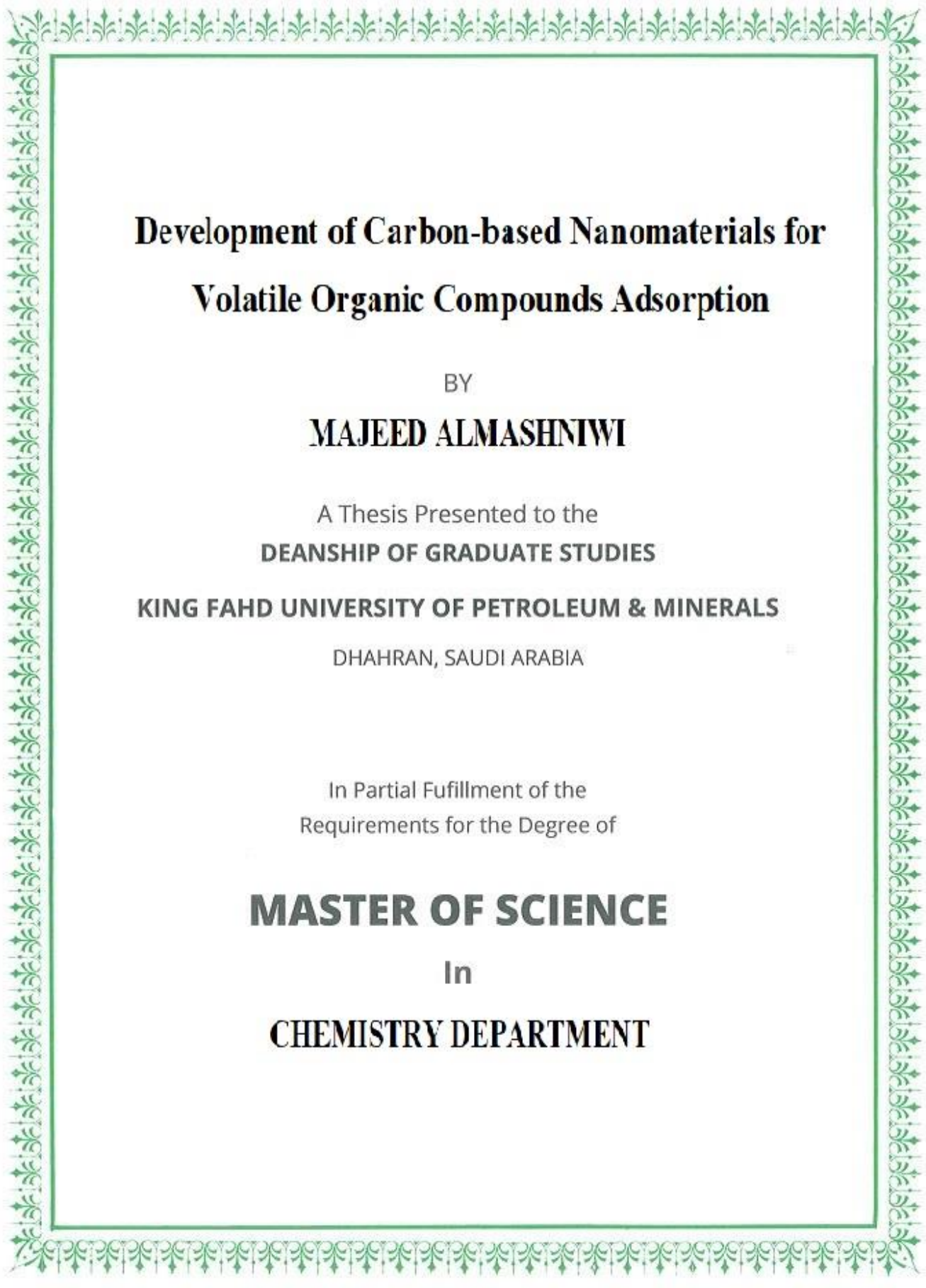




Development of Carbon-based Nanomaterials for Volatile Organic Compounds Adsorption

BY

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A Thesis Presented to the

DEANSHIP OF GRADUATE STUDIES

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN, SAUDI ARABIA

In Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE

In

CHEMISTRY DEPARTMENT

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN- 31261, SAUDI ARABIA

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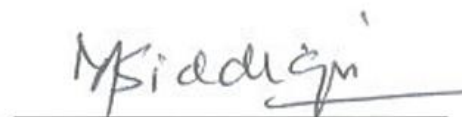
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Dedication

I dedicate this thesis to my family and friends.

I dedicate this thesis to everyone who lends a helping hand, and to those who believe in me and led me towards success.

Special thanks to my Advisor Prof: Abdulrahman Al-Arfaj and team member Dr. Tawfik Abdo Saleh and Dr. Mohammad Nahid Siddiqui and colleagues for their support and encouragement in my life.

ACKNOWLEDGMENTS

بسم الله الرحمن الرحيم

All praises are to Allah, I am very grateful to Allah for His mercy and protection for me to complete this work as well as my master's program successfully.

Peace and blessing be always upon the Prophet Muhammad, his family, his companions, and his followers until Hereafter.

I would like to express my deepest gratitude and appreciation to my supervisor, Prof. Abdulrahman Al-Arfaj, who was more of a friend and mentor, than a professor. I acknowledge him for his great leadership support and valuable advice during my graduate studies. Thank you very

much for the words of inspiration and encouragement throughout this research. and thanks to committee members,

Tewfik Abod Saleh and Dr. Mohammad Nahid Siddiqui for their cooperation, interest, and valuable advice.

Special thanks to my mother and family, my relatives, and my colleagues for their motivation and support. and all the students who have been part of my life in KFUPM.

Finally, I thank all my management at SABIC, who have given me a chance to complete my higher education, and special thanks to especially King Fahd University of Petroleum & Minerals (KFUPM) for granting me a master full-time

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LIST OF ABBREVIATIONS

CNT: Carbon nanotube

Activated carbon: AC

PCNT: copolymer-modified CNT

PAMC: copolymer-modified carbon

GC: gas chromatography

VOCs: Volatile organic compounds

XRD: X-ray Diffraction

FTIR: Fourier Transform Infrared Spectroscopy

SEM: Scanning Electron Microscopy

ABSTRACT

Full Name : [Majeed Yahya Almashnawi]

Thesis Title : [Development of carbon-based nanomaterials for Volatile Organic Compounds adsorption]

Major Field : [Chemistry]

Date of Degree : [December, 2023]

The significant proportion of volatile organic compounds (VOCs) present in industrial wastewater poses challenges for effective reuse and application. Current VOC-remediation methods exhibit inefficacy, may present safety concerns, and lack extensive evaluation in practical scenarios. Therefore, it is crucial to create materials that can effectively remove volatile organic compounds (VOCs) from polluted water sources. Activated carbon and carbon nanotubes have garnered significant attention for their exceptional physical and chemical properties, making them highly promising for the remediation of VOC-contaminated water. This research recommends creating and analyzing activated carbon, which can be manufactured from palm shells and changed with polymers, as well as carbon nanotubes, which can also be manipulated with polymers. XRD, SEM/EDXS, and FTIR will be used to analyze the physical and chemical compositions of the copolymer-modified carbon and polymer-modified CNT. Following that, we have examined various treatment parameters to assess the efficacy of adsorption with changing VOC concentrations, contact times, and dosages of copolymer-modified CNT and copolymer-modified carbon. Headspace gas chromatography with mass spectrometry (HSS-GC-MS) will be used to trace the residual volatile organic compounds (VOCs) in water. The study's goal is to determine the most efficient adsorption treatment settings as well as assess the adsorbent's performance and efficiency in removing volatile organic compounds (VOCs) from polluted water.

ملخص الرسالة

الاسم الكامل: مجيد يحي المشنوي

عنوان الرسالة: تطوير مواد نانوية تعتمد على الكربون لامتصاص المركبات العضوية المتطايرة من الماء

التخصص: كيمياء

تاريخ الدرجة العلمية: ديسمبر 2023

تشكل النسبة الكبيرة من المركبات العضوية المتطايرة (VOCs) الموجودة في مياه الصرف الصناعي تحديات أمام إعادة الاستخدام والتطبيق الفعال. تُظهر طرق معالجة المركبات العضوية المتطايرة الحالية عدم الفعالية، وقد تمثل مخاوف تتعلق بالسلامة، وتفتقر إلى التقييم الشامل في السيناريوهات العملية. لذلك، من الضروري إنشاء مواد يمكنها إزالة المركبات العضوية المتطايرة (VOCs) بشكل فعال من مصادر المياه الملوثة. لقد حظي الكربون المنشط وأنابيب الكربون النانوية باهتمام كبير لخصائصها الفيزيائية والكيميائية الاستثنائية، مما يجعلها واعدة للغاية لمعالجة المياه الملوثة بالمركبات العضوية المتطايرة. ويوصي هذا البحث بإنشاء وتحليل الكربون المنشط والذي يمكن تصنيعه من قشور النخيل وتغييره بالبوليمرات، وكذلك أنابيب الكربون النانوية التي يمكن معالجتها بالبوليمرات أيضاً. سيتم استخدام XRD و SEM/EDXS و FTIR لتحليل التركيبات الفيزيائية والكيميائية للكربون المعدل بالبوليمر المشترك والأنابيب النانوية الكربونية المعدلة بالبوليمر. بعد ذلك، سنقوم بفحص معايير العلاج المختلفة لتقييم فعالية الامتزاز مع تغيير تركيزات المركبات العضوية المتطايرة، وأوقات الاتصال، وكمية المواد الكربونية المعدلة بالبوليمر والكربون المعدل بالبوليمر. سيتم استخدام كروماتوغرافيا الغاز في مساحة الرأس مع قياس الطيف الكتلي (HSS-GC-MS) لتتبع تراكيز المركبات العضوية المتطايرة المتبقية في الماء. الدراسة خلصت إلى تحديد طريقة لاستخدام المواد الكربونية المعدلة بالبوليمر لاستخدامها في إزالة الملوثات العضوية بكفاءة بالإضافة إلى تقييم أداء المادة المازة وكفاءتها في إزالة المركبات العضوية المتطايرة من المياه الملوثة.

CHAPTER 1

INTRODUCTION

1.1 Background

Water is essential for the existence of all living beings. Water and air are the most valuable natural resources on the planet. It is required for the growth and maintenance of the human body, as well as the control of numerous biological functions. Water transports solid suspended particles as well as dissolved contaminants throughout its movement. Because of the presence of heavy metals and unbalanced minerals, it becomes polluted and hazardous to human health (Jequier et al., 2010). Metal pollution occurs as a result of atmospheric deposition, weathering, or the discharge of agricultural, residential, or industrial runoff. 60% of an adult's body weight is approximated. The water produced by metabolism or food consumption is insufficient to meet our body's demands. As a result, we must monitor our drinking water on a frequent basis. Water is an essential component of all cells, tissues, and organs. Water serves several functions in the human body. It serves as a construction material, a solvent, a reaction medium, a transporter for nutrients and waste products, a lubricant, and a shock absorber. (Balbus et al., 2001).

Several water resources are contaminated by hazardous physical, chemical, and biological pollutants. At least 2.5 billion people live in underdeveloped nations with unsanitary water systems, and over 780 million people do not have the right to clean drinking water. As a result, over 2.3 billion people worldwide are suffering from water-related sickness. Chemicals at excessive concentrations or in short quantity in water can

cause a variety of ailments such as goiter and cancer. Many gastrointestinal disorders are frequent as a result of a lack of cleanliness and improved sewage treatment, incorrect processing, and the usage of highly polluted water (Opinya et al., 1987). Dental fluorosis is caused by a low or high quantity of fluoride ions in water. Goiter is caused mostly by a low iodine content in humans. If everyone had safe drinking water and adequate sanitation, there would be around 200 million instances of diarrhoea and 2.1 million fatalities per year. (Sim et al., 1987) Toxic inorganic compounds in water can cause a variety of acute and chronic health problems, including vomiting, nausea, disorientation, lung irritation, skin rash, and even death. As a long-term consequence, cancer, birth abnormalities, organ damage, and various mental and immune system diseases have been observed. According to the WHO, there are 1400 million billion litres of water in total. However, because 97% of this water is sea water and only 3% is pure water, the majority of it is not suitable for drinking. Only 1% of the water available for drinking is routed through the polar icecaps and glaciers, with the majority of the water going to agriculture rather than drinking or any other use. In the current situation, just 80% of the people in urban areas and 11% in rural regions have access to piped water.

Water is required not just for drinking but also for a variety of other economic activities such as agriculture, animal production, forestry, industrial operations, hydropower generation, fishing, and other creative activities. Because of major causes such as rising population, industrialization, and urbanization, the feasibility and quality of water, whether surface or ground, have deteriorated. Many freshwater sources are polluted as a result of the use of pesticides in agricultural areas and other human activities that alter the physical, chemical, and biological processes associated with water resources. (Balbus et al., 2001)

Ensuring the availability and supply of clean water is crucial for various environmental and societal processes. Water is vital for the survival of aquatic species, as well as for drinking, domestic use, industry, energy production, and agriculture. However,

water faces numerous challenges that make it scarce and polluted. These challenges stem from both human activities such as industrialization, urbanization, and intensive farming, as well as natural influences like climate change. Water pollution, caused by harmful organic and inorganic substances is a major global problem. Many of these pollutants are non-biodegradable, remaining in the environment and accumulating in the food web. Among these pollutants, volatile organic compounds (VOCs) are particularly toxic. Not only are VOCs hazardous on their own, but they can also react with other gases in the air, leading to the production of new pollutants. (Zhang et al., 2020)

1.2 Significance of VOCs Removal from Water

Volatile organic compounds (VOCs) play a significant role in air pollution and have various impacts on human health and the environment. When released into the air, these compounds can react with other pollutants and sunlight, leading to the formation of ground-level ozone and harmful air pollutants such as particulate matter. These pollutants can result in respiratory issues, eye irritation, and other health problems for humans. In addition to their impact on human health, VOCs also contribute to the formation of smog and can have detrimental effects on ecosystems. They can react with nitrogen oxides and sunlight to create ground-level ozone, which can harm plants, damage crops, and reduce agricultural yields. VOCs also play a role in the formation of secondary organic aerosols, which can lead to the formation of haze and affect visibility in urban areas. Due to the potential health and environmental impacts associated with VOCs, efforts have been made to regulate and reduce their emissions. Regulations are in place for various industries to limit VOC emissions and promote the use of cleaner technologies and processes. Additionally, individuals can take steps to minimize their contribution to VOC emissions by using low-VOC or zero-VOC products, ensuring proper ventilation when using potentially emitting products, and employing sustainable transportation options. Overall, understanding and addressing

the sources and impacts of VOCs is crucial for improving air quality, protecting human health, and preserving the environment. VOCs in the environment and indoor air have caused serious environmental and health issues. Many VOCs are known to contribute to air pollution, smog formation, and the development of ground-level ozone, all of which can have negative impacts on human health, such as respiratory issues and eye and throat discomfort. Furthermore, certain VOCs are classified as harmful air pollutants, and they have been linked to long-term health hazards such as an increased risk of cancer. (Zhang et al., 2020)

Removing volatile organic compounds (VOCs) from water is crucial due to the severe ecological impacts they can have on aquatic ecosystems. Accumulating in the tissues of organisms, VOCs can lead to health issues and death, disrupt the ecosystem's balance, and affect biodiversity. Additionally, the contamination of drinking water by VOCs poses significant risks to human health, causing various problems such as liver and kidney damage, reproductive issues, and cancer. VOCs also contribute to atmospheric pollution by reacting with other pollutants to form ground-level ozone and smog, which harm human health, respiratory systems, and the environment. The long-term effects of VOC contamination are problematic as they persist in the environment, threatening ecosystems and human health if not effectively removed. Regulatory compliance is necessary to prevent water contamination, and removing VOCs is essential to meet these standards and prevent legal consequences. In conclusion, effective removal of VOCs is necessary to protect ecosystems, maintain biodiversity, ensure clean drinking water sources, prevent atmospheric pollution, and comply with regulatory standards, safeguarding both the environment and human well-being.

1.2.1 Protection of Human Health:

Additionally, as these harmful VOCs can easily leach into groundwater and contaminate water sources, it becomes crucial to implement effective measures for

their removal. By removing VOCs from water, we not only safeguard the quality and purity of our drinking water but also prioritize the well-being and longevity of human health. Moreover, protecting water sources from VOCs contamination is vital as it can prevent potential health risks associated with prolonged exposure to these hazardous substances. Hence, investing in advanced water treatment technologies to remove VOCs is paramount to ensuring the safety and sustainability of our water resources and safeguarding the overall health of the population.

1.2.2 Safe Drinking Water:

Water quality is a significant issue for public health authorities all around the world. VOCs in drinking water can have an unpleasant taste and odor, making it unappealing. Furthermore, even at low concentrations, the presence of some VOCs might pose considerable health hazards. The removal of VOCs from water is critical for providing communities with safe and visually acceptable drinking water.

