COMPARATIVE STUDY ON PERFORMANCE OF NANO-ADSORBENTS FOR WATER TREATMENT

Thesis submitted towards the partial fulfilment of Master of Engineering degree in Chemical Engineering

by

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DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC ETHICS

I hereby declare that this thesis contains literature survey and original research work by the undersigned candidate, as part of his "***Master of Engineering in Chemical Engineering***" studies. All information in this document have been obtained and presented in accordance with academic rules and ethical conduct.

I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to research work.

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CERTIFICATION

This is to certify that **SAUBHIK MALIK**, final year student in Master of Chemical Engineering examination in the department of Chemical Engineering, Jadavpur University, bearing Registration No: 145132 has successfully completed the thesis work entitled **"COMPARATIVE STUDY ON PERFORMANCE OF NANO-ADSORBENTS FOR WATER TREATMENT."** under the guidance of **Prof. (Dr.) Chiranjib Bhattacharjee** during his master degree curriculum. This work has not been reported earlier anywhere and can be approved for submission in partial fulfilment of the requirements for the Master of Engineering in Chemical Engineering.

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This thesis is hereby approved as the creditable study of an engineering subject carried out and presented in a manner satisfactory to warrant its acceptance as prerequisite to the degree for which it has been submitted. It is understood by this approval that the undersigned don't endorse or approve any statement made, opinion expressed or conclusion drawn therein but approve the thesis only for purpose of which it is submitted.

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1. ABSTRACT:

Synthesization and characterization of novel composite GO-TiO_2-$MnFe_2O_4$ to efficiently remove various dye from water has been carried out. The magnetic nanoparticles were synthesized through chemical precipitation using sodium hydroxide in one pot method. Based on the advantages of graphene oxide, TiO2, and Manganese ferrite the nanocomposite exhibited visible light absorption, magnetic properties, and adsorption capacity. On characterization, X-ray diffraction results revealed the formation of pure crystalline nanoparticles. Chemical bond energy was confirmed through Fourier transform infrared Spectroscopy analysis. Scanning Electron Microscopy showed spherical shaped nanoparticles. Confirm the size range of the nano-particle in nano-range (>100 mm). Nano-particle size was found to be 65.4 to 92.7mm. Energy dispersive X-ray spectroscopy analysis confirmed high purity for the synthesized nanoparticles. Isotherms and kinetic studies were performed to explore the sorption mechanism. The experiments fitted well with Langmuir model and pseudo-First order was the best fit for Victoria blue and Methylene Blue. Brilliant green adsorption follows the Freundlich isotherm and pseudo-1st-order kinetic models. Results demonstrate that methyl blue (MB) adsorptive removal capacity reaches 97.12% within 145 min and maximum uptake value is 188.7 mg/gm. Various research work consistently demonstrates the exceptional magnetic properties of MnFe2O4. Due to the remarkable magnetic properties exhibited by the synthesized material, the process of easily separating it becomes feasible, thereby enabling its subsequent reuse post the completion of the adsorption experiment. This advantageous characteristic of the material not only aids in efficient separation but also contributes to promoting sustainability by facilitating its repeated utilization. Therefore, the magnetic nanoparticles can be used as potential nano adsorbent for the degradation of dyes without affecting the environment.

Instrument Credentials:

INSTRUMENT NAME	MANUFACTURER
D.I Water	**SARTORIUS &MILIPORE SYSTEM, FRANCE**
Weight Balance	**SARTORIUS**
Magnetic Stirrer	**TARSON**
Oven	**CONCEPTS INTERNATIONALS**
Vacuum Drying Instrument	**BOROSIL**
UV-Vis Spectrophotometer	**VARIAN**
Ultrasonicator	**SARTORIUS**
Ph Test Probe	**SARTORIUS**

Table 1: Various Instrument and their Manufacturer

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CHAPTER-1
INTRODUCTION

1. INTRODUCTION:

Water is one of the major constituents of life and a plentiful major resource on Earth; the very first life form originated in the sea. About 3/4th part of the Earth is water. Water is fundamental for all life forms to exist on this planet. With increasing population and industrialization, the naturally occurring ring water resources are getting more and more contaminated. Currently, 44% of all wastewater on Earth returns to the environment untreated. This means that human waste, household sewerage, and sometimes toxic and even medical waste are released directly into the planet's ecosystems. Water pollution happens when hazardous chemicals and toxins contaminate water sources, seriously lowering water quality which, in turn, harms ecosystems and human health. Water can be easily contaminated with various toxic substances and hazardous compounds from factories, cities and farms since these dissolves in it much more easily than in any other fluid on Earth[1].

According to the World Health Organization (WHO), around 2 billion people worldwide consume water that is contaminated.

- Drinking water that contains hazardous micro-organisms can spread diarrhea and diseases such as cholera. Every year, polluted drinking water causes 485,000 diarrhea-related deaths.
- 368 million people use unsafe sources of water.
- In addition, 80% of the waste in the water comes from the land.
- Annually, ocean waste kills almost a million seabirds and marine life.

There are many causes of water pollution. Industries and industrial sites across the world are a major contributor to water pollution. The increase in industrial set-ups has led to the increased production of industrial wastes. These industrial wastes cause major environmental havoc by polluting the water, air and soil. The quality and quantity of wastewater generated depends on the type of industry: it can contain non-biodegradable waste such as heavy metals, pesticides, plastic etc. and biodegradable compounds such as paper, leather, wool etc. Industrial wastewater can be toxic, reactive, carcinogenic or ignitable[2].

Agriculture plays a major role in water pollution. Farms discharge large quantities of agrochemicals, organic matter, drug residues, sediments and saline drainage into water bodies. In order to protect their crops from bacteria and insects, farmers often use chemicals and

pesticides. When these substances seep into the groundwater, they can harm animals, plants and humans. Additionally, when it rains, the chemicals mix with rainwater, which then flows into rivers and streams that filter into the ocean, causing further water pollution[3].

Releasing sewage into rivers introduces a large amount of nutrients into the water. This process, known as eutrophication, can have serious consequences. 'When sewage is released into rivers, it contains a lot of nitrogen and phosphorous. 'A large amount of algae has an impact on the rest of the ecosystem, such as blocking out the light that plants need for photosynthesis. When these plants, and the algae itself, start to die, they are eaten by a lot of bacteria which reduces oxygen in the water, killing fish and other organisms.

INDUSTRY	MAJOR WATER POLLUTANTS
Textile Industry	Sodium Hydroxide, Surfactants, Hydrogen peroxide, Sodium Silicate, high pH NaOH
Petrochemical	benzene, ethylene oxide, formaldehyde, chloroprene, PFAS, vinyl chloride, and trichloroethylene
Dye Manufacturing	Copper, Salt, Sulfides, Colour, Formaldehydes
Plastic Industry	Perfluorooctanoic acid (PFOA), lead, mercury, cadmium, diethylhexyl phthalate
Paint manufacturing	Chromium, zinc, lead, volatile organic compounds (VOCs)
Agriculture	Fertilizers, pesticides, insecticides

Table 2: Major water pollutants from various Industry

Nowadays great attention has been focused on elimination of the effluents due to their potential toxicity and visibility problems. Various methods of treatment for effluents removal are adopted in order to decrease their impact on the environment. These methods include adsorption, coagulation/flocculation, photo-catalytic decolonization, ozonation, microbial decomposition, wet air oxidation, sono-chemical and electrochemical methods. Among various methods of dye removal, adsorption has been reported to be the most effective method that provides promising results[4].

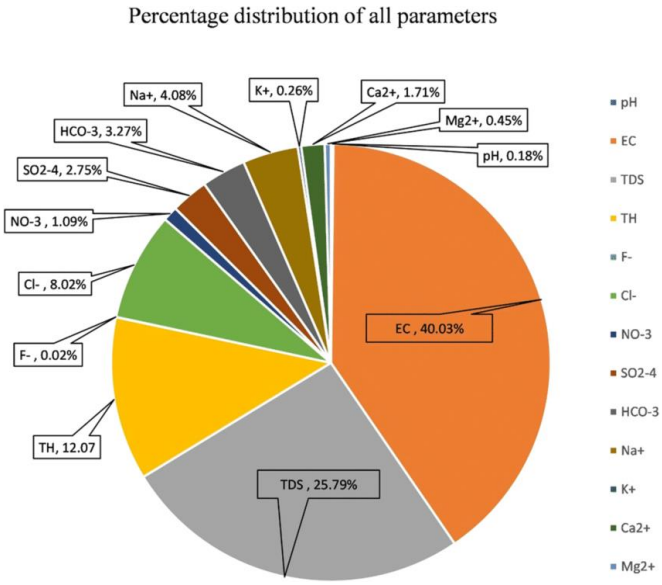


Figure 1: various water pollutant in Waste-Water

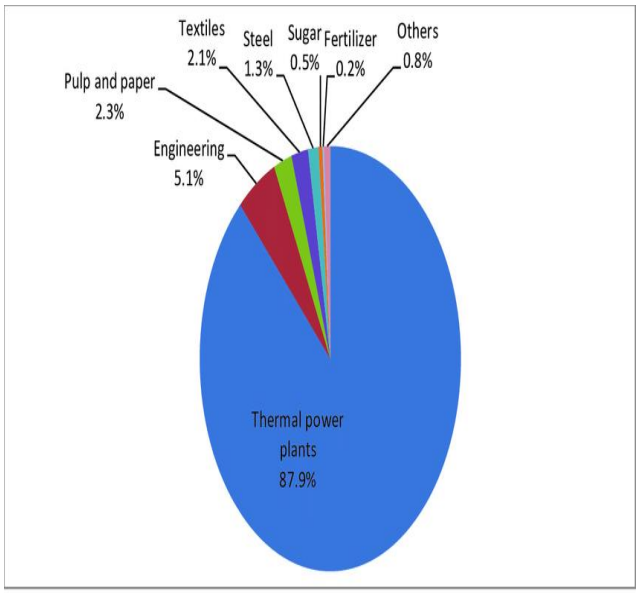


Figure 2: Pollutant from various Industry

Nanotechnology has made significant strides in water treatment, offering innovative solutions to improve water quality. It allows the development of nano-materials like nano-adsorbents, nano clay, nano-composites, catalysts, reagents, and many more, which are the most efficient tools discovered till now. Here are some key aspects related to nanotechnology in water treatment: Silver, Copper, and Zero-Valent Iron (ZVI) Nanoparticles: Researchers are exploring the use of these nanoparticles for water purification. Their large surface-to-volume ratio enhances the adsorption of chemical and biological particles, making them effective in removing contaminants[5]. Nano-membranes: These specialized membranes have nanoscale pores that allow selective filtration. Nano-membranes can remove impurities, bacteria, and even viruses from water. Nano-adsorbents: Nano-materials with high adsorption capacity can capture pollutants. They can be used to remove heavy metals, organic compounds, and other harmful substances from water. Nanomaterials are very useful for removing any emerging pollutants like pharmaceuticals, trace elements, and particulate matter in the range of 0.1-651mg/g in wastewater[6].

CHAPTER-2

Aims And objectives

2. Aims And objectives:

Aims & Objectives of the proposed work:

1. Synthesis of Nano adsorbent for wastewater remediation purposes.

2. Synthesis and characterization of nano adsorbent.

3. Performance study and removal efficiency study of the nano adsorbent.

4. Focusing on process development for removing contaminants to obtain contaminant free water.

CHAPTER-3

Literature Review

3. Literature Review:

Al-Ghouti et. al. (2020) Adsorption is a widely used separation and purification process, where physical or chemical bonds form between a solid medium and a fluid. Adsorption isotherm models help predict adsorption mechanisms and determine solid-water distribution coefficients. This review paper discusses the use of mono/multi-parametric isotherm models and their applications. It critically reviews 15 mono-parametric models and 10 multi-parameter models, using mathematical error functions for optimization. The paper also discusses the importance of understanding equilibrium data for adsorption data optimization[7].

Al-Maliky et. al. (2021) The study determined the pH point of zero charge (pHpzc) of concrete particles using the Mass Titration method. The adsorbent removed fluoride from water, providing insight into the attraction and repulsion between the adsorbent and adsorbates[8].

Rakhshaee et. al. (2011) The removal of methylene blue (MB) from aqueous solutions by stabilized Fe3O4 nano-particles with apple waste pectin increased due to crosslinking agents. Thermodynamic studies showed that adsorption equilibrium constant and maximum capacities increased with temperature, with FN-PAA having the highest rate constants. The adsorption force arrangement of MB was obtained as FN-PAA > FN-PAG > FN-PA[9].

Anoob et. al. (2024) Clean water is crucial for human health and is the 6th goal of the United Nations' sustainable development goals. Pharmaceutical contaminants are major pollutants in water bodies worldwide. Efficient and sustainable treatment is challenging due to their complex chemical compositions and cost. This review explores innovative applications of nanotechnology-based adsorption techniques, focusing on Carbon nanotubes (CNTs) as a nonadsorbent with higher potential. Implementing these treatments can help achieve the Sustainable Development Goals (SDGs) for the world[10].

Kumari et. al. (2019) Nanotechnology, a promising and underexplored field, has the potential to revolutionize waste water treatment. This review highlights the potential of nano-particles (NPs) in advancing waste water treatment and enhancing water supply. It discusses the concept of adsorption and various nano-adsorbents used in waste water treatment. The review also discusses the harmful effects of dyes, pesticides, and heavy metals in waste water

and the various adsorbents researchers use to efficiently remove them. The review establishes the potential of nano-adsorbents for waste water treatment[11].

Kyzas et. al. (2015) This review article discusses the potential of nanomaterials as nanoadsorbents, a promising technique for decontaminating wastewater from dyes and heavy metals. It evaluates the advantages and drawbacks of various nanoadsorbents, their implications for public health, and their potential for environmental sustainability[12].

Ahmadi et. al. (2020) This research aimed to optimize the removal of Acid Blue 92 (AB92) dye from synthetic effluents using neodymium oxide nanoparticles. The adsorption process was optimized using central composite design based on response surface methodology (RSM). The optimal conditions were pH = 3.15, AB92 concentration = 138.5 mg/L, nanoadsorbent dosage = 0.83 g/L, and contact time of 50 minutes. The developed model was significant for AB92 adsorption at a 95% confidence level[13].

Albatrni et. al. (2021) This review paper compares two wastewater treatment technologies for mercury removal: adsorption and membrane separation. Adsorption yields high percentage removals and selectivity, while membrane separation offers low capital and operating costs. Both techniques can be enhanced with functional groups like thiols. Adsorption offers benefits like low capital and operating costs, ease of operation, and potential applications in solid media. The adsorption process is considered the feasible option for mercury removal[14].

Kumar et. al. (2014) The study demonstrates that single-layer graphene oxide and manganese ferrite magnetic nanoparticle hybrids possess excellent adsorption properties for the efficient removal of heavy metals from contaminated water. The nanohybrids were characterized using various methods, including atomic force, scanning electron microscopy, Raman spectroscopy, X-ray diffraction, and surface area measurements. Their reusability, magnetic separation ease, high removal efficiency, and fast kinetics make them attractive low-cost adsorbents[15].

Sharma et. al. (2015) The 21st century's challenge is providing clean and affordable water by protecting and purifying polluted waters. Advances in carbon- and iron-based nanomaterials, such as graphene-carbon nanotubes-iron oxides, have been made to efficiently remove pollutants and inactivate viruses and bacteria in water. These nanostructures exhibit large surface areas and sorption sites, but challenges remain in implementing this technology in real water treatment[16].

enu et. al. (2017) Heavy metals in wastewater pose a significant threat to humans and aquatic ecosystems. Adsorption is a cost-effective and eco-friendly method for removing these metals. Commercial and natural bioadsorbents are used, with high removal capacity, particularly for chromium, cadmium, and copper. This review article compiles information on these adsorbents[17].

Ain et. al. (2020) This study demonstrates a simple and fast method for synthesizing magnetic graphene oxide (MGO) by combining iron particles with graphene oxide. The adsorption performance of MGO was evaluated using various parameters, and the maximum adsorption capacities were found to be 200, 24.330, 62.893, 63.694, and 51.020 mg/g for heavy metal ions. The study also examined MGO's action against microbial activity, proving it as a competent adsorbent and disinfectant for safe drinking water[18].

Abdel-Fadeel et. al. (2022) This project presents an eco-friendly method for removing toxic dyes like Brilliant Green and Acid Red from aquatic solutions using Halloysite nanoclay as an absorbent surface. The process involves adsorption of dyes on the HNC solid phase, with a capacity of 12.5 mg/g for A.R dye and 13.9 mg/g for B.G dye at optimal conditions. The kinetic and thermodynamic data confirm the pseudo-second-order kinetic model's ability to describe the adsorption process[19].

Zhang et. al. (2019) Zinc oxide/polypyrrole nanocomposites were fabricated and analyzed for their ability to remove brilliant green from aqueous phase. The nanocomposites showed high adsorption capacity, with a maximum of 140.8 mg/g at room temperature. Thermodynamic parameters confirmed the spontaneous and endothermic nature of brilliant green adsorption. Reuseability of the nanocomposites showed potential for dyeing effluent purification[20]

Paul et. al. (2024) The pharmaceutical and textile industry faces increasing environmental threats, necessitating sustainable solutions. A bio-nanocomposite (ZnMg@PH) was prepared using Phyllanthus sp. leaf extract, zinc oxide, and magnesium doping for removing crystal violet, brilliant green, and diclofenac sodium. The nanosorbent showed substantial pore volume, a hexagonal crystalline lattice, and excellent adsorption-desorption efficiency. Its thermodynamic nature was endothermic and spontaneous, making it a greener alternative for effective removal of dyes and drugs[21].

