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## **Summary and Conclusions**

Metal nanoparticles (MNPs) (sizes ranging from 1-100 nm) are an attractive class of nanomaterials that have attracted the scientists, engineers, and researchers from several fields of study. The properties of MNPs diverge dramatically from those of their bulk counterparts; the most noticeable are their nano size and high surface area relative to volume. These properties make them effective for catalysis and adsorption, as more active sites are available for chemical reactions and molecule adsorption, and on the other hand, it can lead to increased reactivity and potential toxicity, which is an essential consideration in their use, especially in biomedical and environmental applications. Polymers play an important role in the synthesis of MNPs as they act as templates, stabilizers, and growth regulators for potent MNPs. By modifying the polymer's properties, such as chain length or functional groups, one can tailor the MNPs to desired specifications. Polymer mediated MNPs often exhibit enhanced properties compared to simple MNPs with a combination of polymer and MNP properties.

In the present thesis work, the Pluronic surfactants (PEO-PPO-PEO triblock copolymers) also known as Poloxamers were used for the development of polymer mediated MNPs. Pluronics act as stabilizing agents for MNPs by forming a protective layer around them. This prevents their aggregation, ensuring colloidal stability and preventing the MNPs from undergoing precipitation or agglomeration. The amphiphilic nature of Pluronics allows for control over the size and morphology of MNPs, with adjusting the concentration, composition, and molecular weight of Pluronics. The synthesis of MNPs using Pluronics is relatively straight forward and scalable, making it an attractive method for large-scale production. Not only that, the other polymer that has also been used in the present thesis work is chitosan for the development of MNP composites. In the present thesis work, we developed and well-characterized CuNPs and SiO<sub>2</sub>NPs using Pluronic polymers and chitosan as stabilizing agents and/or capping agents for the useful applications of antimicrobial activity, dye degradation, gas adsorption, and dye removal. To summarize the present thesis work, mainly six chapters are reported.

### **Chapter 1: General Introduction**

In this chapter, the introduction of MNPs and polymer mediated MNPs was reported with adequate required information. The synthesis approaches and their route methodologies for MNP fabrication are furnished with proper drawings. The role of polymers in stabilizing MNPs, preventing aggregation, and producing stable MNPs has also been shown with the

latest literature citations. Chapter shows the significance of Pluronic mediated MNP development and research covered in the material science. The chapter also highlights the potential applications of Pluronic mediated MNPs in various fields, positioning them as promising materials for future research and development.

### **Chapter 2: Materials and characterization methods**

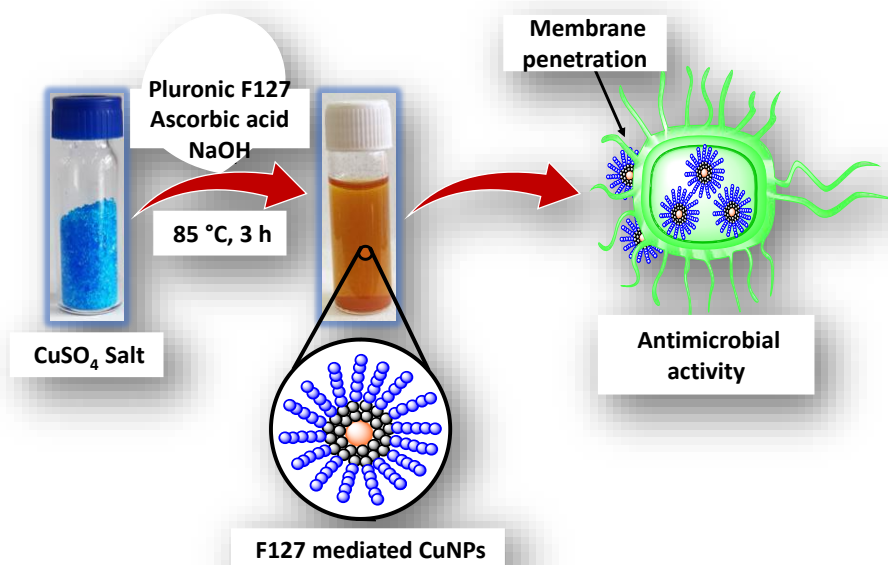
This chapter provides a comprehensive overview of the materials used in the study, including their molecular structure, specifications, and procurement details. The key materials like Pluronic polymers, chitosan, ascorbic acid, and peanut shell were discussed. Furthermore, the brief of organic textile dyes used in the research work, i.e., CR, MO, MB, and RhB dyes, was furnished with their purchasing details.

