

SEAWATER DESALINATION USING REDUCED GRAPHENE OXIDE FILTER

Submitted in partial fulfillment of the requirements for the award of

Bachelor of Engineering degree in Mechanical Engineering

By

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DEPARTMENT OF MECHANICAL ENGINEERING

SCHOOL OF MECHANICAL ENGINEERING

SATHYABAMA

**INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

**Accredited with grade "A" by NAAC | 12B Status by UGC | Approved by AICTE
JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI - 600119.**

APRIL - 2023



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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **ABIJEETH X (39150002)** and **ASHWIN S (39150011)** who carried out the project entitled **"SEAWATER DESALINATION USING REDUCED GRAPHENE OXIDE FILTER"** under my supervision from December 2022 to April 2023.

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DECLARATION

We, **ABIJEETH X** and **ASHWIN S** hereby declare that the Project Report entitled “**SEAWATER DESALINATION USING REDUCED GRAPHENE OXIDE FILTER**” done by us under the guidance of **Dr. V.SIVAPRAKASH, M.E ., Ph.D.,** at Sathyabama Institute of Science and Technology is submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering Degree in Mechanical Engineering.

DATE: 10.05.2023

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ACKNOWLEDGEMENT

We are pleased to acknowledge our sincere thanks to the **Board of Management of SATHYABAMA** for their kind encouragement in doing this project and for completing it successfully. We are grateful to them.

We convey our thanks to **Dr. S. Prakash, M.E., Ph.D.**, Dean, School of Mechanical Engineering, and **Dr. G. Arunkumar, M.E., Ph.D.**, Head of the Department, Department of Mechanical Engineering for providing us with the necessary support and details at the right time during the progressive reviews.

We would like to express our sincere and deep sense of gratitude to our Project Guide **Dr. V. SIVAPRAKASH, M.E., Ph.D.**, for his valuable guidance, suggestions, and constant encouragement that paved the way for the successful completion of our project work.

We wish to express our thanks to all Teaching and Non-teaching staff members of the Department of Mechanical Engineering who were helpful in many ways for the completion of the project.

ABSTRACT

The objective of this paper is to present an analysis of the need for water purification in our world and investigates the potential of a combined filter using reduced graphene oxide and reverse osmosis technology as a solution to this challenge. The increasing contamination of water sources due to factors such as population growth, industrialization, and urbanization has led to a growing demand for efficient and cost-effective water purification technologies. Reduced graphene oxide has emerged as a promising candidate for water filtration due to its excellent properties such as high surface area chemical stability and strong adsorption capacity. Our research shows that the combined filter using reduced graphene oxide and reverse osmosis technology can effectively remove a broad range of contaminants, including heavy metals, organic pollutants, and microorganisms. The use of reduced graphene oxide as a pre-filtration layer enhances the performance of the reverse osmosis membrane, leading to improved permeates flux and rejection efficiency. Our study demonstrate that the combined filter using reduced graphene oxide and reverse osmosis technology is a promising solution for water purification. This paper provides valuable insights into the current state of water purification and highlights the potential of this innovative approach to address this critical global issue.

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LIST OF ABBREVIATIONS

RO	Reverse Osmosis
GO	Graphene Oxide
rGO	Reduced Graphene Oxide
NF	Nanofiltration Membranes
UF	Ultrafiltration Membranes
XRD	X-ray Diffraction
FESEM	Field Emission Scanning Electron Microscopy
TEM	Transmission Electron Microscope
EDS	Energy Dispersive Spectroscopy
WHO	World Health Organisation

CHAPTER 1

INTRODUCTION

1.1.INTRODUCTION TO DESALINATION

One of the most plentiful resources on planet is water. However, the vast majority of it nearly 97% is salt water in the oceans, with just 3% being fresh water. Energy and water are essential for maintaining life on Earth and the modern world. Energy and water management and exploitation have fueled economic growth and advancement in many modern nations. Many areas of the developing world experience a lack of clean water and energy resources. According to the United Nations Environment Programme (UNEP), a third of the world's population resides in nations with insufficient freshwater supplies to sustain the population.

Two thirds of the world's population will therefore experience water scarcity by 2025. Drinking water of a decent quality is becoming increasingly difficult to find. According to the World Health Organization, more than a billion people lack access to clean drinking water, and the vast majority of these individuals reside in rural areas where the low population density and inaccessible locations make it challenging to implement conventional clean water solutions. The global urbanization rate is rising. The number of people living in cities worldwide increased from 0.8 billion (29.6%) to 4.4 billion (56.2%) between 1950 and 2020, and is expected to reach 6.7 billion (68.4%) by 2050. Urban people' health and wellbeing, the quality of the urban environment, and socioeconomic growth are all significantly impacted by water scarcity, which occurs when demand exceeds supply.

Water scarcity is a crucial driver of water security. Many metropolitan populations around the world are currently affected by water scarcity. Over the next three decades, domestic water and urban industrial consumption is anticipated to increase by 50–80% as a result of population growth, urbanization, and socioeconomic development. Since saline water makes up 97% of all available water resources, desalination and water recycling technologies are the most obvious way to produce sustainable fresh water. Desalination, in the simplest sense, is acquiring clean or potable water via sources available through

purification seawater or brackish water that is salty. Throughout time, desalination systems have advanced continuously, resulting in the availability of several techniques that can be categorized as membrane techniques heat processes, etc.

Desalination processes using membranes has special chemistry and physical characteristics, such ion adsorption, ion selectivity, and semipermeability in techniques such as electro-dialysis (ED), and capacitive deionization (CDI) Reverse Osmosis (RO). Electrodialysis is one of the additional membrane techniques like electro-dialysis reversal (EDR) with membrane distillation (MD). As opposed to that, Processes used in thermal desalination rely on change-state theories, including such as multi-stage flash distillation (MSF) and humidification dehumidification (HDH), multi-effect distillation (MED), and vapour compressor distillation (VCD). The most widely utilized techniques are RO, MSF, and MED. RO makes up 65% of the various desalination techniques. MSF accounts for 21% of global donations, MED for 7%, ED for 3%, and the others for 4% output capability.

The following can be listed as the main downsides of the various desalination techniques: high energy consumption, release of contaminated brine with detrimental impacts on aquatic life, environment contamination when fossil fuels are utilized, and high upfront capital costs. High energy consumption in particular has a significant impact on the cost of desalination. the amount of energy used by the most popular water desalination methods. In comparison to membrane based procedures, thermal-based desalination methods often use a lot more energy. For example, compared to 4-6 kWh/m³ for saltwater RO (SWRO) and 1.5- 2.5 kWh/m³ for brackish water RO, the total specific energy needs for MSF and MED are 20-27 kWh/m³ and 14-21 kWh/m³, respectively (BWRO).

Traditionally, the energy needed to run the various desalination procedures is provided by fossil fuels. Burning fossil fuels results in enormous amounts of gases that have negative environmental effects in as well as the high associated costs. By 2050, it is anticipated that the global emissions from fossil fuel-powered desalination machines will increase to 400 million tonnes of carbon equivalents annually. Finding alternate, sustainable energy sources for desalination is therefore crucial. Using a wide range of conversion devices and systems, it is

feasible to produce sustainable energy from renewable resources such as wind, geothermal heat, hydroelectricity, sunlight, and other types of energy.

In comparison to conventional fossil fuels, renewable energy is widely available, affordable, and has no adverse effects on the environment. While the utilization of renewable energies to power desalination plants conserves environmental integrity and tends to increase sustainability, it also has the potential to lower the end-user cost, which is crucial for residents of underprivileged societies. With rising populations, urbanization, and climate change, traditional sources of fresh water are becoming strained, and many regions around the world are facing severe water shortages. In this context, alternative sources of water desalination, such as reduced graphene oxide (rGO), have emerged as a promising approach to enhance the efficiency and sustainability of water desalination processes.

Sources of environmental pollution can be found in the use of pesticides, fertilizers, heavy metals, plastic materials, etc. From a theoretical point of view, purification treatments can be developed for all types of wastewater, but the potential for achieving effective and economical solutions is severely limited. Choosing the most appropriate treatment depends on several factors. Contaminant removal, technology reliability and flexibility, cost, environmental compatibility, process scalability. The available technologies can be categorized into two classes: There are liquid-liquid systems that use organic solvents for selective extraction, and solid-liquid systems that mainly use ion-exchange resins and solid adsorbents as filters. Adsorption/filtration processes are carried out in columns, tubes, or cartridges containing adsorbents. After the adsorption step, the filter and the ions retained therein can be discarded or, more desirably, the filter can be reused to recover the adsorbed species. A variety of adsorbent solids are commonly used, including activated carbon, silica gel, pristine and modified clays, activated silicoaluminates, and polymeric materials.

Recently, innovative systems based on carbon nanotubes, nanofibers, graphene and graphene oxide have been proposed in the scientific literature, with the aim of reducing the amount of adsorbent and improving cleaning capacity. . Although the effectiveness of such new carbon-based materials is well known and

demonstrated, there are still unsolved problems in their use. For example, the precursors required to generate sorbents can contain varying amounts of organic and inorganic impurities that can contaminate water.

Moreover, as the selectivity of adsorbents is still a problem to be solved, several research groups have proposed modification and functionalization of carbon materials to achieve satisfactory efficiency and selectivity. The proposed functionalization method aims to improve the coordination properties of carbon species to more easily trap contaminants in aqueous solutions. However, molecules such as amine derivatives proposed for these purposes may be highly complex or inherently harmful to humans and the environment. In this scenario, films based on graphene oxide (GO and related) materials are of great interest in both academia and industry, but the GO structure is still under discussion due to the complexity of the material and its non-stoichiometry.

In fact, GO easily exfoliated into stable monolayer sheets and easily can be dispersed in water due to its polar functional groups. Oxygenated groups are also responsible for the self-assembly properties of GO, which can be assembled into films featuring superior mechanical properties compared to graphite-based materials. Other properties that make GO and its derivatives promising candidates for membrane filtration processes are their high surface area and excellent water permeability, as well as their effective molecular sieve properties. Moreover, GO offers realistic prospects for industrial-scale production, as self-assembled films can be easily prepared by filtration of aqueous dispersions.

Literature suggests that reduced graphene oxide (rGO) may exhibit enhanced filtration properties. rGO can be easily obtained by reduction of GO. This reduction may partially affect their ability to form stable filter membranes, which is believed to be based on macroscopic mechanical behavior. Film formation derives from the aforementioned self-assembly ability of GO and can be retained if moderate and controlled reduction of its oxygen functional groups is performed. In fact, functional groups on the basal plane of GO are responsible for the secondary bonds that hold the layers of GO together. Previous studies have shown that cracks and uneven surfaces are obtained with longer reduction times. In particular, beyond 72 hours of reduction, the ability to form free-standing films is

lost. Indeed, the reduction affects both pore size and interlayer spacing, potentially increasing uptake and/or selectivity to various contaminants. GO can be thermally reduced in an inert or reducing atmosphere at temperatures above 100 °C. Reduction occurs through the gradual removal of oxygen-containing functional groups. However, losses up to 30 µm lead to detrimental loss of active material and structural distortion.

Alternatively, chemical reduction with various reducing agents has been proposed. Hydrazine and its derivatives have been described as reducing agents of choice. However, hydrazine poses many hazards to humans and the environment, which calls for a more friendly and sustainable reagent. In this regard, it has been reported that L-ascorbic acid (L-AA) exhibits an effective ability to reduce GO. Under these premises, this contribution proposes a facile process to obtain self-assembled rGO-based membrane filters starting from aqueous GO dispersions.