Nasiri et. al. (2022) Methylcellulose (MC) is a popular commercial cellulose ether due to its biodegradability, biocompatibility, and toxicity. A unique magnetic nano-adsorbent,

CoFe2O4@MC/activated carbon, was synthesized for Reactive Red 198 (RR198) dye removal. The nano-adsorbent was characterized using various techniques, and its crystal structure was found to maintain its properties. The adsorption process was found to be exothermic, with maximum removal efficiencies of 92.2% and 78% for synthetic and real wastewater samples[22].

Baig et. al. (2020) The synthesized nickel (II) oxide nanoparticles were used for the adsorptive removal of hazardous azo dye from aqueous solutions. Advanced analytical techniques were used to characterize the nanomaterial. The adsorption process was tested, and the nanomaterial showed fast removal of 95.22% methyl orange at pH 6 with a 0.05 g dose. The optimum conditions for dye removal were optimized using the Taguchi L9 (3^3) orthogonal array experimental design. The regeneration capacity of the nanoparticles proves its importance in industrial wastewater treatment[23].

Baig et. al. (2020) This study synthesized zinc oxide, copper oxide, manganese dioxide, and magnesium oxide nanoparticles from Leucaena leucocephala leaves for the removal of Reactive Golden Yellow-145 (RY-145) and Direct Red-31 (DR-31) dyes. The nanoparticles were characterized using scanning electron microscope (SEM) and Fourier Transform Infrared Spectroscopy (FTIR). The adsorption capacities of the nanoparticles were optimized for RY-145 and DR-31, with MgO having the highest adsorption capacities. The adsorption processes were well-fitted to pseudo-second-order kinetics, and both dyes followed a Langmuir isotherm. Thermodynamics investigations revealed spontaneous dye adsorption onto MgO and MnO_2, with ZnO being non-spontaneous in both dyes. The maximum desorption of 78-86% was achieved using 0.2 N and 0.4 N NaOH for adsorbed RY-145 and DR-31 dyes. This study determines the potential efficacy of green nano-adsorbents for the removal of dye from textile wastewater[24].

CHAPTER-4

Wastewater treatment Methods

4. Wastewater treatment Methods:

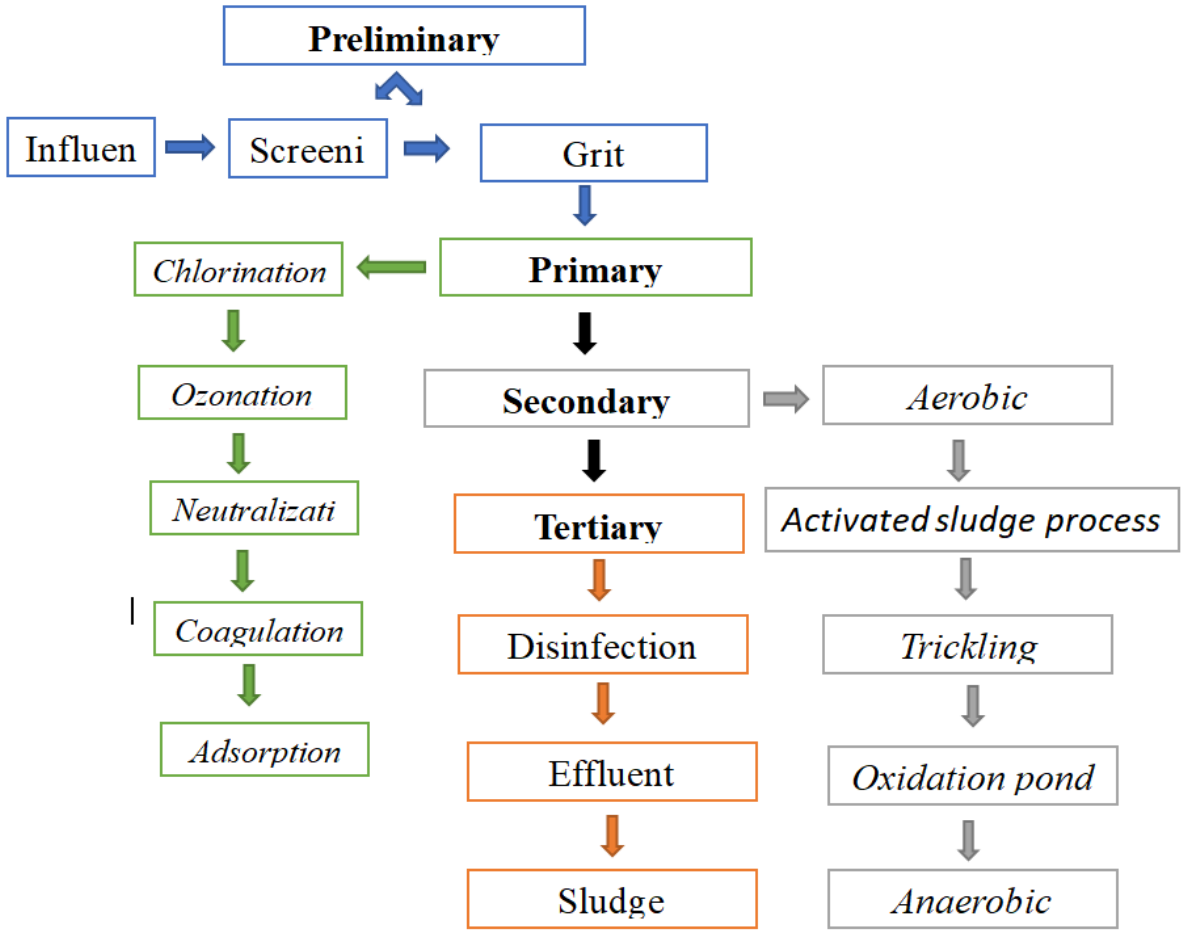


Figure 3: Various Wastewater Treatment

4.1. Preliminary treatment:

The purpose of preliminary treatment is to get the wastewater ready for further treatment steps. The goal of the preliminary phase is to safeguard the infrastructure and water treatment equipment, increasing their longevity and guaranteeing their long-term viability and effectiveness. There are few steps in preliminary treatment such as:

4.1.1. Sedimentation: Sedimentation, a well-utilized method by municipalities in water treatment processes, involves the physical removal of suspended solids from water through the force of gravity. This process is essential for achieving clean water standards, as it effectively separates particles based on their size and weight. Municipalities employ sedimentation tanks, also known as primary clarifiers, to facilitate this process. These tanks provide the necessary detention time, typically around two hours, for the suspended solids to settle at the bottom of the tank due to gravity[25]. As the sewage slowly passes through these tanks, the heavier

particles gradually sink, ensuring that the water becomes clearer and cleaner. This gradual settling process is vital for wastewater treatment facilities to effectively purify water before further treatment steps. Proper sedimentation plays a crucial role in the overall efficiency and success of water treatment operations, demonstrating the significance of this physical water treatment process in maintaining water quality standards and safeguarding public health and the environment[26].

4.1.2. Screening: Screens made of long, closely spaced, narrow metal bars block floating debris such as wood, rags, and other bulky objects that could clog pipes or pumps. Wastewater flows through the screen, which captures larger objects. The size of the openings or mesh depends on the type of screen and the specific needs of the treatment plant. Captured debris is collected by mechanical systems such as conveyors or rakes and is then transported to a disposal area. For bar screens, this might involve a rake mechanism that lifts the debris out of the water and into a trough for removal[27]. Some screens, especially mechanical ones, have built-in cleaning mechanisms to prevent clogging and ensure consistent operation. For example, rotating screens might have brushes or sprays to clean the mesh. Regular maintenance is required to ensure screens are functioning properly. This includes checking for clogs, ensuring that cleaning mechanisms are working, and replacing worn or damaged components[28].

4.1.3. Aeration: Aeration is a fundamental and indispensable process in the realm of water treatment, playing a crucial role in wastewater treatment facilities. This critical method involves the meticulous blending of water with air to effectively eradicate dissolved gases from the water column. These unwanted gases can comprise a range of substances such as carbon dioxide, volatile organic chemicals (VOCs), and an array of other volatile compounds that can compromise the water quality. By infusing air or oxygen into the water mass, aeration serves to alleviate issues related to odor, taste, and color that may otherwise impair the water's properties. The central aim of aeration revolves around enhancing the dissolved oxygen levels within the water, a pivotal aspect that fosters the growth and sustenance of aerobic bacteria. These beneficial microorganisms rely on oxygen to facilitate the decomposition of organic matter and the abatement of pollutants present in the water body. Furthermore, aeration acts as a catalyst in removing specific substances like iron and manganese by catalyzing their oxidation process. Notably, this process also proves to be instrumental in the elimination of harmful elements such as hydrogen sulfide, ammonia, nitrogen compounds, phosphorus, as

well as contaminants like pesticides, herbicides, heavy metals, and even radioactive particles that may pose a risk to environmental and human health alike**.**[29].

4.1.4. Flotation: Flotation, a separation process with its roots in mineral processing, has stood the test of time as an efficient technique. The crux of this method lies in the introduction of gas bubbles to serve as the medium of transport. By strategically utilizing these bubbles, suspended particulate matter, which exhibits hydrophobic properties or has been conditioned to do so, becomes attached to them. This unique attachment propels the particles towards the surface of the water solution, defying the natural pull of gravity.

The versatility of flotation extends beyond mere separation - it has found its niche in the recovery of heavy metal ions through various mechanisms. Depending on the specific requirements, ion flotation, precipitate flotation, or sorptive flotation, aided by adsorbents such as powdered activated carbon, zeolites, and goethite, prove to be effective avenues. These myriad mechanisms showcase the adaptability and efficiency of flotation in different scenarios[30].

Noteworthy methods like dispersed-air flotation, which encompasses electroflotation, and dissolved-air flotation (DAF) have gained prominence in this realm. Among these, DAF, grounded in Henry's law, emerges as a widely used technique in the domain of water treatment. Its prevalence underscores the importance and effectiveness of flotation, particularly in the context of environmental preservation and resource reclamation[31].

4.2. Primary Treatment:

Following the completion of the Preliminary Treatment phase, the wastewater progresses to the Primary Treatment stage where a series of essential processes are carried out to enhance the overall quality of the water. At this point, the main objectives remain consistent with the aim of diminishing contaminants present in the water, as well as effectively managing floating debris and debris that settles due to gravitational forces[32]. Essentially, the primary treatment plays a crucial role in laying the groundwork for subsequent treatment procedures by significantly reducing the levels of total suspended solids (TSS) and biochemical oxygen demand (BOD) in the wastewater. It is imperative to note that TSS refers to the particles that are suspended within the wastewater, while BOD is a key indicator of the amount of pollutants that are being absorbed by the water. By focusing on these parameters, the initial treatment

phase can successfully achieve a removal rate of approximately 25–40% for BOD and 50–70% for TSS, thereby paving the way for the upcoming secondary treatment phase. This primary treatment phase acts as a pivotal component in the overall wastewater treatment process by substantially improving the quality of the water before it advances to subsequent treatment stages, ensuring that the water is in an optimal condition for further processing[33].

4.2.1. Chlorination: Chlorination is a chemical disinfection method used to treat water and make it safe for public consumption. The process involves adding various types of chlorine or chlorine-containing substances to the water source to oxidize and disinfect it. Chlorination is effective against bacteria and viruses, making it a reliable method for disinfection. While it may not inactivate all microbes (some protozoan cysts are resistant), it is still valuable for eliminating many other contaminants. Chlorination is relatively inexpensive and easy to implement compared to other water treatment methods. It's especially useful in emergency situations, where it can quickly reduce pathogen overload[34].

4.2.2. Ozonation: Ozonation is a highly effective water treatment process that harnesses the potent oxidizing properties of ozone, a robust oxidant, to target and eliminate a wide range of contaminants present in water sources. By utilizing the exceptional oxidative power of ozone, this method works efficiently to degrade and remove pollutants in water through a series of chemical reactions. When ozone is introduced into the water supply, it initiates a rapid and thorough oxidation process that actively breaks down harmful substances like bacteria, viruses, and metals present in the water system. Through a series of redox reactions, ozone, in its molecular form (O_3), disrupts the structural integrity of organic matter found in the membranes of microorganisms, leading to the destruction and elimination of these troublesome contaminants. Additionally, ozone exhibits the capacity to precipitate iron, manganese, and copper, transforming them into solid particles that can be easily separated and filtered out from the water using standard mechanical filtration methods or specific activated carbon filters. This comprehensive treatment approach not only ensures the removal of diverse pollutants but also enhances the overall quality of the treated water, making it safer and suitable for various application[35].

4.2.3. Neutralization: Neutralization is a crucial process that focuses on modifying the pH levels of either acidic or alkaline wastewater towards a neutral state. Through careful adjustment, the aim is to align the pH to a level that is considered safe for eventual discharge into water bodies or for subsequent treatment processes. This involves incorporating specific

neutralizing agents into the wastewater to effectively bring about the desired pH balance. By achieving this equilibrium, the wastewater can be rendered less harmful and more environmentally friendly[36]. Moreover, neutralization plays a pivotal role in ensuring compliance with regulatory standards and guidelines governing the release of wastewater into the environment. The selection of appropriate neutralizing agents is based on various factors, including the initial pH of the wastewater, the desired target pH level, and the specific characteristics of the contaminants present in the water. It is crucial to carefully monitor the neutralization process to guarantee its effectiveness and to prevent any adverse impacts on the environment. Overall, neutralization serves as a fundamental step in the wastewater treatment process, contributing significantly to the protection of water resources and ecosystem health[37].

4.2.4. Coagulation: Coagulation involves adding iron or aluminium salts (such as aluminium sulphate, ferric sulphate, ferric chloride, or polymers) to water. These chemicals are called coagulants, and they have a positive charge. The positive charge of the coagulant neutralizes the negative charge of dissolved and suspended particles in the water. When this reaction occurs, the particles bind together, forming larger particles or flocs. This process is sometimes also called flocculation. The larger flocs are heavy and quickly settle to the bottom of the water supply. This settling process is called sedimentation[38].

4.2.5. Adsorption: Adsorption is the mechanism in which a molecule or ion present in a gaseous or liquid bulk phase remains on a solid surface. Here molecule or ion is an adsorbate and solid used for adsorption is known as adsorbents[39]. Adsorption is a fascinating phenomenon that occurs when tiny dissolved molecules or fine particles found in water interact with and bond to the surface of a specialized filter medium known as an adsorbent. This interaction is governed by intricate forces, particularly the attractive electrical forces and energy variances, such as the well-known van der Waals forces. These forces play a crucial role in facilitating the adhesion of molecules to the filter medium's surface, creating an effective bond that allows the particles to adhere and remain in place. The process of adsorption is essential in various applications, ranging from water treatment to air purification, as it enables the removal of contaminants and impurities by trapping them effectively on the filter surface. Through this mechanism, adsorption contributes significantly to enhancing the quality and purity of water and other fluids processed through suitable filter media, thereby ensuring better environmental and health outcomes. The intricate interplay of forces, both chemical and

physical, within the adsorption process underscores the complexity and effectiveness of this purification technique, highlighting its significance in enabling the separation and removal of undesirable components from water sources. As a fundamental concept in filtration and purification technologies, adsorption has been widely studied and harnessed to develop advanced filtration systems that offer efficient and reliable treatment solutions for various industries and applications[40].

4.3. Secondary Treatment

4.3.1. Aerobic: Aerobic wastewater treatment is a biological technique that uses oxygen to break down organic contaminants and other pollutants such as nitrogen and phosphorus[41]. Treatment of sewage water from industries or domestic sources is becoming increasingly crucial in modern times due to the growing concerns over environmental pollution. In addressing the challenge of treating concentrated industrial wastewater, the adoption of aerobic treatment methods has emerged as a viable alternative to the slower anaerobic processes commonly employed. This shift towards aerobic treatment is primarily motivated by its cost-effectiveness in terms of operation and maintenance, making it an appealing choice for businesses seeking sustainable and efficient solutions. The escalating interest in aerobic wastewater treatment as a reductive medium underscores its potential to significantly reduce contaminants in a manner that is both practical and cost-efficient. Notably, this method offers a readily accessible means of effectively degrading pollutants, which contributes to its rising popularity as an environmentally friendly solution for managing wastewater effectively. By leveraging the inherent advantages of aerobic treatment, industries and local authorities can address the pressing need for more efficient and sustainable sewage treatment practices. The ease of implementation, combined with the proven effectiveness of aerobic treatment in degrading contaminants, further reinforces its status as a preferred choice for mitigating the environmental impact of wastewater discharges. In essence, the widespread adoption of aerobic treatment signifies a positive step towards achieving a cleaner and more sustainable approach to managing industrial and domestic wastewater.[42]

4.3.2. Activated sludge process: The activated sludge process is a biological wastewater treatment method used to remove organic pollutants from sewage or industrial wastewaters.