The characterization methods employed in the thesis work are UV-Vis and fluorescence spectroscopy for absorbance, solubility, and amount of substances; DLS, Zeta Potentials, and Rheology to determine particle size, surface charge, and viscosity; This chapter provides a systematic overview of the instruments used, including FTIR for functionality present in the material; XRD for assessing the nature and structural arrangement; FE-SEM and TEM for examining shape and morphology; EDX for determining the elemental compositions in the materials; and TGA for calculating the percentage of material degradation.

### **Chapter 3: Pluronic mediated copper nanoparticles for antimicrobial applications: Investigating the role of Pluronic concentration**

The development of CuNPs with antimicrobial activities shows high potential for various clinical applications. In this chapter, Pluronic F127 mediated CuNPs with improved oxidative stability using a simple process that included environment-friendly Vitamin C (ascorbic acid) as a reducing agent and F127 polymer as a stabilizing agent were reported. The optimization of the reducing agent, the molar ratio of ascorbic acid-to-Cu<sup>2+</sup> salt, was investigated (15:1). The synthesized F127 mediated CuNPs were characterized using UV-Vis, DLS, Zeta potential, XRD, FE-SEM, and EDX analysis. The better efficiency and decrease in particle size of F127 mediated CuNPs were observed with increasing the F127 concentration. The F127 mediated CuNPs are fcc-structured, crystalline, and free of any impurities of CuO or Cu<sub>2</sub>O. The F127 mediated CuNPs showed highly potent antimicrobial activities. Results suggest that with a high concentration of F127 in the formation of CuNPs, there was potent antibacterial behaviour found on Gram-negative as well as Gram-positive bacteria. Not only that, similarly, these CuNPs also showed better antifungal activities against the studied fungi

cells. The representative time-induced analysis of antifungal activity against *F. oxysporum* confirms the stability and efficient activity of F127 mediated CuNPs with high polymer concentrations. Finally, this chapter study indicated that Pluronic F127 mediated CuNPs could be a new way to fight both human and plant pathogens. *This work has been published in the ChemistrySelect (Wiley), 2022,7(31), p.e202201477. doi.org/10.1002/slct.202201477*

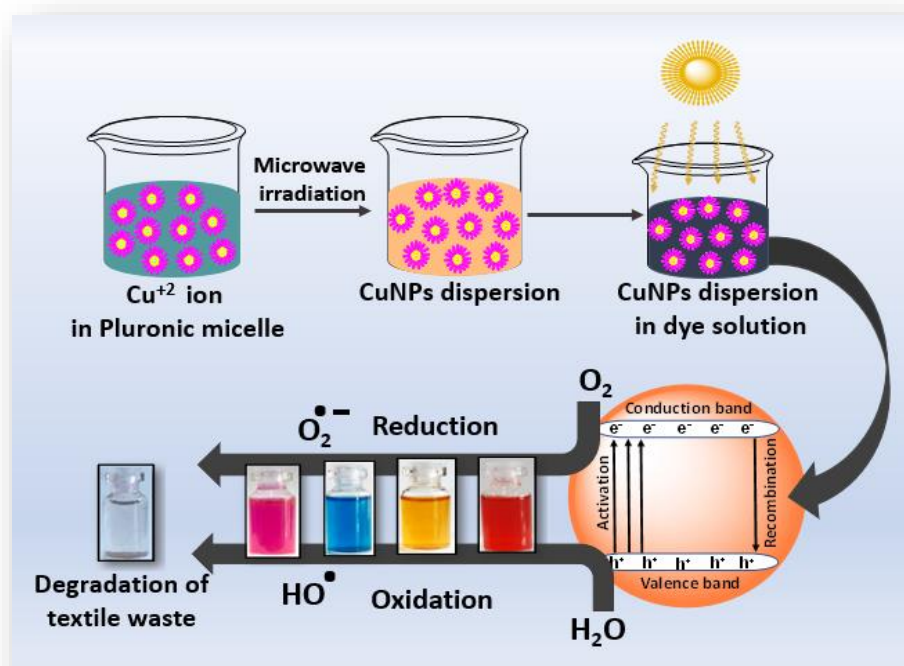


**Figure 7.1:** Graphical representation of Pluronic F127 mediated CuNPs for their potent antimicrobial application

### Chapter 4: Pluronic mediated copper nanoparticles as photocatalyst for dye degradation

In this chapter, Pluronic mediated copper nanoparticles (CuNPs) were fabricated using the reducing agent sodium borohydride in the micellar media of different Pluronics (L121, P123, and F127) using cost-effective microwave techniques. The characterization of the blank and Pluronic mediated CuNPs was done using the multi-technique approach. Results clearly showed that the hydrophilic PEO and hydrophobic PPO parts of the Pluronic have a notable influence on the uniformity, particle size, and morphology, as well as the stability of the CuNPs. Highly hydrophilic F127, as CuNPsF7, shows the best performance among all other systems. The developed CuNPsF7 was investigated as a powerful photocatalyst for the degradation of textile anionic (CR and MO) and cationic (MB and RhB) dyes. When compared to blank CuNPs, the results confirmed that the CuNPsF7 followed pseudo-first-order kinetics and significantly increased the rate and efficiency of dye degradation. The