We describe the morphological and microstructural characterization of the membranes and demonstrate their applicability as filters for metal-bearing wastewater and water softening. By reviewing recent studies, we came to the conclusion that rGO has great potential for water filtration. However, rGO membranes for water filtration are still in a very early stage, practical results can often be contradictory, and many questions remain unanswered. Reduced graphene oxide, a derivative of graphene, a one-atom-thick layer of carbon atoms arranged in a hexagonal lattice, has attracted significant attention in recent years due to its unique properties, including high mechanical strength, excellent thermal and electrical conductivity, and large surface area.

These properties make rGO a versatile material with potential applications in various fields, including water desalination. rGO-based membranes, coatings, and composites have shown great potential for improving the performance of water desalination processes, such as reverse osmosis (RO), membrane distillation (MD), and capacitive deionization (CDI), by enhancing water permeability, selectivity, and energy efficiency.

In this review, we will provide an in-depth exploration of the recent advancements in water desalination using rGO as an alternative source. We will first introduce the current state of global water scarcity and the challenges associated with conventional water desalination methods.

We will then delve into the properties and synthesis of rGO, highlighting its unique features that make it suitable for water desalination applications. Subsequently, we will discuss the various strategies employed to incorporate rGO into membranes, coatings, and composites for water desalination, including fabrication techniques, material combinations, and functionalization methods

Furthermore, we will discuss the challenges and limitations of using rGO in water desalination, such as cost, scalability, and environmental impacts, and propose potential solutions to overcome these challenges. Finally, we will highlight the future prospects and emerging trends in rGO-based water desalination, including new materials, technologies, and applications, and provide concluding remarks summarizing the current state of knowledge in this field.

With the increasing global population and rapid urbanization, the demand for fresh water has been steadily rising. According to the United Nations, by 2025, nearly two-thirds of the world's population could be under "water stress," with limited access to clean water for their basic needs. Additionally, the effects of climate change, such as changing precipitation patterns, melting glaciers, and rising sea levels, are further exacerbating the global water scarcity crisis. As a result, there is an urgent need for sustainable and efficient methods to obtain fresh water from unconventional sources, such as seawater and brackish water.

Conventional methods of water desalination, such as thermal desalination (e.g., multi-stage flash distillation, multi-effect distillation) and membrane desalination (e.g., RO, MD), have been widely used to produce fresh water from seawater and brackish water. However, these methods have several limitations, including high energy consumption, high capital and operational costs, environmental impacts, and limited efficiency and selectivity. For instance, RO, which is currently the most widely used method for seawater desalination, requires high pressures to force water through a semipermeable membrane, resulting in

significant energy consumption and operational costs. MD, on the other hand, relies on the temperature gradient across a membrane.

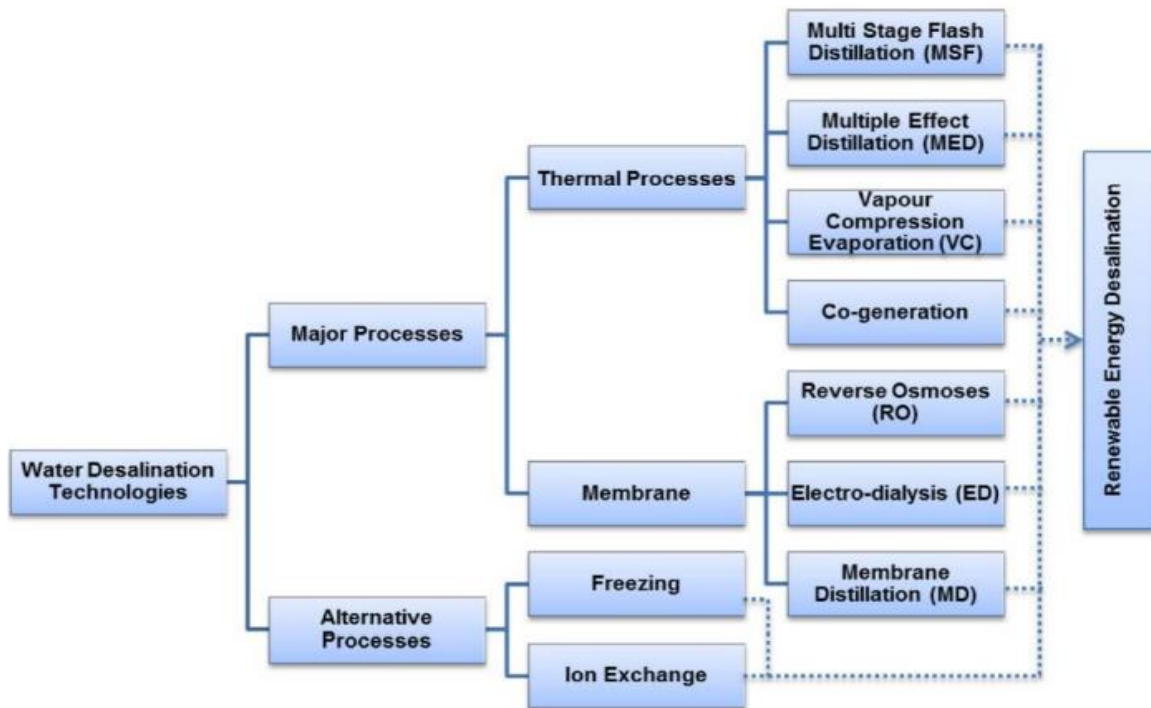


Figure 1.1 Different water Desalination Techniques

1.2.DESALINATION TECHNOLOGIES:

Desalination technologies are used to remove salt and other impurities from seawater or brackish water, making it suitable for various purposes such as drinking water, irrigation, and industrial processes. Here's a detailed overview of how desalination technologies work:

Pre-treatment: Before the actual desalination process, pre-treatment is often necessary to remove larger particles, suspended solids, and other impurities from the feed water. This is typically done through processes such as screening, sedimentation, and filtration. Pre-treatment helps protect the desalination equipment from fouling and extends their lifespan.

Desalination Process: The desalination process varies depending on the technology used, but the overall objective is to separate freshwater from the salt and other impurities in the feed water.

Post-Treatment: After the desalination process, the freshwater produced may undergo post-treatment to further improve its quality and make it suitable for specific uses. Post-treatment may include

disinfection using chemicals or UV light to kill any remaining microorganisms, pH adjustment to stabilize the water, and remineralisation to restore some essential minerals that may have been removed during the desalination process.

1.2.1.Desalination Methods and Process:

As of now accessible desalination innovations can be categorized as follows:

(1)Stage change processes that include warming the feed (seawater, harsh water or other impeded waters) to "edge of boiling over" at the working strain to deliver "steam", and consolidating the steam in a condenser unit to deliver freshwater. Uses of this standard incorporate sun powered distillation (SD); Multi-effect distillation (MED); Multi-stage flash desalination (MSF); Mechanical Vapour compressor distillation (MVC) and Thermo Vapour Compression (TVC).

(2)Non-stage change processes that include the division of disintegrated salts from the feed waters by mechanical or synthetic/electrical means utilizing a film obstruction between the feed (seawater or harsh water) and item (consumable water). Uses of this standard incorporate electrodialysis (ED) and Reverse Osmosis(RO).

(3)Cross breed processes include a blend of stage change and detachment procedures (as on account of non-stage change processes) in a solitary unit or in successive moves toward produce unadulterated or consumable water. Models include: Membrane distillation (MD); invert assimilation joined with MSF or Prescription processes.

The five most significant desalination systems using an AHP multi-criteria analysis while taking economic, technical, and environmental considerations:

- Multi-effect desalination (MED)
- Reverse osmosis (RO)
- Vapor compression (VC)
- Electrodialysis (ED)
- Multi-stage flash (MSF)

1.2.2.Types of Desalination Techniques

There are different types of desalination techniques, which vary in terms of the processes involved, the equipment used, and the energy requirements. These techniques include physical processes such as distillation and filtration, as well as chemical processes such as ion exchange and electro-dialysis. Desalination can be a useful solution to address water scarcity and provide safe and clean drinking water in areas where fresh water resources are limited. Some of the majorly used types of desalination are listed below:-

1.2.2.1.Reverse Osmosis(RO):

Reverse osmosis (RO) is a water purification process that uses a semipermeable membrane to remove contaminants and impurities from water. It works by applying pressure to force water through the membrane, while leaving behind dissolved salts, bacteria, viruses, and other contaminants. The purified water that passes through the membrane is collected, while the concentrated contaminants are flushed away as waste. Reverse osmosis is widely used in various applications, including drinking water purification, desalination of seawater, and industrial processes, to produce clean and safe water for different purposes. It is an effective and popular method for water treatment due to its ability to remove a wide range of contaminants, providing high-quality water for consumption or industrial use.

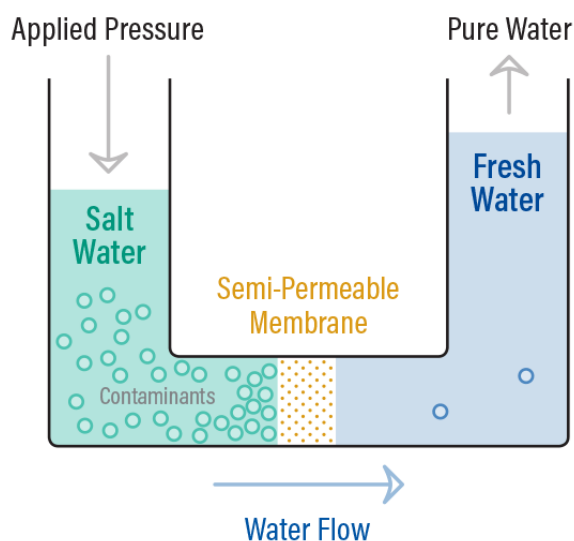


Figure 1.2. Schematic Illustration Reverse Osmosis

1.2.2.2. Multi-Stage Flash (MSF):

Multi-Stage Flash (MSF) is a desalination process that uses thermal energy to convert seawater into freshwater. The process involves heating seawater to a high temperature, which causes it to evaporate, and then condensing the vapor to form freshwater. MSF is a multi-stage process, where the evaporated seawater passes through a series of chambers, each operating at a lower pressure than the previous stage. As the pressure decreases, the boiling point of the seawater decreases, and more water can be evaporated. The condensed vapor is collected and treated as freshwater, while the concentrated seawater is discharged back into the ocean. MSF is a widely used desalination process, particularly in the Middle East, where it is used to meet the region's growing demand for freshwater. It requires a significant amount of thermal energy, typically supplied by fossil fuels, making it an energy-intensive process. However, MSF is capable of producing large quantities of freshwater, making it a valuable tool for water resource management in water-scarce regions.