1.2.3 Environmental Protection:

Volatile Organic Compounds (VOCs) are a major concern when it comes to environmental protection, particularly in relation to water pollution. When these harmful chemicals enter aquatic systems, they have the potential to wreak havoc on the delicate balance of natural ecosystems and pose severe threats to aquatic life. One of the devastating consequences of VOC contamination in water is the bioaccumulation process that occurs in fish and other aquatic organisms. As these chemicals enter the water, they are absorbed by organisms such as zooplankton, which are then consumed by small fish. The VOCs do not break down easily and tend to accumulate in the fatty tissues of these animals over time. As larger fish feed on these smaller ones, the VOCs build up in their bodies, resulting in higher concentrations. This bioaccumulation not only affects the individual organisms but also disrupts entire food chains and food systems within aquatic ecosystems. Predatory fish, such as larger predatory fish or

birds, that feed on contaminated smaller fish are exposed to even higher levels of VOCs. This process can lead to several detrimental effects, including reduced reproductive success, impaired growth and development, and overall increased vulnerability to diseases and other stressors. Moreover, when VOC-contaminated water is discharged into rivers, lakes, or seas, it significantly harms the surrounding aquatic ecosystems and biodiversity. The toxic chemicals can easily spread and contaminate larger bodies of water, causing widespread damage. The effects can be far-reaching, impacting not only the aquatic organisms but also the plants, insects, and other organisms that depend on them for survival. The destruction of aquatic life due to VOC contamination ultimately disrupts the intricate web of life that exists in natural ecosystems. The loss of key species can lead to imbalances in population dynamics, affecting the overall health and stability of these ecosystems. Additionally, the loss of biodiversity can have cascading effects, impacting human communities that rely on these ecosystems for sustenance, livelihoods, and recreation. To mitigate the risks associated with VOCs in water, it is crucial to prioritize effective wastewater treatment and adopt sustainable practices in industries that produce these compounds. Implementing stricter regulations and monitoring systems can help minimize the discharge of VOC-contaminated water into natural bodies of water. By doing so, we can protect our fragile aquatic ecosystems, preserve biodiversity, and safeguard the health and well-being of future generations.

1.2.4 Regulatory Compliance:

Volatile organic compounds (VOCs) are chemical compounds that easily evaporate into the air at room temperature. They can be found in various industrial processes, solvents, fuels, and household products. When improperly managed, these compounds can contaminate drinking water sources and wastewater, posing health and environmental risks. To protect public health, many nations have established stringent regulations to limit VOC levels in drinking water and wastewater disposal. These regulations are typically enforced by governmental agencies, and compliance is mandatory for companies and utilities. Failure to comply with these standards can

result in legal ramifications, fines, and reputational damage. In order to meet these regulatory criteria, effective VOC removal techniques are necessary. A range of technologies and processes are available for this purpose, depending on the specific requirements and circumstances of each situation. These techniques include, but are not limited to:

1. **Activated Carbon Filtration:** Activated carbon is a porous material that can adsorb VOCs from water, effectively removing them. This technique is commonly used in drinking water treatment plants and can be very efficient in removing a wide range of VOCs.

2. **Air Stripping:** This method involves passing contaminated water through aeration columns or towers, where VOCs can transfer from the water to the air. The air is then treated separately to remove the VOCs.

3. **Biological Treatment:** Certain types of bacteria can break down VOCs into less harmful substances through metabolic processes. This technique is often used in wastewater treatment plants, where microorganisms can biodegrade VOCs.

4. **Membrane Filtration:** Membranes with fine pores can physically separate VOCs from water, ensuring their removal. This process is commonly used in water treatment and can effectively remove VOCs, although it may require additional treatment steps for complete removal.

1.2.5 Industrial Processes:

High-purity water plays a paramount role in numerous sectors, such as semiconductor manufacture, chemical production, and medicine. The stringent demand for purity is driven by the fact that even minuscule levels of volatile organic compounds (VOCs) present in industrial water can have detrimental effects on product quality and manufacturing efficiency. Hence, the elimination of VOCs becomes critical for maintaining uninterrupted industrial operations and ensuring the highest standards of product quality. In the realm of semiconductor manufacturing, where precision and

accuracy are of utmost importance, any trace amounts of VOCs present in the water used can lead to impurities on the silicon wafer surfaces. This can result in compromised performance of microchips and an overall reduced product yield. The stringent quality control measures put in place by semiconductor manufacturers require the implementation of reliable VOC elimination techniques to guarantee flawless production processes. Similarly, in the chemical production industry, where a vast array of compounds is synthesized, any contamination of high-purity water with VOCs can have severe consequences. The presence of VOCs in water used as a reactant or solvent can introduce impurities into the final chemical products, leading to compromised quality and potentially hazardous outcomes. By prioritizing VOC elimination, chemical manufacturers can uphold the integrity of their processes, ensuring the delivery of high-quality and safe products. The importance of high-purity water and VOC elimination also extends to the pharmaceutical and medical sectors. These industries heavily rely on water for various applications, such as formulation, cleaning, and irrigation. The presence of even trace amounts of VOCs in the water used in drug manufacturing or medical equipment cleaning processes can potentially impact the efficacy and safety of the final pharmaceutical products. Guaranteeing the elimination of VOCs is therefore crucial for pharmaceutical companies to maintain regulatory compliance and safeguard patient health.

1.2.6 Groundwater Remediation:

Volatile Organic Compounds (VOCs) are organic chemicals that have high vapor pressure at room temperature, making them prone to off gassing and easy distribution in the environment. Many industrial activities and processes involve the use and production of VOCs, which can lead to their release into the groundwater. Contaminated groundwater is a significant concern because it is a vital source of drinking water for many communities. In addition, it can also harm ecosystems and pose risks to human health. Therefore, it is crucial to remove VOCs effectively from groundwater to restore contaminated sites and prevent further environmental damage.

There are several effective methods for VOC removal from groundwater, depending on the specific contaminants and site conditions. Some common techniques include air stripping, carbon adsorption, chemical oxidation, and bioremediation. Air stripping is a widely used method that involves exposing contaminated groundwater to air through aeration or bubbling. VOCs evaporate into the air, leaving the water clean. This method is effective for VOCs with low boiling points, such as gasoline components. Carbon adsorption involves passing contaminated groundwater through activated carbon filters. The carbon adsorbs the VOCs, removing them from the water. This method is useful for a wide range of VOCs and is often combined with other treatment techniques for enhanced removal. Chemical oxidation utilizes powerful oxidizing agents, such as hydrogen peroxide or ozone, to break down the VOCs into harmless byproducts. This method is effective for some hard-to-treat VOCs, but it can be costly and may generate additional waste. Bioremediation leverages the power of microorganisms to break down and metabolize VOCs. These microorganisms can be naturally occurring or introduced to the site. Bioremediation is a sustainable and cost-effective approach for VOC removal, especially for certain organic compounds like petroleum hydrocarbons. It is worth noting that the effectiveness of these methods can vary depending on the site-specific conditions and the type and concentration of VOCs. Therefore, a thorough site assessment and remediation plan tailored to the specific situation are essential.

Overall, effective VOC removal from groundwater is vital for contaminated site restoration and preventing further harm to the environment. It requires a combination of site characterization, appropriate treatment technologies, and regular monitoring to ensure the successful restoration of contaminated sites and the protection of groundwater resources.

1.2.7 Research and Development:

Volatile Organic Compounds (VOCs) are carbon-based chemicals that easily evaporate at room temperature. They can be found in many common laboratory chemicals, solvents, and experimental materials. Since these compounds can contaminate water and potentially interfere with scientific analysis, it is crucial to remove VOCs from laboratory water systems used in research institutes and laboratories. Having water free of pollutants, especially VOCs, is essential to ensuring reliable and accurate results in scientific experiments and analysis. VOCs can negatively influence the outcome of experiments by introducing unwanted variables or interfering with the intended chemical reactions. Researchers rely on precise measurements and controlled conditions, and the presence of VOCs in water can compromise the integrity of their work. One of the primary reasons for removing VOCs from laboratory water systems is to avoid cross-contamination. Laboratory water is often used in various experiments and analyses, and any VOCs present in the water can transfer to different samples and materials, leading to inaccurate results. Additionally, some VOCs are known to be harmful to human health, and their presence in the laboratory environment can pose risks to researchers and lab personnel. Several methods can be employed to achieve VOC-free laboratory water. The most common approach is to use dedicated water purification systems specifically designed to remove VOCs. These systems utilize various purification technologies, like activated carbon filters, advanced oxidation processes, and membrane filtration, to effectively eliminate VOCs. Regular maintenance and monitoring of these systems are essential to ensuring their continued effectiveness. By ensuring that laboratory water is free from VOCs, research institutes and laboratories can enhance the reliability and correctness of their results. This practice contributes to the overall advancement of scientific knowledge and promotes the development of innovative solutions and technologies.

1.2.8 Reduction of Environmental Footprint:

Because VOCs are volatile, they can contribute to air pollution when they are discharged into the atmosphere from bodies of water. Reduced VOC emissions from water lead to improved air quality and a smaller environmental imprint. (Pico et al. (2008)

In conclusion, the importance of VOC removal from water can be seen in its effects on human health, environmental preservation, regulatory compliance, industrial operations, and overall water quality. Addressing VOC pollution in water sources is an important first step towards obtaining sustainable and healthy water supplies for current and future generations.

1.3 Thesis Objectives:

The main aim of this work was to develop adsorbents that can be efficiently used to remove volatile organic compounds (VOCs) from wastewater. The specific objectives that will help achieve the main objective are as follows:

- ✓ To synthesize copolymer-modified CNT (PCNT).
- ✓ To synthesize copolymer-modified carbon (PAMC) derived from local palm shells.
- ✓ To evaluate the adsorption performance with different concentrations of VOCs and different contact time and dosage of copolymer-modified CNT and copolymer-modified carbon.

Carbon-based materials and nanomaterials have gained significant attention in recent years due to their unique properties and potential applications in various fields including environmental remediation. One promising application is their ability to adsorb VOCs from

water, which is a major concern for both human health and environmental pollution. Activated carbon adsorption of VOCs in water treatment is of interest. These materials and other forms of carbon nanostructures can be in the form of particles, nanoparticles, nanotubes, or graphene sheets, which provide a large surface area and high reactivity for adsorption. To evaluate the effectiveness of these carbon structures in removing VOCs from water, it is crucial to analyze the residual VOCs remaining in the water after the adsorption process. The most suitable instruments for this analysis are headspace gas chromatography (HS-GC) with a flame ionization detector (FID) and mass spectrometry (MS). Headspace gas chromatography with a flame ionization detector (HS-GC-FID) is a widely used technique for analyzing VOCs in various samples. The principle behind this technique involves heating the sample in a closed system, which allows the VOCs to volatilize into the gas phase. The gas phase is then injected into the GC column, where the VOCs are separated based on their volatility and detected by the FID. Mass spectrometry (MS) is another powerful technique used for the analysis of VOCs. It provides high sensitivity and selectivity, allowing for the identification and quantification of a wide range of compounds. In this research, the use of HS-GC-MS is particularly advantageous as it provides both qualitative and quantitative information about the residual VOCs in water. By employing both HS-GC-FID and HS-GC-MS, researchers can accurately measure the concentration of residual VOCs in water after the adsorption procedure. This information is vital for assessing the effectiveness of carbon-based materials in removing VOCs and optimizing their adsorption capabilities. In this work the proposed materials were tested for the removal VOCs and HS-GC was used for the analysis.

1.4 Types of Techniques

1.4.1 Water Remediation Techniques

In recent decades, the continual expansion of industrial activity has resulted in a large rise in the release of pollutants into the environment, with volatile organic compounds (VOCs) being of particular concern. Because of their negative effects on ecosystems and

human health, these chemicals, which are frequently found in industrial wastewater streams, constitute a serious challenge to environmental sustainability. The high quantity of VOCs in industrial wastewater impedes optimal reutilization and safe disposal, necessitating effective remediation solutions. (Wang et al., 2019)

As a result, in order to fulfil the demand for safe drinking water, these chemicals must be eliminated from the water. Water treatment and recycling technology uses processes like filtration (Giwa, Adewale, et al., 2018), coagulation (Sillanpää, Mika, et al., 2018), ion exchange (McCleaf, Philip, et al., 2017), reverse osmosis (Luo, Wenhai, et al., 2017), adsorption (Peng, Weijun, et al., 2018) The majority of these therapy units are costly. Because of its low cost and efficiency, adsorption is a promising alternative treatment approach. Nonetheless, the material's properties and design significantly limit its performance.

1.4.2 Physical Treatment:

The employment of physical procedures to remove pollutants is referred to as a physical approach. Sedimentation, filtration, and centrifugation are examples of these techniques. Sedimentation causes solid particles to settle at the bottom of a container, whereas filtration traps particles using porous materials. Centrifugation separates particles from water by using centrifugal force.

1.4.3 Chemical Treatment:

Chemical treatment methods remove impurities through chemical reactions. Coagulation and flocculation are processes that entail the addition of chemicals to water in order to destabilize and agglomerate particles for easier removal. Chemical precipitation is a technique for combining insoluble chemicals with dissolved pollutants to allow them to settle out of the water.

1.4.4 Adsorption:

Adsorption is a widely recognized and effective method for removing pollutants from water. This process involves the attraction of pollutants to the surface of adsorbent materials and their subsequent capture. Adsorbents, such as activated carbon or graphene, possess a large surface area and numerous active sites, which enhances their ability to attract and adsorb pollutants. One of the major advantages of adsorption is its effectiveness in removing a wide range of pollutants, including organic molecules, heavy metals, and certain pollutants. Organic molecules, such as pesticides, pharmaceuticals, and industrial chemicals, can be effectively adsorbed onto the surface of adsorbent materials, leading to their removal from water sources. Additionally, heavy metals, including lead, mercury, and arsenic, can also be adsorbed and retained by adsorbents, mitigating their detrimental effects on the environment and human health. Adsorption is commonly employed in various water treatment processes, such as activated carbon filtration systems and adsorbent-packed columns. These systems provide a means of removing pollutants at both the industrial and household scales. Adsorption can be used for the treatment of drinking water, wastewater, and even the remediation of contaminated sites. Furthermore, adsorption is a cost-effective and versatile method for pollutant removal. Activated carbon and graphene, two commonly used adsorbents, are readily available and can be easily regenerated or replaced when saturated with pollutants. The effectiveness of the adsorption process can be optimized by controlling factors such as contact time, concentrations of pollutants, and pH levels. However, it is important to note that adsorption is not a universal solution for all types of pollutants. Some pollutants may not be well adsorbed by commonly used adsorbents, and alternative treatment methods may be required. Additionally, the disposal or regeneration of spent adsorbents should be carefully managed to avoid secondary pollution.

1.4.5 Biological Treatment:

In recent years, there has been a growing interest in using biological techniques for water treatment due to their effectiveness, cost-efficiency, and environmental sustainability. Some examples of these techniques include activated sludge treatment, constructed wetlands, and bioremediation. Activated sludge treatment involves the use of microorganisms in a mixed culture called activated sludge to break down and digest organic matter in wastewater. This process takes place in large, aerated tanks and includes aeration, settling, and the removal of excess sludge. The treated water can then be discharged or reused. Constructed wetlands mimic natural water purification processes by using wetland plants and microorganisms in the soil to treat wastewater. Nutrients are absorbed and removed by the plants, while organic pollutants are degraded by microorganisms. These wetlands can be designed as surface flow or subsurface flow systems. Bioremediation involves the use of microorganisms to break down or transform organic pollutants in contaminated water sources. This process converts pollutants into less harmful substances, such as carbon dioxide and water. Bioremediation can be carried out on-site or off-site and can be applied to various types of organic pollutants. These biological techniques have proven to be effective in eliminating organic pollutants, improving water quality, and protecting ecosystems. They offer several advantages over traditional methods, including lower energy requirements, reduced chemical use, and minimal production of harmful byproducts. As a result, these techniques are increasingly being adopted in water treatment facilities worldwide.

1.4.6 Membrane Filtration:

Membrane filtration technologies separate pollutants based on their size and molecular weight. Microfiltration (MF) uses larger pore size membranes to remove particles, bacteria, algae, solids, and some protozoa. Ultrafiltration (UF) utilizes smaller pore size membranes to remove smaller particles, colloids, proteins, microorganisms, and some viruses. Nanofiltration (NF) employs membranes with even smaller pores to remove divalent ions, larger organic molecules, and color-causing compounds. Reverse osmosis

(RO) uses membranes with extremely small pores to reject almost all solutes, including salts, solids, organics, bacteria, and viruses. These technologies are efficient, customizable, and can be integrated into existing water treatment systems for various pollution control needs.

The water remediation approach used is determined by the exact pollutants present, the water source, and the target water quality. To accomplish thorough water treatment, a mix of treatments is frequently used. Water remediation is critical for preserving clean and safe water supplies, safeguarding ecosystems, and minimizing the environmental and health consequences of water pollution.

The current remediation strategies used to remove VOCs from water have significant drawbacks. They frequently have low effectiveness, require expert personnel to operate, pose safety hazards, and lack validation via real-world tests. As a result, the need for novel methods to address these difficulties is becoming increasingly important. The use of carbon-based nanomaterials in the treatment of polluted water has received a lot of interest in this area, owing to their exceptional physicochemical features and potential for effective pollutant removal.