The process begins in an aeration tank where air (or oxygen) is injected into the wastewater. This promotes the growth of aerobic microorganisms (bacteria and protozoa) that can digest

organic matter. These microorganisms clump together by a process called flocculation. As they do so, they entrap fine particulate matter, resulting in a liquid that is relatively free from suspended solids and organic material. Next, the wastewater flows into a settling tank. Here, the biological flocs (also known as the "sludge blanket") settle to the bottom, separating them from the clear treated water. Part of the waste sludge is recycled back to the aeration tank to maintain the microbial population. The remaining waste sludge is removed for further treatment and disposal. There are various plant types that use the activated sludge process, including package plants, oxidation ditches, deep shaft/vertical treatment, surface-aerated basins, and sequencing batch reactors (SBRs). Different methods are used for aeration, such as diffused aeration, surface aerators (cones), or, rarely, pure oxygen aeration.

4.3.3. Trickling filtration: The trickling filter process is another fascinating method used in wastewater treatment. A trickling filter is a fixed-bed bioreactor that plays a crucial role in secondary wastewater treatment. It removes coarse particles, suspended organic and inorganic waste, and small colloids from the primary effluent. Unlike the activated sludge treatment, which uses a suspended growth system, the trickling filter follows an attached growth system. In this system, microbial slime (also known as biofilm) grows on a medium to degrade waste from primary sewage[43].

4.3.4. Oxidation pond: An oxidation pond, also known as a lagoon or water stabilization pond, is a fascinating secondary wastewater treatment method. An oxidation pond stabilizes domestic, trade, and industrial waste using microbial interactions (primarily bacteria and algae). The treatment of wastewater using the interaction of bacteria, algae, and sunlight inside shallow confinement known as oxidation pond is one of the techniques of wastewater treatment. The essence of treating wastewater and effluent using the oxidation pond is basically structured to reduce and remove the pathogens and organic matters contained in wastewater. The wastewater stabilization pond has numerous advantages such as adequate treatment compartments, accurate balancing of temperature and other parameters as dissolved oxygen (DO), nutrient and organic matters[44]. It resembles a large, shallow pond with a water depth of 2-6 feet. Sunlight and oxygen are essential for the secondary treatment of organic and inorganic waste from raw sewage and industrial effluents.

Bacteria in the oxidation pond oxidize organic waste from domestic and industrial sewage, releasing carbon dioxide, water, and ammonia. Algal growth occurs in the presence of sunlight. Algae utilize inorganic waste produced during organic matter decomposition and release

oxygen. Algae and bacteria work together: Bacteria use oxygen from algae to oxidize biodegradable organics, while algae reduce inorganic wastes like nitrogen and phosphorus. Due to this dual oxidation-reduction process, oxidation ponds are sometimes called “Redox ponds.” The sludge from oxidation ponds can be used as manure for irrigation processes.

4.3.5. Anaerobic digestion: Anaerobic digestion is a fascinating biological process used in wastewater treatment. Anaerobic digestion involves the degradation of organic material by anaerobic bacteria (in the absence of oxygen). The process produces **biogas**, primarily composed of methane (CH_4) and carbon dioxide (CO_2). Anaerobic digestion occurs naturally in various environments, such as the stomachs of ruminants, marshes, sediments in lakes, municipal landfills, and even municipal sewers. Its environmental benefits include efficient removal of biodegradable organic compounds and the production of valuable biogas. significant sludge, anaerobic treatment minimizes excess sludge production[45].

Process Steps: **Acidification**: Organic material undergoes acidification, breaking down into simpler compounds. **Lysis/Liquefaction**: During this phase, acid digestion occurs, further breaking down the material. **Gasification**: Acids are converted into methane (CH_4) and carbon dioxide (CO_2), forming biogas.

4.4. Tertiary Treatment:

Tertiary wastewater treatment plays a crucial role in the wastewater treatment process by providing the final stage of purification. Following primary and secondary treatments that effectively eliminate a substantial amount of contaminants, tertiary treatment takes water quality to a higher level by applying advanced techniques. This stage rigorously removes remaining impurities, ensuring that the treated water meets stringent quality standards before being released back into the environment[46]. Moreover, tertiary treatment can effectively remove microorganisms and other pollutants that have managed to persist through the initial treatment stages. By utilizing processes such as filtration, disinfection, and advanced oxidation, tertiary treatment ensures that the treated water is safe for various purposes, including discharge into water bodies or reuse for irrigation and industrial processes. Overall, the meticulous nature of tertiary treatment not only safeguards the environment but also contributes to public health by providing clean and safe water resources[47].

4.4.1. Disinfection: Water disinfection is a fundamental process undertaken to eradicate pathogenic microorganisms present in water, thus rendering it safe for human consumption. By effectively eliminating these harmful pathogens, water disinfection significantly contributes to safeguarding public health and preventing the transmission of waterborne diseases. This crucial practice involves the application of various methods, such as the use of chemicals or ultraviolet (UV) light, to target and destroy bacteria, viruses, and other contaminants in water sources. Through the meticulous process of treating water, whether by introducing disinfecting agents or employing advanced technology like UV radiation, the ultimate goal is to ensure that water is free from harmful impurities and remains safe for consumption. By disrupting the growth and reproduction of microorganisms that could pose threats to human health, water disinfection stands as a pillar of protection, guaranteeing that the water we drink is devoid of any potentially hazardous elements that can compromise our well-being. Moreover, the practice of water disinfection not only serves to purify water but also acts as a preventative measure, fortifying our defense against waterborne illnesses and upholding the standard of water quality essential for sustaining healthy communities[48], [49].

4.4.2. Oxidation: Oxidation in water treatment is a crucial process that utilizes oxidizing agents to convert contaminants into less dangerous or non-toxic compounds. It reduces both organic and inorganic impurities, including viruses, heavy metals, and organic waste[50].

Methods of Oxidation:

- **Chemical Oxidation**: Various chemicals (such as chlorine, ozone, or hydrogen peroxide) are used to facilitate oxidation reactions.
- **UV Light**: Ultraviolet (UV) light can also induce oxidation by generating reactive species.
- **Advanced Oxidation Processes (AOPs)**: AOPs involve hydroxyl radicals (·OH) and other oxidative species to efficiently break down contaminants[51]

4.4.3. Activated carbon treatment: Activated carbon plays a crucial role in water treatment as it removes impurities and contaminants. Activated carbon works through a process called adsorption. When water flows through activated carbon, its porous structure attracts and binds to impurities and particles present in the water. The impurities are effectively trapped within the carbon's pores and removed from the water[52].

4.4.4. Ion exchange: Ion exchange is a powerful water treatment process that effectively removes undesirable ionic contaminants from water by exchanging them with other ionic substances. The process works by **exchanging** these ions with others that have a similar charge[53].

- Two groups of ions are involved:
    - **Positively charged ions (cations)**: These are exchanged during water treatment.
    - **Negatively charged ions (anions)**: They are also exchanged to remove contaminants like nitrate, arsenic, sulfate, and fluoride.

- Types of Ion Exchange Resins:
    - Strong Acid Cation (SAC) Resins: These neutralize strong bases, replacing cations with hydrogen ions. They work across all pH ranges.
    - Strong Base Anion (SBA) Resins: They neutralize strong acids, commonly used in water softening and demineralization.
    - Weak Acid Cation (WAC) Resins: These neutralize strong bases and produce carbonic acid. They're efficient in regeneration.
    - Weak Base Anion (WBA) Resins: They remove acids like sulfuric, nitric, and hydrochloric acid[54].

CHAPTER-5

Experimental Procedures

5. Isotherm and kinetic Studies:

5.1. Isotherm: Adsorption process is considered as one of the most used separation and purification processes, in which adsorption occurs by the formation of the physical or chemical bonds between a porous solid medium and a mixture of liquid or gas multi-component fluid. By taking into consideration the equilibrium data and the adsorption properties of both the adsorbent and the adsorbate, adsorption isotherm models can describe the interaction mechanisms between the adsorbent and the adsorbate at constant temperature. Therefore, understanding modelling of the equilibrium data is a very essential way of predicting the adsorption mechanisms of various adsorption systems. It depends on the adsorbed species, adsorbate, adsorbent, and various physical properties of the solution including pH, ionic strength, and temperature[55].

Adsorption isotherms, which are a common name of equilibrium relationships, are essential for optimization of the adsorption mechanism pathways, expression of the surface properties and capacities of adsorbents, and productive design of the adsorption systems since they explain how pollutants interrelate with the adsorbent materials[56].

Adsorption Kinetics describes the rate at which solute is adsorbed and the resident time of the adsorbates on the solid-liquid interface. Adsorption isotherms play important role in determining the interaction between adsorbate and adsorbent and the optimum adsorption capacity of adsorbent. It could also be defined as the formation of layer of adsorbate on the surface of an adsorbent by the attraction of Van der Waals' forces. Adsorption isotherms are useful in describing the interaction between adsorbate and adsorbent. They play important roles in determining the optimum adsorption capacity of adsorbent and indicate how efficient an adsorbent can adsorb, and also allows an estimation of the validity of adsorbent's application optimum adsorption capacity of adsorbent and indicate how efficient an adsorbent can adsorb, and also allows an estimation of the validity of adsorbent's application[57].

5.2. Kinetic: The kinetic of the adsorption systems were studied using the pseudo-first-order, pseudo-second-order, Elovich, Avrami and fractional power models. Adsorption Kinetics is an important factor that defines the effectiveness of sorption. Kinetics of adsorption basically describes the rate at which solute is adsorbed and the resident time of the adsorbates on the

solid-liquid interface. Adsorption velocity depends upon the number of particles adsorbing on the adsorbent surface per second and the number of particles colliding in unit area per second[57].

5.1.1. Pseudo first order (Largergren model):

The model considers the rate of change that occurs in the uptake of adsorbate at a particular reaction time to be directly proportional to the difference in the concentration and rate at which the adsorbate is removed with time[58]. The model also known as Largergren model is represented by the equation below

$$\ln(q_e - q_t) = \ln q_e - k_1 \times t$$

Where:

q_e is the adsorption capacity of the adsorbent at equilibrium (mg.g-1)

qt is the adsorption capacity of the adsorbent at time t (mg.g-1)

Kt is the rate constant for pseudo first order adsorption (min-1).

When values of ln ($q_e - q_t$) were correlated linearly with t. The plot of log ($q_e - q_t$) versus t gives a relationship that is linear from which kt and qe can be determined from the slope and intercept of the plot.

5.1.2. pseudo–second-order kinetic model

The pseudo–second-order kinetic model is based on the assumption that the rate-limiting step is chemical sorption or chemisorption and predicts the behavior over the whole range of adsorption. In this condition, the adsorption rate is dependent on adsorption capacity not on concentration of adsorbate. One major advantage of this model over Lagergren first order is that the equilibrium adsorption capacity can be calculated from the model; therefore, there is theoretically no need to evaluate adsorption equilibrium capacity from experiment. [4]

$$\frac{t}{q_e} = \frac{1}{K_2} \cdot \frac{1}{qe^2} + \frac{1}{q_e}$$

5.2. pH effect test:

In preparation, a 5 ppm mother solution of dye was meticulously crafted. This solution was carefully dispensed into 7 separate containers, each receiving a 20 ml portion of the 5 ppm dye solution. To explore the impact of pH on dye concentration, each container was delicately adjusted to a different pH level. The containers were then left undisturbed for a period of 24 hours, allowing the dye solutions to settle and react accordingly. Upon completion of the incubation period, the concentration of dye in each container was delicately examined using UV vis spectroscopy to determine any variations that may have occurred due to the pH adjustments. This meticulous process allowed for a comprehensive assessment of the dye's behavior under different pH conditions, providing valuable insights into its stability and solubility characteristics.

5.3. Thermodynamic Analysis of Dye Adsorption:

The effect of temperature on the adsorption of dye onto GO-TiO_2-$MnFe_2O_4$ was investigated to understand the thermodynamic properties of the process. Adsorption experiments were conducted at temperatures of 17°C, 27°C, and 37°C. The equilibrium data were fitted to the Langmuir isotherm model, and the equilibrium constants KKK were derived for each temperature.

The Gibbs Free Energy change (ΔG°) was calculated using the formula:

$$\Delta G^\circ = -RT \ln K$$

The results indicated that ΔG° was negative at all temperatures, confirming that the adsorption process is spontaneous. The Van't Hoff equation was used to determine the enthalpy (ΔH°) and entropy (ΔS°) changes. A positive ΔH° value suggested that the adsorption process is endothermic, with increased adsorption efficiency at higher temperatures. The positive ΔS° indicated an increase in disorder or randomness in the system during adsorption.

These findings provide valuable insights into the nature of the adsorption process and suggest that temperature plays a significant role in optimizing dye removal. Further studies could explore the impact of other factors and different adsorbents to enhance the practical applications of dye adsorption technologies.

CHAPTER-6

Materials and methods

6. Synthesis of Nano-materials:

6.1. Materials & Methods Involved:

6.1.1. Material:

Graphene oxide (GO), Titanium dioxide (TiO_2), Ferric chloride ($FeCl_3$), Manganese sulphate ($MnSO_4$), Sodium hydroxide (NaOH), Brilliant Green Reagent, Methylene Blue, Hydrochloric Acid.

6.1.2 Preparation:

Preparation of Nano-Adsorbent:

0.5 g of graphene oxide was dispersed in 200 ml of water. The solution was magnetically agitated for 30 minutes, followed by 30 minutes of ultra-sonication. After that, 1 g of titanium oxide was added, and the mixture was once again magnetically stirred for 30 minutes before being subjected to 30 minutes of ultra-sonication and kept in magnetic stirring for 24 hours.

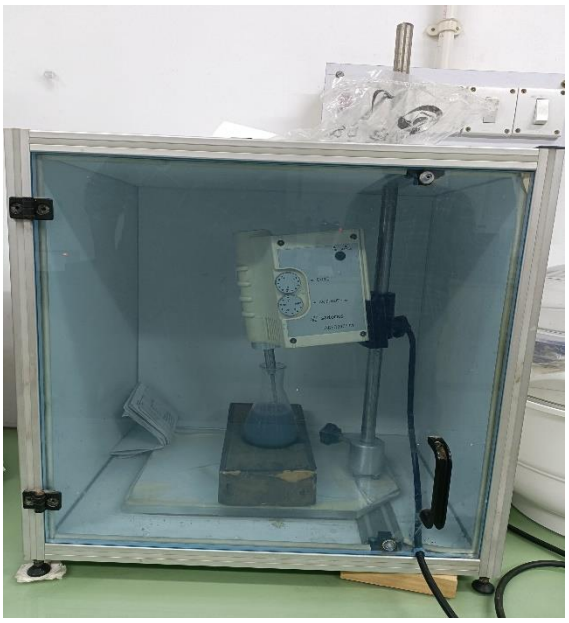


Figure 4 : Sonication Process



Figure 5: Stirring for 24 hour

The reaction mixture was subjected to the addition of 0.5 g MnSO4.H2O, followed by magnetic stirring for 30 minutes, and after that received 2 gm of Anh. Fecl3 addition. At that point, the pH measured of the reaction medium was 1.5, indicating it was highly acidic. The solution was

subsequently heated to 800ºC and kept there. 5M NaOH was added micro drop-wise to take the pH of the solution around 11.5 under continuous stirring and heating.



Figure 6: Neutralization using pH meter



Figure 7: vacuum filter

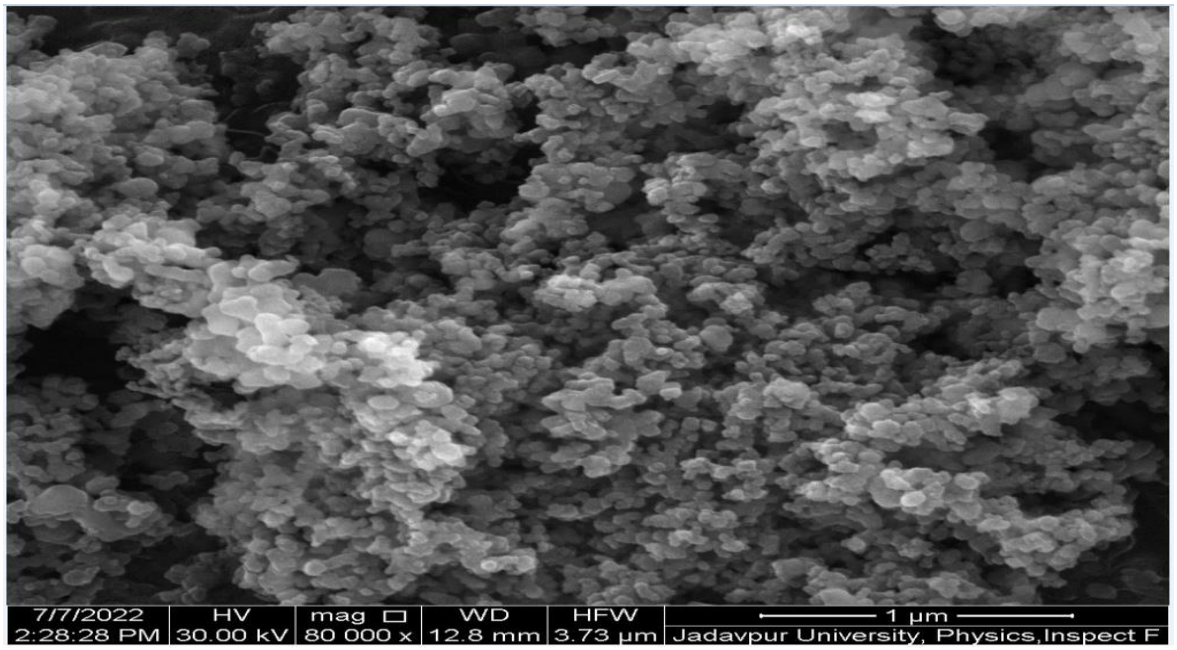
As it is a pH control reaction, to neutralize the solution simultaneously change the water of the solution and check the pH value using a pH pen, this process was carried forward until the pH value was achieved around 7. The final mixture was collected, centrifuged, and air-dried using a vacuum filter. Dried composite material is heated to 450ºC in the presence of air. After calcination, the composite material was mortared for use as an adsorbent.