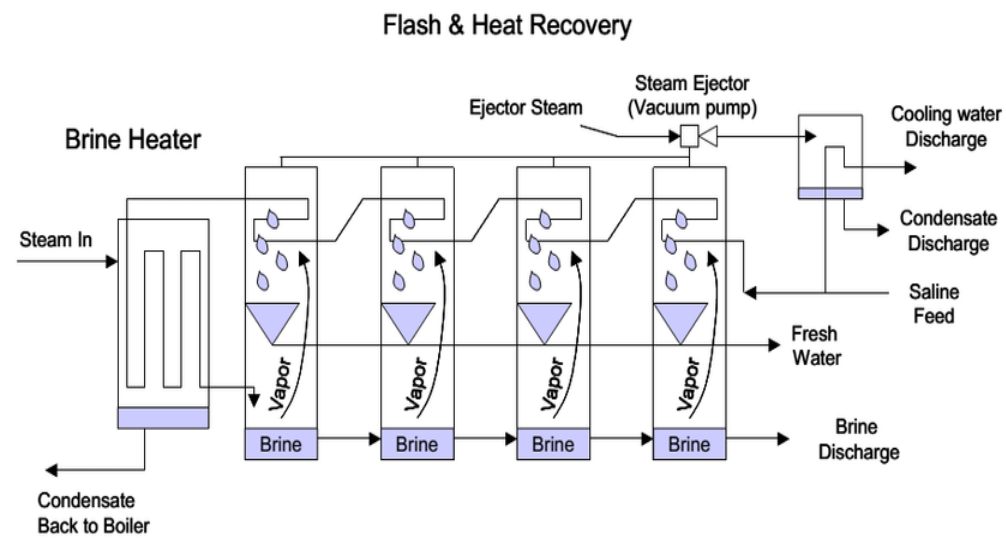


Figure 1.3. Multi Stage Flash Desalination

1.2.2.3. Electrodialysis (ED):

Electrodialysis (ED) is a desalination process that uses an electric field to remove ions from water, resulting in the production of freshwater. ED works by passing water through a series of ion exchange membranes, which are selectively permeable to ions based on their charge. When an electric potential is applied

across the membranes, positively charged ions (cations) are drawn towards the negatively charged membrane (called the cathode), while negatively charged ions (anions) are drawn towards the positively charged membrane (called the anode). As a result, the ions are effectively removed from the water and concentrated in separate streams, while purified water is collected in the middle. The concentrated streams containing the removed ions are typically discharged as brine or further processed for disposal or recovery of valuable components.

ED is known for its ability to selectively remove specific ions, making it suitable for desalination of brackish water or for targeted removal of contaminants from water sources. It is a relatively energy-efficient process compared to other desalination methods, as it does not require high temperatures or pressure. ED is used in various applications, including drinking water production, wastewater treatment, and recovery of valuable substances from process streams in industries.

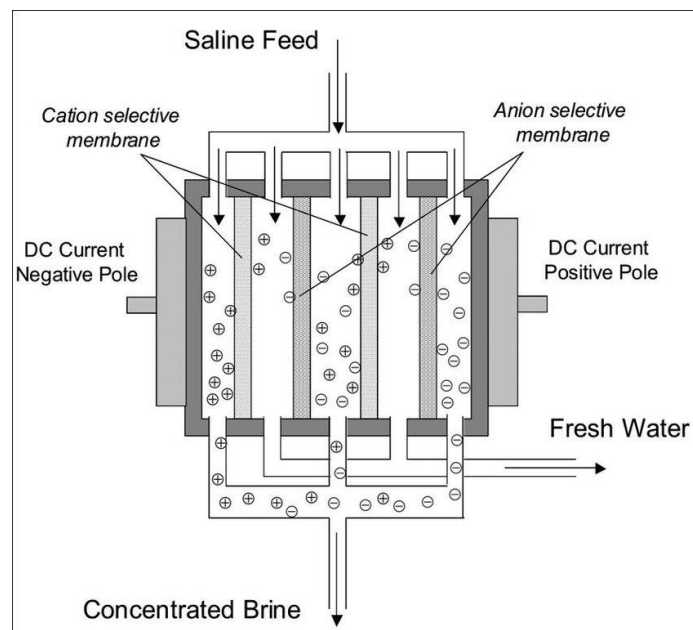


Figure 1.4. Schematic Illustration Electrodialysis

1.2.2.4. Nanofiltration (NF)

Nanofiltration (NF) is a water treatment process that uses a semi-permeable membrane with pore sizes between those of reverse osmosis (RO) and ultrafiltration (UF) to separate water from dissolved ions, organic compounds, and

particles. NF is a pressure-driven process that utilizes a selectively permeable membrane to allow certain substances to pass through while retaining others. The membrane acts as a barrier, allowing water molecules and smaller ions to pass through, while larger molecules such as salts, some dissolved organics, and particles are rejected and retained by the membrane. NF is commonly used for water softening, color and odor removal, and removal of specific contaminants such as bacteria, viruses, and certain ions. NF is widely used in various applications, including drinking water treatment, wastewater treatment, and industrial processes, as it can effectively remove a wide range of contaminants while maintaining the essential minerals and maintaining a higher flow rate compared to RO. It is a relatively energy-efficient process compared to RO, as it operates at a lower pressure, making it suitable for a variety of water treatment needs.

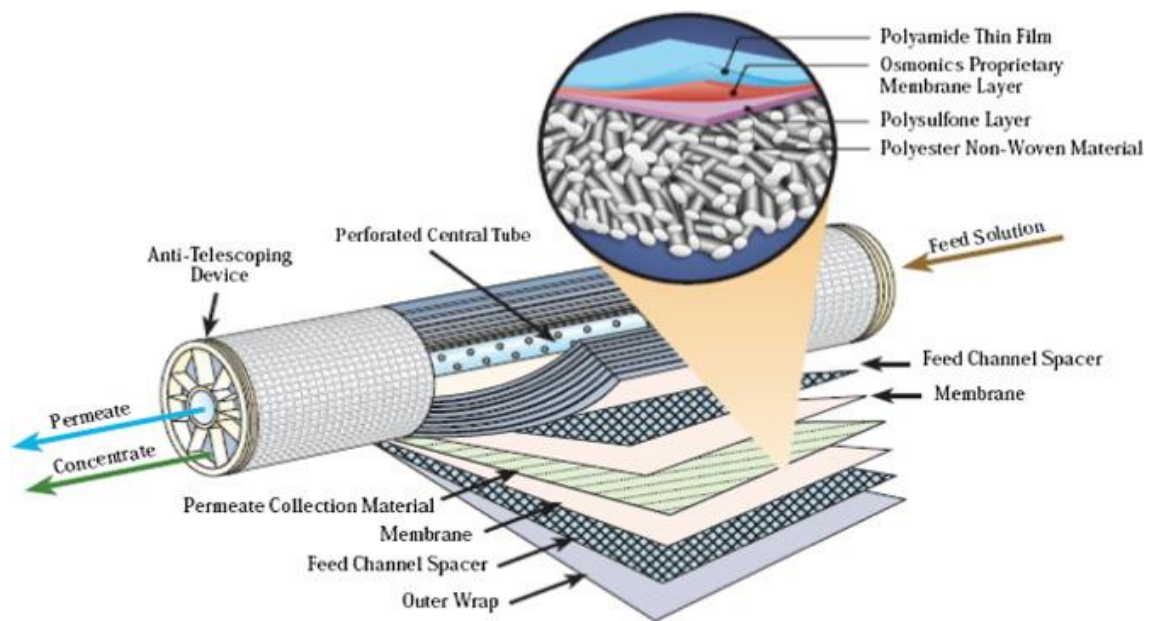


Figure 1.5 Three Dimensional View of Nanofiltration Membrane

1.2.2.5. Membrane Distillation

Membrane distillation (MD) is a water desalination process that uses a semi-permeable membrane to separate water from contaminants through vaporization and condensation. It is a thermally-driven process that relies on the difference in vapor pressure across the membrane to induce the separation. In MD, heated saline water is brought into contact with one side of the membrane,

while a colder stream is maintained on the other side. The temperature difference creates a vapor pressure gradient, causing water molecules to evaporate from the hot side and pass through the membrane as water vapor. The water vapor then condenses on the cold side of the membrane, forming purified water, while the contaminants are left behind. The purified water is collected as distillate, while the concentrated solution is discharged as brine.

MD is known for its ability to remove a wide range of contaminants, including dissolved salts, bacteria, and other impurities, making it suitable for desalination of seawater or brackish water, as well as treatment of wastewater. MD is considered to be a relatively energy-efficient process, as it can utilize low-grade waste heat for the evaporation process, and it operates at low pressures compared to other desalination methods. However, MD is still considered a developing technology and has certain limitations, such as the potential for membrane fouling and the need for further research and development for commercial-scale applications.

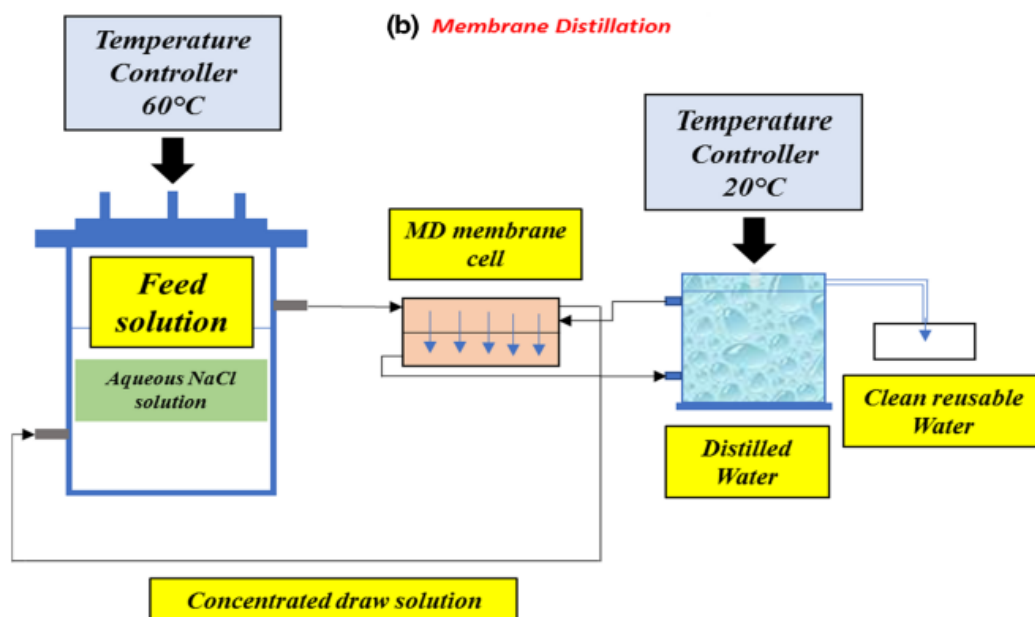


Figure 1.6 Schematic Illustration of Membrane Desalination

CHAPTER 2

LITERATURE SURVEY

2.1 LITERATURE SURVEY

This study presents the main factor contributing to the formation of composites in this study is the redox-like reaction between reduced graphene oxide (rGO) and the metal precursor. As the metal precursors are reduced, rGO undergoes progressive oxidation, resulting in the formation of graphene oxide, and the resulting metal nanoparticles are closely anchored onto the rGO sheets. The size of the nanoparticles can be controlled by adjusting the precursor concentration. rGO and its composites, including rGO-MnO₂ and rGO-Ag, exhibit excellent uptake capacity for Hg(II). In addition to water purification, these composites have wide-ranging applications in diverse fields such as catalysis and fuel cells.(Sreeprasad et al. 2011)

In this paper the efficiency of separating dyes using membranes made from graphene oxide (GO) depends on three main factors: (a) the ability of GO to absorb organic dye molecules, (b) the interaction between charged dyes and the negatively charged GO sheets through electrostatic forces, and (c) the physical sieving effect of 2D nanochannels that is controlled by their size, known as the size exclusion effect. High-performance composite membranes of rGO/MoO₂ and rGO/WO₃ for nanofiltration (NF) applications were fabricated by growing metal oxide nanoparticles in-situ on the surface of rGO membranes exhibit high rejections of approximately 100% for dye molecules and high water. These excellent properties suggest promising applications of these composite membranes in water purification, and it is also speculated that a wide range of composite membranes based on graphene could be designed and fabricated for broader separation applications.(Thebo et al. 2018)(Gao et al. 2020)

This paper analyses the detection and removal of pollutants from water is crucial for maintaining water quality and protecting human health and the environment. Graphene oxide (GO), a starting material that can be reduced to graphene through thermal or chemical methods, has been proven to be an effective adsorbent for removing toxic compounds such as heavy metals, dyes,

formaldehyde, humic acid, and ammonia. A simple methodology was adopted to immobilize the composites on a low-cost and inert support, such as river sand, which is abundantly available and environmentally friendly. A biomaterial was used as a binder for this process. The results show that RGO composites exhibit high distribution coefficients (K_d) and superior performance in removing Hg (II) from both distilled water and real water sources. The membranes allow ions from common salts to pass through, but retain some larger ions. Narrow capillaries enable rapid permeation by monolayer or bilayer water, while blocking helium in humidity-free conditions, but allowing penetration in humid gas. Dry laminates are vacuum-tight, but act as molecular sieves when immersed in water, blocking solutes with hydrated radii larger than 4.5 Å. (Ray 2015) (Kavitha 2022)..