CHAPTER2

LITERATURE REVIEW

2.1 Types of Technique

2.1.1 Advances in Adsorption-based Water Remediation

Nanotechnology is becoming increasingly important in science and engineering. The extraordinary properties of nanostructured materials have created several demanding opportunities in a variety of study domains. Water technology is one such topic, which includes the construction of extremely efficient techniques. Despite advances in material production, there is always a need for effective nano-adsorbents to remove contaminants to lower levels in order to accomplish ultra-deepwater purification. (Saha et al. 2017) As adsorbents, carbon-based compounds such as carbon nanotubes and activated carbon have traditionally been employed. Nonetheless, their activity is restricted to the surface. As a result, functionalization of carbonaceous materials is required to improve their performance.

The purpose of this study was to look at the use of carbon to treat water for VOCs and to evaluate Headspace Gas Chromatography with a flame ionization detector and Mass Spectrometry. (VOC) measurements and treatment are required since some of the chemicals in this class are hazardous. There are various effective strategies for reducing VOCs in water. One approach for removing these dangerous volatile organic compounds

is to employ carbon materials. The ability of impurity adsorption of carbon to eliminate VOCs from water.

Several materials, including graphene and activated carbons, have been used to successfully separate, purify, recover, and store VOCs. Furthermore, in addition to removing these species, porous adsorbents might be used to monitor and regulate the amount of harmful water contaminants. As a result, activated carbon or graphene has garnered more attention in recent years because it offers a number of technical benefits over more traditional types of this widely used porous material. These advantages include quicker adsorption kinetics, higher efficiency, and a bigger capacity for adsorption due to their larger surface area and pore volume.

The adsorption potential is determined by the characteristics of VOCs and graphene-based nanohybrids. VOC adsorption also involves interactions such as hydrogen bonds, hydrophobic interactions, and electrostatic interactions. The advantages of graphene nanohybrids are their low cost, adaptability, and large surface area.

Water vapor may be absorbed competitively in activated carbon fabric and can even diminish the adsorption capacity of regenerated activated carbon. It is common in indoor spaces and in many industrial gas streams. Understanding water vapor adsorption and its effects on activated carbon cloth is essential for designing carbon adsorption technologies. They discovered that water vapor had an effect on benzene adsorption that began with about 65% of the pollutant and became more prominent as the pollutant concentration grew. As the pollutant concentration increased, the decreased benzene adsorption capacity

owing to higher pollutant was minimized. Up to 90% RH, acetone has low adsorption capability on activated carbon fabric.

2.1.2 Headspace gas chromatography (GC)

With technological improvements over the last few years, gas chromatography has proven to be a superior technique over others concerning the analysis of volatile organic compounds. Although modern analytical gas chromatography provides good sensitivity and selectivity and enables a large analytical scope of analytes, an aqueous sample can hardly be injected directly. Either the water itself is not compatible with the injection device and the column chemistry, or high-boiling compounds present in the sample will foul the injection device. Various time-consuming and laborious sample preparation solutions have been provided over the years that resolve the above problems.

Headspace gas chromatography injects gas directly into a gas chromatographic column from the top or "head" of a sealed container containing a liquid or solid brought to equilibrium for separation and analysis of VOCs in water. In this technique, only the most volatile compounds make it to the column.

Adsorption experiments in about 20.0 mL glass vials may be done in-situ gas chromatography utilizing a novel experimental technique that allows for direct gas chromatography measurements after adsorption without the need for additional sample processing. Headspace gas chromatography with a flame ionization detector and Mass Spectrometry (HSS-GC-MS and HSS-GC-FID) are the ideal devices for measuring the residual VOCs in water following the adsorption process. The combined approach of HSS-GC-MS and HSS-GC-FID should have a broad application range and analytic scope in

terms of analytes. Because only substances that partition into the gaseous head space above the sample will reach the injector and column, quantitative analysis of headspace samples is a particularly appropriate approach to combine with GC.

2.1.3 Graphene-Based Materials in Environmental Remediation

Because of its remarkable mechanical, electrical, and thermal characteristics, graphene, a single sheet of carbon atoms organized in a hexagonal lattice, has sparked tremendous interest in a variety of sectors. Because of its vast surface area, strong electrical conductivity, and chemical stability, it is an excellent choice for a wide range of applications, including environmental remediation. (Wang et al., 2019)

Because of their unique features and many uses, graphene-based materials have emerged as potential instruments in the field of environmental remediation. (2018) (Zhu et al.) These materials, which are predominantly composed of a single layer of carbon atoms organized in a hexagonal lattice, have excellent electrical conductivity, mechanical strength, and surface area, making them well-suited for tackling a variety of environmental concerns. (2018, Li et al.) The following is a synopsis of the function and importance of graphene-based materials in environmental remediation:

2.1.4 Adsorption of Contaminants:

Graphene-based materials, such as graphene oxide (GO) and reduced graphene oxide (rGO), have a highly porous structure and a high concentration of functional groups, making them good adsorbents for a wide range of pollutants. Through physical and chemical interactions, they may successfully absorb organic contaminants, heavy metals,

colors, and even gases from air and water. Graphene materials are useful for cleaning water and air due to their enormous surface area and strong adsorption capability.

2.1.5 Water Purification:

Membranes and filters made from graphene, with a focus on graphene oxide, have shown exceptional capabilities in purifying water. They effectively remove pollutants, nanoparticles, and ions, resulting in improved water quality. Additionally, by modifying graphene materials with specific functional groups, their selectivity and efficiency in eliminating specific contaminants can also be enhanced.

2.1.6 Wastewater Treatment:

Graphene-based composites are increasingly being used in wastewater treatment methods. Organic pollutant degradation and hazardous chemical reduction can be aided by graphene-based nanocomposites acting as catalysts or photocatalysts. They have the potential to increase the efficiency of advanced oxidation processes (AOPs) and aid in the removal of persistent organic pollutants from industrial and municipal wastewater. (Xu et al, 2008; Gong et al, 2018)

In conclusion, graphene-based materials provide a cutting-edge and long-term strategy for tackling environmental issues. Their multifunctional features, including adsorption capacity, catalytic activity, and sensing capabilities, have the potential to revolutionize environmental remediation procedures, ensuring cleaner air and water, preserving ecosystems, and protecting human health. Ongoing research and development in this sector

holds considerable potential for novel approaches to major environmental concerns. Researchers have recently concentrated on improving the efficacy of graphene-based materials for VOC removal from water by integrating polymers into the composite structure.

In this regard, the research conducted by Xi et al, 2022 focuses on tackling indoor air pollution produced by volatile organic compounds (VOCs) using photocatalytic oxidation (PCO) approaches. Specifically, the researchers used a benign and effective ultraviolet (UV)-assisted photoreduction approach to create a new p-n heterojunction photocatalyst composed of p-type photo reduced graphene oxide (PRGO) and n-type titanium dioxide (TiO₂). This GT-12 PRGO-TiO₂ photocatalyst displayed dramatically increased photoactivity, eliminating 100% of VOC (50 mg/m³ methanol) under UV light and 24.3% under visible light. The improved performance was due to the p-n heterojunction's greater built-in potential and a smaller band gap, which reduced charge carrier recombination and increased light absorption, respectively. The principal reactive species responsible for photocatalytic activities were found to be $h\nu B^+$ species and O₂ radicals in the study, providing vital insights into the potential of PRGO-TiO₂ as an effective p-n heterojunction photocatalyst. (Xi et al. 2022)

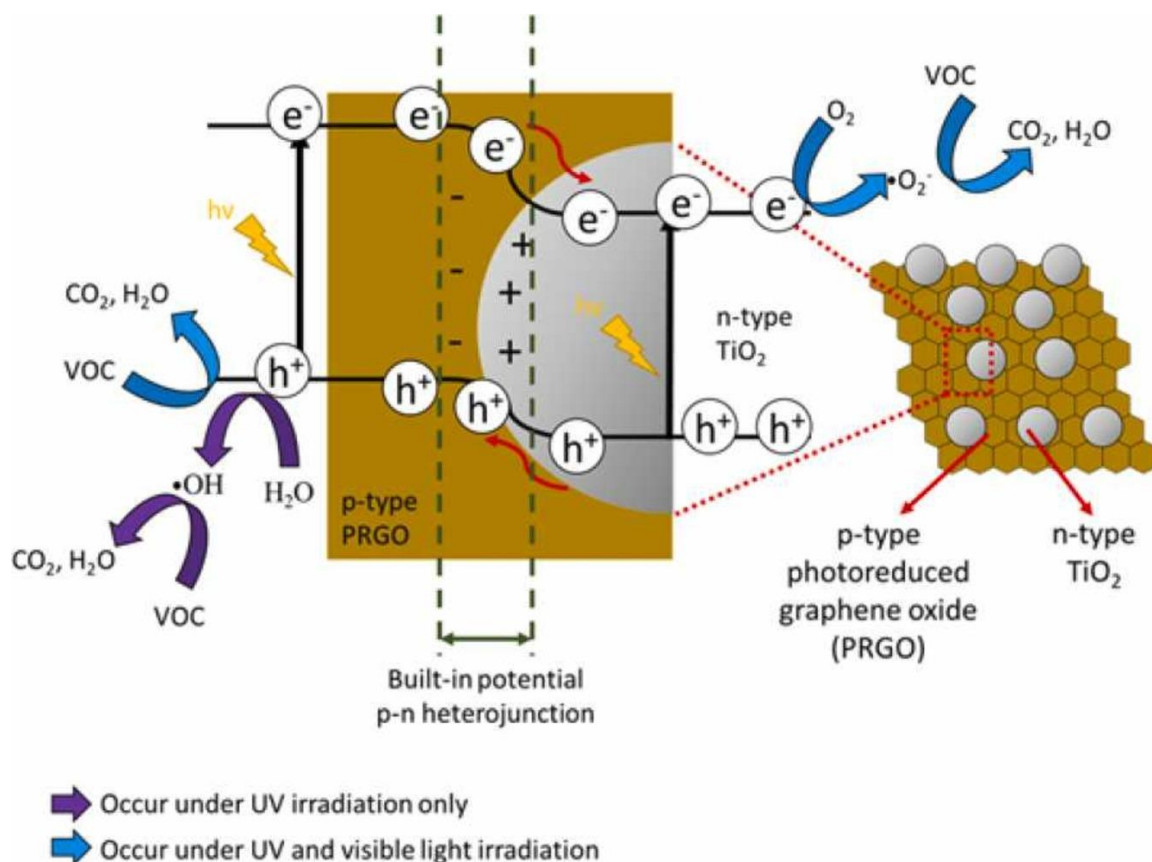


Figure 1: Photocatalyst-based water remediation.

By improving the creation and characterization of polymer-modified graphene composites, this research aims to close current gaps in the removal of VOCs from polluted water. This study aims to establish optimized treatment conditions, quantify adsorption capacities, and evaluate the efficiency of these composites through systematic investigation and experimentation, ultimately contributing to the sustainable management of industrial wastewater and the preservation of environmental quality.

Figure 2 depicts a recent research study in which single-walled carbon nanotubes (CNTs) were inserted into a copolymer membrane consisting of poly(N-isopropylacrylamide)-co-(acrylamide) to separate water from an oil combination. CNTs were chosen because of their oleophilic property, which attracts oil. The resultant copolymer membrane, reinforced

with single-walled CNTs, has a 99.99% oil removal efficiency. Furthermore, the membrane demonstrated a photothermal-response feature, which enhanced the water flow across it when exposed to light. These discoveries have not only enhanced the use of CNTs-based polymers for oil removal but have also prompted research groups to investigate novel polymer composites that make use of CNTs' unique features. (2015; L. Hu et al)

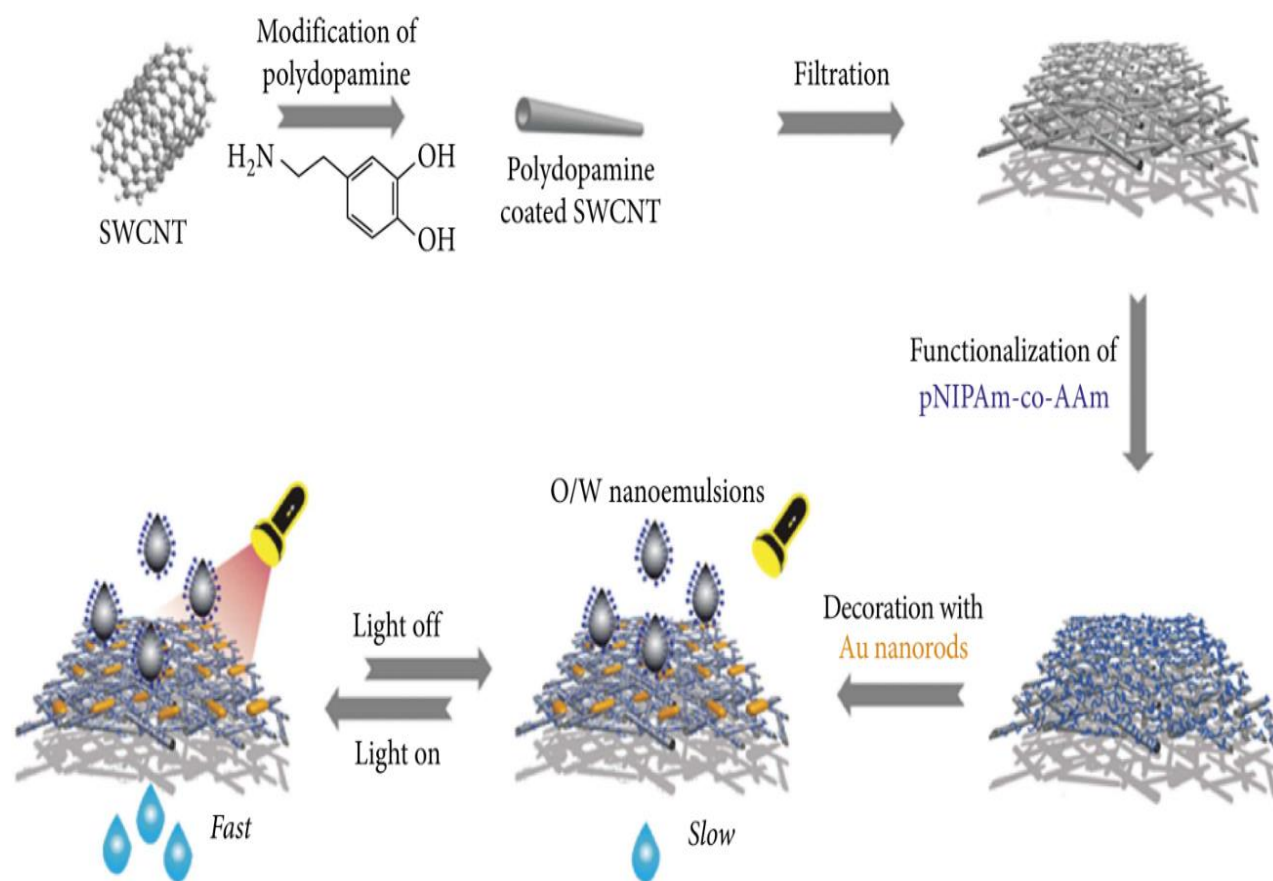


Figure 2: CNTs for oil removal from water.

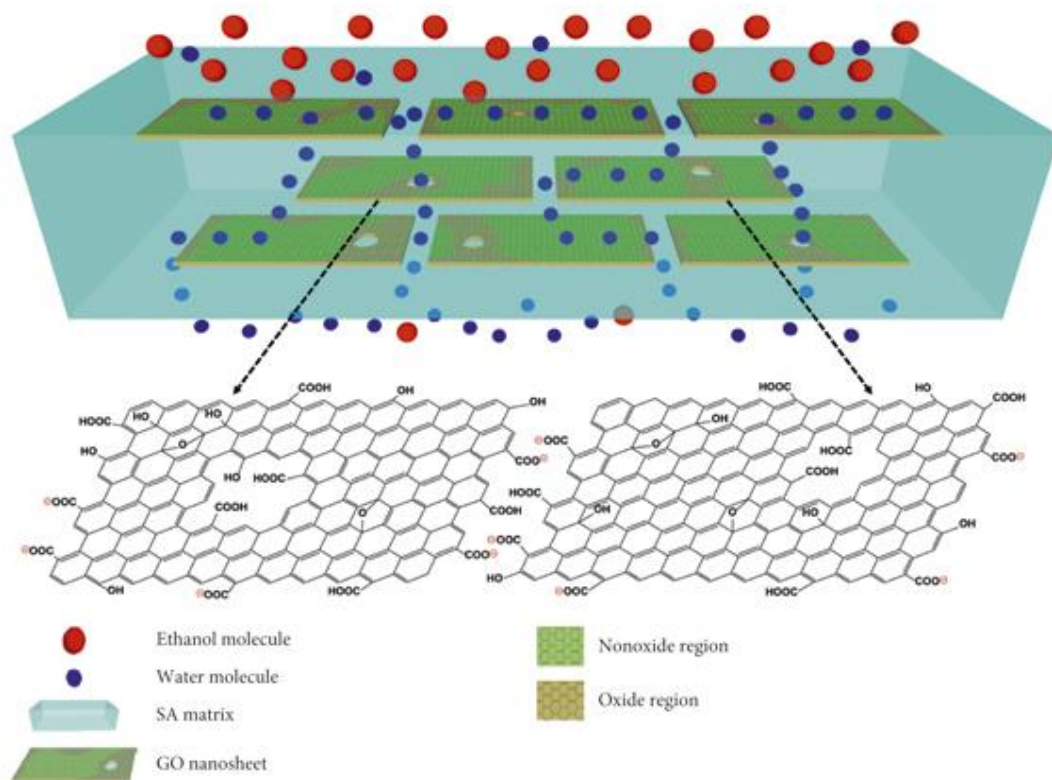


Figure 7: Sod. alginate blend for selective water permeation.