potency of the photocatalyst plays an effective role in generating superoxide anion radicals and hydroxyl radicals ( $\text{HO}^\bullet$ ), which are the active species for degrading the organic dyes. The chapter study provides a facile and cost-effective approach to fabricating Pluronic mediated CuNPs photocatalysts for degradation of the highly toxic organic dyes from waste water and textile industry effluents. *This work has been published in the Journal of Materials Today Communications (Elsevier), 2023, 37, p.106990. doi.org/10.1016/j.mtcomm.2023.106990*

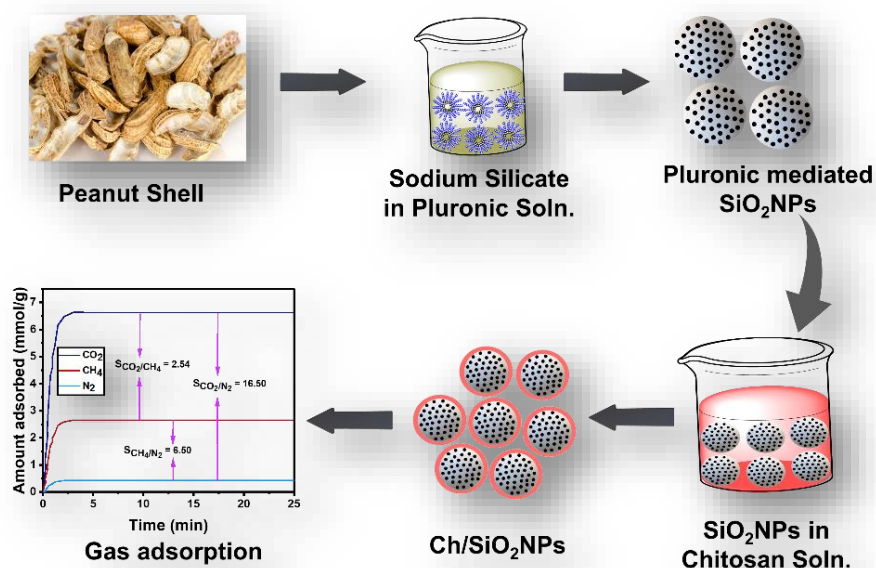


**Figure 7.2:** Fabrication of CuNPs with the help of Pluronic micelles using microwave techniques, which act as powerful nano catalysts to remove organic dyes from textile industry waste water.

## Chapter 5: Pluronic mediated silica nanoparticles with chitosan as composite for gas adsorption

$\text{SiO}_2$ NPs manufactured from sustainable sources have versatile applications in a wide range of materials, including adsorbents, catalysts, paints, fuel cell membranes, and Li-ion batteries. In this chapter, the  $\text{SiO}_2$ NPs (92.84%  $\text{SiO}_2$  content, spherical, 18 nm-in-size) were prepared from peanut shell ash (PSA) assisted through various Pluronic surfactants. Pluronic mediated  $\text{SiO}_2$ NPs were reacted with chitosan without any crosslinkers or activators to develop chitosan-modified  $\text{SiO}_2$ NPs (Ch/ $\text{SiO}_2$ NPs) biosorbents. The developed biosorbent was characterized through multi-techniques, i.e., DLS, EDX, Zeta potential, TEM, XRD,

FTIR, TGA, and BET. The Ch/SiO<sub>2</sub>NPs have porous (pore volume: 0.83 cm<sup>3</sup>/g and pore size: 1.35 nm), sphere-shaped, uniformly coarse surfaces (surface area: 830 m<sup>2</sup>/g), and an average particle size of 45.8 nm. The Ch/SiO<sub>2</sub>NPs exhibit a strong attraction towards organic molecules and showed good adsorption of CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub> gases. Results showed that at 25°C, Ch/SiO<sub>2</sub>NPs had a maximum CO<sub>2</sub> adsorption capacity of 6.70 mmol/g. The Ch/SiO<sub>2</sub>NPs showed effective results for CO<sub>2</sub> adsorption due to the mesoporous texture, which facilitates easier movement of CO<sub>2</sub> molecules, and the high content of amine groups in chitosan, which enhances affinity towards CO<sub>2</sub> gas. It also showed exceptional selectivity for CO<sub>2</sub> when compared to N<sub>2</sub>, with a selectivity ratio (S<sub>CO<sub>2</sub>/N<sub>2</sub></sub>) of 16.50. This chapter study proves that the sustainable synthesis with the use of peanut shell, Pluronics, and chitosan, the biosorbent chitosan-modified silica nanoparticles (Ch/SiO<sub>2</sub>NPs), has become a promising material for catalytic applications. *This work has been communicated in the New Journal of Chemistry (RSC), October 2024.*