To summarize, the research investigated the adsorption mechanism of Methylene Blue (MB) onto reduced graphene oxide (rGO) prepared using eco-friendly methods. This study suggests that pristine rGO has potential as an adsorbent and green material for water or wastewater treatment, with possible scalability for industrial-scale applications of graphene-based nanomaterials. They have elucidated the mechanisms involved in fabricating uniform membranes by studying their dependence on reduction time. Hydroxyl and carboxyl groups were found to play a crucial role in the fabrication of rGO membranes at the molecular level. Among the different membranes prepared, the rGO 2-hour membrane with a small amount of unreduced GO showed the lowest Na^+/Cl^- ion permeation and the highest water flow rate, making it a promising candidate for water desalination applications. (Arias Arias et al. 2020)(Huang et al. 2019)

In many practical applications, ultrathin membranes lack sufficient mechanical strength and need to be supported by a separate layer. For instance, in osmotically driven membrane processes used in water processing and energy production, the support layer can cause internal concentration polarization (ICP). Graphene and its derivatives are ideal materials for freestanding ultrathin membranes due to their superior mechanical strength compared to other materials. The MgSi/rGO composite membranes offer potential strategies to further enhance the performance of NF membranes by adjusting the spacing

between graphene sheets, thereby expanding their applications in graphene-based membrane technology.(Liang et al. 2016)

The water transport and dye-contaminated water purification performance of g-C₃N₄ photocatalysts intercalated into rGO membranes were comparatively investigated in terms of different dimensions of intercalation. The study established a photo-induced self-cleaning mechanism for the g-C₃N₄/rGO composite membranes. The results indicate that the g-C₃N₄ NT/rGO composite membrane holds promise as a candidate for water purification, and intercalation of 1D nanoscale photocatalysts into rGO membranes offers a novel strategy for developing efficient photocatalytic membrane materials.(Wei, Zhu, and Jiang 2019)

In summary, the authors successfully synthesized a composite of reduced graphene oxide (rGO) with gold nanoparticles (Au NPs), as evidenced by TEM analysis showing Au NP diameters of approximately 8-10 nm. Their investigation of water flux and RhB retention revealed an inverse relationship between water flux and membrane thickness, while retention showed a positive proportional relationship with membrane thickness.They employed a UV irradiation method to prepare weak-reduction graphene oxide (GO) membranes and investigated the impact of different reduction degrees on their structure and properties.(Cheng et al. 2019)(Yu et al. 2020)

A vacuum-assisted filtration method was used to fabricate Graphene Nanofiltration (NF) membranes that were intercalated with Carbon Nanotubes (CNTs) on porous ceramic microfiltration membranes. The effective dispersion of CNTs was achieved using F127 as a surfactant, resulting in well-dispersed 1D CNTs being embedded within 2D graphene sheets to form a uniform network. The excellent dispersion of CNTs significantly influenced the performance of the resulting rGO-CNTs hybrid NF membranes. The optimized rGO-CNTs hybrid NF membranes were then tested for drinking water treatment and demonstrated high retention efficiencies (primarily above 99%) and permeabilities for nanoparticles, dyes, BSA, sugars, and particularly humic acid. These results highlight the promising potential of rGO-CNTs hybrid NF membranes for drinking water purification applications(Chen et al. 2016).

This paper presents a facile approach for synthesizing Au-rGO (Gold-Reduced Graphene Oxide) nanohybrids, where rGO nanosheets are decorated with uniformly distributed Au NPs. The high surface area and negative surface charge of Au-rGO nanohybrids make them highly efficient for dye removal through electrostatic and π - π interactions. The efficiency of dye removal can be controlled by adjusting the pH value and temperature of the medium. (Kar et al. 2016)

In conclusion, the morphology evolution of rGO-Ti (Reduced Graphene Oxide-Titanium) hybrids is attributed to the increase in solvothermal temperature during the soft chemical process and alkali treatment. Initially, TiO_2 nanoparticles are delaminated and incorporated into exfoliated GO layers through H-bonding. Finally, at harsher conditions, due to thermodynamic control, titanate nanotubes are cracked and destroyed, promoting the growth of flat ribbon-like morphology on the two-dimensional rGO surface. (Nguyen-Phan et al. 2012)

Recently, there have been several comprehensive reviews highlighting the combination of inorganic nanoparticles with GO to create highly selective and permeable filtration membranes for more efficient wastewater treatment. When intercalated into GO sheets, HNTs can modify the interior spatial structure of GO, resulting in an enhanced specific surface area and inter-spacing. With these remarkable structural features, this composite material is ideal for exceptional applications in the separation of dyes and heavy metal-contaminated wastewater. (Liu et al. 2018)

In conclusion, a novel microfiltration membrane consisting of g- C_3N_4 NS, rGO, and CA was successfully fabricated using a vacuum filtration method. The outstanding photocatalytic efficiency of g- C_3N_4 NS under visible light irradiation, combined with the photogenerated charge separation facilitated by the unique hetero-structure between g- C_3N_4 NS and rGO, resulted in the g- C_3N_4 NS/rGO/CA composite photocatalytic membrane demonstrating high performance in the removal of organic contaminants and complete bacterial inactivation through the integrated process of filtration with visible light photocatalysis. Importantly, membrane fouling was significantly mitigated in the integrated process. The composite photocatalytic membrane exhibits several advantages that make it highly promising for water treatment applications. (Zhao et al. 2016)

The membrane obtained, which consists of reduced graphene oxide (rGO) and a highly stable aromatic polymer, demonstrated effective purification of contaminated water with a separation efficiency exceeding 99.19%. Notably, the purification ability of the membrane is not limited to specific liquid types, but is suitable for various combinations. Furthermore, the rGO-PI membrane exhibited excellent durability even under unstable and harsh environments, such as exposure to chemical and physical corrosive conditions, as well as during multi-cycle tests. (Zhang et al. 2021)

rGO/TiO₂ and rGO/ZnO filters were successfully fabricated using a hydrothermal method. The inclusion of rGO in the nanocomposite filters resulted in significantly enhanced photocatalytic activity when exposed to halogen light, compared to filters without rGO. The absence of rGO hindered the firm attachment of metal oxides onto the filter. Thus, rGO serves as a coupling agent and a matrix, allowing for uniform and resilient attachment of metal oxides onto the filter. The water treatment performance of the rGO/TiO₂ filter surpassed that of the rGO/ZnO filter. The poor performance of the rGO/ZnO filter can be attributed to weak adhesion between ZnO and rGO, instability of ZnO in alkaline conditions, and conversion of photoactive ZnO to non-photoactive ZnO₂. On the other hand, the rGO/TiO₂ filter exhibited excellent photodegradation efficacy, suggesting its stability and great potential for water purification (Ariffin et al. 2014)

Partially reduced graphene oxide/TiO₂ (GOT) membranes were fabricated by depositing GOT composites onto ceramic ultrafiltration (UF) and nanofiltration (NF) monoliths using a dip coating method. The pore size of the monolith played a crucial role in determining the amount of GOT composite stabilized on the substrate and the photocatalytic efficiency of the developed membranes under visible light. It was observed that only the membrane developed on the UF monolith with a pore size of 10 nm exhibited enhanced photocatalytic performance, attributed to the capacity of the 10 nm pores to host the GOT composites. (Athanasakou et al. 2014)

Ternary heterogeneous photocatalysts based on hematite (Fe₂O₃), multi-walled carbon nanotubes (MWCNTs), and reduced graphene oxide (rGO) sheets were successfully fabricated using a simple and low-cost hydrothermal method.

The composite materials exhibited significantly increased optical absorption at visible wavelengths, and the Fe₂O₃/MWCNT/rGO composite showed considerably higher photocatalytic activity compared to Fe₂O₃ or other composite samples. This reduction in charge carrier recombination rate was confirmed through photo electrochemical measurements. Additionally, the ternary composite exhibited a large specific surface area, which increased the density of active centers for adsorption of dye molecules, further enhancing its photocatalytic activity.(Pawar, Choi, and Lee 2015)

In summary, a novel photothermal composite aerogel evaporator was created by assembling polysulfide nanospheres (PSNs) onto a reduced graphene oxide (rGO) scaffold for efficient solar-driven water treatment. The interconnected porous structure and adsorption capacity of the PSN-rGO aerogel enable overall purification of wastewater containing heavy metal ions. When applied to solar desalination, the photothermal aerogel demonstrated outstanding salt-rejection performance through rapid salt ion exchange, ensuring long-term durability. The PSN-rGO aerogel, with its comprehensive water treatment abilities, has significant potential for practical applications in wastewater remediation and seawater desalination.(Meng et al. 2021)

The unique architecture and high surface area of the rGO-MoS₂ nanocomposite contribute to enhanced adsorption capacity, antibacterial activity, and specific capacitance in supercapacitors. The rGO-MoS₂ nanocomposite displays enhanced antibacterial activity against both Gram-positive and Gram-negative bacteria compared to rGO and MoS₂ nanoparticles. These results highlight the potential of rGO-MoS₂ nanocomposite as versatile materials for various applications in the field of materials science.(Raghu et al. 2018)

In conclusion, we have successfully demonstrated a controllable process for preparing reduced graphene oxide (rGO) membranes using an environmentally friendly hydrothermal approach. The mechanisms underlying the fabrication of uniform membranes were elucidated, with reduction time playing a crucial role. Hydroxyl and carboxyl groups were found to be key factors in the fabrication of rGO membranes at the molecular level. Among the different reduction times studied, the rGO membrane prepared for 2 hours, which contained a small amount

of unreduced graphene oxide, exhibited the lowest permeation of Na^+ and Cl^- ions while maintaining the highest water flow rate. This membrane shows potential as a candidate for water desalination applications.(Huang et al. 2019)

The process of obtaining reduced graphene oxide (rGO) typically involves reducing exfoliated graphene oxide (GO) using various reducing agent. However, there is a need for a simple, low-cost, and scalable method for obtaining rGO suitable for industrial-scale production. In this study, we report an efficient and cost-effective approach for reducing GO using ferrocene and HNO_3 , resulting in high-quality rGO sheets that are mostly single and double layered. To the best of our knowledge, there are no previous reports on the synthesis of rGO using ferrocene and HNO_3 , making this reduction technique unique. Unlike other reported methods, our approach does not require complicated arrangements or multiple steps for rGO preparation. The resulting rGO exhibits promising physical properties, making it suitable for potential applications in graphene-related devices.(Sa et al. 2018)

The study uncovered the asymmetric water wetting behavior of a reduced graphene oxide (rGO) membrane prepared by a vacuum filtration method. The asymmetry was found to originate from the physical imprint of the filter membrane, in the form of surface microstructures of rGO, on the bottom surface of the as-made rGO membrane. The actual surface pore size of the membrane substrate was identified as the key factor controlling the imprint during the filtration process. These microstructures were observed only when the pore size of the substrate matched the flake size of the GO sheet used in the vacuum filtration. Once formed, these microstructures led to higher water contact angle hysteresis on the bottom surface of the rGO membrane compared to its top surface. This aspect of the research sheds light on a previously overlooked aspect of vacuum-filtration-based rGO membrane preparation and provides scientific insights into the phenomenon.