In a similar study, researchers used poly(N,N-2-ethyl amino ethyl methacrylate), a temperature-responsive polymer, to graft graphene oxide and build an ultrafiltration-specific nanomembrane. Poly(N,N-2-ethyl amino ethyl methacrylate) was crucial in producing regulated pore diameters in the membrane, which were driven by stimuli such as carbon dioxide and argon. The amine group of the poly(N,N-2-ethyl amino ethyl methacrylate) polymer reacted with carbon dioxide while submerged in water, becoming protonated and then deprotonated when exposed to argon. As shown in Figure 4, this dynamic change in the polymer's structure has a direct influence on the separation properties of the cast membrane. This nanofiltration membrane was tested for its ability to

reject dyes such as rhodamine-B and methylene orange, with outstanding average rejection rates of 98.9% and 96.5%, respectively. Furthermore, the membrane demonstrated exceptional resistance to several salts, including magnesium, calcium, and sodium chlorides. (L. Dong et. al, 2018).

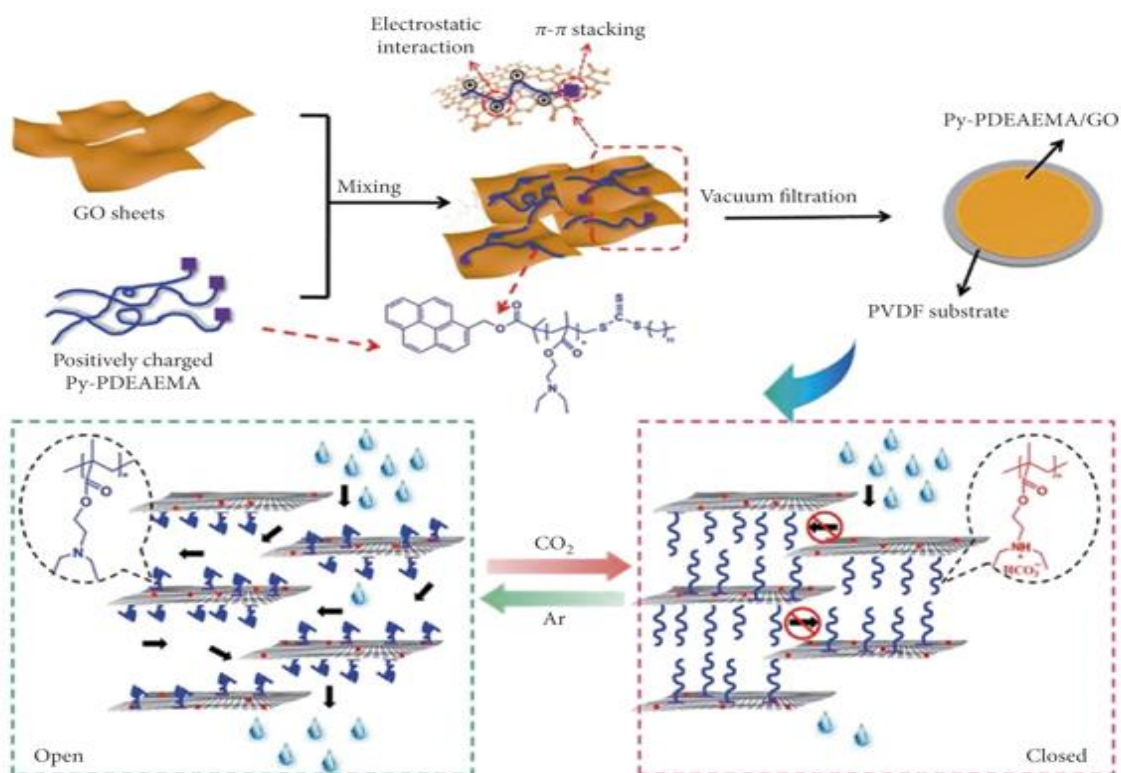


Figure 8: Graphene oxide composite for dye and salt rejection.

Polymer-modified anionic clays have been investigated as promising adsorbents for water purification. Figure 5 shows a recent study that used a novel composite made of magnesium-aluminum-based layered double hydroxides (LDH) and polydopamine to remove copper ions from aqueous solutions. The results of this investigation demonstrated a significant improvement in copper ion adsorption efficiency. Notably, as compared to the pristine layered double hydroxides, the composite had twice the adsorption capacity for

copper ions, with a maximum adsorption capacity of 193.78 mg/g. Importantly, the composite was reusable, with its adsorption capacity remaining unchanged after four cycles of usage. The underlying adsorption process consisted predominantly of electrostatic interactions with copper ions (J. Dou et al, 2019).

Figure 9: Elimination of copper ions from water-by-water polymer-modified clay.

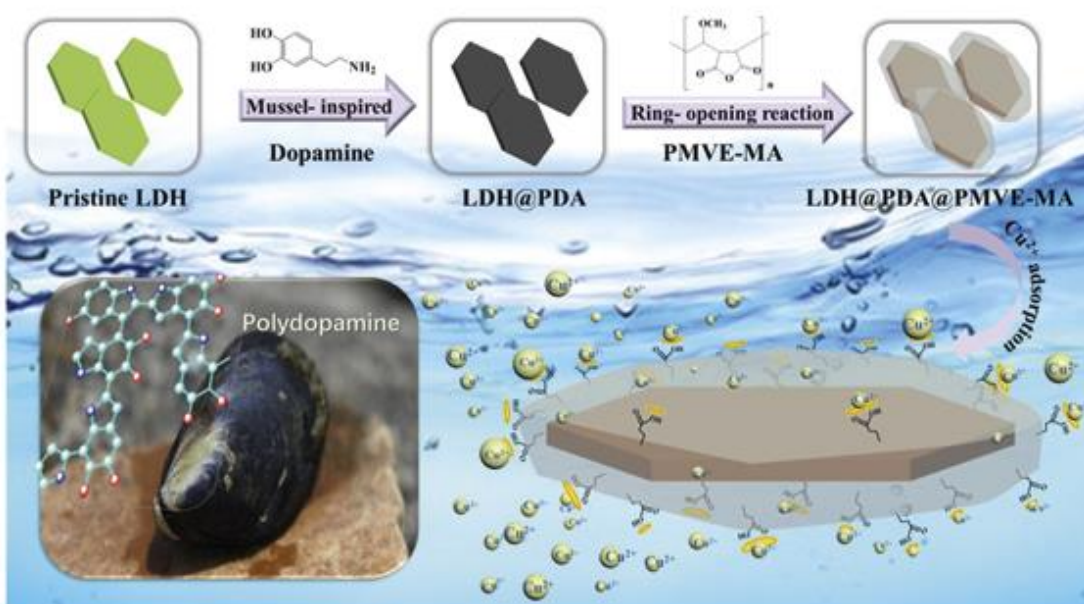


Figure 10: Elimination of copper ions from water-by-water polymer-modified clay.

Carbon nanotubes (CNTs) have been developed as a revolutionary technique for the elimination of formaldehyde, a recognized gaseous carcinogenic contaminant in indoor air, by Shenyang and colleagues. They created a CNT/activated carbon fiber (ACF) filter medium by chemical vapor deposition of CNTs on pure ACF. Using a low starting formaldehyde concentration, the effectiveness of formaldehyde removal was evaluated for both the CNT/ACF and ACF filter medium. When compared to ACF, the CNT/ACF

material performed better, with a greater initial removal efficiency and a threefold improvement in formaldehyde removal per unit weight. Notably, the CNT/ACF material showed a slight increase in pressure resistance. Furthermore, when compared to comparable filter media in the literature, the CNT/ACF material demonstrated much better formaldehyde adsorption capacity and significantly reduced pressure resistance. This study highlights the potential of CNT/ACF composites as a viable technique for removing formaldehyde from indoor air. (2017, Shenyang et al.)

Dai Z et al. investigated the previously unknown application of carbon-catalyzed persulfate activation to remove gaseous volatile organic compounds (VOCs), revealing insight on the complicated mechanisms driving their elimination. The study investigates the elimination of VOCs by persulfate-based advanced oxidation processes (P-AOPs) over single-walled carbon nanotubes (SWCNT) using theoretical chemistry calculations. According to the findings, distinct VOCs preferentially cling to SWCNT, with the degree of this adsorption dependent on their polarizability. Furthermore, the study demonstrates that PMS, a key component in the process, can be effectively activated on SWCNT, generating highly reactive $\bullet\text{OH}$ radicals due to the robust interaction between PMS and SWCNT. Using formaldehyde as an example, the study discovers a very fast breakdown process with no hazardous byproduct CO. This study gives critical insights into the removal of VOCs by SWCNT/P-AOPs, focusing on the underlying processes involved in VOC adsorption, PMS activation, and the following removal route.

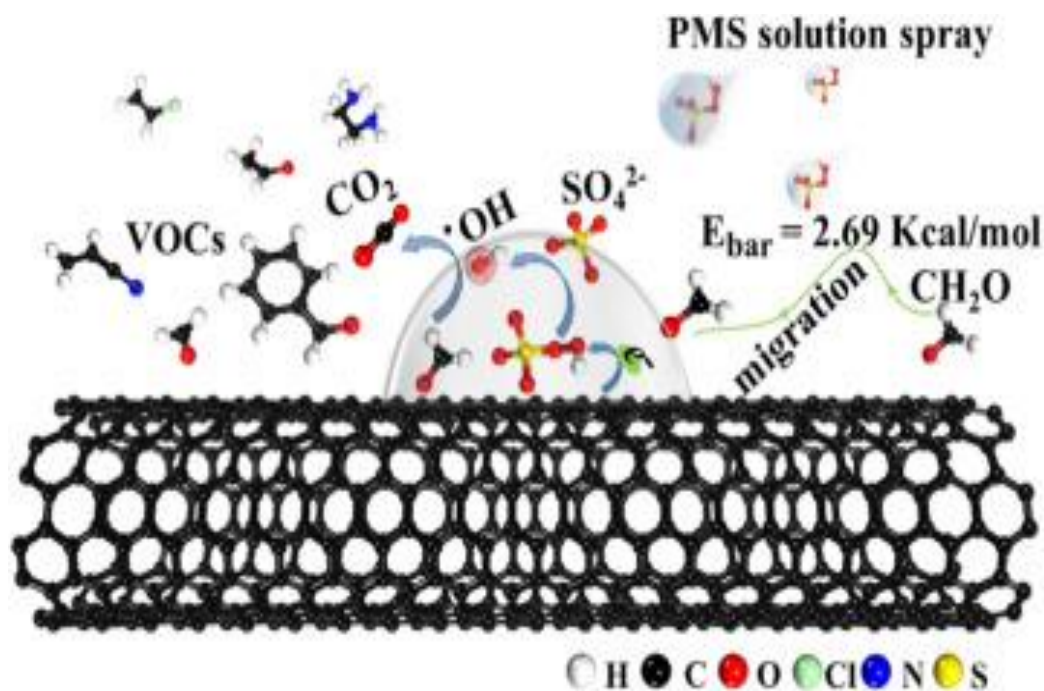


Figure 11: VOCs removal carbon nanotube system.

Finally, the literature review on "Polymer-modified graphene composites for the removal of VOCs from water" highlights the rising interest in and promise of employing advanced materials in environmental remediation procedures. The combination of graphene and polymers in composite materials has considerable potential for tackling the essential issue of VOC removal from water sources. Throughout this examination, we've seen a variety of tactics and procedures used to create these composites, such as surface modification, functionalization, and various polymer matrices. These customized composites have various benefits, such as increased adsorption capabilities, greater stability, and effective VOC elimination. However, obstacles and knowledge gaps remain, such as improving composite synthesis procedures, understanding long-term stability, and dealing with real-world application scenarios. Future research should focus on closing these gaps so that polymer-modified graphene composites may be used as effective and sustainable VOC removal solutions, contributing to the preservation and conservation of our water resources.

Carbon nanotubes (CNTs) stand out among carbonaceous materials, with a wide collection of unique properties spanning the electrical, mechanical, and chemical domains. Their large surface area and remarkable strength cement their place in the material science scene. CNTs, in particular, have received a lot of attention for their ability to thrive as adsorbents, a position that holds a lot of potential. These nanotubes' unique architectures enable them to develop powerful connections with organic molecules. This connection is based on a variety of non-covalent forces, including hydrogen bonding, which involves the exchange of hydrogen atoms between CNTs and organic molecules, allowing for strong adhesion. Furthermore, p-p stacking, a form of aromatic stacking interaction, is important in adsorption processes because it promotes binding between CNTs' flat aromatic surfaces and organic molecules. Electrostatic forces generated by charged species promote further adsorption by establishing attractive interactions between oppositely charged substances. CNTs may cling to a wide spectrum of organic molecules thanks to Van der Waals forces, which include dispersion forces and dipole-dipole interactions. Finally, hydrophobic interactions take use of hydrophobic molecules' inherent inclination to cluster together in the presence of water, boosting CNT adsorption capabilities even more. To summarize, the numerous factors at work highlight carbon nanotubes' great potential as better adsorbents, suggesting a future where they are exploited for a wide range of applications, from environmental cleanup to enhanced drug delivery systems. (Pyrzynska and colleagues (2008)).

Sae-Khow et. al studied a groundbreaking approach is presented, focusing on the creation of innovative composite membranes immobilizing carbon nanotubes (CNIM) designed for the pervaporative extraction of organic compounds from aqueous solutions. These

nanotubes are strategically embedded within the pores of a composite matrix, effectively serving as unique sorption sites that introduce supplementary pathways to augment the transport of solutes. This innovation profoundly influences both the partitioning and diffusion processes occurring within the membrane. Depending on the specific process conditions, the CNIM exhibits a remarkable increase in efficiency, with organic removal rates boosted by an impressive 108%, accompanied by a significant 95% enhancement in mass transfer rates. Notably, the CNIM system showcases a multitude of advantages, such as heightened recovery rates at low solute concentrations, reduced operating temperatures, and the capacity to accommodate higher flow rates. Collectively, these attributes culminate in more energy-efficient processes, positioning CNIM as a promising breakthrough in the field of organic pollutant removal from aqueous matrices. Notably, the CNIM system has several advantages, including increased recovery rates at low solute concentrations, lower operating temperatures, and the ability to tolerate larger flow rates. These characteristics, when combined, result in more energy-efficient operations, establishing CNIM as a promising innovation in the field of organic pollutant removal from aqueous matrices.

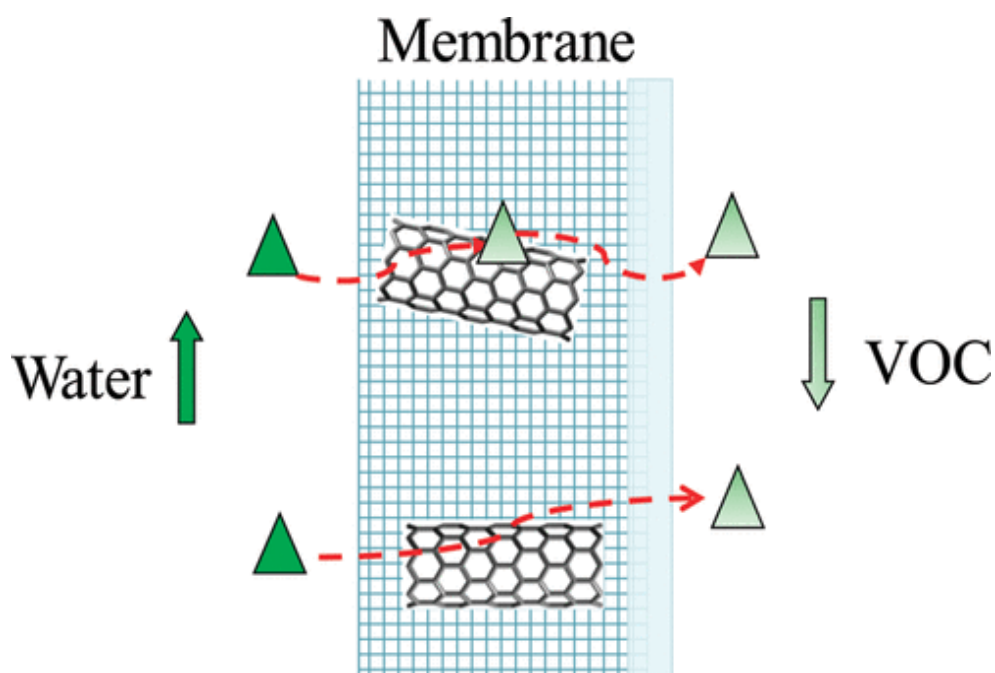


Figure 12: Carbon membrane for VOCs removal.

