise overview of graphene, delving into its fundamental properties. Emphasis is placed on the advantages linked to the functionalization of NCs comprising GO and metal oxides. Through this exploration, the foundational concepts and characteristics of graphene oxide and its role in nanocomposite materials are established.

Chapter 2 delves into a comprehensive exploration of synthesis routes, principles, and the applications of characterization techniques employed in the research. The synthesis of nanocomposites with metal oxides involved the laboratory preparation of graphite oxide using a previously established method. The chapter further delves into the functionalization of graphene-metal oxide nanocomposites with surfactants and DESs. To elucidate the structural, chemical, microscopic, and physical aspects of the nanocomposites, this chapter introduces and discusses major characterization techniques. These techniques encompass Fourier transform infrared spectroscopy (FTIR), X-ray diffraction studies (XRD), UV-visible absorption spectroscopy (UV-Vis), Thermogravimetric analysis (TGA), Differential scanning calorimetry (DSC), Field emission scanning electron microscopy (FESEM), Transmission electron microscopy (TEM), energy dispersive X-ray (EDX), Contact angle, and Tensile strength.

In **Chapter 3 and Chapter 4**, the synthesis of nanocomposites continued with graphene oxide–zirconium oxide (GO@ZrO_2) and graphene oxide–titanium oxide nanocomposites (GO@TiO_2), respectively. Following synthesis, these nanocomposites underwent modification using a cationic gemini surfactant (CGS, butanediyl-1,4, bis (N, N-hexadecyl ammonium) dibromide (16-4-16)), dodecyl trimethyl ammonium bromide (DTAB), or DES (reline, ChCl; urea, 1:2 molar ratio). The resulting adsorbent materials were thoroughly characterized using various physicochemical techniques. To assess their efficacy, methylene blue (MB) was employed as a model adsorbate to investigate its adsorption and removal from aqueous solutions utilizing the modified nanocomposites. The adsorption data were then compared with those of other similar reported adsorbents. Remarkably, the DES-based advanced material demonstrated ultrafast MB adsorption compared to the surfactant-modified nanocomposites. These findings highlight the promising potential of the developed nanocomposites for efficient and rapid adsorption applications.

Chapter 5 explores the photophysical behavior of rhodamine B (RB) within deep eutectic solvents (DESs), both with and without the presence of GO or ionic surfactants. The impact of GO, surfactant, or the combination of GO and surfactant on controlling the movement of RB at various sites, including the GO surface, surfactant micelle, DES surface, or background solvent, is extensively discussed through fluorometric analysis. Moreover, the modifications inspired by reline in DESs have been observed to alter the interactions between RB and GO, sodium dodecyl sulfate (SDS, an anionic surfactant), or Cetyltrimethylammonium bromide (CTAB, a cationic surfactant). The DES-controlled cationic vs. zwitterionic form of RB plays a pivotal role in its interaction and sustained movement towards the GO surface, micellar surface, or the formation of negatively charged ion pairs with SDS monomers. These insights contribute to a deeper understanding of the intricate interplay between DES components, surfactants, and GO in influencing the photophysical behavior of RB, providing valuable information for potential applications in controlled-release systems and sensing devices.

In **Chapter 6**, the fabrication of Mixed Matrix Membranes (MMMs) unfolded through the utilization of a standard phase inversion technique, renowned for its cost-effectiveness and time efficiency. This process involved the combination of polycarbonate (PC) and polystyrene (PS) with nanofillers, including GO and ZrO_2, at concentrations ranging from 2 wt% to 20 wt%. Additionally, membranes were crafted using DES. The resulting MMMs underwent comprehensive characterization utilizing various techniques. Benefiting from the excellent surface characteristics of ZrO_2, the heightened sorption capacity of GO, and the enhanced thermal stability attributed to DES, MMMs exhibited significantly improved gas permeability and gas selectivity beyond the capabilities of conventional membrane materials. Permeability data with various environmental gases, such as CO_2, N_2, O_2, and CH_4, were acquired and used to determine selectivities, showcasing the potential of these MMMs for advanced gas separation applications.

7.2 Future Perspective

This integration demonstrates significant potential for addressing environmental challenges; however, untapped potential exists that requires further exploration and enhancement. Advanced functionalization strategies have shown promise, particularly with the use of DES and surfactants. However, continuous efforts are needed to delve into more sophisticated functionalization techniques to precisely tailor the properties of NCs. This precision will enable more targeted and efficient dye adsorption for wastewater treatment and gas sensing applications.

Deeper exploration of functionalization techniques can involve investigating novel surfactants and DES formulations for enhanced control over surface functionalities, expanding versatility. NCs can play a broader role in environmental applications, including efficient pollutant removal through photodegradation processes using the synergistic effects of DES and surfactants.

Beyond current applications, future exploration can create multifunctional NCs with diverse functionalities such as catalysis, controlled drug release, and advanced sensing capabilities, broadening their utility across various fields. With unique properties introduced by metal oxides, surfactants, and DES, NCs have potential in energy storage and conversion devices. Investigations can explore their applicability in high-performance batteries, supercapacitors, and emerging energy technologies. Addressing the challenges related to large-scale production and commercialization is pivotal. Future endeavors should focus on optimizing synthesis processes, ensuring scalability, and exploring cost-effective methods for integration into various industries.

The continuous pursuit of excellence in this field remains essential for harnessing the full potential of graphene oxide-based metal oxide nanocomposites modified with surfactants and DESs. This 'next-generation material' not only captures the attention of eager researchers but also inspires fresh ideas for addressing challenging situations in the realms of green and sustainable advancements, coupled with solutions for environmental concerns.