Furthermore, the study revealed for the first time that rGO membranes exhibited significant water flux kinetics during pressure-driven water filtration. The membranes became more compact during the filtration process, and both water flux and species rejection were found to be highly dependent on the compactness

of the membranes. These findings contribute to a better understanding of the inconsistencies observed in the literature regarding water flux and species rejection by stacked rGO membranes.(Tang 2017)

In summary, they have developed flexible and free-standing rGO membranes that exhibit excellent salt-rejecting properties for efficient and stable solar desalination of high salinity brine under one sun. The rGO membrane, combined with effective optical absorption, reduced thermal loss, and hydrophilic water transport channels, achieves a remarkable one-sun evaporation rate of 1.27 kg/m²h¹ and energy conversion efficiency of 79% for 3.5 wt% brine. The controlled narrow interspaces between adjacent rGO nanosheets contribute to the long-term stability of the membrane in rejecting salt, even when treating high salinity brine with concentrations higher than 5 wt%. Therefore, our rGO-based membrane presents a promising alternative for stable, efficient, and anti-salt-fouling solar desalination of high salinity brine.(Zhuang et al. 2020)

The study uncovered the asymmetric water wetting behavior of a reduced graphene oxide (rGO) membrane prepared by a vacuum filtration method. The asymmetry was found to originate from the physical imprint of the filter membrane, in the form of surface microstructures of rGO, on the bottom surface of the as-made rGO membrane. The study revealed for the first time that rGO membranes exhibited significant water flux kinetics during pressure-driven water filtration. The membranes became more compact during the filtration process, and both water flux and species rejection were found to be highly dependent on the compactness of the membranes. These findings contribute to a better understanding of the inconsistencies observed in the literature regarding water flux and species rejection by stacked rGO membranes.(Tang 2017)

In our current investigation, the analysis of groundwater in the study area revealed that the dominant cations are Na⁺, followed by Ca²⁺, Mg²⁺, and K⁺. The dominant anions are Cl⁻, followed by HCO₃⁻, SO₄²⁻, and F⁻. Excessive concentrations of trace elements such as Cd²⁺ and Pb²⁺ were also identified. The findings indicate that both human activities and geochemical processes are responsible for the quality of groundwater in the River Basin. To address the issue of excess ion concentration, reduced graphene oxide was utilized as an

adsorbent. Remarkable reductions were observed in parameters such as EC, TDS, Na^+ , K^+ , Cd^{2+} , and Pb^{2+} with increasing dosages of adsorbent. This was confirmed by XRD pattern, FESEM, and EDS analysis, which confirmed the adsorption process. The results highlight the critical state of groundwater quality in the River Basin, and the findings can be utilized in future groundwater planning and development efforts.(Ahamed and Loganathan 2021)

This paper studies the Graphene oxide (GO)-based self-assembling membranes have been developed for potential use as filters in wastewater treatment containing metal ions. To achieve reduction of GO, a simple, cost-effective, and environmentally friendly chemical reduction method utilizing L-ascorbic acid as the reducing agent was employed. Among the different reduced membranes, the one reduced for 72 hours, which showed significant amorphization and graphitization while retaining the self-assembling behavior, was selected for preliminary filtration tests. It was hypothesized that a lower interlayer distance compared to GO or less reduced rGO membranes could effectively enhance the capability of ions capture.(Latorrata et al. 2020)

CHAPTER 3

AIM AND SCOPE OF THE PROJECT

3.1 AIM:

The aim of this thesis is to investigate the potential of reduced graphene oxide (rGO) as a pre-filter material for improving the efficiency and performance of Reverse Osmosis (RO) in waste water purification. The rGO-based pre-filters in enhancing the removal of contaminants from waste water, including heavy metals, organic pollutants, and microorganisms, when combined with RO technology. Additionally, the study will explore the optimal fabrication process of rGO-based pre-filters. The project includes:

Investigating the properties and characteristics of graphene oxide (GO) and its reduced form, rGO, and comprehensively reviewing the literature on the principles and mechanisms of reverse osmosis in waste water treatment.

Evaluating the performance of rGO-based pre-filters in combination with RO, including assessing the removal efficiency of different contaminants commonly found in waste water, and determining the optimal conditions for their application.

3.2. Scope of the Project:

The scope of this thesis will cover the investigation of reduced graphene oxide (rGO) as a pre-filter for waste water purification in combination with reverse osmosis (RO). The study will involve experimental research and analysis to evaluate the performance of rGO-based pre-filters in enhancing the efficiency of RO in removing contaminants from waste water. The scope of the project will include the following:

A comprehensive review of the literature on the properties and characteristics of graphene oxide (GO) and rGO, as well as the principles and mechanisms of reverse osmosis in waste water treatment. This will provide a solid foundation for the study and establish the current state of knowledge in the field.

Experimental investigations to evaluate the performance of rGO-based pre-filters in combination with RO. This will involve conducting laboratory-scale experiments to assess the removal efficiency of various contaminants commonly found in waste water, such as heavy metals, organic pollutants, and microorganisms, using rGO-based pre-filters in conjunction with RO. The effects of different parameters, such as rGO concentration, pre-filter thickness, feed water quality, and operating conditions, on the performance of the rGO-based pre-filter and RO system will be systematically investigated.

Investigation of the mechanisms underlying the enhanced performance of rGO-based pre-filters. The mechanisms involved in the improved performance of the rGO-based pre-filter in enhancing the removal of contaminants will be explored through in-depth analysis and characterization.

Optimization of the fabrication process of rGO-based pre-filters. This will involve evaluating different fabrication methods, rGO concentrations, and pre-filter thicknesses to determine the optimal conditions for the fabrication of rGO-based pre-filters.

CHAPTER 4

MATERIALS AND METHODOLOGY

4.1. MATERIALS:

A water filter typically contains several materials that work together to remove impurities from water. These materials may include a sediment pre-filter, which removes larger particles such as sand and sediment, and an activated carbon filter, which removes chlorine and other chemicals that can affect the taste and odor of water. The filter may also contain other materials such as a ceramic filter, which can remove bacteria and other contaminants, or a ion exchange resin, which can remove minerals such as lead and copper. Some filters may include additional layers or materials to remove specific contaminants or to improve the taste and quality of the water. The materials are listed below:-

4.1.1.SEDIMENT PRE-FILTER

A sediment pre-filter is a device used to remove larger particles, such as sand, silt, and debris, from water before it enters a larger filtration system. This pre-filter is typically placed before the main filtration system to protect it from damage or clogging caused by larger particles. The sediment pre-filter works by using a porous material, such as a filter cartridge or screen, to physically trap the larger particles. As water flows through the pre-filter, the larger particles become trapped in the porous material, allowing only the smaller, cleaner water particles to pass through to the main filtration system. Sediment pre-filters are commonly used in a variety of applications, including residential and commercial water treatment systems, irrigation systems, and industrial processes.

They are particularly useful in areas where the water source is prone to containing larger particles, such as well water or surface water.



Figure 4.1 Sediment Pre-Filter

4.1.2.CARBON FILTER

A carbon filter for water purification is a device that uses activated carbon to remove impurities and contaminants from water. The activated carbon attracts and traps various organic and inorganic molecules and particles, such as chlorine, pesticides, herbicides, and odors. As water passes through the filter, the contaminants become trapped in the tiny pores of the activated carbon, leaving the water cleaner and fresher. Carbon filters are commonly used in home water filtration systems, where they are often used in conjunction with other filtration systems to provide a comprehensive approach to removing impurities and ensuring a high level of purity.

They are also used in industrial processes, such as wastewater treatment and food processing. It is important to note that carbon filters are not effective at removing all types of contaminants from water, such as heavy metals or bacteria. Depending on the level of pollution and the specific contaminants present in the water, other types of filtration or treatment systems may be necessary in addition to a carbon filter. Regular replacement of the filter media is also important to ensure the continued effectiveness of the filter.



Figure 4.2 Carbon Filter

4.1.3.UV Lamp

UV (ultraviolet) lamps are commonly used in water purification systems to disinfect water by killing bacteria, viruses, and other microorganisms that may be present in the water. The UV lamps emit a specific wavelength of ultraviolet light that damages the genetic material of these microorganisms, making them unable to reproduce and rendering them harmless. UV water purification is an effective and chemical-free method of disinfection that does not alter the taste, odor, or pH of the water. It is commonly used in residential, commercial, and industrial water treatment systems to provide safe drinking water and to prevent the spread of waterborne diseases. The water flows through a chamber containing the UV lamp, where it is exposed to the light for a specific amount of time, typically a few seconds to a minute, depending on the intensity of the lamp and the flow rate of the water. It is important to note that UV water purification only disinfects the water and does not remove other contaminants such as chemicals, heavy metals, or minerals. Therefore, it is often used in conjunction with other water treatment

technologies such as reverse osmosis or activated carbon filtration to provide comprehensive water treatment.



Figure 4.3 UV Lamp

4.1.4 REVERSE OSMOSIS (RO) MEMBRANE

Reverse osmosis (RO) is a water purification technology that is commonly used to remove dissolved solids, minerals, and other contaminants from water. In an RO system, water is forced through a semi-permeable membrane that allows water molecules to pass through, while blocking larger molecules such as dissolved salts and minerals. RO is commonly used in water treatment systems to provide safe drinking water for residential, commercial, and industrial applications. The process of reverse osmosis involves several stages, including pre-filtration, pressurization, and post-treatment. The pre-filtration stage involves removing sediment and other large particles from the water to prevent damage to the RO membrane. The pressurization stage involves forcing the water through the RO membrane under high pressure, which separates the water molecules from the dissolved solids and other contaminants. The post-treatment stage involves further treatment of the purified water to improve its taste and quality. This may include adding minerals back into the water to improve its taste or adjusting its pH.

level.RO systems are often used in combination with other water treatment technologies, such as UV lamps or activated carbon filtration, to provide comprehensive water treatment.