Carbon membranes have developed as an extremely effective and long-term option for removing Volatile Organic Compounds (VOCs) from water. These membranes have a unique porous structure that provides a large surface area and adsorption capacity, making them suitable for absorbing and concentrating VOCs from water sources. Carbon membranes' adsorption capabilities, along with their high chemical stability, allow them to selectively collect a wide spectrum of organic contaminants while allowing water molecules to flow through. This selective penetration guarantees that VOCs are removed from water efficiently, resulting in cleaner and safer water sources. Carbon membranes are also very adaptable and may be modified to target specific VOCs, making them a useful tool for solving pollution concerns in a variety of industrial and environmental situations. They are a potential technique for tackling VOC pollution in water resources, helping to

the preservation of water quality and environmental well-being due to their efficiency and sustainability.

Ghrabli et al. devised a unique approach for modifying poly(vinylidene fluoride) (PVDF) membranes to improve their performance in the removal of hazardous volatile organic compounds (VOCs) from water by membrane distillation. The fluorinated surface was activated with piranha reagent and then grafted with 1H,1H,2H,2H-Perfluorooctyltriethoxysilane (FC6). For comparison, octyl group functionalized membranes were also evaluated. A thorough assessment of the membranes utilizing multiple methodologies revealed considerable performance increases. Notably, the flow of EtAc and the permeation selectivity index (PSI) increased significantly from virgin membranes to 1-minute activated and FC6-functionalized samples. These adjustments also resulted in changes in material characteristics, such as increased roughness, contact angle, and mechanical properties, all of which contributed to the membranes' improved performance. 2018; Al-Gharabli et al.



Figure 13 :VOCs removal membrane

To summarize, the removal of Volatile Organic Compounds (VOCs) from water using carbon materials is a very successful and ecologically friendly method. Carbon compounds, such as activated carbon, carbon nanotubes, and graphene-based materials, have shown extraordinary adsorption capabilities, making them suitable candidates for VOC removal from water sources. Their distinct surface characteristics and porosity provide an abundance of adsorption sites, allowing for the effective collection of a wide spectrum of organic contaminants. Furthermore, the tunability of these materials enables adsorbents to be customized to target specific VOCs, increasing their selectivity. This technique not only treats water pollution but also provides a possible route towards sustainable water resource management. As the globe grapples with environmental issues, carbon materials play an important role in ongoing efforts to assure the supply of clean and safe water for future generations.

CHAPTER 3

EXPERIMENTAL

3.1 GC (gas chromatography):

The analysis of the samples was performed using an Agilent Technologies 7890B GC (gas chromatography) system coupled with an Agilent 5977B MSD (mass spectrometry detector) in Palo Alto, CA, USA. The purpose of this analysis was to separate the components in the samples. To achieve this separation, a DB-5MS capillary column from Agilent Technologies was utilized. This column had a length of 30 meters, an inner diameter of 250 μm , and a film thickness of 0.5 μm . The choice of this specific column was based on its ability to provide efficient separation for the target compounds. Carrier gas used for the analysis was helium, which was maintained at a pressure of 16.52 psi. This pressure was selected to ensure that benzene, the target compound, had a retention time of 5.25 ± 0.05 minutes. Retention time is a crucial parameter used to identify and quantify compounds in gas chromatography. The GC oven program was initiated at a temperature of 40°C and held for 8 minutes. After the initial hold, the temperature was ramped up to 172°C at a rate of 6°C per minute. This temperature program was designed to optimize the separation of the components in the samples. The injector temperature was set to 250°C, which facilitates the vaporization and injection of the sample into the GC column. The use of a high injector temperature helps to ensure efficient sample introduction and

vaporization. A small split ratio of 1:10 (sample to carrier gas) was utilized in this analysis. The split ratio determines the amount of sample injected into the GC carrier gas flow. In this case, a small split ratio was used to prevent overloading of the column and ensure accurate analysis. In summary, the analysis was conducted using an Agilent Technologies GC system coupled with an MSD detector. A DB-5MS capillary column was employed for efficient separation, and the analysis conditions, including temperature, pressure, and split ratio, were carefully chosen to achieve accurate and reliable results.

3.2 Static Gas Extraction Methods:

A sample preparation method for identifying volatile chemicals in solid and liquid samples is headspace GC. The technology has been around since the late 1950s and is still in use today. Only the gas phase above the sample is injected into the GC column using this approach. The popularity of headspace analysis can be attributed to its ease of use and the fact that it is a highly clean technique for delivering volatile analytes into a gas chromatograph; the injector mechanism and column should require little maintenance. A liquid sample that will be studied using the headspace technique is typically collected from the source and chilled in a container that is filled to the brim with the sample so that no volatiles are lost. The liquid or solid sample is put in a vial at room temperature just prior to analysis, with a large quantity of headspace over the sample; the vial is then sealed and heated. The analytes (volatile chemicals) start to travel into the gas phase above the sample until they attain equilibrium. The ratio of analyte concentrations in the gas phase to those in the liquid or solid phase is constant at this point. The partition coefficient, K , is defined as the constant.

$$K = \frac{C_S}{C_G}$$

where C_S is the analyte concentration in the sample after equilibrium (the term C_L may be used if the sample is a liquid) and C_G is the analyte concentration in the gas phase after equilibrium.

The partition coefficient decreases with increasing temperature and fluctuates with changes in the matrix; for example, when organic analytes are dissolved in water, the addition of salts decreases K .

Figure 1 depicts the equilibration process for a liquid sample, where C_O represents the original concentration of analyte in the sample, C_L represents the concentration of the analyte in the liquid phase after equilibration, C_G represents the concentration of the analyte in the gas phase after equilibration, V_L represents the volume of the liquid phase in the headspace vial, and V_G represents the volume of the gas phase in the headspace vial.

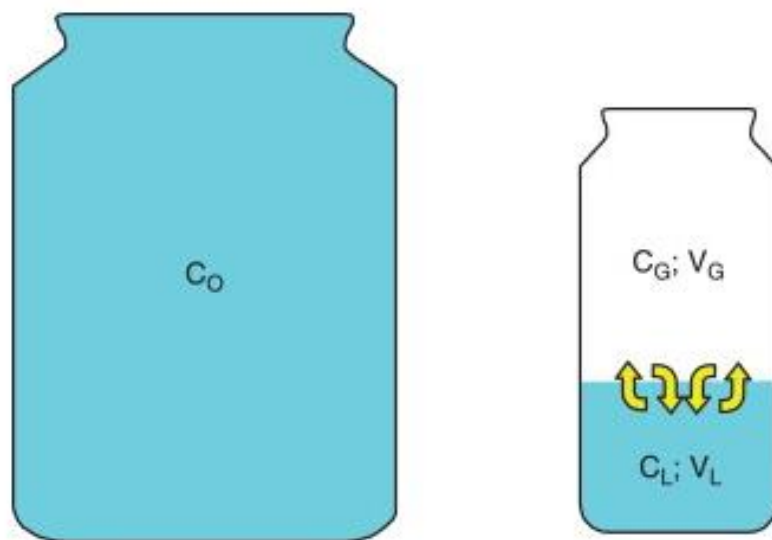


Figure 9: Headspace vial

After reaching equilibrium, an aliquot of the gas-phase sample is withdrawn from either the headspace vial or a headspace instrument with a gas sample valve and put into the gas chromatograph.

Analytes with a very high partition coefficient prefer to remain in the sample phase, whereas those with a low partition coefficient tend to concentrate in the gas phase, as shown by the equation above. As a result, headspace detection limits for analytes in a compatible sample matrix (such as methanol in water) will be substantially higher (lower sensitivity) than headspace detection limits for analytes in an incompatible sample matrix (toluene in water).

3.3 Gerstel multi-Purpose Sampler:

A Gerstel multi-purpose sampler in the headspace sampling procedure is to automate and enhance the efficiency of the process. The Gerstel multi-purpose sampler is a highly versatile instrument that can perform various tasks, including sample preparation, liquid sample injection, solid sample extraction, and more. In the case of headspace sampling, the multi-purpose sampler can automate the process of generating the headspace gas from a sample and transferring it to the analytical instrument, such as a gas chromatograph (GC). This automation significantly reduces human involvement and potential errors while achieving a higher throughput of sample analysis.

The Gerstel multi-purpose sampler offers precise control over various aspects of the headspace sampling procedure, such as temperature, time, and agitation, ensuring consistent and reproducible results. It can also handle different sample matrices, volumes, and types, allowing for a wide range of applications, from the analysis of volatile compounds in pharmaceuticals to the quality control of food and beverages. Overall, the Gerstel multi-purpose sampler enhances the efficiency, accuracy, and reliability of the headspace sampling procedure, making it an essential tool for laboratories involved in analytical chemistry, environmental analysis, forensics, and other fields.

The headspace sampling procedure was conducted in an automated manner using a Gerstel Multi-purpose sampler. First, a 20-ml vial designed for headspace sampling was filled with 10.0 ml of either a water sample or a standard. The vial was then placed in an agitator set at a temperature of 80°C for 30 minutes to allow the system to reach equilibrium. This ensures that the vapors in the headspace of the vial accurately represent the analytes present

in the sample. After the 30-minute equilibration period, 500 µl of the vapor phase was injected into a split injector at a speed of 1000 µl/s. The injector temperature was maintained at 250°C to ensure efficient vaporization of the sample.

A split ratio of 1:10 was employed during the injection process, meaning that only 1/10th of the injected sample entered the analytical column, while the remaining 9/10ths were vented out. This split ratio helps prevent overload of the column and ensures better separation and detection of analytes in the sample.

3.4 MS Instrumental (MS):

The Agilent 5977B Mass Selective Detector (MSD) is a state-of-the-art analytical instrument used in a wide range of applications, including environmental analysis, pharmaceutical research, forensic analysis, food safety testing, and more. It is designed to identify and quantify various chemical compounds in complex samples accurately and efficiently. The instrument is equipped with a high-performance quadrupole mass filter, which allows for selective filtering of ions based on their mass-to-charge ratio. This enables the precise identification and quantification of target compounds. The Agilent 5977B MSD features enhanced sensitivity and dynamic range, allowing for the detection of low-level analytes in complex matrices. It also offers a wide mass range, allowing users to analyze a diverse range of compounds. The instrument integrates with Agilent's Mass Hunter software, which provides powerful data analysis and reporting capabilities. It also offers various ionization techniques, such as electron ionization (EI) and chemical ionization (CI),

allowing for flexibility in sample analysis. Key features of the Agilent 5977B MSD include:

1. **High sensitivity:** The instrument is capable of detecting analytes at low concentrations, making it ideal for trace-level analysis.
2. **Robust performance:** The MSD is designed to deliver consistent results, even with challenging samples or complex matrices.
3. **Wide mass range:** The instrument can handle a broad range of molecules, from small organic compounds to large biomolecules.
4. **Fast data acquisition:** With high-speed scanning capabilities, the MSD can acquire data rapidly, increasing sample throughput.
5. **Advanced data analysis:** The Mass Hunter software offers advanced data processing and reporting tools, enabling quick and reliable data interpretation. Overall, the Agilent 5977B MSD is a versatile and reliable analytical instrument that provides accurate and precise analysis of chemical compounds in a wide range of applications.

In this study, the mass spectrometer was used with specific instrumental settings. The electron ionization mode was selected with an energy of 70 electron volts (eV). The full-scan range for ion detection was set from 29 to 250 atomic mass units (amu). To improve selectivity and sensitivity, the selected ion recording option was employed, where specific ions were chosen for detection. In a given time window, a group of compounds was combined, and the two most abundant ions were recorded. The identification of peaks was

confirmed by the presence of target and qualifier ions at the appropriate retention time.

Table 1 provides a summary of the ions detected in different time windows.



Figure 10: Agilent Technologies 7890B GC (gas chromatography) system coupled with an Agilent 5977B MSD with Gerstel Multi-Purpose Sampler

Table 1: Recorded ions in various time windows

Window (min)		Ions recorded (m/z in Dalton)
Start time	End time	
0	3.73	49, 50, 52, 61, 63, 65, 84, 86, 96, 98
3.74	4.58	47, 61, 62, 83, 85, 96, 98, 128, 130, 132
4.59	5.72	51, 61, 63, 64, 75, 77, 78, 82, 97, 99, 110, 112, 117, 119

5.73	7.10	62, 63, 95, 107, 130, 132, 174
7.11	8.18	93, 95, 174
8.19	9.64	75, 77, 129
9.65	10.62	65, 75, 77, 91, 92, 110
10.63	11.73	41, 76, 78, 92, 97
11.74	13.51	107, 109, 127, 129, 131, 164, 166, 188
13.52	15.84	51, 77, 91, 105, 106, 112, 114, 117, 119, 131, 133
15.85	17.00	78, 91, 103, 104, 106, 171, 173, 175
17.01	18.29	51, 75, 77, 91, 105, 106, 110, 112, 156, 158
18.30	19.76	63, 77, 91, 105, 120, 126, 128, 156, 158
19.77	22.99	91, 105, 111, 119, 120, 134, 146, 148
23.00	25.05	75, 155, 157
25.06	End of run	128, 129, 145, 180, 182, 223, 225, 227

3.5 Reagents:

In this experiment, a stock solution of 52 volatile organic compounds (VOCs) at a concentration of 2000 µg/ml in methanol was purchased from SPEX Certiprep – 5242-VCX. This stock solution was labelled as catalogue number 5242-vcx. The calibration process involved the preparation of standards using methanol as the solvent. These methanol standards were then diluted in water to obtain concentrations ranging from 0 to 300 µg/l. The specific concentrations used in the study are provided in the results section of the analysis. To determine the recovery rates, external spiking studies were conducted. Methanol standards were spiked into the samples under investigation. It should be noted that the water used for diluting the stock solution and preparing the standards for spiking was obtained from a Milli-Q purification system.

Table 2: Reagents from SPEX Certiprep – 5242-VCX.

Components	
1,1,1,2-Tetrachloroethane	1,2,4-Trimethylbenzene
1,1,1-Trichloroethane	1,2-Dibromo-3-chloropropane
1,1,2,2-Tetrachloroethane	1,2-Dibromoethane
1,1,2-Trichloroethane	1,2-Dichlorobenzene

1,1-Dichloroethane	1,2-Dichloroethane
1,1-Dichloroethene	1,2-Dichloropropane
1,1-Dichloropropene	1,3,5-Trimethylbenzene
1,2,3-Trichlorobenzene	1,3-Dichlorobenzene
1,2,3-Trichloropropane	1,3-Dichloropropane
1,2,4-Trichlorobenzene	1,4-Dichlorobenzene
2,2-Dichloropropane	Chloroform
2-Chlorotoluene	cis-1,2-Dichloroethene
4-Chlorotoluene	cis-1,3-Dichloropropene
Benzene	Dibromochloromethane
Bromobenzene	Dibromomethane
Bromochloromethane	Ethylbenzene
Bromodichloromethane	Hexachlorobutadiene
Bromoform	Isopropylbenzene
Carbon tetrachloride	Methylene chloride
Chlorobenzene	m-Xylene

Naphthalene	sec-Butylbenzene
n-Butylbenzene	Styrene
n-Propylbenzene	tert-Butylbenzene
o-Xylene	Tetrachloroethene
p-Isopropyltoluene	Toluene
p-Xylene	trans-1,2-Dichloroethene
trans-1,3-Dichloropropene	Trichloroethene

3.6 Scanning Electron Microscope (SEM):

A focused electron beam is used in a scanning electron microscope (SEM) to scan the surface of a material, creating pictures. Based on the interactions between the electrons and the atoms in the sample, these pictures give information on the surface topography and chemical composition of the sample. The position of the electron beam is paired with the intensity of the received signal as it is scanned in a precise pattern to form a picture. The Everhart-Thornley detector, which collects secondary electrons generated by excited atoms, is the most often employed mode in SEM. The topography of the specimen can impact the number of secondary electrons detected and the consequent signal intensity.



Figure 11: Scanning Electron Microscope Analyzer QUANTA FEG 250

3.7 X-ray Diffraction (XRD):

X-Ray diffraction analysis (XRD) is a nondestructive technique for determining a material's crystallographic structure, chemical composition, and physical characteristics. It works by using the constructive interference of monochromatic X-rays with a crystalline sample. X-rays are shorter wavelength electromagnetic radiation produced by decelerating

electrically charged particles with sufficient energy. XRD involves collimating and directing the produced X-rays to a nanomaterial sample, where the interaction of the incident rays with the sample generates a diffracted ray, which is then detected, processed, and tallied. A diffraction pattern is created by plotting the intensity of diffracted rays dispersed at different angles of the material.



Figure 12: X-ray Diffraction Analyzer Rigaku Ultima.