CHAPTER-7

CHARACTERIZATION

7. Characterization:

7.1. FESEM Results and EDS analysis



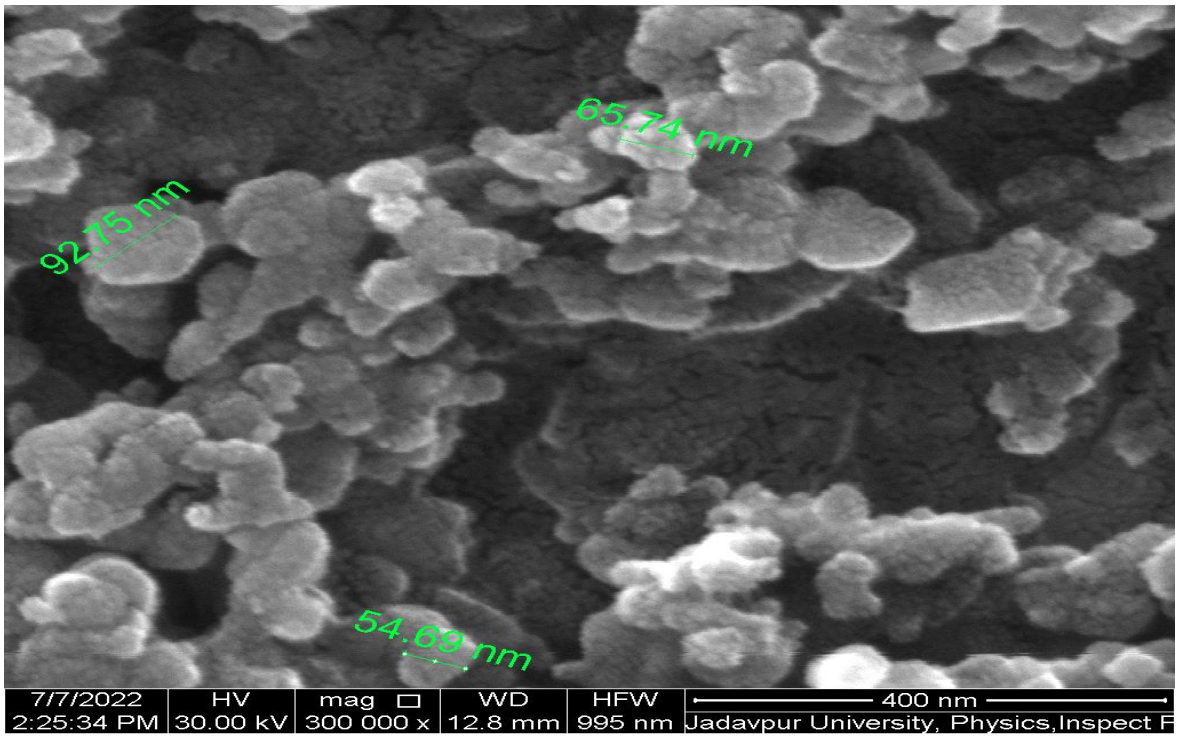
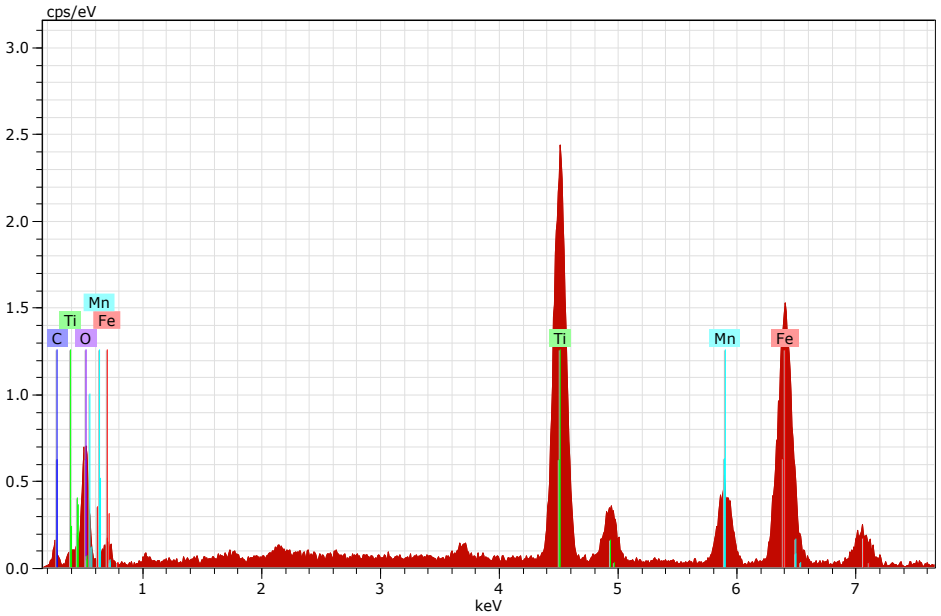
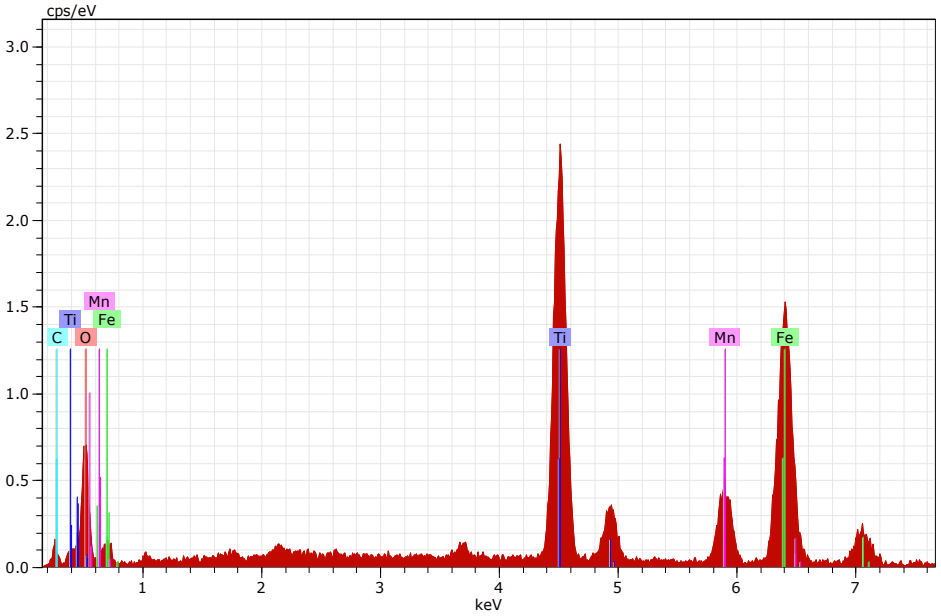


Figure 8 : **(a)Surface morphological characteristics (b) Particle size**

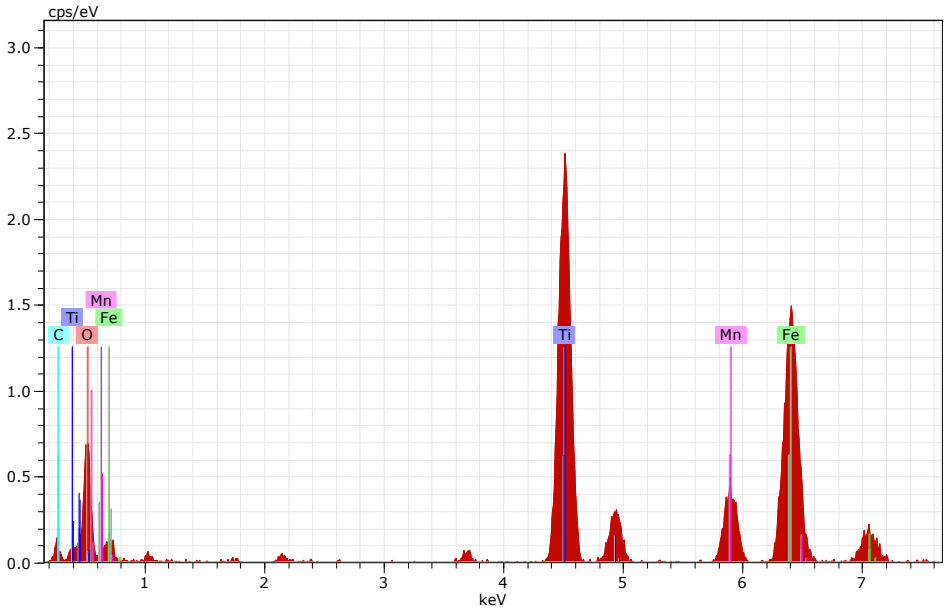
Application Note

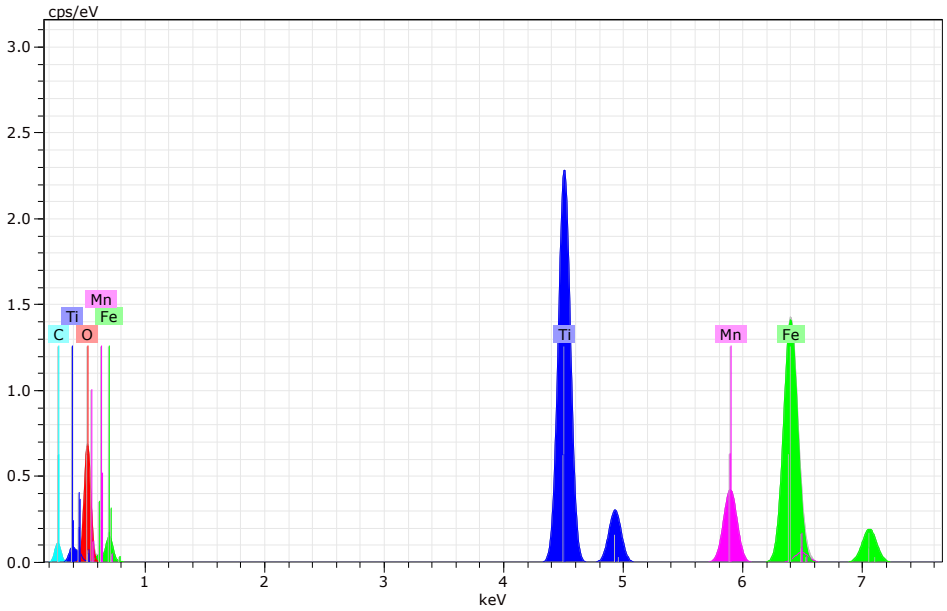
Company / Department





2/10/2023


cps/eV
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cps/eV
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Spectrum: EXTERNAL.txt

Element	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Compound	norm. Comp. C [wt.%]	Error (3 Sigma) [wt.%]
Oxygen	24.34	30.74	59.14		0.00	14.33
Iron	25.63	32.36	17.84	FeO	41.63	2.21
Titanium	22.51	28.43	18.28	TiO2	47.42	2.05
Carbon	0.00	0.00	0.00		0.00	0.00
Manganese	6.71	8.47	4.75	MnFe2O4	10.94	0.75
Total:	79.19	100.00	100.00			

FESEM analysis of the synthesized nanoparticles reveal the surface morphology of the particles, particles were mostly consisted of round shaped crystals with a size range of 50-90 nm. Elemental composition is also revealed from EDS Analysis of nano-particles. Table.10 shows that Ti, Mn, Fe content is around 47%, 11%, 41% respectively. EDS Analysis of coated membrane was also done. Elemental composition is also concurring with the successful synthesis of the nano-composite.

Element	Weight Percentage (%)
Titanium (TiO_2)	47.42
Iron (FeO)	41.63
Manganese ($MnFe_2O_4$)	10.94

Table 3: Analysis of SEM

7.2. FTIR ANALYSIS

Analysis of FTIR data of GO-TiO_2-$MnFe_2O_4$

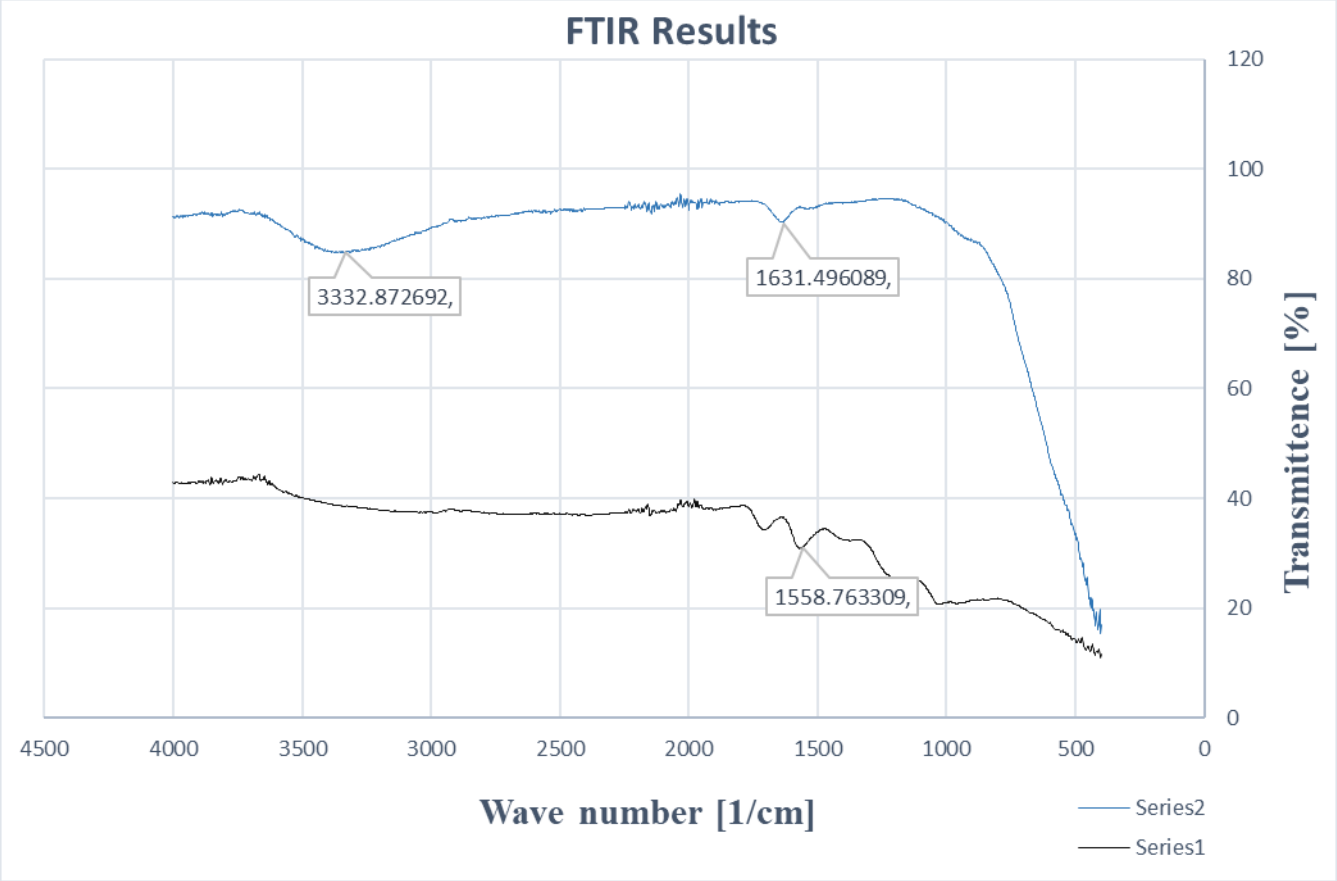


Figure 9: Analysis of FTIR data of GO-TiO_2-$MnFe_2O_4$

In the study of FTIR spectra of GO, TiO2, MnFe2O4, and GO-TiO2-MnFe2O4, various characteristic peaks were identified. The broad peaks at 3200 cm-1 were found to correspond to the stretching mode of O-H bonds, indicating the presence of OH groups in GO. The band observed at 1720 cm−1 was attributed to the carboxyl group, while a distinct sharp peak at 1615 cm−1 was linked to resonance peak due to the stretching and bending vibrations of water's OH groups. Furthermore, the peak detected at 1350 cm-1 was associated with the C-OH group, and the one at 1110 cm-1 was related to C-O-C stretching. Additionally, the peak seen at 1600 cm-1 corresponded to the vibrational mode of the C=O group. Notably, at 1680 cm-1, there was an indication of the presence of C=C. In the fingerprint zone, peaks ranging from 500 cm-

1 to 400 cm-1 were identified as Manganese Spinel Ferrite characteristics, while peaks at 1000 cm-1 and 800 cm-1 to 700 cm-1 were associated with Mn-Fe-O linkage, signifying two sets of peaks for tetrahedral and octahedral sites. The introduction of Ti doping led to differences in peak intensity compared to existing literature, further supporting the hypothesis. Notably, the formation of GO-Spinel Ferrite was attributed to peak shifts and the reduction in GO intensity as previously reported, supporting the conclusion that GO-Spinel Ferrite was indeed formed based on the observed data.