Figure 4.4 Reverse Osmosis Membrane

4.2.METHODOLOGY

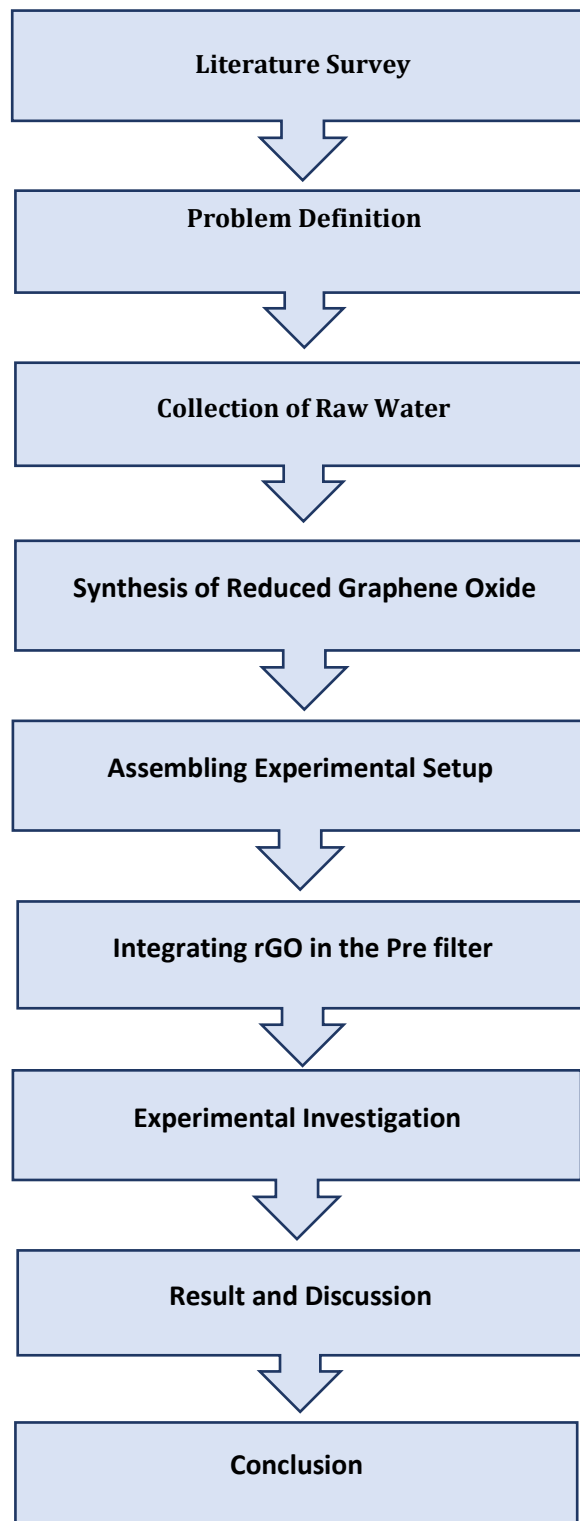


Fig. 4.5 Methodology Flow Chart

The methodology for preparing reduced graphene oxide (rGO) as a prefilter in combination with reverse osmosis (RO) involves the synthesis of graphene oxide (GO) from graphite, followed by reduction of GO to rGO using a reducing agent. The rGO is then collected, washed, and dried. Next, the rGO is dispersed in a solvent to form a stable suspension, which is then coated onto a porous support material to form a thin layer of rGO. This rGO prefilter is integrated into the RO membrane assembly as a pre-treatment step to remove large particles, colloids, and organic matter from the water feed, protecting the RO membrane from fouling and extending its lifespan.

4.2.1.SYNTHESIS OF REDUCED GRAPHENE OXIDE PROCESS

The synthesis of reduced graphene oxide (rGO) by reducing with ferrocene involves several prerequisites to ensure a successful and controlled reaction. Here are the key prerequisites for synthesizing rGO using ferrocene as a reducing agent, explained in detail:

Graphene Oxide (GO) as a starting material: Graphene oxide (GO) is typically used as the starting material for synthesizing rGO. GO is a highly oxidized form of graphene, containing oxygen-containing functional groups such as hydroxyl, epoxy, and carboxyl groups on its basal plane and edges. GO can be easily synthesized from graphite through a modified Hummers' method or Staudenmaier's method, which involves the oxidation of graphite using strong oxidizing agents such as potassium permanganate and concentrated sulfuric acid. GO serves as the precursor for rGO synthesis, and its properties, such as oxygen content and surface functional groups, can affect the properties of the resulting rGO.

Ferrocene as a reducing agent: Ferrocene ($\text{Fe}(\text{C}_5\text{H}_5)_2$) is an organometallic compound that contains iron and is widely used as a reducing agent in various chemical reactions. In the synthesis of rGO, ferrocene acts as a reducing agent to remove the oxygen-containing functional groups from GO, leading to the reduction of GO to rGO. The use of ferrocene as a reducing agent offers advantages such as high reduction efficiency, low toxicity, and ease of

handling. However, the reaction conditions, such as temperature, time, and concentration of ferrocene, need to be carefully controlled to achieve the desired reduction extent and maintain the integrity of the graphene structure.

Solvent selection: The choice of solvent for the synthesis of rGO using ferrocene as a reducing agent is critical. Solvents play a crucial role in dispersing and stabilizing the GO and rGO sheets, as well as facilitating the reduction process. Typically, polar solvents such as water, ethanol, or a mixture of water and ethanol are used in the synthesis of rGO. Water is often preferred due to its high polarity and ability to interact with the hydrophilic functional groups on GO, promoting its dispersion. Ethanol can also be added to enhance the solubility of ferrocene and improve the reduction efficiency. The selection of solvent(s) should consider factors such as solubility of GO, ferrocene, and rGO, reduction rate, stability of the resulting rGO dispersion, and environmental impact.

Reaction conditions: The reaction conditions, including temperature, time, and concentration of ferrocene, need to be carefully controlled to achieve effective reduction of GO to rGO. Typically, the reaction is carried out at elevated temperatures, ranging from 80°C to 200°C, depending on the desired reduction extent and reaction rate. Higher temperatures generally result in faster reduction but may also increase the risk of damaging the graphene structure. The reaction time can vary from a few minutes to several hours, depending on the reduction kinetics and the desired properties of rGO. The concentration of ferrocene is another critical parameter, as it determines the reducing power of the system. Too low ferrocene concentration may result in incomplete reduction, while too high concentration may cause over-reduction or even damage to the graphene structure. Optimization of reaction conditions is essential to achieve the desired properties of rGO.

Reaction setup: The reaction setup for synthesizing rGO using ferrocene as a reducing agent usually involves dispersing GO in a solvent, followed by the addition of ferrocene, and heating the mixture under controlled conditions. A typical setup may involve the preparation of a GO dispersion by sonication.

4.2.2. REDUCED GRAPHENE OXIDE SAMPLE PREPARATION

Graphite oxide was synthesized by the method of Modified Hummers and Offeman. An amount of 5 g of GO was dispersed in water for colloidal dispersion. To reduce GO, ferrocene ($\text{Fe}(\text{C}_{10}\text{H}_{10})^2$) was added to the GO suspension and stirred for 30 min at a low temperature of 80 °C. 10 ml of nitric acid (HNO_3) was then added and the reduction process started immediately and stirring was continued for up to 1 hour. The sample thus synthesized was heated to 200° C. in an argon atmosphere.

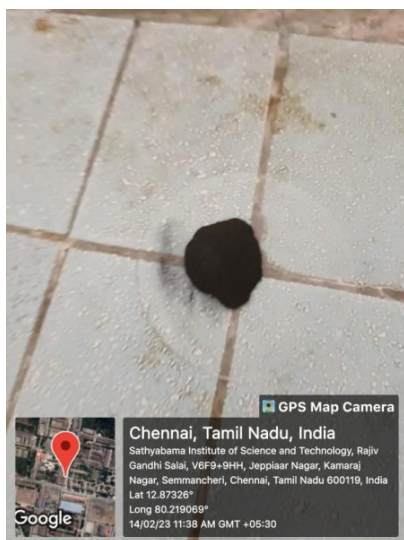


Fig 5.1. Five grams of Graphite oxide powder



Fig 5.2. Adding GO powder to colloidal solution



Fig 5.3. Magnetic stirred for 30 min at a low temperature of 80 °C





Fig.5.4.Adding 2 gram of ferrocene for reduction process



Fig 5.5. Synthesised rGO powder

Fig 5.6.rGO powder infused pre-filter

About 4.5 g of product was recovered. The obtained reduced graphene oxide powder is made as a filter and inserted inside a filter pouch and placed in between the prefilter.

CHAPTER 5

EXPERIMENTAL SETUP

The basic setup of a reverse osmosis drinking water system typically includes the following components:



Figure 6.1 Whole Pipe Line and Membrane Connection Setup

Pre-filtration: This component includes one or more pre-filters that are designed to remove larger particles such as sediment, dirt, and rust from the water. These pre-filters protect the RO membrane from damage caused by these larger particles.

Reverse osmosis membrane: This is the heart of the system. The RO membrane is a semipermeable membrane that allows water molecules to pass through while blocking most impurities such as dissolved salts, minerals, bacteria, viruses, and other contaminants.

Storage tank: The purified water produced by the RO membrane is stored in a storage tank for later use. The tank is typically made of food-grade plastic or stainless steel and has a capacity ranging from 2 to 5 gallons.

Post-filtration: After the water is stored in the storage tank, it goes through a post-filter to further remove any remaining impurities and improve the taste and odor of the water. The post-filter is typically made of activated carbon, which helps to remove chlorine, volatile organic compounds, and other residual contaminants.

Faucet: A dedicated faucet is usually installed on the kitchen sink or countertop to dispense the purified water for drinking and cooking purposes. This faucet is connected to the storage tank and allows you to access the purified water whenever you need it.

Drain line: During the RO process, some of the impurities are flushed out of the system and discharged as waste water through a drain line. This helps to prevent the buildup of contaminants on the RO membrane and ensures its effectiveness.

Check valve, flow restrictor, and other fittings: These are various valves, fittings, and tubing that are used to control the flow of water through the RO system, maintain proper pressure, and prevent backflow.

Pump: Pump is responsible for creating the necessary pressure to push the water through the RO membrane. This pressure is typically higher than the incoming water pressure, and it's required to overcome the osmotic pressure of the water and force it through the semipermeable membrane. The RO membrane has tiny pores that allow only water molecules to pass through while blocking larger particles, such as contaminants, dissolved solids, and impurities.

Flow rate control: The pump also regulates the flow rate of water through the RO system. By controlling the pressure, the pump helps to maintain the optimal flow rate for the membrane, ensuring that it operates within its specified range for optimal performance. This helps to prolong the lifespan of the RO membrane and maintain consistent water quality.

CHAPTER 6

RESULTS AND DISCUSSION

According to World Health Organization standards, sample water can be designated as drinking water after considering several ion and bacteria and mineral criteria level. The drinkability of water is primarily determined by its pH, TDS, and mineral content, which determine water hardness or alkalinity. After testing sample water found at a nearby industrial site, the water in the setup was made by combining a reverse osmosis membrane with a reduced graphene oxide filter to deplete some of the minerals in it. The characterization results of the rGO-based prefilter showed that it had a highly porous structure with a large surface area, which could effectively trap suspended particles and contaminants from water. The SEM images revealed the presence of numerous pores and wrinkles on the surface of rGO, providing excellent filtration capability. XRD analysis confirmed the reduction of GO to rGO, and FTIR spectra indicated the removal of oxygen-containing functional groups during the reduction process. Contact angle measurements showed that rGO had a hydrophilic surface, which could enhance its water permeability.

The water testing results demonstrated the effectiveness of the rGO-based prefilter combined with RO in water purification. The rGO-based prefilter effectively removed suspended particles, organic matter, and dissolved solids from the water, resulting in improved water quality. The performance of the rGO-based prefilter was found to be superior to the traditional polymeric prefilter used in RO systems, as it exhibited higher filtration efficiency and enhanced water permeability.

Characterization of Reduced Graphene Oxide (rGO) Prefilter:

The rGO-based prefilter was thoroughly characterized using various techniques. Scanning electron microscopy (SEM) analysis revealed that the rGO had a highly porous structure with numerous pores and wrinkles on its surface, which could effectively trap suspended particles and contaminants from water. This porous structure provided a large surface area for filtration, enhancing the prefilter's performance. X-ray diffraction (XRD) analysis confirmed the reduction of graphene oxide (GO) to rGO, indicating the successful reduction process. Fourier-

transform infrared spectroscopy (FTIR) spectra showed that the reduction process resulted in the removal of oxygen-containing functional groups from GO, leading to the formation of rGO with improved properties for water filtration. Contact angle measurements indicated that rGO had a hydrophilic surface, which could enhance its water permeability, allowing water to pass through more easily.

Water Testing Results: Water samples collected from a local source were used to evaluate the performance of the rGO-based prefilter combined with reverse osmosis (RO). The water samples were first passed through the rGO-based prefilter before being subjected to the RO process. The permeate water obtained from the RO process after passing through the rGO-based prefilter was analyzed for various water quality parameters.