3.8 Fourier Transform Infrared Spectroscopy (FTIR):

Fourier transform infrared spectroscopy is a technique for obtaining an infrared spectrum of a solid, liquid, or gas's absorption or emission. An FTIR spectrometer obtains high-resolution spectral data over a large spectral range at the same time. This provides a substantial advantage over a dispersive spectrometer, which measures intensity across a limited range of wavelengths at a time.

Model: Niclot IS 10

SMART iTR

In ATR sampling, the infrared (IR) light travels through a crystal, is totally internally reflected at least once at the crystal-sample interface, and the reflected light travels to the FTIR detector. During the internal reflection, a part of the IR light travels into the sample, where it can be absorbed. This is called the evanescent wave. The penetration depth of the evanescent wave into the sample is defined by the refractive index difference between the sample and the ATR crystal. To account for different sample types and different path length requirements, several materials with different refractive indices are used as ATR sensors



Figure 13: Fourier Transform Infrared Spectroscopy Analyzer Niclot IS 10

CHAPTER4

RESULTS AND DISCUSION

4.1 Characterization

4.1.1 Surface oxidation of MWCNTs

In a three-neck round-bottomed flask (500 mL), CNT was combined with nitric acid (69%, AnalaR grade) (1 g CNT/10 mL). A reflux condenser is affixed to the flask's core. For 48 hours, the system was refluxed at 120 °C with continual agitation. The product was then allowed to cool to ambient temperature. Following that, the oxidized CNT solution was filtered and rinsed with deionized water until pH neutral, and the product was dried in a suitable vacuum oven for 24 hours at 60 °C before being crushed.

4.1.2 Synthesis of polymer modified CNT

The CNT (10g) was disseminated in 200 mL of deionized ethanol and 200 mL of water in a flask for the manufacture of polymer modified CNT. The mixture was sonicated to ensure thorough dispersion. Following that, 10 g of acrylamide ($\text{CH}_2=\text{CHC}(\text{O})\text{NH}_2$) was added while stirring. The system had been thoroughly mixed. Then, under stirring, 10 g of methacrylic acid ($\text{H}_2\text{C}=\text{C}(\text{CH}_3)\text{COOH}$ includes 250 ppm MEHQ as an inhibitor, 99%) was progressively added. The system's temperature was maintained at 50 °C by using nitrogen. Then, for polymerization commencement, potassium persulfate was added. The system

was stirred for 24 hours. The polyacrylate-modified CNT (PCNT) was isolated and rinsed with deionized water before drying in a vacuum oven.

4.1.3 Preparation of activated carbon

Palm shells were converted into activated carbon. The shells were cleaned and dried. They were then pulverized into a uniform micro size using a jaw crusher. They were then thermally treated in a horizontal furnace for 3 hours at 200 °C. The obtained carbon was chemically treated with nitric acid (2M) under reflux at 90 °C for 6 hours. The created carbon was then separated, washed, and dried.

4.1.4 Synthesis of polymer modified carbon

To make polymer modified carbon, carbon (10g) was dispersed in 200 mL of deionized ethanol and 200 mL of water in a flask. The mixture was sonicated to ensure thorough dispersion. Following that, 10 g of acrylamide ($\text{CH}_2=\text{CHC}(\text{O})\text{NH}_2$) was added while stirring. The system had been thoroughly mixed. Then, under stirring, 10 g of methacrylic acid ($\text{H}_2\text{C}=\text{C}(\text{CH}_3)\text{COOH}$ includes 250 ppm MEHQ as an inhibitor, 99%) was progressively added. The system's temperature was maintained at 50 °C by using nitrogen. Then, for polymerization commencement, potassium persulfate was added. The system was stirred for 24 hours. The polyacrylate-modified carbon (PAMC) product was separated and cleaned with deionized water before being dried in a suitable vacuum oven.

4.2 SEM Examination for polyacrylate-modified CNT:

Performing a full investigation requires planning and deep analysing. Therefore, two samples were examined (polyacrylate-modified CNT and activated caron) the sample will analysis by scanning electron microscope (SEM), and energy dispersive X-ray spectroscopy (EDS) to study the surfaces morphology and analyse the materials inside of samples to identify the present elements.

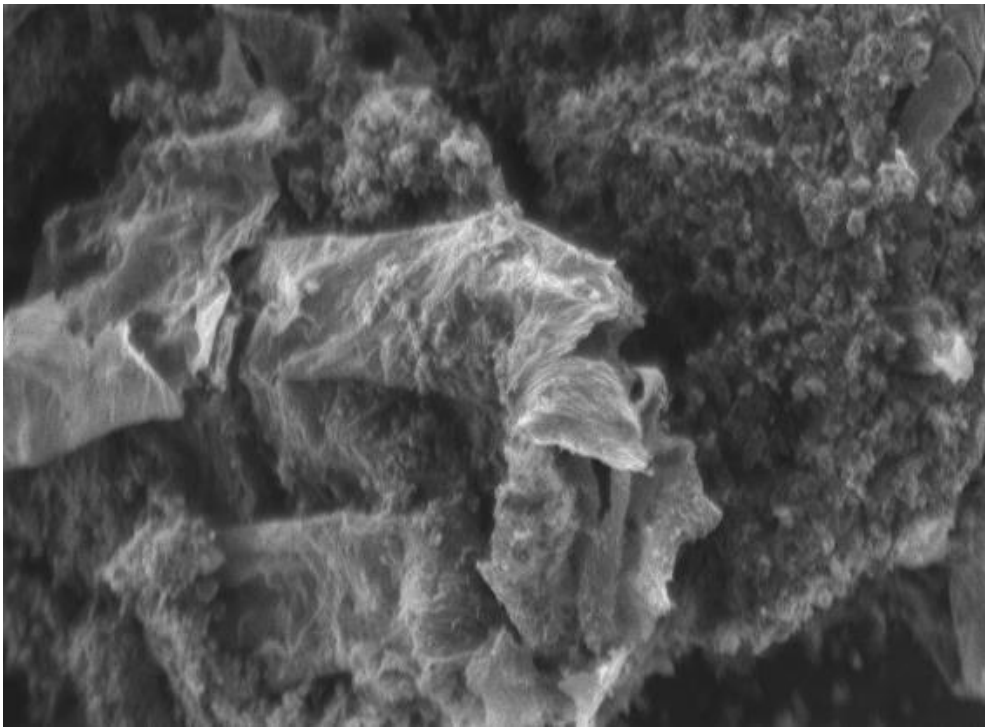


Figure 14: Photo by SEM for the polyacrylate-modified CNT.

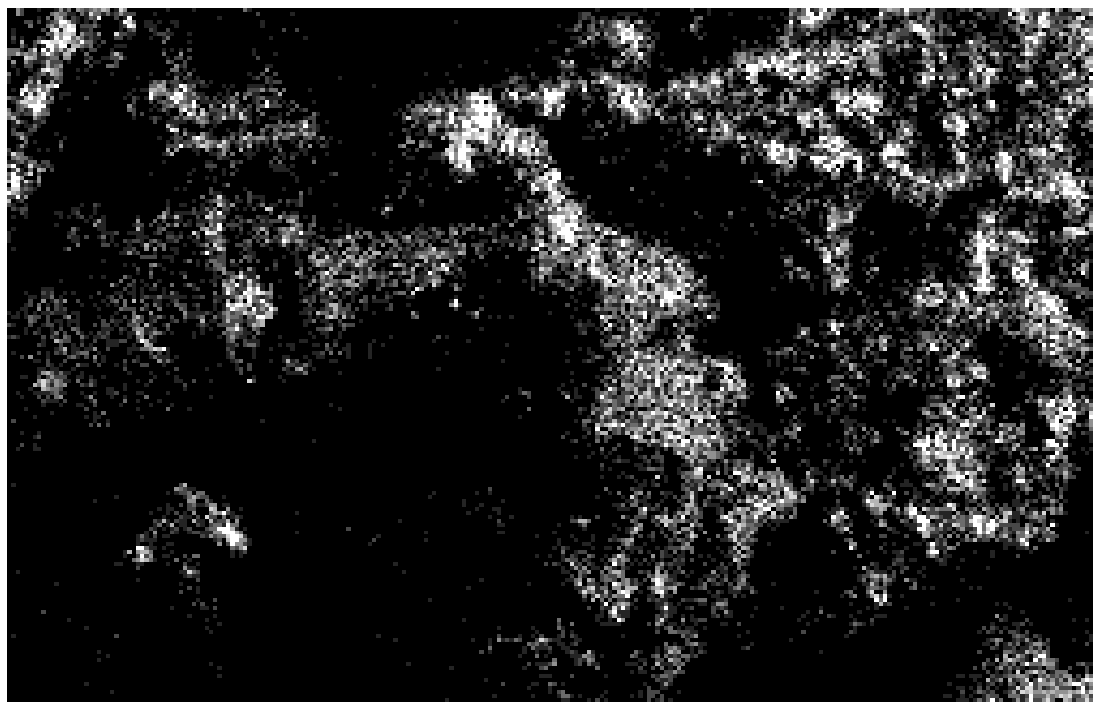


Figure 15: SEM mapping image of carbon element in the polyacrylate-modified CNT



Figure 16: SEM mapping image of gold element (used to coat the sample during SEM imaging) in the polyacrylate-modified CNT.

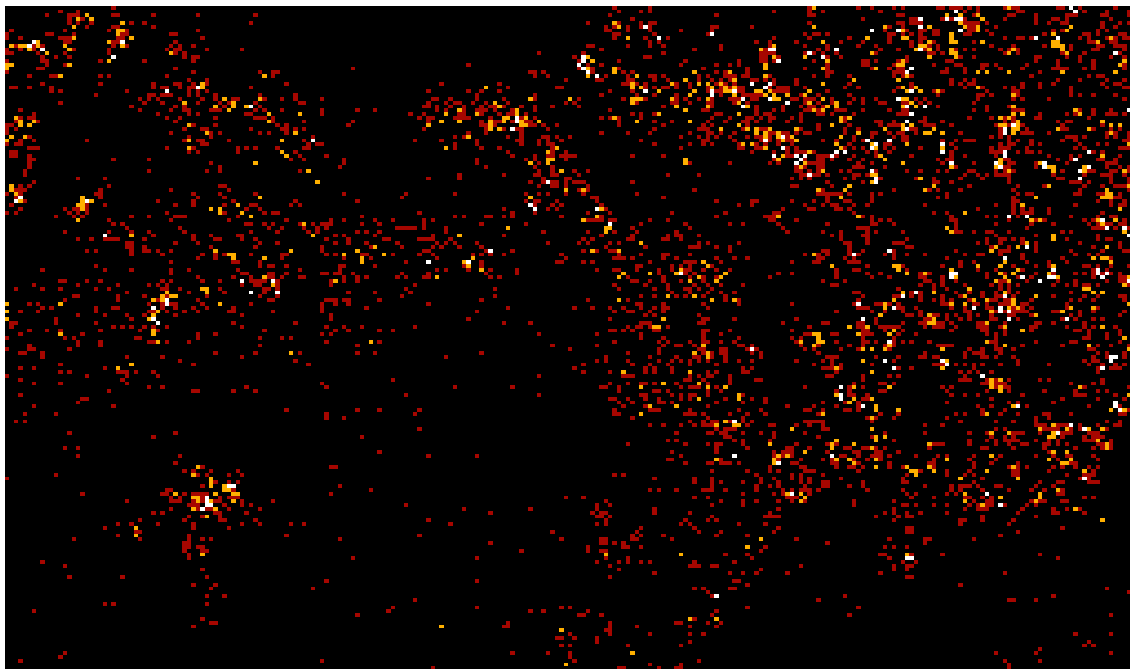


Figure 17: SEM mapping image of Nitrogen element in the polyacrylate-modified CNT.

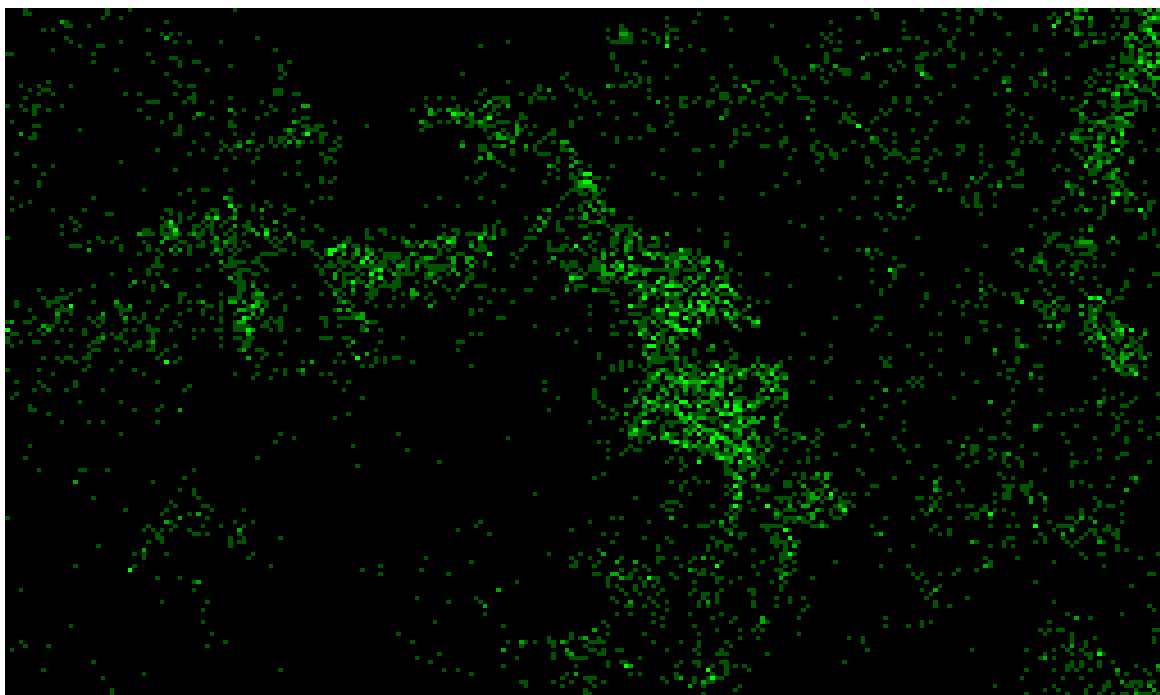


Figure 18: SEM mapping image of Oxygen element in the polyacrylate-modified CNT.

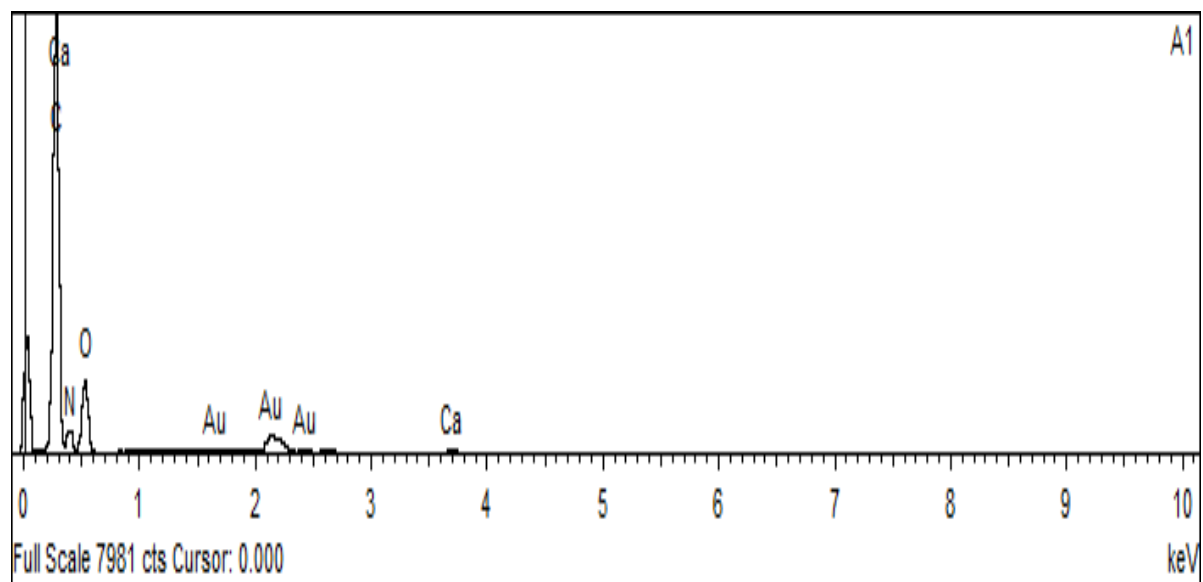


Figure 19: EDX spectrum for the polyacrylate-modified CNT.