7.3. XRD Analysis:

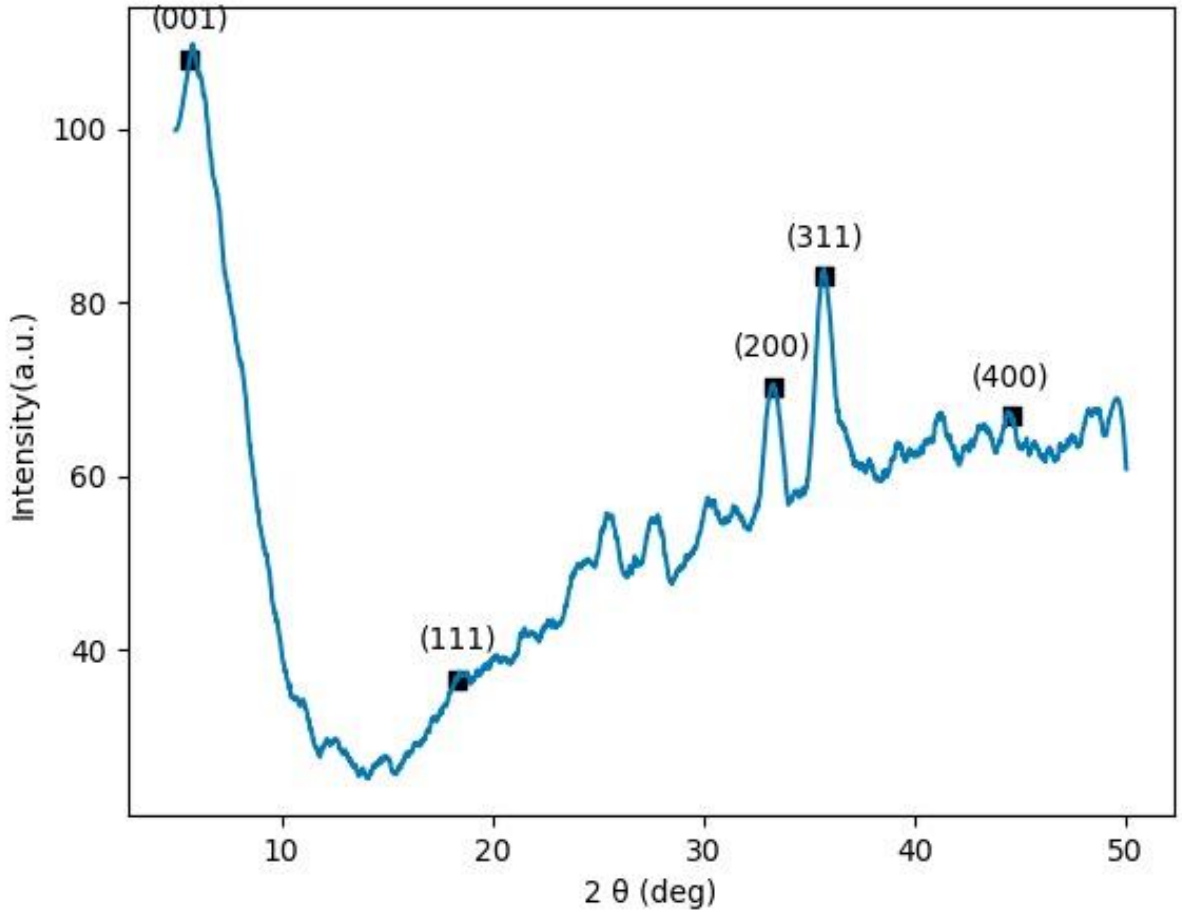


Figure 10: XRD Analysis

The figures in depict the indexed XRD patterns obtained from the nano-particles that were synthesized. To record the X-ray diffraction (XRD) spectra of the nanocomposites created, a PANalytical 2550-PC X-ray diffractometer was utilized. Notably, the XRD pattern of the

nanoparticles exhibits distinct peaks at specific angles, notably at 2θ = 18.8°, 35.90°, 35.86°, 37.94°, 44.03°, 54.39°, 57.74°, and 63.02°, corresponding to the (111), (200), (311), (222), and (400) planes, which are indicative of the crystalline structure of MnFe2O4 nanoparticles. Of particular significance is the peak at the (311) plane, reflective of the characteristic phase of MnFe2O4 nanoparticles. Through validation, it was confirmed that the formation of single-phase spinel structures had occurred, with an additional phase detected at (001) due to stacking in GO. The hkl indices observed were (001), (111), (200), (311), and (400), affirming the presence of the spinel structure with planes such as (111), (200), (311), and (400) being key indicators.

7.4. TGA Analysis:

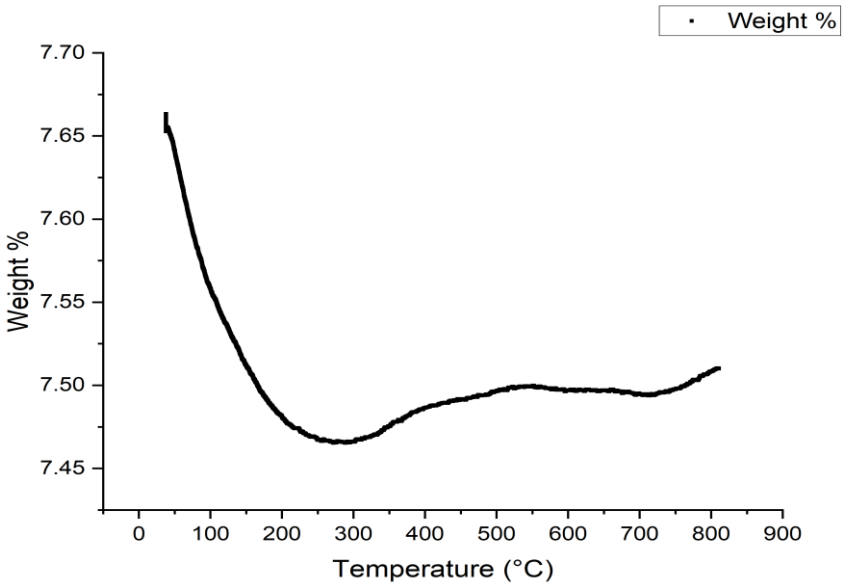


Figure 11: TGA Analysis

TGA measures the change in the weight of a sample as a function of temperature or time under a controlled atmosphere. Indicates the thermal stability and decomposition of the material. Shows the temperatures at which different components of the material decompose or volatilize. An initial weight loss at lower temperatures up to 150°C can indicate the presence of adsorbed water or solvents. Nano-adsorbent contains organic groups observe weight loss at intermediate temperatures. Significant weight loss in a specific temperature range might be due to the decomposition of organic components or coatings on the nano-adsorbent. Some materials undergo phase transitions or oxidation reactions, which can also be observed as changes in the

weight-loss profile. After complete decomposition of organic components, a residual weight is often left behind, which can be attributed to the inorganic components or the magnetic material itself.

7.5. Point of Zero Charge (PZC):

Materials: Five clean measuring flask and incubator have been used in the test. The pH of the mixture was adjusted by using 0.01N HCL and/or 0.01N NaOH solution. The pH was measured with a pH meter. A solution of 40mg nano-particles and 40 ml of 0.09M Nacl was made.

Methods:

- Solution of 40mg nano-particles and 40ml of 0.09 M Nacl with 6.6 pH arranged in five different measuring flasks.
- Initial pH (pH_i) Was adjusted using 0.01M HCL or NaOH.
- After shaking for 24 hour long in incubator final pH (pH_f) value also measure.
- Difference in initial and final (ΔpH) was calculated and computed as follow

$$\Delta pH = pH_i - pH_f$$

- A plot of ΔpH vs pH_i was drawn taking in Y and X axes respectively.
- The value of pH_i at which ΔpH was zero was denoted by the point of zero charge.

Flask no	pH initial	pH final	Del.pH
1	2	2.2	-0.02
2	4	5.5	-1.5
3	6	6.6	-0.6
4	8	6.9	1.1
5	10	7.5	2.5

Table 4: Point of Zero Charge (PZC)

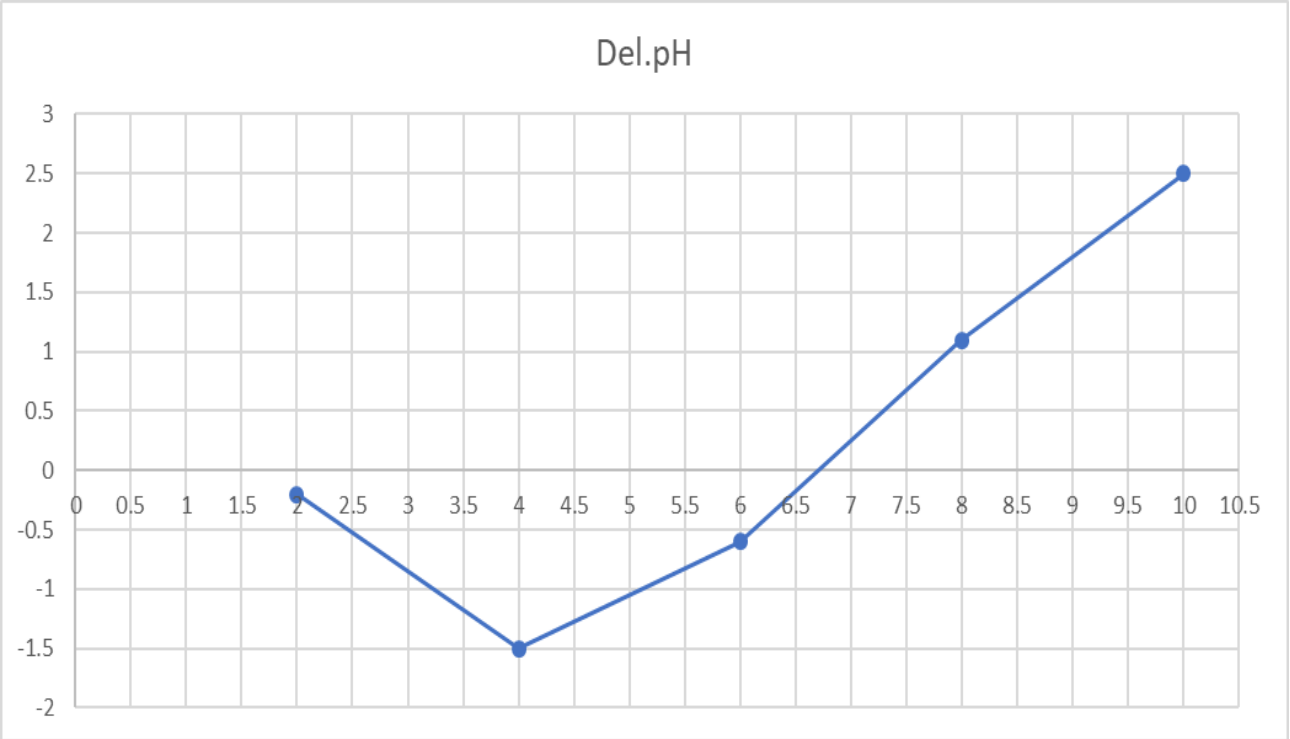


Figure 12: ΔpH vs pH_i

7.6. Zeta Potential:

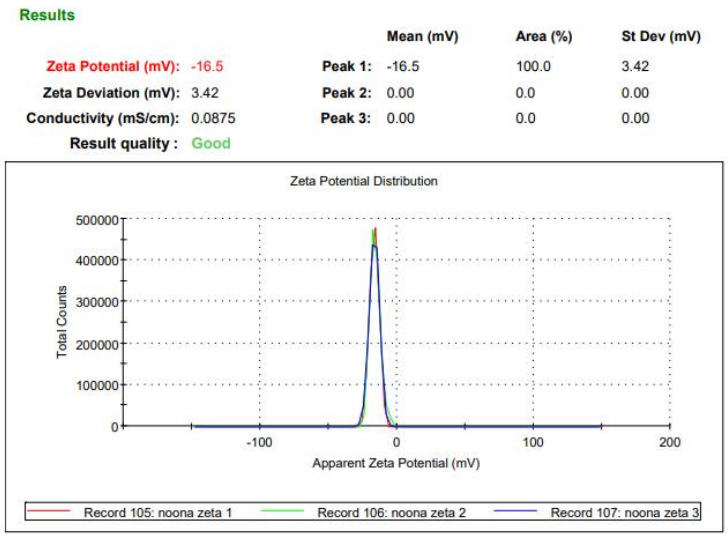


Table 5: Zeta Potential Graph

Zeta potential is a fundamental parameter that characterizes the electrostatic potential at the shear plane of a particle suspended in a liquid. It provides insight into the stability of colloidal systems by indicating the degree of repulsion or attraction between particles. In this study, zeta potential was measured using a microelectrophoresis technique, which involves applying an electric field to induce particle movement and calculating the zeta potential based on the particle's velocity**.** The magnitude of the zeta potential can be directly related to the stability of the colloidal dispersion. Particles with high absolute values of zeta potential (typically > ±30 mV) are generally well-dispersed and stable, as the electrostatic repulsion prevents aggregation. Conversely, low zeta potential values may suggest poor stability and a tendency for particle flocculation.

CHATER-8

RESULT AND DISCUSSION

8. Result & Discussion

8.1. Effect of contact time:

The rate of adsorption, which refers to the process of molecules adhering to a surface, is significantly impacted by the duration of contact between the adsorbent and the adsorbate. Specifically, in the case of BG dye being adsorbed onto a fixed 4mg nano-adsorbent, various time intervals were examined to ascertain the pattern of adsorption. Interestingly, during the initial phase, lasting between 0 and 45 minutes, a sharp and rapid increase in the adsorption rate of BG dye was noted, independent of the suspension temperature. This heightened activity can be attributed to the abundant activated sites present on the adsorbent at the beginning of the process, facilitating the adsorption of BG dye efficiently. However, as time progressed beyond the 105-minute mark, a noticeable shift in the adsorption kinetics was observed across all instances. This deceleration in the adsorption rate is largely a result of the decreasing concentration gradient of BG dye in the solution, coupled with the slower diffusion rate towards the solid surface. Additionally, as the process advances, there is a gradual decrease in the number of active adsorption sites on the adsorbent material, further contributing to the decreased rate of adsorption post the initial phase.

The attainment of equilibrium takes place after agitating the solutions containing the adsorbent up to 145 min and once equilibrium was attained, the percentage of adsorption of dye did not show any appreciable change with time.

This may be due to the availability of vacant surface sites during the preliminary stage of adsorption, and after a certain time period the vacant sites get occupied by dye molecules which lead to create a repulsive force between the adsorbate on the adsorbent surface and in bulk phase.

Sample (PPM)	Time (Min)	Concentration (mg/L)	ln concentration	1/c
7.5	45	5.6	1.722766598	0.178571
7.5	65	4.5	1.504077397	0.222222
7.5	85	4.1	1.410986974	0.243902
7.5	105	3.5	1.252762968	0.285714
7.5	125	3.2	1.16315081	0.3125
7.5	145	2.9	1.064710737	0.344828
7.5	165	2.9	1.064710737	0.344828