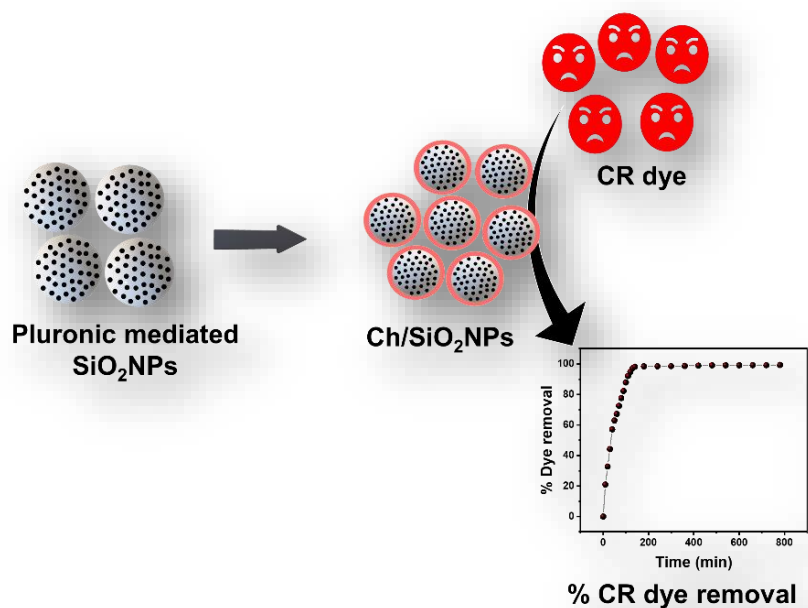
**Figure7.3:** Graphical representation of developed Ch/SiO<sub>2</sub>NPs biosorbent for gas adsorption applications

### Chapter 6: Pluronic mediated silica nanoparticles with chitosan as composite for the dye removal

The developed chitosan modified SiO<sub>2</sub>NPs (Ch/SiO<sub>2</sub>NPs) biosorbent using Pluronic mediated SiO<sub>2</sub>NPs shown in chapter 5 was significantly studied here for adsorption and dye removal of CR dye in this chapter. The Ch<sub>1.0</sub>/SiO<sub>2</sub>NPs biosorbent has performed significantly for CR dye

## Chapter-7: Summary and Conclusions

adsorption and shows almost 98.40% CR removal efficiency with a dose of 50 mg. The kinetic studies of CR dye removal followed the pseudo-second-order model and confirmed the endothermal adsorption process involves chemical interactions between the adsorbate (CR dye) and adsorbent (Ch/SiO<sub>2</sub>NPs). The isotherm measured at a temperature of 50 °C yielded the maximum adsorption capacity as determined by the Liu model. The adsorption capacity of the biosorbent towards CR dye was five times faster at a higher 50°C than the lower 10°C temperature. The thermodynamic functions  $\Delta G$ ,  $\Delta H$ , and  $\Delta S$  provided confirmation of the endothermic and spontaneous nature of the adsorption process. The obtained results demonstrate the high efficiency of a Ch/SiO<sub>2</sub>NPs biosorbent, which possesses remarkable capacity and kinetics. The Ch/SiO<sub>2</sub>NPs were reusable up to six cycles after CR adsorption, which was commendable. This chapter's studies proved that the biosorbent Ch/SiO<sub>2</sub>NPs using biocompatible and nontoxic sources like peanut shell, Pluronics, and chitosan have become potent materials for dye removal studies from waste water treatment or textile effluents. *This work has been communicated in the New Journal of Chemistry (RSC), October 2024.*



**Figure 7.4:** Graphical representation of synthesized biosorbent (Ch/SiO<sub>2</sub>NPs) used as a dye removal

## ***Chapter-7: Summary and Conclusions***

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Overall, the present thesis work demonstrated the synthesis of polymer mediated MNPs (specifically CuNPs and SiO<sub>2</sub>NPs) using Pluronic polymers as main stabilizing agents and/or reducing agents along with conventional ones. The developed Pluronic mediated CuNPs showed excellent antimicrobial and dye degradation applications, and Pluronic mediated SiO<sub>2</sub>NPs, when modified with chitosan, found better adsorbents for applications of gas adsorption and organic dye removal.