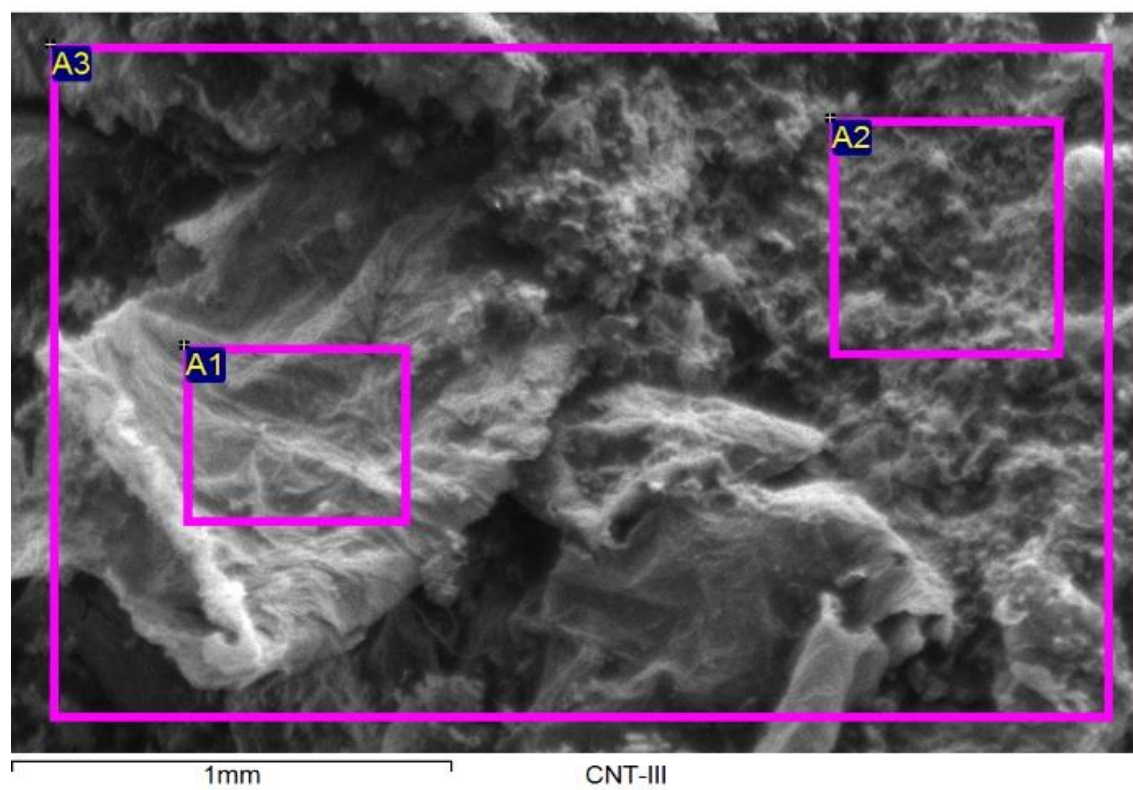


Figure 20: SEM image for the polyacrylate-modified CNT

Table 3: EDX analysis of element for the polyacrylate-modified CNT

Spectrum	In stats.	N	O	Cl	Ca	Ni	Au	Total
A1	Yes	29.74	63.71		0.47		6.08	100.00
A2	Yes	57.90	35.75			0.64	5.72	100.00
A3	Yes	41.77	51.83	0.26	0.35		5.78	100.00
Max.		57.90	63.71	0.26	0.47	0.64	6.08	
Min.		29.74	35.75	0.26	0.35	0.64	5.72	

A1: Area 1

A2: Area 2

A3: Area 3

Max: maximum

Min: Minemum

4.3 SEM Examination for polyacrylate-modified carbon:

A thorough inquiry necessitates careful preparation and in-depth analysis. As a result, two samples (polyacrylate-modified CNT and polyacrylate-modified carbon) were studied. The samples were analyzed using a scanning electron microscope (SEM) and energy dispersive X-ray spectroscopy (EDS) to research the surface morphology and analyze the contents inside the samples to identify the existing elements.

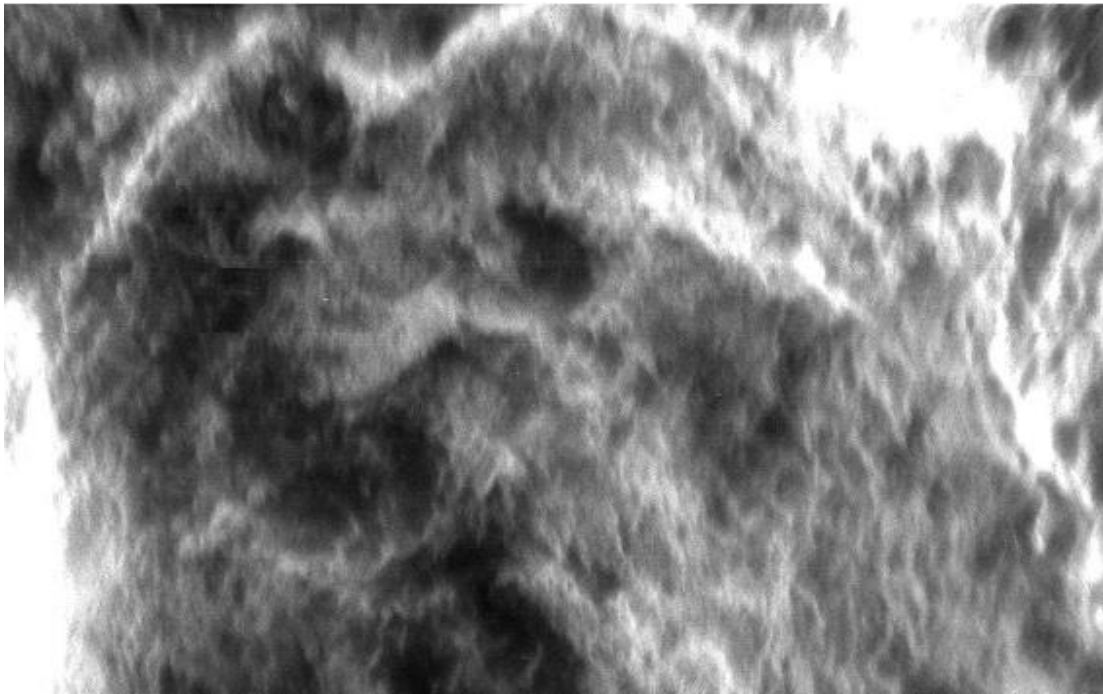


Figure 21: Photo by SEM for the polyacrylate-modified carbon.

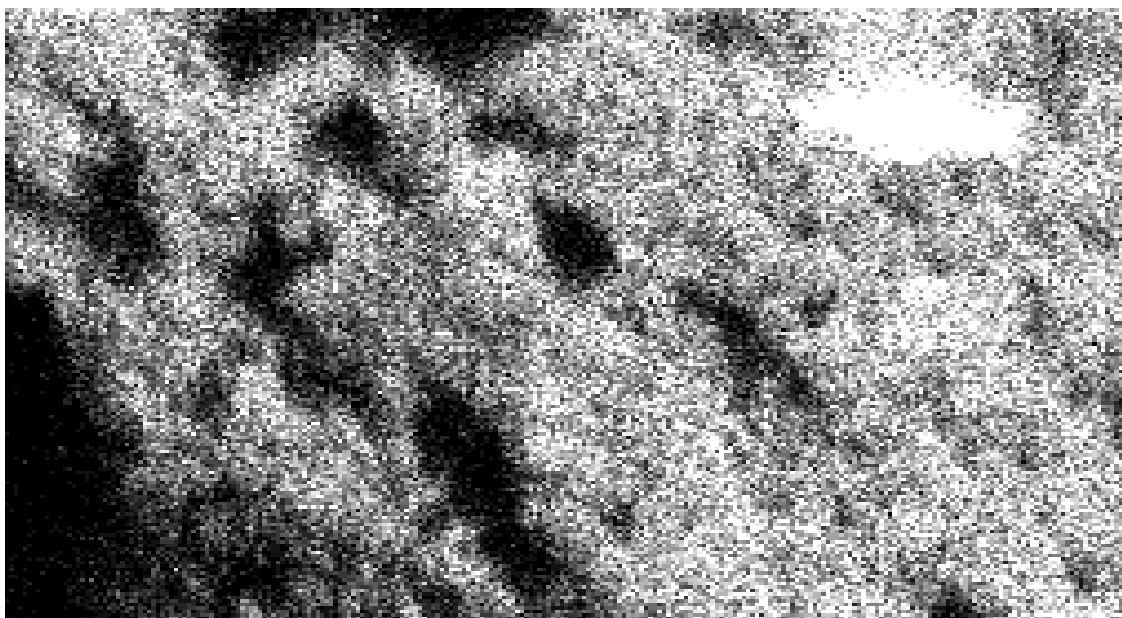


Figure 22: SEM mapping image of Carbon element in the polyacrylate-modified carbon.

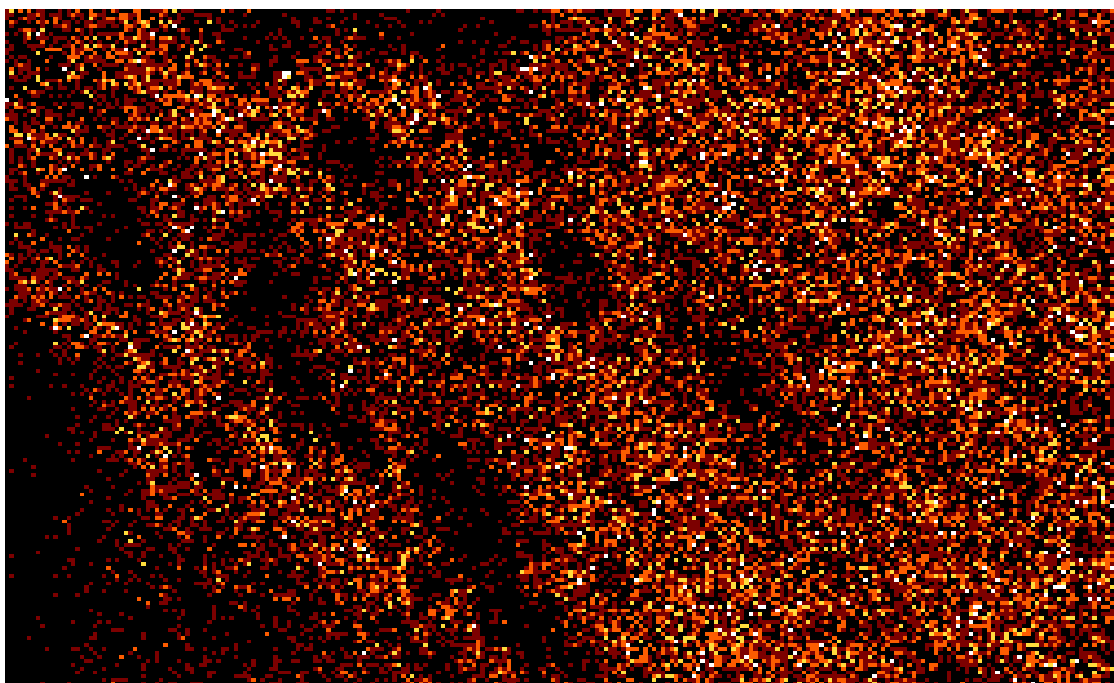


Figure 23: SEM mapping image of Nikal element in the polyacrylate-modified carbon.

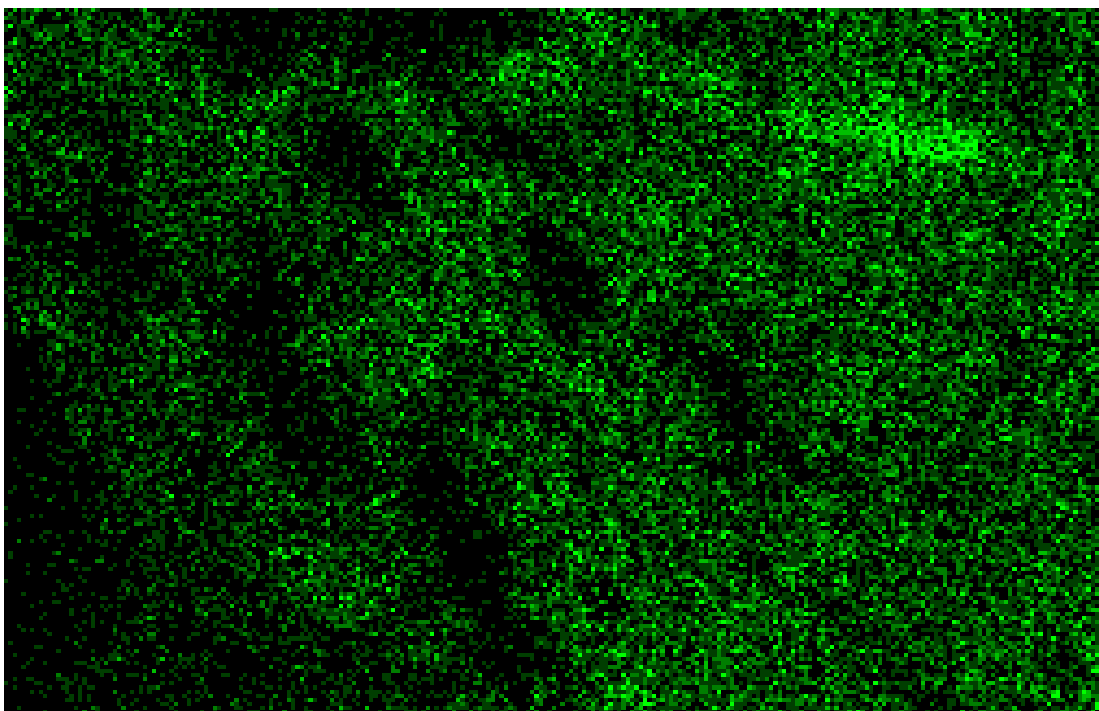


Figure 24: SEM mapping image of oxygen element in the polyacrylate-modified carbon.



Figure 25: SEM mapping image of Gold element (used during collecting SEM images) in the polyacrylate-modified carbon

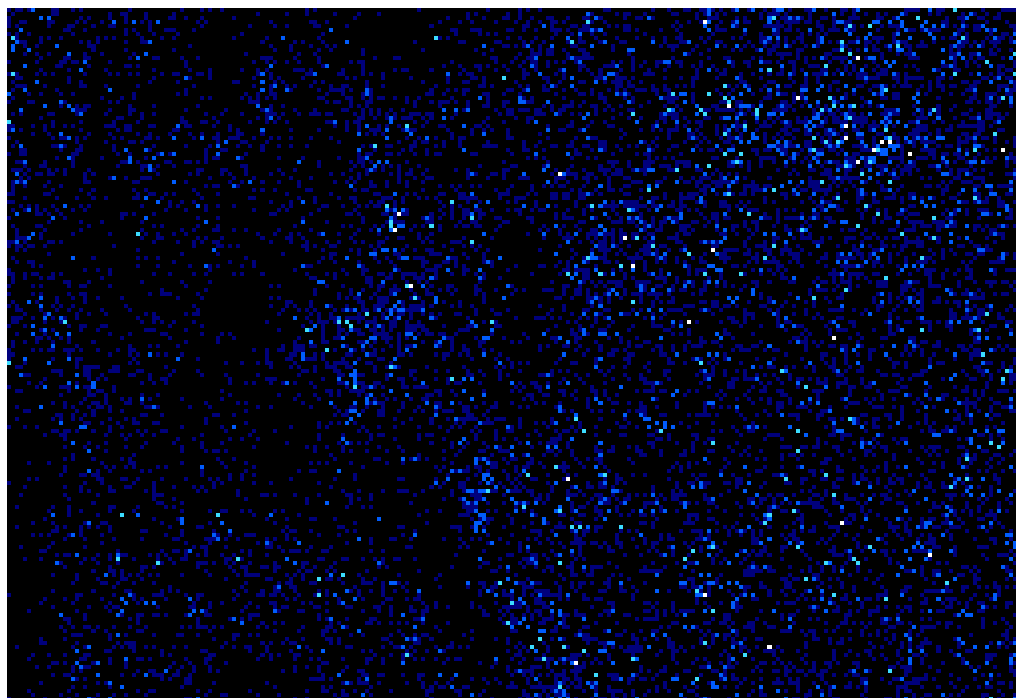


Figure 26: SEM mapping for Silicon element in the polyacrylate-modified carbon.

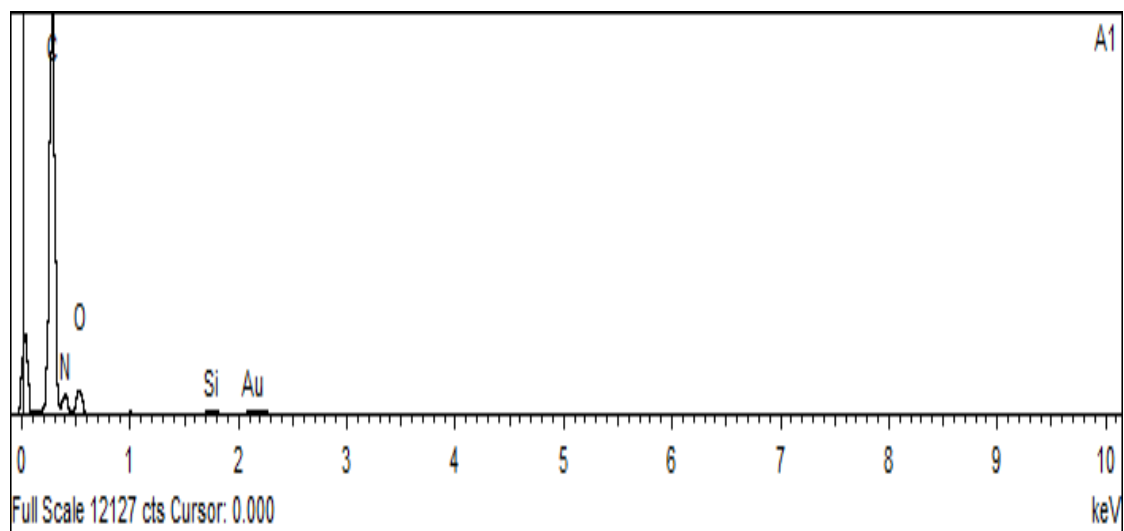


Figure 27: EDX spectrum of the polyacrylate-modified carbon.