Table 5: Concentration of Brilliant Green with various Time

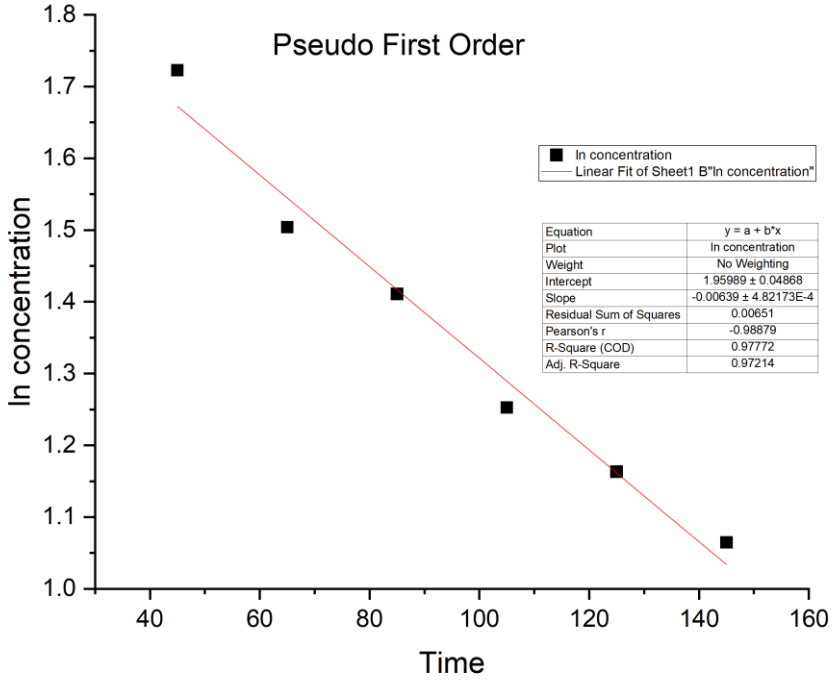


Figure 13: Pseudo First order kinetic data for brilliant green

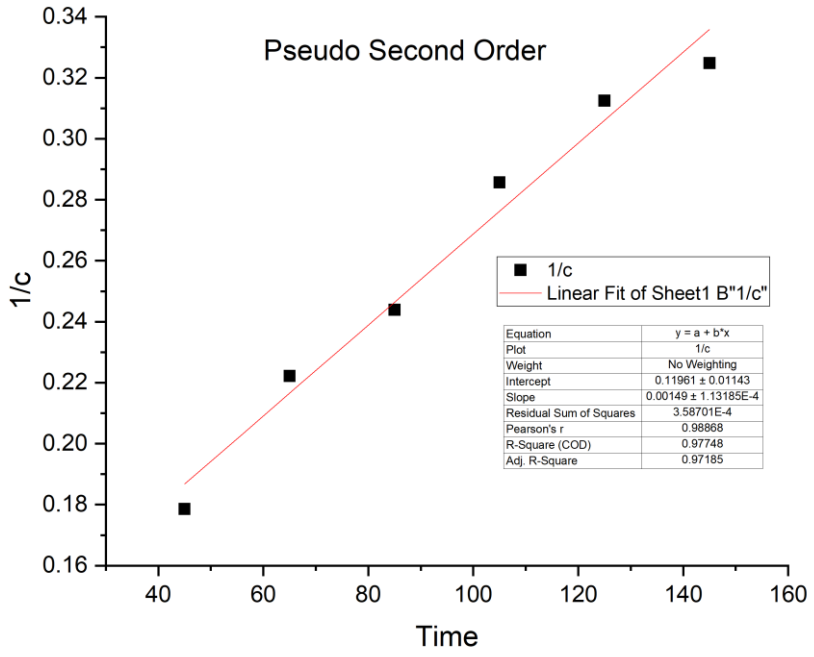


Figure 14: Pseudo Second order kinetic data for brilliant green

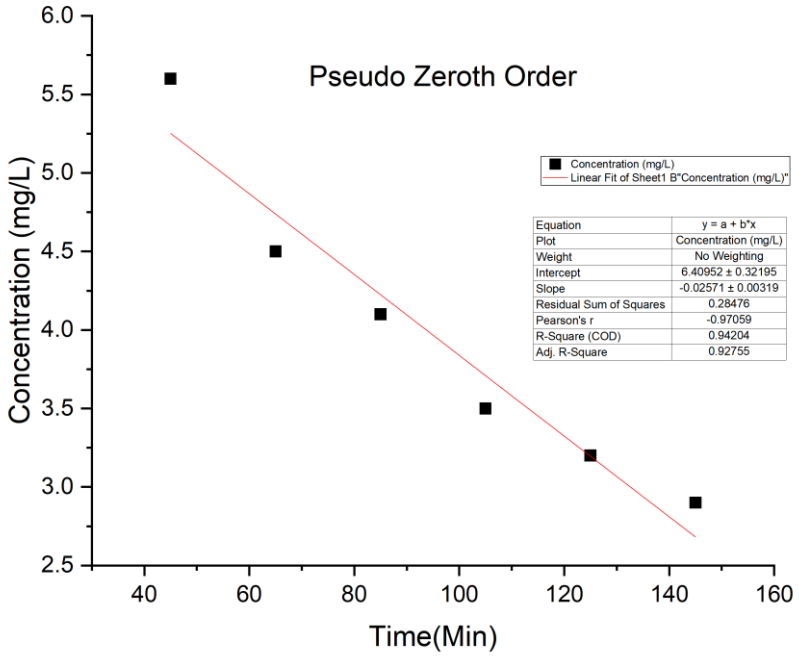


Figure 15: Pseudo Zeroth order kinetic data for brilliant green

In the study conducted on the adsorption of Victoria blue dye, a fixed 4mg nano-adsorbent was utilized and observed at various time intervals to assess the adsorption rate. Notably, after a duration of 105 minutes, it was consistently observed that the adsorption rate of Victoria blue dye exhibited slower kinetics across all instances. This phenomenon can be attributed to the gradual decline in the concentration gradient of Victoria blue, causing a deceleration in the diffusion rate towards the solid surface. This reduction in the concentration gradient leads to a decrease in the number of active sites available on the adsorbent material, which ultimately contributes to the slower adsorption kinetics observed. The intricate interplay between the diminishing concentration gradient of Victoria blue, the sluggish diffusion rate towards the solid surface, and the decline in the number of active adsorption sites highlights the complex nature of the adsorption process. This nuanced understanding sheds light on the dynamics at play during the adsorption of Victoria blue dye onto the nano-adsorbent, emphasizing the importance of considering factors such as concentration gradients, diffusion rates, and active site availability when analysing adsorption kinetics.

Sample (PPM)	**Time (min)**	**Concentration (mg/L)**	**Ln (Concentration)**	**1/ Conc**
25	45	22.41	3.109507	0.044622
25	65	19.87	2.989211	0.050327
25	85	15.29	2.727199	0.065402
25	105	12.5	2.525728	0.08
25	125	9.14	2.212660	0.109409
25	145	7.44	2.006870	0.134408

Table 6: Concentration of Victoria blue with various Time

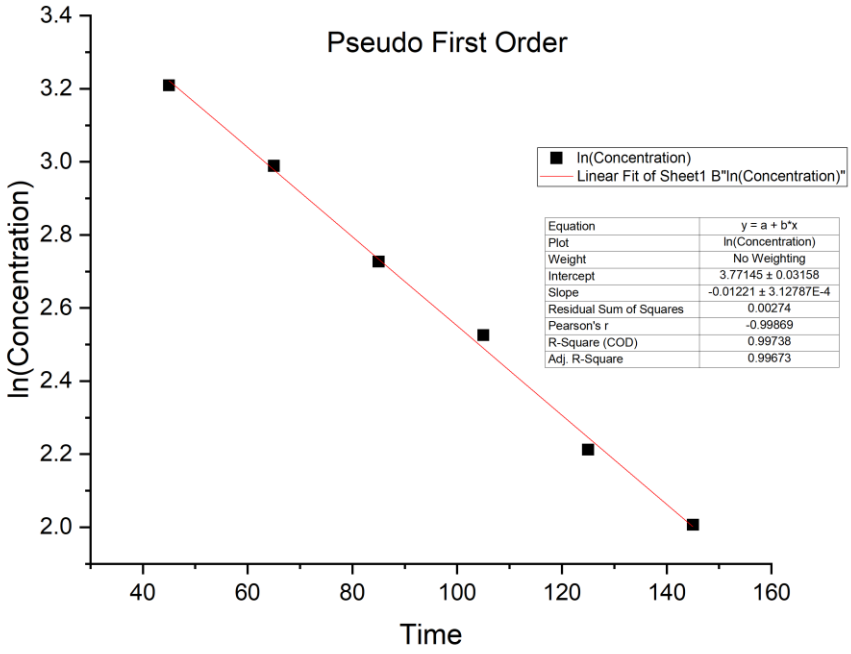


Figure 16: Pseudo first order kinetic data for Victoria blue

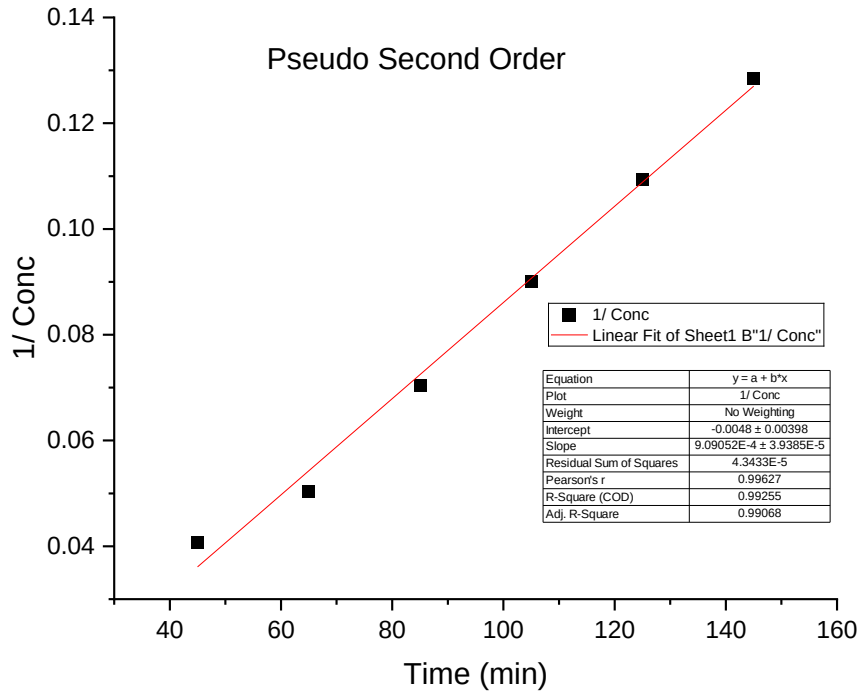


Figure 17: Pseudo Second order kinetic data for Victoria blue

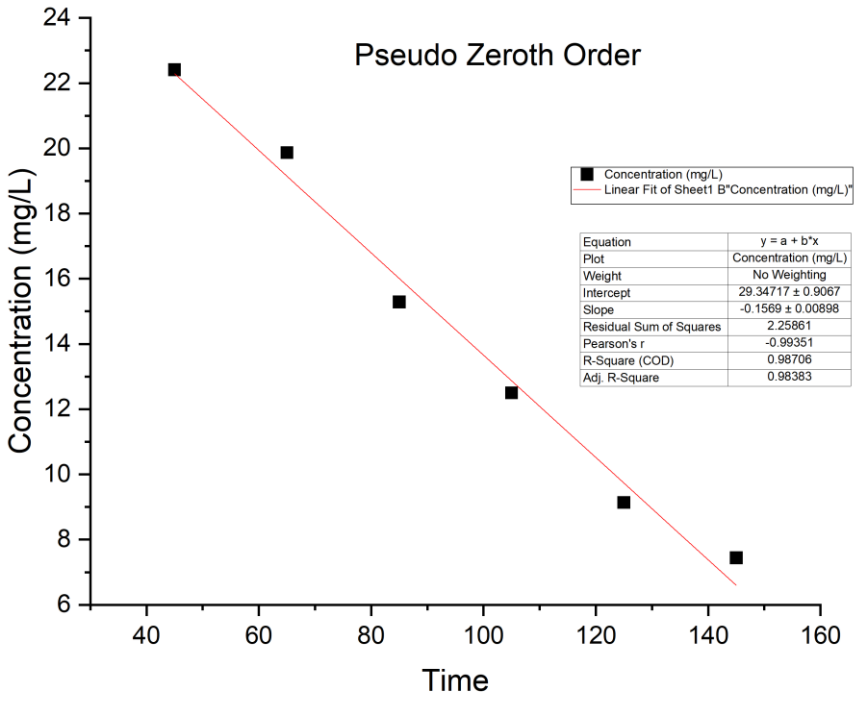


Figure18: Pseudo zeroth order kinetic data for Victoria blue

Over time, the concentration of methylene dye in a solution typically decreases as a result of various factors. Additionally, chemical reactions with Nano-adsorbent in the solution can lead to a reduction in dye concentration. A notable observation occurred after 145 minutes, illustrating a significant removal of methylene dye concentration, with approximately 97% being successfully eliminated through the use of a nano adsorbent. This high removal efficiency underscores the effectiveness of the chosen adsorbent material in reducing the concentration of the dye within the solution. Furthermore, the successful removal of such a high percentage of the dye concentration within a relatively short time frame suggests that employing nano adsorbents could be a practical and efficient strategy for treating and managing dye-contaminated solutions.

Effect of methylene Blue with Time:

Sample (PPM)	Time (min)	Concentration (mg/L)	Ln (Concentration)	1/ Conc
50	45	42.46	3.806662	0.023552
50	65	33.87	4.174387	0.029525
50	85	25.30	4.442651	0.039526
50	105	12.25	4.65396	0.081633
50	125	7.41	4.828314	0.134953
50	145	1.44	4.976734	0.694444

Table 7: Concentration of Methylene blue with varying time

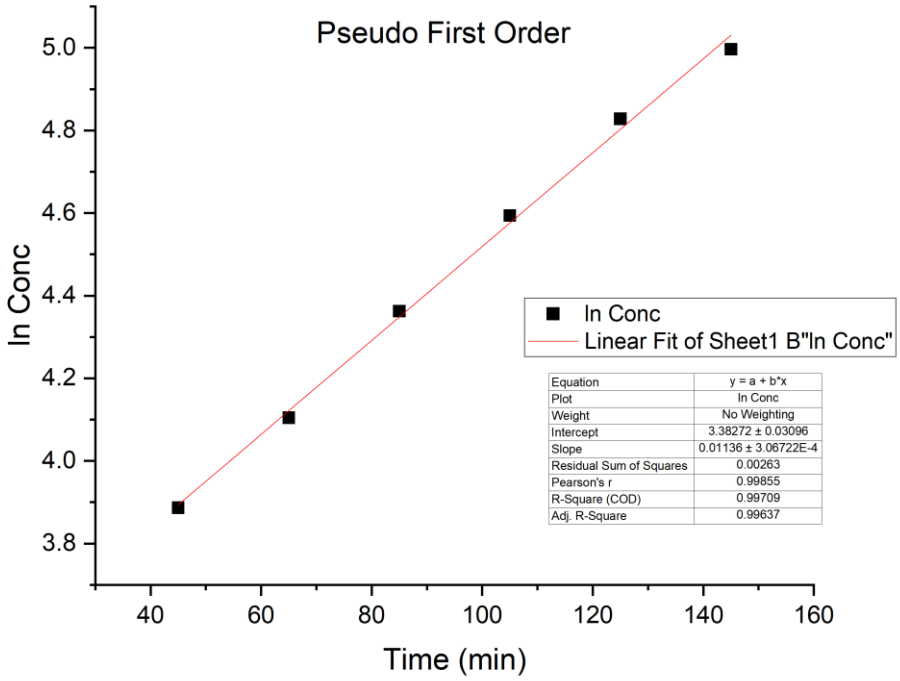


Figure19: Pseudo first order kinetic data for Methylene Blue

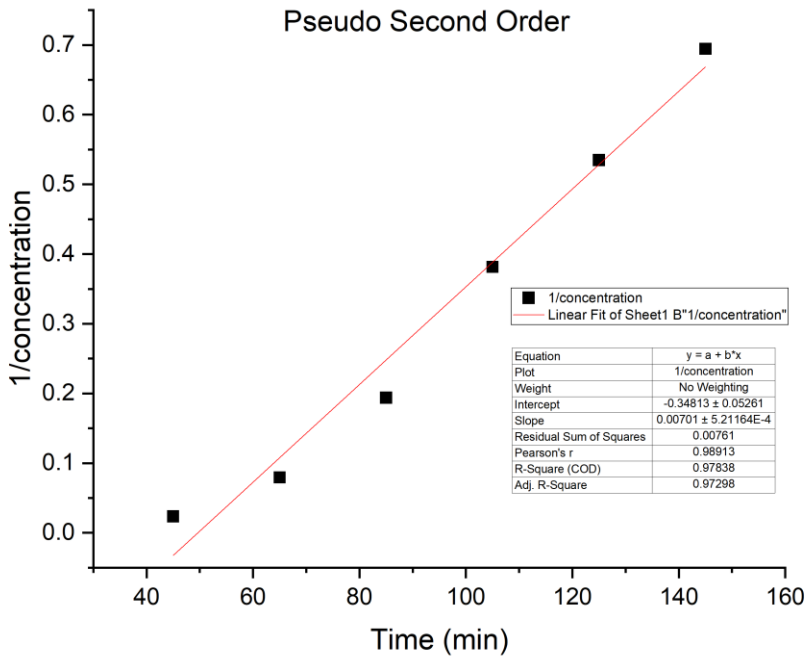


Figure 20: Pseudo Second order kinetic data for Methylene Blue

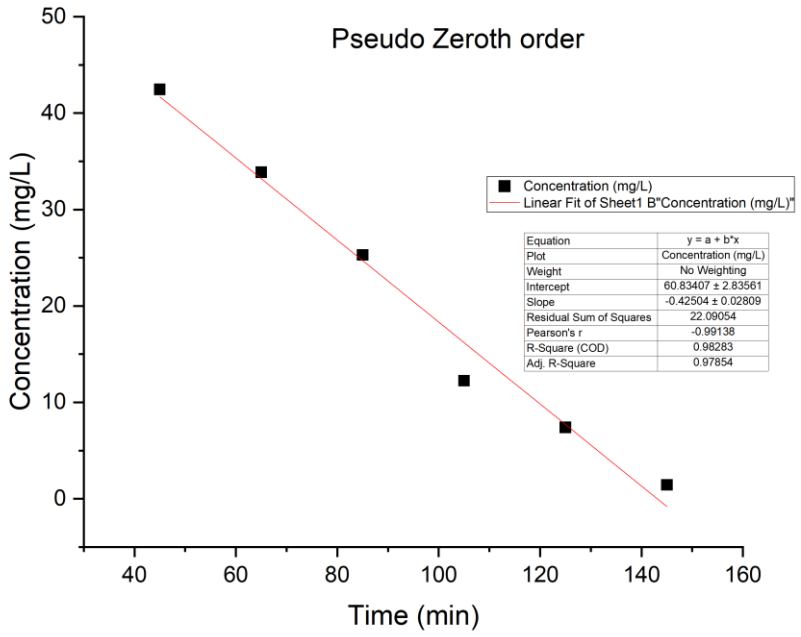


Figure 21: Pseudo zeroth order kinetic data for Methylene Blue

8.2. Effect of pH:

pH, representing the acidity or alkalinity of a solution, plays a crucial role in various industrial processes, particularly in the realm of dye and heavy metal removal through adsorption mechanisms. Understanding the intricate relationship between pH levels and adsorption phenomena is essential for optimizing the efficiency of sorbent materials. The interaction between surface charges of these materials and the ionization states of acidic and basic compounds is profoundly influenced by the specific pH of the solution in question.