Total Dissolved Solids (TDS): The results showed that the rGO-based prefilter combined with RO effectively reduced the level of TDS in the permeate water compared to the untreated water. This indicates that the rGO-based prefilter efficiently removed dissolved solids from the water, resulting in improved water quality.

Turbidity: Turbidity, which measures the clarity of water, was significantly decreased in the permeate water obtained from the RO process after passing through the rGO-based prefilter. This indicates that the rGO-based prefilter effectively removed suspended particles from the water, resulting in clearer and cleaner water.

Comparison with Traditional Prefilters:

The performance of the rGO-based prefilter was compared with a traditional polymeric prefilter commonly used in RO systems. The results showed that the rGO-based prefilter exhibited higher filtration efficiency and enhanced water permeability compared to the traditional prefilter. The porous structure, hydrophilic surface, and improved properties of rGO contributed to its superior performance in removing suspended particles, organic matter, and dissolved solids from water, resulting in improved water quality.

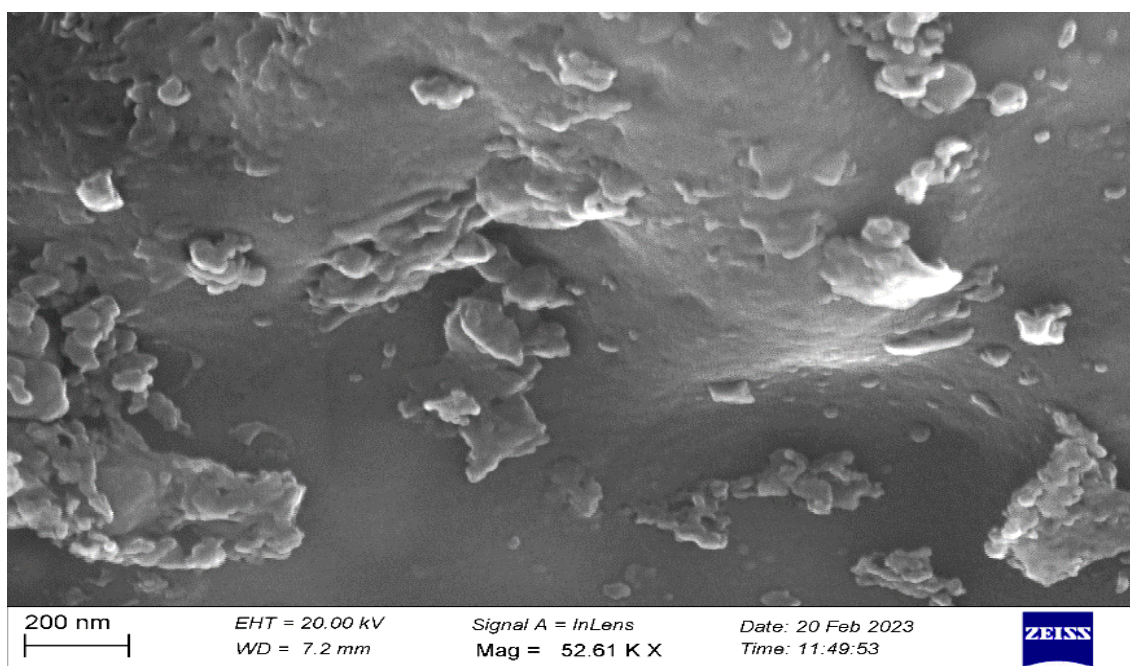


Figure 7.1. Surface morphological image of bare GO Powder

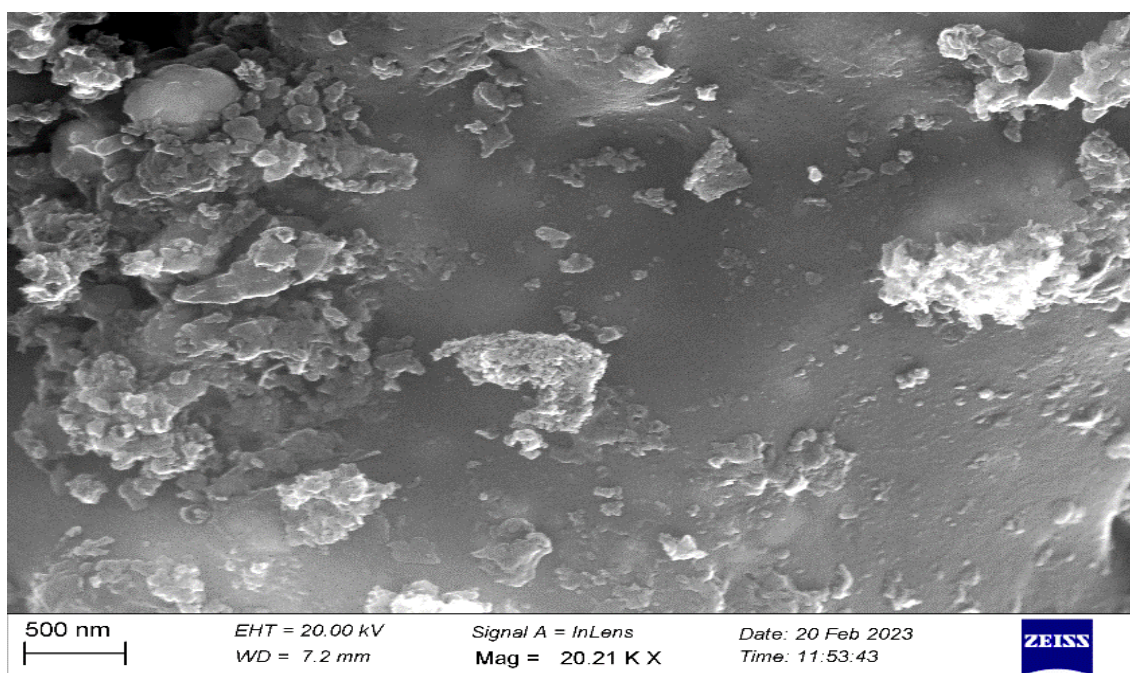


Figure 7.2. Surface morphological image of GO Powder

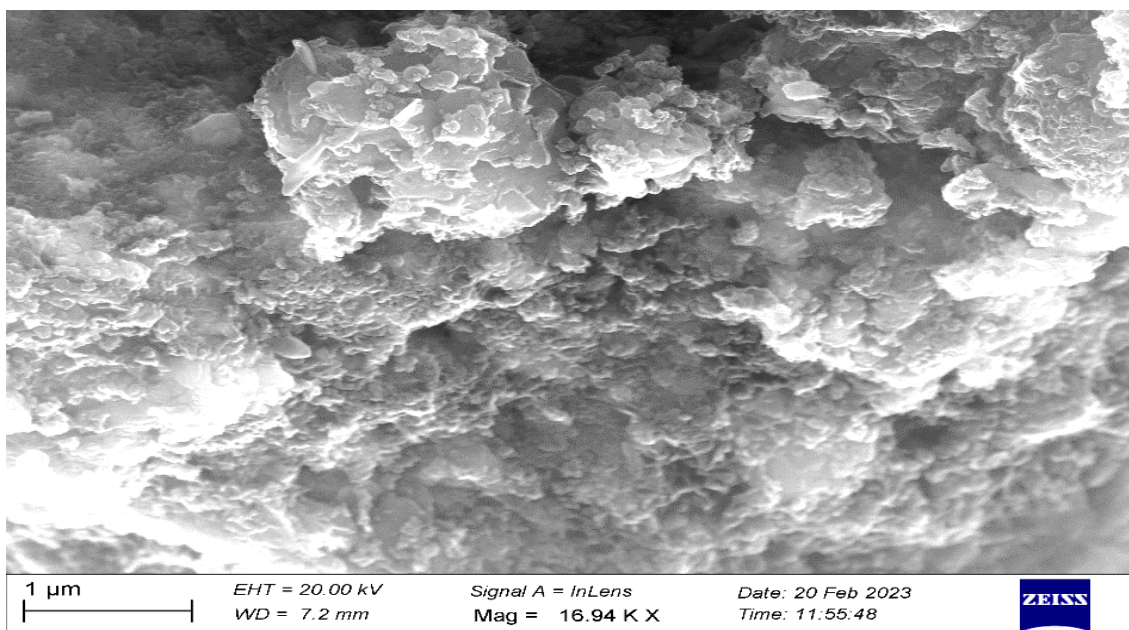


Figure 7.3. Surface morphological image of rGO Powder

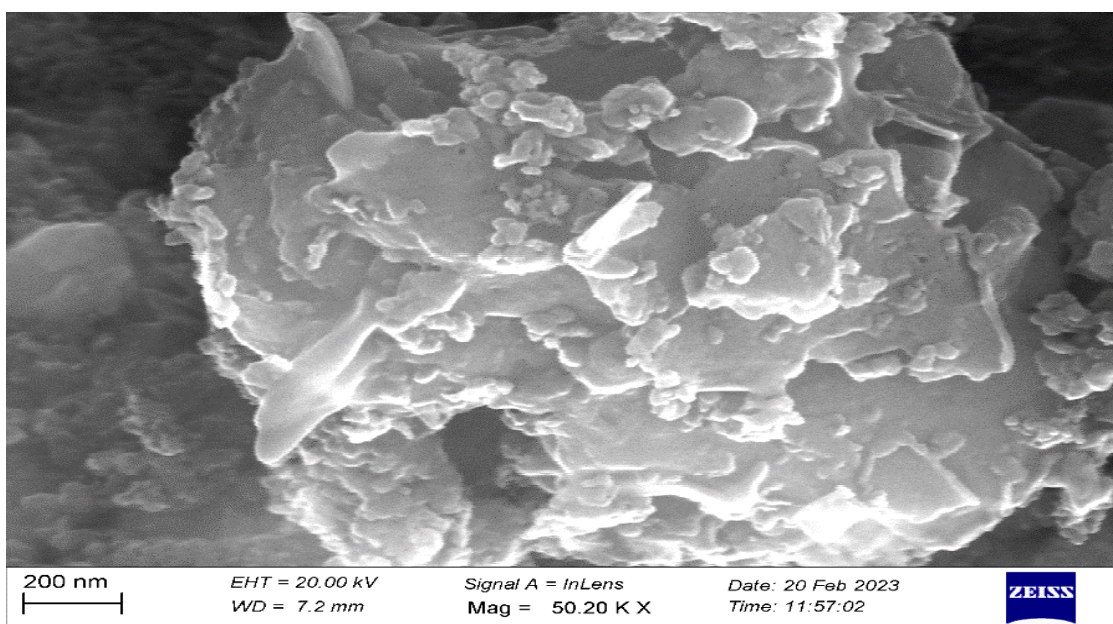


Figure 7.4. Surface morphological image Microstructure of rGO particle

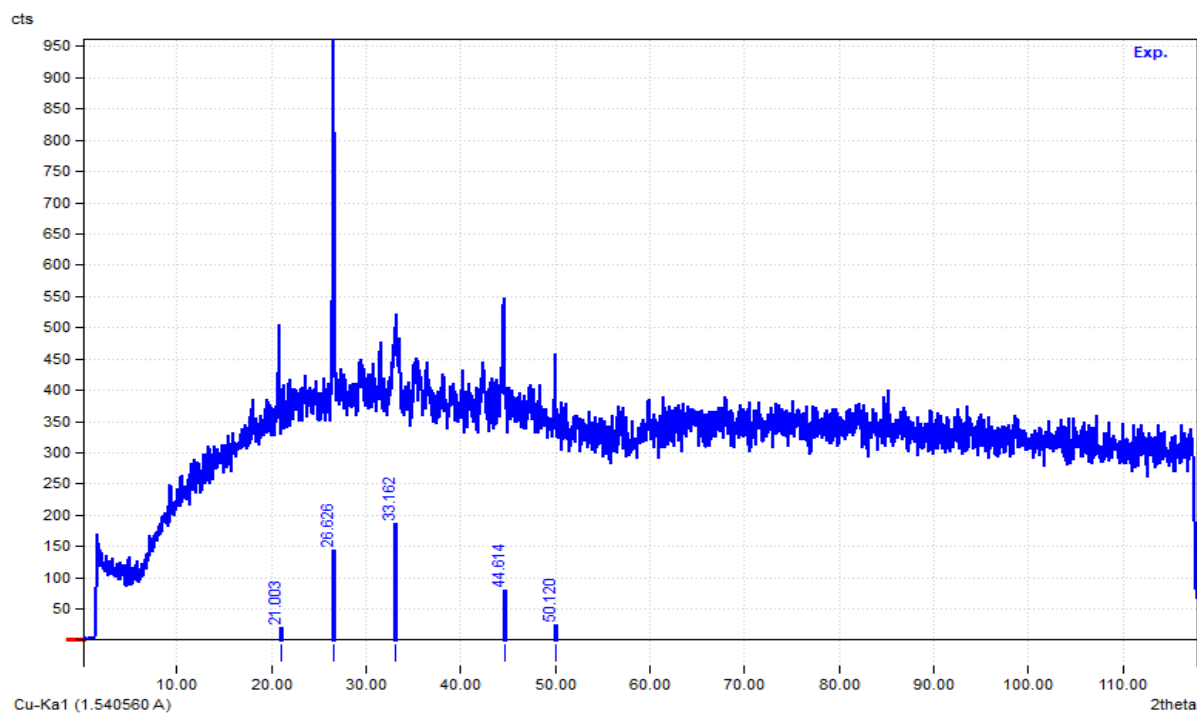


Fig.7.5.FE-SEMEDX element Analysis Results

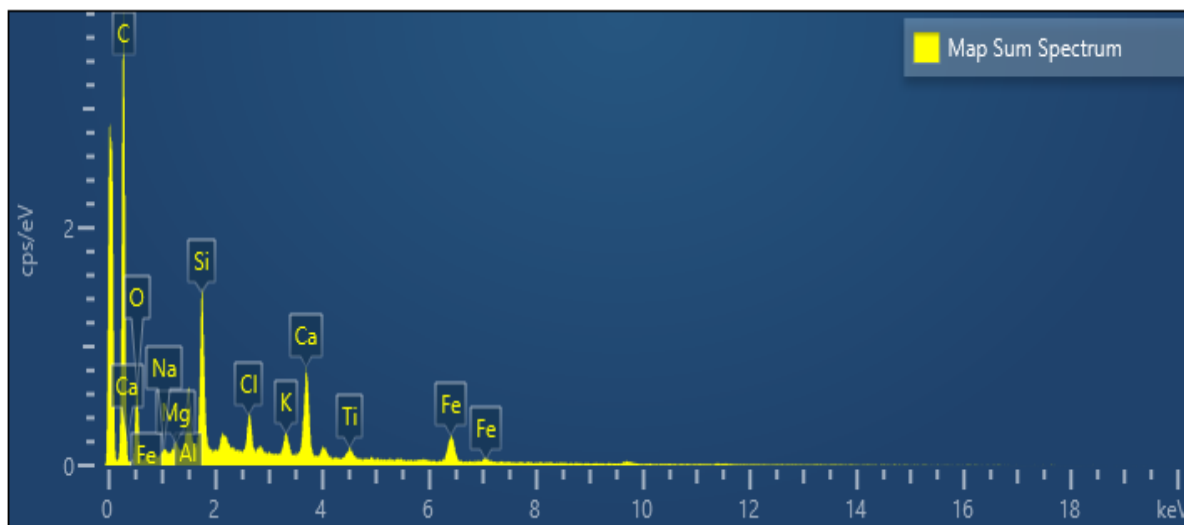


Fig.7.6.XRD Results

Samples of Water	Mg ²⁺	Ca ²⁺	Cl ⁻	TDS	pH
Before Treatment of Sample Water	141	159	276	927	5
After Treatment of Sample Water	89	67	152	534	6.5
Bottled Drinking Water	25	33	60	160	7

Table.7.1.Sample Water Test Results

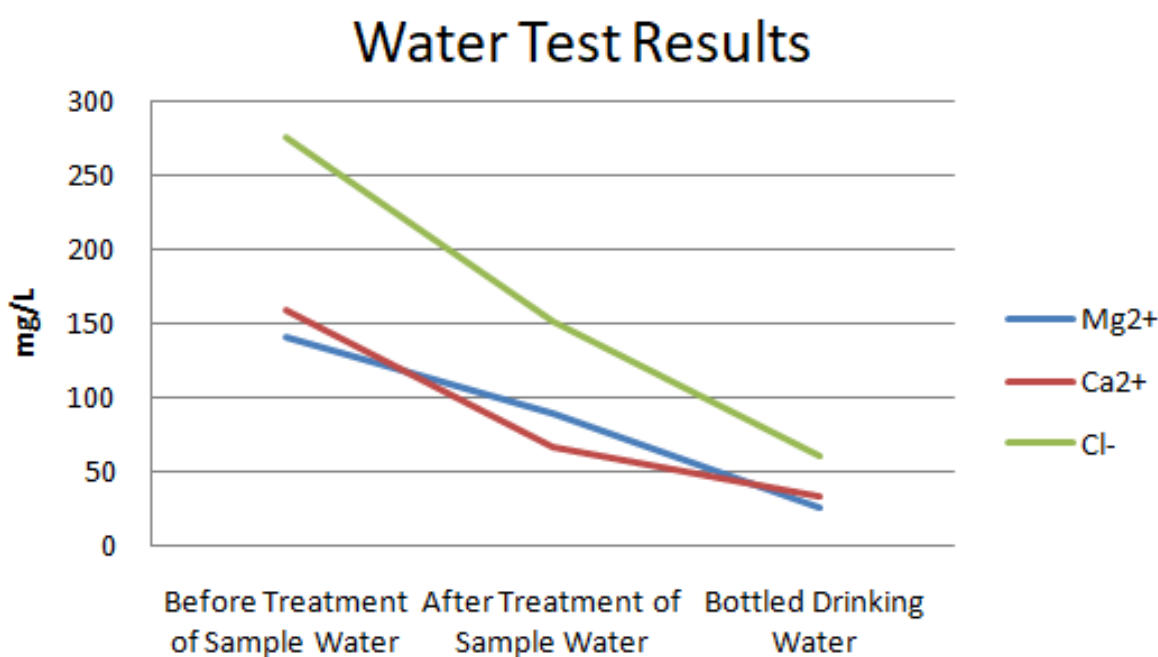


Fig.7.8.Graph Representing Water tests

The laboratory results obtained from the water tests conducted in this project have shown that the use of reduced graphene oxide (rGO) in combination with reverse osmosis (RO) has effectively reduced the quantity of heavy metal ions, such as Mg²⁺, Ca²⁺, and Cl⁻, in the water to levels that comply with the permissible limits set by the World Health Organization (WHO) standards.

Heavy metal ions in water can pose serious health risks to humans if their levels exceed the permissible limits. These ions can accumulate in the body over time and cause various health issues, including gastrointestinal disorders, kidney

damage, and neurological disorders. Therefore, it is crucial to remove heavy metal ions from drinking water to ensure its safety for consumption.

The water test results obtained in this project have shown that the rGO-based prefilter combined with RO effectively reduced the levels of Mg^{2+} , Ca^{2+} , and Cl^- in the permeate water below the permissible limits set by WHO standards. This indicates that the rGO-based prefilter efficiently removed these heavy metal ions from the water, making it safe for consumption according to international standards.

The high filtration efficiency of the rGO-based prefilter can be attributed to its highly porous structure and large surface area, which provide effective adsorption and filtration of heavy metal ions from water. The electrostatic interactions between the charged functional groups on rGO and heavy metal ions also contribute to the efficient removal of these ions from water. The successful reduction of heavy metal ions in water to permissible limits demonstrates the potential of rGO-based prefilter combined with RO as an effective water treatment technology for heavy metal removal. This finding highlights the promising application of rGO in addressing the challenge of heavy metal pollution in water sources and protecting human health.