By manipulating the initial pH of the solution, it is possible to modulate the uptake rates of contaminants, with potential enhancements or reductions depending on the targeted processes. In scenarios where the pH value is lower, the adsorption of cationic dyes tends to be negatively impacted, leading to decreased uptake rates. Conversely, for anionic dyes, the percentage of dye uptake is typically higher under such conditions. Research findings suggest that cationic dye adsorption is typically more favorable when the pH exceeds the point of zero charge (pHpzc), thanks to the presence of specific functional groups like the OH- group.

On the other hand, the adsorption of anionic dyes is often more efficient at pH levels below the pH_{pzc} threshold, where the surface of the sorbent material experiences a positive charge. This nuanced interplay between pH dynamics and adsorption behavior highlights the intricate nature of industrial processes aimed at detoxifying aqueous solutions from dyes and heavy metals. Understanding these subtleties can provide valuable insights into improving the effectiveness of water treatment and pollutant remediation methods.

pH of the solution	Initial Concentration (PPM)	Final concentration
13	5	0.1859
11	5	0.1762
9	5	0.1568
7	5	0.2433
5	5	0.2268
3	5	0.1795
1	5	0.1535

Table 8: Effect Of pH of Brilliant Green



Figure 22: Concentration Change in various pH

8.3. Effect of Temperature:

In the investigation focusing on understanding the temperature dependencies associated with the dyes adsorption process within the specified range of 290–310 K, a notable observation was made regarding the significant variability in the effect of temperature on the adsorption behavior. The study specifically delved into how different temperatures, namely 290 K, 300 K, and 310 K, impacted solutions containing brilliant green concentrations of 1 ppm, 3 ppm, and 5 ppm. To conduct these insightful experiments effectively, Nano-adsorbent and Graphene were employed in precise amounts of 2 mg/20 ml each, with an optimal contact duration of 1 hour carefully considered.

Solution Concentration	Temperature		
	17^0C	27^0C	37^0C
1PPM	10%	10%	20%

3PPM	20%	43%	60%
5PPM	26%	44%	68%

Table 9: Effect of temperature on Brilliant Green Dye using Nan0-adsorbent

Solution Concentration	Temperature		
	17^0C	27^0C	37^0C
1PPM	0%	10%	10%
3PPM	16%	36%	38%
5PPM	20%	40%	46%

Table 10: Effect of temperature on Brilliant green dye using GO

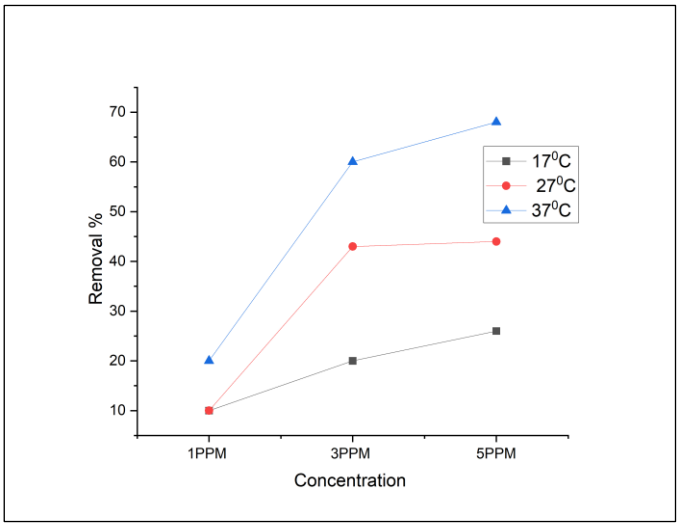


Figure 23: Effect of Temperature on BG in presence of nano-adsorbent

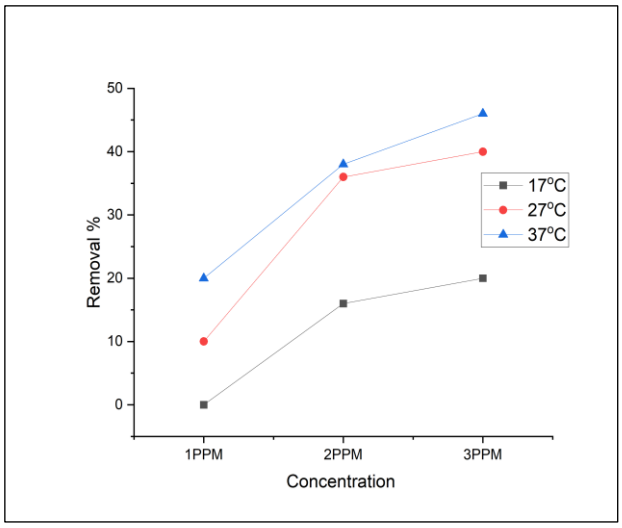


Figure 24: Effect of Temperature on BG in presence of GO

while using varying concentrations of Victoria blue solution (15ppm, 20ppm, and 25ppm). Notably, Nano-adsorbent and Graphene were incorporated in the study at a specific ratio of 2mg per 20ml, with an optimized contact time set at a duration of 3 hours for effective interaction. The depicted experimental outcomes clearly showcase a positive correlation between temperature elevation and the efficiency of dye removal. This observation suggests that elevated temperatures play a crucial role in enhancing dye removal efficiency, showcasing a noticeable increase in the removal capacity as the temperature rises.

Solution Concentration	Temperature		
	17^0C	27^0C	37^0C
15PPM	56%	70%	77%
20PPM	39%	67%	75%
25PPM	36%	64%	68%

Table11: Effect of temperature on Victoria Blue Dye using Nano-adsorbent

Solution Concentration	Temperature		
	17^0C	27^0C	37^0C
15PPM	61%	67%	71%
20PPM	35%	63%	67%
25PPM	30%	60%	62%

Table 12: Effect of temperature on Victoria Blue Dye using GO

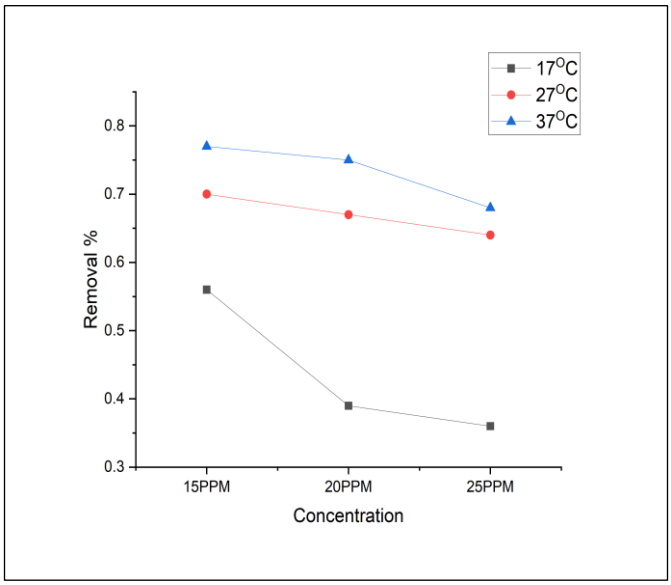


Figure 25: Effect of Temperature on VB in presence of nano-adsorbent

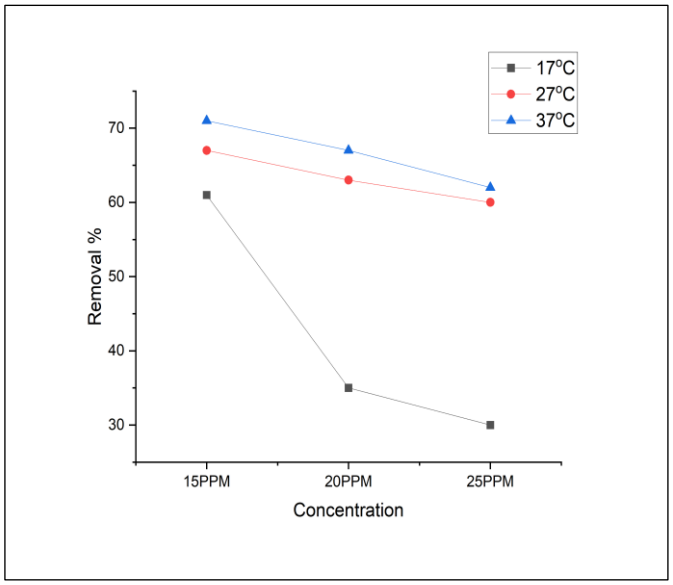


Figure 26: Effect of Temperature on VB in presence of nano-adsorbent

Upon analysis of the experimental data, a noticeable trend emerged revealing an increase in the amount of dye removal as the temperature rose. This observation indicates that higher temperatures positively influence the efficiency of dye removal, highlighting how alterations in the diffusion rate of dye molecules lead to changes in the adsorbents' equilibrium capacity. Through this dynamic interplay between temperature and adsorption mechanisms, the potential for enhancing the efficacy of dye removal processes becomes apparent, showcasing the importance of understanding the intricate relationship between temperature and adsorption efficiency.

Reaction Order	Zeroth Order	First Order	Second Order
Rate Law	Rate= $K[A]^0$	Rate= $K[A]^1$	Rate= $K[A]^2$
Integrated Rate Law	$[A]=[A]_0 - Kt$	$Ln[A]= -kt + ln[A]_0$	$1/[A]= Kt +1/[A]_0$
Characteristic Kinetic Plot	[A] vs t	ln[A] vs t	1/[A] vs t
Slop of the kinetic plot	-K	-K	K
Unit of Rate Constant	$MolL^{-1}.sec^{-1}$	Sec^{-1}	$Lmol^{-1}.sec^{-1}$

Table 13: Various Reaction Order and Rate Law

8.4. Kinetic study:

The measurement of kinetics holds significant importance when it comes to determining the optimal operational parameters for full-scale batch processes, as it can offer crucial insights into the design and implementation of effective sorption systems. In this study, the kinetics of various dye adsorption processes onto nanoparticles were analyzed by fitting pseudo-zeroth-order, pseudo-first-order, and pseudo-second-order models. Figures 16 to 24 visually illustrate the application of these kinetic models to the equilibrium data for brilliant green (BG), Victoria blue (VB) and methylene blue, while Tables 9 present the resulting kinetic parameters. It was observed that the pseudo-zeroth-order and pseudo-Second-order models did not provide reliable fits for the adsorption of brilliant green, Victoria blue and methylene blue due to low R-squared values and discrepancies in the experimental values. Notably, the linearity observed

in the ln(concentration) vs. Time graph for brilliant green, Victoria blue and methylene blue indicates a pseudo-first-order reaction, supported by the high R-squared value of 0.97214, 0.99673 and 0.99637.

8.5. Dye Removal Test:

8.5.1. Methylene blue Removal:

Initial Concentration (PPM)	Final Concentration (PPM)	Percentage removal (%)	Maximum uptake (mg/gm)
20	0.98	95.10	19.02
50	1.44	97.12	48.6
100	5.24	94.76	94.7
200	11.30	94.35	188.7

Table 14: Maximum uptake with varying solute conc. For methylene blue

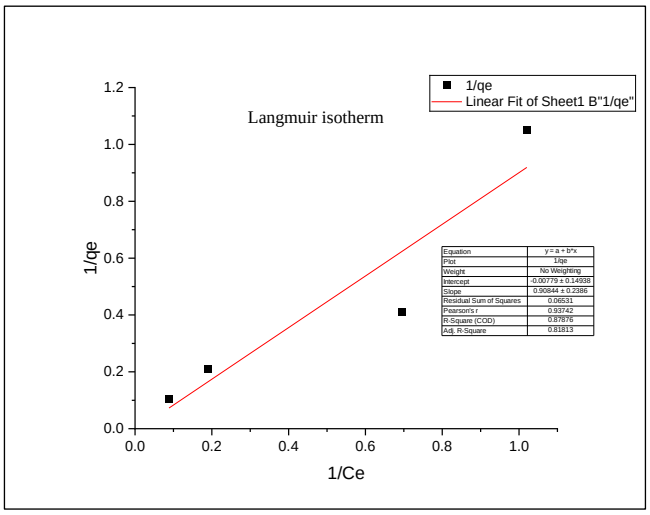


Figure 27: Langmuir isotherm for methylene blue removal

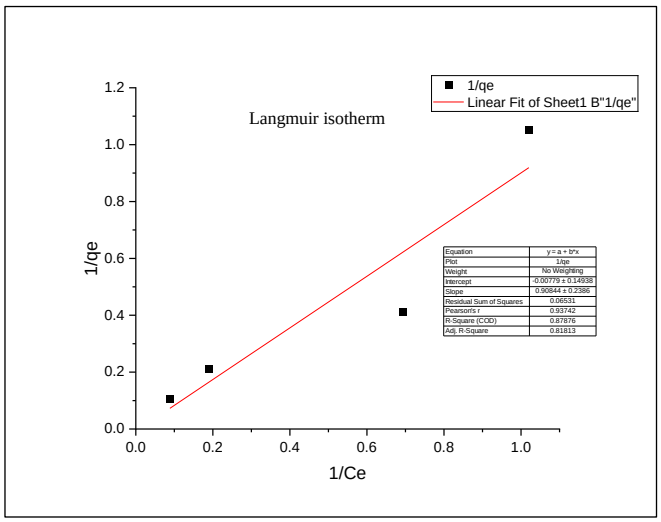


Figure 28: Freundlich isotherm for methylene blue removal

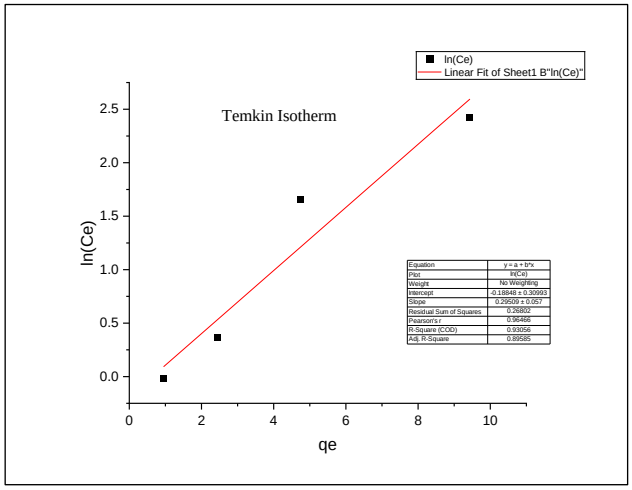


Figure29: Temkin isotherm for methylene blue removal

Langmuir isotherm	
Intercept	-0.00461
Slope	1.00504
q_{max}	0.769669
K_L	0.079498
R_L	1.596235
R^2	0.97836
Freundlich isotherm	
Intercept	0.10346
Slope	0.83242
1/n	0.83242
k_f	1.2689953
R^2	0.89713
Temkin Isotherm	
Intercept	-0.18848
Slope	0.29509
K_L	0.52796
R^2	0.81813

Table 15: Isotherm for methylene blue dye

8.5.2. Victoria blue Removal:

In preparation for the experiment, Victoria meticulously prepared a stock solution with a concentration of 50 ppm. To establish the calibration curve, she carried out the necessary dilutions and proceeded to measure the absorbance using a UV-Visible Spectrophotometer set to a specific wavelength of 610 nm. Once the measurements were complete, she carefully transferred 20 ml of each diluted solution into separate miniature test tubes. Next, to introduce the nanoparticle, she precisely added 2 mg of the prepared material into each test tube and

initiated agitation using a vortex shaker for a duration of 30 minutes. After the shaking process, to allow for effective adsorption of the nanoparticles, the test tubes were left undisturbed for a resting period of 20 minutes. This sequence of steps ensured the proper mixing and reaction of the nanoparticle material with the diluted solutions, enabling the adsorption process to take place efficiently. Victoria's systematic approach and attention to detail throughout the experimental procedure showcased her proficiency in handling the various steps involved in the analysis of the samples.