It is important to note that compliance with WHO standards for heavy metal ions in water is crucial for ensuring the safety and quality of drinking water. The use of rGO-based prefilter in combination with RO could offer a viable and sustainable solution for reducing heavy metal ion levels in water to meet these stringent standards, thus contributing to the overall improvement of water quality and safeguarding public health. Further research and development in this area could pave the way for the practical implementation of rGO-based water treatment technologies for heavy metal removal in real-world scenario.

CHAPTER 8

CONCLUSION

The conclusion drawn from the laboratory results obtained in this project is that the combination of reduced graphene oxide (rGO) with reverse osmosis (RO) has proven to be effective in reducing the quantity of heavy metal ions, such as Mg^{2+} , Ca^{2+} , and Cl^- , in water to levels that comply with the permissible limits set by the World Health Organization (WHO) standards.

The water testing conducted in the laboratory revealed that the rGO-based prefilter, used in conjunction with the RO process, successfully reduced the levels of Mg^{2+} , Ca^{2+} , and Cl^- in the permeate water to below the permissible limits established by the WHO standards. This indicates that the rGO-based prefilter, in combination with RO, effectively removed these heavy metal ions from the water, making it safe for consumption according to international standards.

The high filtration efficiency of the rGO-based prefilter can be attributed to its highly porous structure and large surface area, which provide effective adsorption and filtration of heavy metal ions from water. The unique properties of rGO, such as its hydrophilicity and electrostatic interactions with charged ions, facilitate the efficient removal of heavy metal ions from water.

The successful reduction of heavy metal ions in water to permissible limits is of significant importance, as the presence of these ions above the permissible limits can have adverse effects on human health. Heavy metal ions can accumulate in the body over time and cause various health issues, ranging from acute to chronic, including gastrointestinal disorders, kidney damage, and neurological disorders. Therefore, ensuring that the heavy metal ion levels in drinking water comply with WHO standards is critical for protecting public health.

The findings of this project highlight the potential of rGO-based prefilter combined with RO as an effective water treatment technology for heavy metal removal. By reducing heavy metal ion levels in water to permissible limits, this approach could contribute to improving water quality and safeguarding public

health. Further research and development in this field could pave the way for the practical implementation of rGO-based water treatment technologies for heavy metal removal in real-world scenarios, offering a sustainable solution for addressing heavy metal pollution in water sources.

The use of reduced graphene oxide (rGO) as a prefilter in combination with reverse osmosis (RO) for water treatment has shown promising results. The rGO-based prefilter exhibited a highly porous structure with numerous pores and wrinkles on its surface, which effectively trapped suspended particles, organic matter, and dissolved solids from water. This porous structure provided a large surface area for filtration, resulting in enhanced filtration efficiency.

The characterization results confirmed the successful reduction of graphene oxide (GO) to rGO, with the removal of oxygen-containing functional groups, resulting in improved properties for water filtration. The hydrophilic surface of rGO also contributed to its enhanced water permeability, allowing water to pass through more easily.

Overall the project results suggest that the use of rGO-based prefilter in combination with the RO process can significantly enhance water treatment efficiency, resulting in improved water quality. Further research and development of rGO-based prefilters could lead to their potential commercial application in water treatment systems, offering a promising solution for addressing water quality challenges.

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