Initial Concentration (PPM)	Final Concentration (PPM)	Percentage removal (%)	Maximum uptake (mg/gm)
5	2.15	57.00	14.25
10	4.37	52.7	26.35
20	8.73	56.35	56.35
25	8.94	64.24	80.3

Table16: Maximum uptake with varying solute conc. For Victoria blue

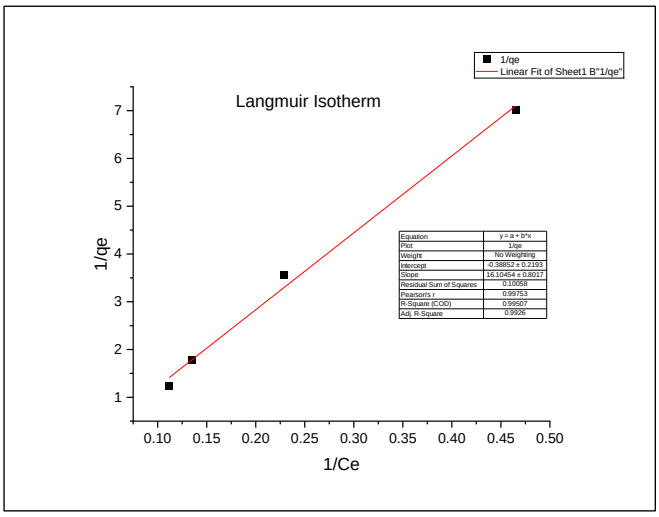


Figure 30: Langmuir isotherm for Victoria blue removal

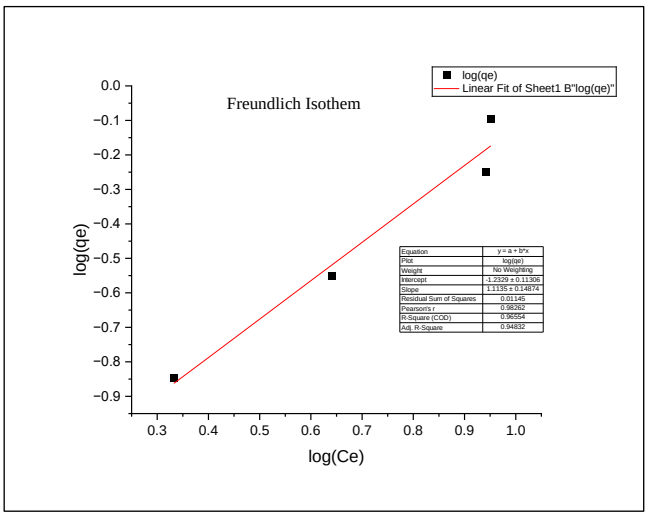


Figure 31: Freundlich isotherm for Victoria blue removal

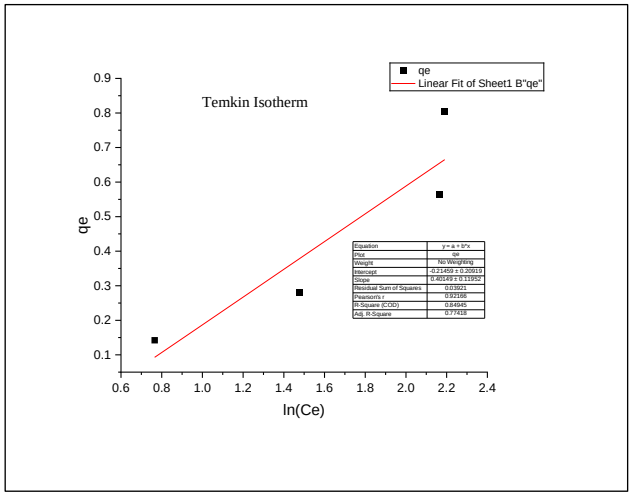


Figure 32: Temkin Isotherm for Victoria Blue Removal

Langmuir isotherm	
Intercept	-0.20449
Slope	15.65472
q_{max}	-4.89021
K_L	-0.31238
R_L	-3.68569
R^2	0.9926
Freundlich isotherm	
Intercept	-1.2329
Slope	1.1135
1/n	1.1135
k_f	0.058492
R^2	0.94832
Temkin Isotherm	
Intercept	-0.21459
Slope	0.40149
K_L	0.585972
R^2	0.77418

Table 17: Adsorption isotherms parameters of Victoria blue on GO-TiO2-MnFe2O4

8.5.3. Brilliant green Removal:

A brilliant green stock solution with a concentration of 20 ppm was meticulously prepared for the experiment. The necessary dilutions were meticulously carried out to establish the calibration curve, and the subsequent absorbance readings were obtained using a UV-Visible

Spectrophotometer set at a specific wavelength of 625 nm. Following the calibration process, 20 ml samples of each dilution were meticulously pipetted into separate test tubes to facilitate further analysis. To initiate the next step of the experiment, precisely 2 mg of a specially prepared nanoparticle solution, consisting of GO-TiO2-MnFe2O4, was introduced into each test tube. The contents of the test tubes were then vigorously mixed in a vortex shaker for a precisely timed duration of 30 minutes to ensure complete dispersion and interaction between the nanoparticle solution and the brilliant green samples. Subsequently, the test tubes were allowed to stand undisturbed for a carefully monitored period of 20 minutes to enable the adsorption process to occur effectively. This meticulous procedure was crucial to knowing the exact mechanism by which the nanoparticles interacted with the brilliant green samples, providing valuable insights into potential applications of this system in further studies and applications.

Initial Concentration (PPM)	Final Concentration (PPM)	Percentage removal (%)	Maximum uptake (mg/gm)
5	1.89	62.20	62.2
7.5	2.92	61.06	91.6
10	4.79	52.09	104.2
20	9.96	50.20	200.8

Table 18: Maximum uptake with varying solute conc. For brilliant green

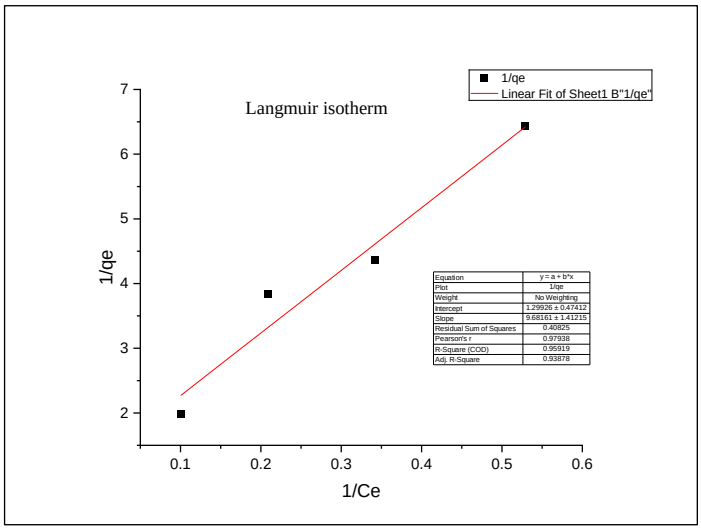


Figure 33: Langmuir isotherm for brilliant green removal

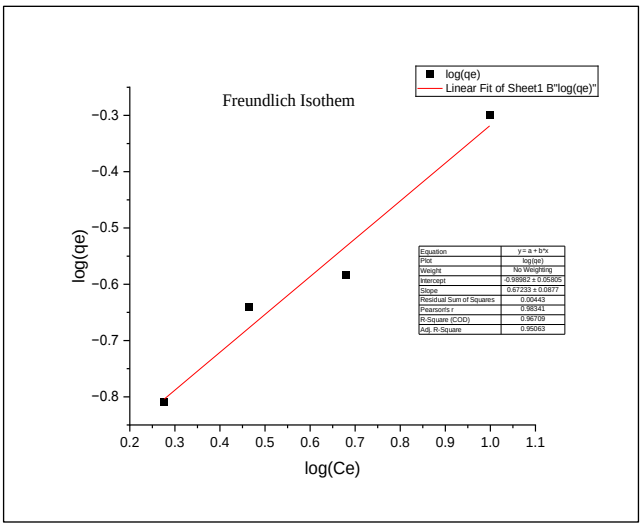


Figure 34: Freundlich isotherm for Brilliant Green removal

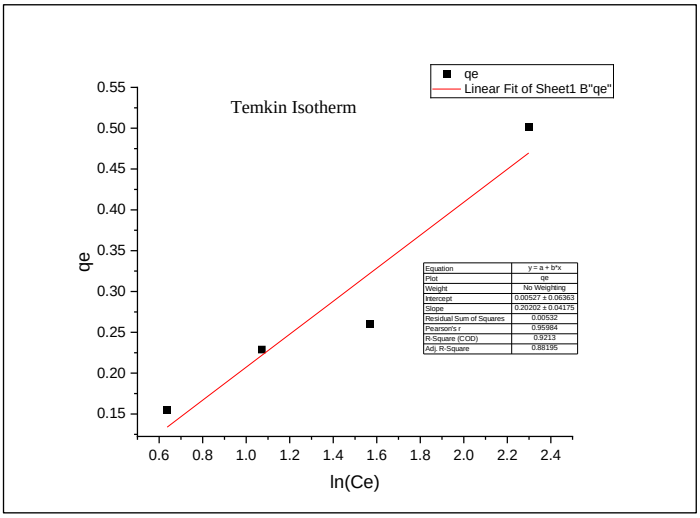


Figure 35: Temkin isotherm for brilliant green removal

Langmuir isotherm	
Intercept	1.29926
Slope	9.68161
q_{max}	0.769669
K_L	0.079498
R_L	1.596235
R^2	0.93878
Freundlich isotherm	
Intercept	-0.98982
Slope	0.67233
1/n	0.67233
k_f	0.102372
R^2	0.95063
Temkin Isotherm	
Intercept	0.00527
Slope	0.20202
K_L	1.02643
R^2	0.88195

Table 19: Adsorption isotherms parameters of brilliant green on GO-TiO2-MnFe2O4

8.6. Isotherm:

The examination of the sorbent's effectiveness in removing industrial dyes from the solution involved analysing its sorption capacity through the application of Langmuir, Freundlich, and Temkin isotherm models. These models not only displayed how surface characteristics

influence the sorbent's affinity in batch culture but also linked these attributes to the dye removal efficiency. The Langmuir isotherm model elucidates the process of monolayer adsorption, emphasizing the presence of a finite number of adsorption sites on the sorbent's surface. Conversely, the Freundlich isotherm model contends that adsorption occurs across the sorbent's heterogeneous surface, reflecting a more complex interaction mechanism. The Temkin isotherm model operates under the assumption that adsorption heat decreases proportionally as the adsorbent surface coverage increases, highlighting a uniform distribution of binding energies until a maximum binding energy is reached. Evaluation of the coefficients of determination (R2) revealed that the Langmuir isotherm model best fitted the data, as indicated by the high R2 value of 0.98828 for Victoria Blue. This supported the notion that VB ion sorption onto adsorbents adhered to a monolayer adsorption mechanism concentrated on specific functional groups or binding sites. In contrast, the Freundlich isotherm model exhibited lower R2 values of 0.9314 for Methylene Blue and 0.9671 for Brilliant Green, suggesting the presence of heterogeneous reaction sites within the nano-adsorbent. Notably, the Freundlich model effectively captured the relationship between the percentage of Methylene Blue, Brilliant Green adsorbed, and their equilibrium concentrations in the solution, providing valuable insights into the adsorption process. Essential adsorption parameters, such as the maximum adsorption capacity (qmax), and additional relevant data are detailed in the table below for comprehensive understanding and comparison of the different models' performance.

8.7. Adsorption Thermodynamics:

It is important to know the thermodynamic parameters in order to get additional information regarding the nature of the adsorption of GO-TiO_2-$MnFe_2O_4$. The effects of temperature (290–310 K) on the adsorption of GO-TiO_2-$MnFe_2O_4$ on various dye. The thermodynamic adsorption parameters, enthalpy change, $\Delta H°$, entropy change, $\Delta S°$ and Gibbs free energy change, $\Delta G°$ were computed with the help of the following equations

$$\Delta G_o = \Delta H_o - T\,\Delta S_o \quad \ldots\ldots\ldots\ldots (1)$$

$$\Delta G_o = -RT\,\ln K_L \quad \ldots\ldots\ldots\ldots\ldots (2)$$

The combined form of Eqs. (1) and (2) gives

$$\ln K = \Delta S_o\, R - \Delta H_o\, RT$$

where R is the universal gas constant (8.314 J K^{-1} mol^{-1}); T is the absolute temperature; K represents the adsorption constants.

Temperature(K)	$\ln K_L$	ΔG◦ (kJ mol−1)	ΔH◦ (kJ mol−1)	ΔS ◦ (kJ mol−1 K−1)
290K	2.525729	-6.34873	47.09446	0.184286877
300K	3.506558	-8.1916		
310K	3.778492	-10.0345		

Table 20: Thermodynamic parameters of the BG adsorption

Temperature(K)	$\ln K_L$	ΔG◦ (kJ mol−1)	ΔH◦ (kJ mol−1)	ΔS ◦ (kJ mol−1 K−1)
290K	3.506558	-8.71589	56.48891	0.224844149
300K	4.620208	-10.9643		
310K	5.010635	-13.2128		

Table 21: Thermodynamic parameters of the VB adsorption

Temperature(K)	$\ln K_L$	ΔG◦ (kJ mol−1)	ΔH◦ (kJ mol−1)	ΔS ◦ (kJ mol−1 K−1)
290K	6.225658	-15.0104	43.46792	0.201731
300K	6.856462	-17.1014		
310K	7.388122	-19.0417		

Table 22: Thermodynamic parameters of the VB adsorption

The Van't Hoff plots for Brilliant green and Victoria blue adsorption, while the associated thermodynamic parameters are listed in Table 20, 21 & 22. The negative ΔG° values which increased with temperature indicate increased spontaneity for adsorption of both dyes. The positive ΔS° values indicate the increased disorder at the interface between the solid adsorbent and the aqueous solution. This further supports the likelihood of occurrence of the process due increased entropy. The positive ΔH° values denote the endothermic nature of the adsorption process for both dyes.

8.8. Comparative Study:

The values of thermodynamic parameters and the best-fit isotherm of dye adsorption on different type of adsorbents.

Adsorbent	Isotherm Type	Temperature (K)	Del. Go (kJ.mol1
Graphene	Langmuir	293	-0.89c [59]
Magnetic graphene-carbon nanotube composite	Langmuir	293 303 313	
GO		293 303 313	−17.87 −18.95 [60] −22.18
GO/Al_2O_3		303	−2.32 [61]
MgO nanostructures	Langmuir	303	−21.1 [62]
GO–Al–O(OH)	Langmuir and Dubinin–Radushkevich isotherm	303	−5.84 [63]
walnut shell–based hydrochar	Langmuir model	298 308 318	−8.763 −9.180 [64] −9.166
TiO2 Nanoparticles		308 313 318	−2.14 [65] −2.52 −2.82
GO/ZTO/TO	Langmuir	293.15 303.15 313.15	−26.81 −29.28 [66] −33.08
PAn/TiO2	Freundlich isotherm	293 313 333	-11.2572 -8.4237 [67] -8.6953

MLMC	Freundlich	298	-24.53 [68]
CoFe2O4@MC/AC	Freundlich isotherm	298 303 308	-20.318 -20.493 [69] -20.666
GO-TiO_2-$MnFe_2O_4$ (MB)	Langmuir model	290 300 310	-15.0104 -17.1014 -19.0417
GO-TiO_2-$MnFe_2O_4$ (VB)	Langmuir model	290 300 310	-8.71589 -10.9643 -13.2128
GO-TiO_2-$MnFe_2O_4$ (BG)	Freundlich isotherm	290 300 310	-6.34873 -8.1916 -10.0345

In the comparative study conducted, an interesting observation was made regarding the Gibbs free energy value of the GO-TiO2-MnFe2O4 nano material, which stood out as superior when compared to other existing materials in the field. This finding hints at the potential of GO-TiO2-MnFe2O4 as a more efficient and effective option within the realm of materials science. The higher quality of this nano material in terms of Gibbs free energy value suggests promising applications and advantages over its predecessors. This implies that further research and exploration into the utilization of GO-TiO2-MnFe2O4 could lead to advancements in various industries and technologies. Therefore, the superior performance of this particular material in terms of Gibbs free energy value highlights its significance and potential within the scientific community. By surpassing existing materials in this aspect, the GO-TiO2-MnFe2O4 nano material demonstrates its capability to push the boundaries of innovation and contribute to the evolution of materials engineering. As such, it presents an exciting opportunity for researchers and engineers to explore and harness the unique properties of this advanced nano material for future developments and discoveries.

CHAPTER 9

9.1. Conclusions

The application of GO-TiO_2-$MnFe_2O_4$ (Graphene Oxide-Titanium Dioxide-Manganese Ferrite) nanocomposites for the removal of dyes from water has shown remarkable effectiveness. Integrated analyses using XRD, SEM, TGA and UV-visible techniques demonstrated that the nanocomposite exhibited a well-defined crystalline phase, sizes of 65.74 to 92.75 nm. This is supported by the observation of negative Gibbs free energy values, which serve as an indicator that the adsorption process is both thermodynamically favourable and spontaneous. GO and TiO_2 is already proven nano-particle for heavy metal removal and have remarkable history in previous work. The synergistic effect of GO, TiO_2 and MnFe2O4 contribute the fact that they have remarkable efficiency for cationic dye removal and suppose to have heavy metal removal also.

Furthermore, the utilization of such nanocomposites presents a promising and sustainable solution for the remediation of water contaminated with various dyes. The significant efficiency of the GO-TiO_2-$MnFe_2O_4$ nanocomposites offers a practical and effective method for addressing the pollution caused by dyes in water. The ability of these nanocomposites to achieve favourable and spontaneous adsorption underscores their potential in contributing to the purification of water resources. Methylene blue's notable removal percentage emphasizes the targeted effectiveness of the nanocomposites, making them a valuable tool in the treatment of dye-affected water bodies.

From the environmental point of view, enhancing the photo-response and improving the visible light absorption spectrum, the coupling between semiconductor nanocomposites and graphene looks tremendously meaningful. Thus, it is supposed that the fabrication of a heterostructure photocatalyst of TiO_2, $MnFe_2O_4$, and GO is promising; the combination of $MnFe_2O_4$ and TiO_2 with p–n heterojunction can enhance the absorption of TiO_2 to the visible light region. Also, supporting both of them with a GO matrix would increase the absorptivity of the pollutants and enhance the charge separation efficiency of TiO_2 and allow easy separation from solution.

With the changes in morphological and rheological properties, there is a need to continuously optimize the synthesis process to unlock the full potential of various future applications, such as mix matrix membrane technology and other application.

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