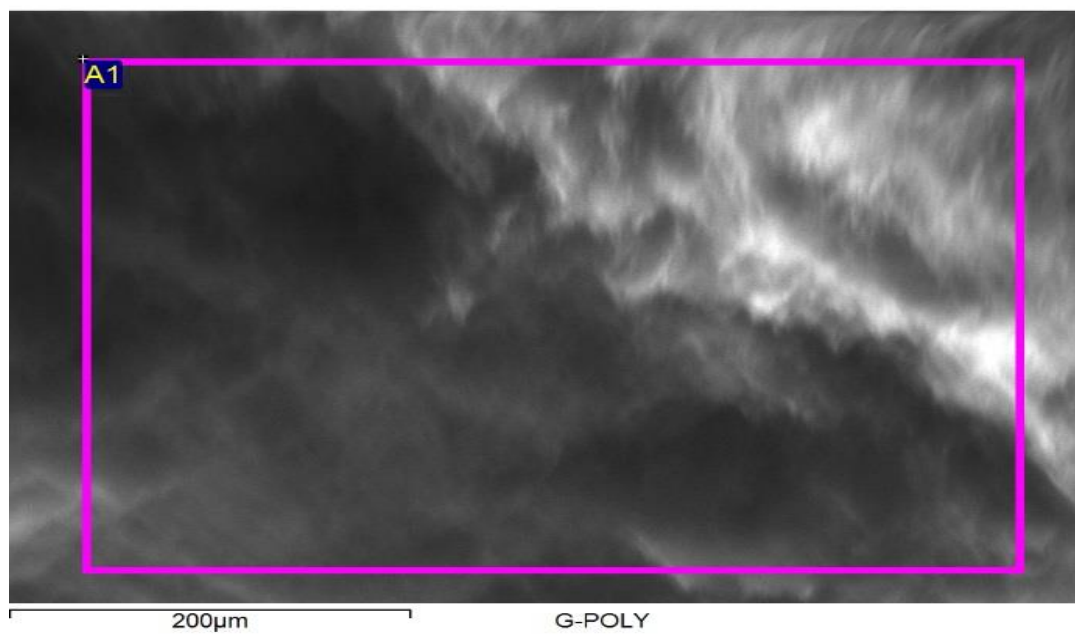


Figure 28: SEM image of the polyacrylate-modified carbon.

Table 4: SEM result for the polyacrylate-modified carbon.

Spectrum	In stats.	C	N	O	Si	Total
A1	Yes	60.01	27.17	12.72	0.10	100.00
Mean		60.01	27.17	12.72	0.10	100.00
Std. deviation		0.00	0.00	0.00	0.00	
Max.		60.01	27.17	12.72	0.10	
Min.		60.01	27.17	12.72	0.10	

All results in weight%

A1: Area 1

MAX: Maximum

MIN: Minimum

4.4 X-ray Diffraction (XRD) for polyacrylate-modified CNT:

X-Ray diffraction analysis (XRD) is a nondestructive technique for determining a material's crystallographic structure, chemical composition, and physical characteristics. The analysis was carried out using RIGAKU Ultima. PDXL2 was the program used to identify them.

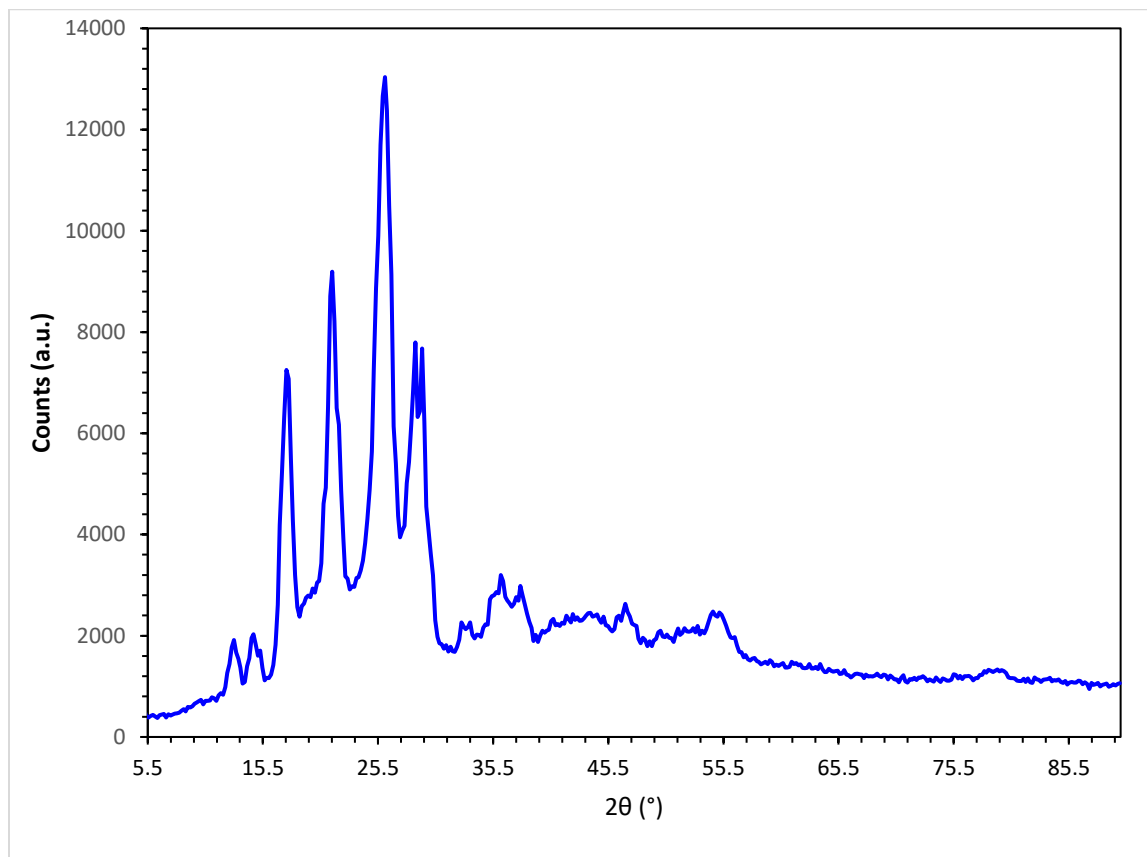


Figure 29: XRD pattern of the polyacrylate-modified CNT.

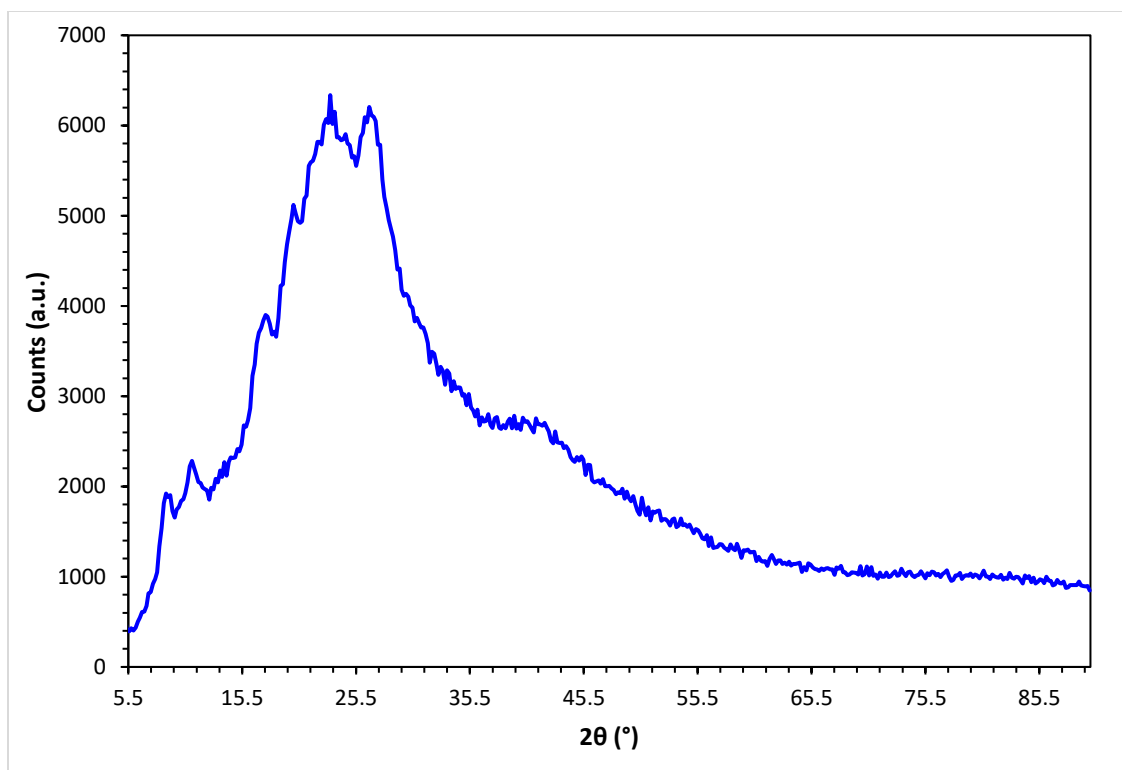


Figure 30: XRD pattern for the polyacrylate-modified carbon..

4.5 Fourier Transform Infrared Spectroscopy (FTIR):

Fourier transform infrared spectroscopy is a technique for obtaining an infrared spectrum of a solid, liquid, or gas's absorption or emission. An FTIR spectrometer obtains high-resolution spectral data over a large spectral range at the same time. This provides a substantial advantage over a dispersive spectrometer, which measures intensity across a limited range of wavelengths at a time.

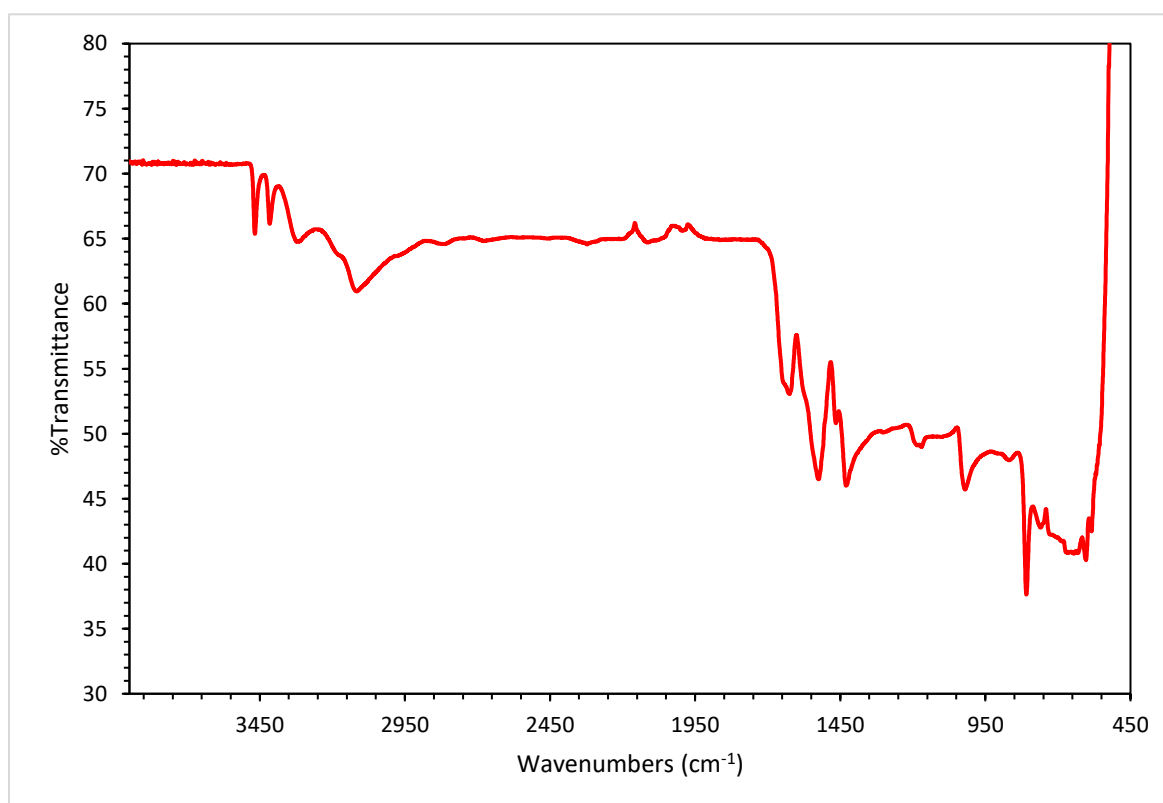


Figure 31: FTIR spectrum for the polyacrylate-modified CNT.

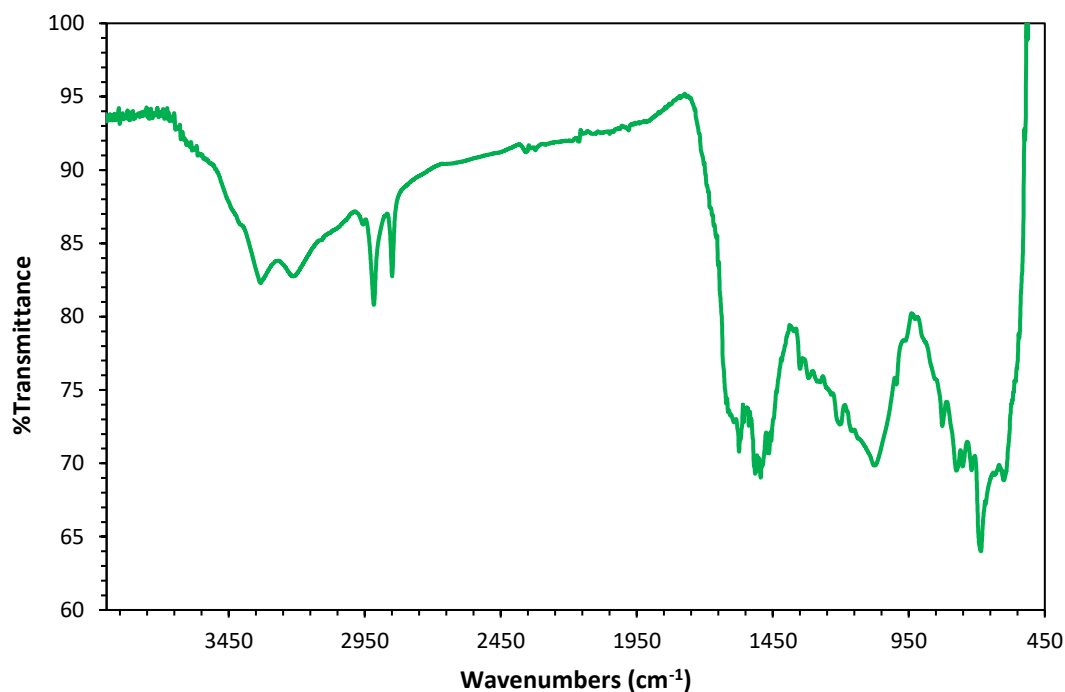


Figure 32: FTIR spectrum for the polyacrylate-modified carbon.

4.6 GC results of the VOCs:

These specific compounds were chosen based on their prevalence in the industrial sector and their potential impact on human health and the environment. dichloroethane, trichloroethylene, and toluene are commonly found in various industrial processes and can be released into the environment as volatile organic compounds (VOCs). The analysis aimed to evaluate the efficiency of headspace extraction, which is a common technique used to assess the concentration of VOCs in air samples. By comparing the results obtained

from the analysis of the standard solutions with the internal standards, researchers could determine the effectiveness of the headspace extraction method in capturing and quantifying these specific compounds. Dichloroethane, trichloroethylene, and toluene are known for their varying properties and behavior in the environment. By including these compounds in the model mixtures, researchers could assess the ability of the headspace extraction method to capture and accurately measure a diverse range of VOCs. The results of this analysis would provide valuable insight into the performance of the headspace extraction technique and its applicability in industrial settings. By using standard solutions with known concentrations of VOCs and internal standards for comparison, researchers could validate the accuracy and reliability of the method. Overall, the selection of these specific compounds in the model mixtures ensured that the analysis accounted for the potential VOCs commonly found in the industrial sector. This knowledge would contribute to the development of effective monitoring and control measures to mitigate the release of harmful VOCs and protect human health and the environment.

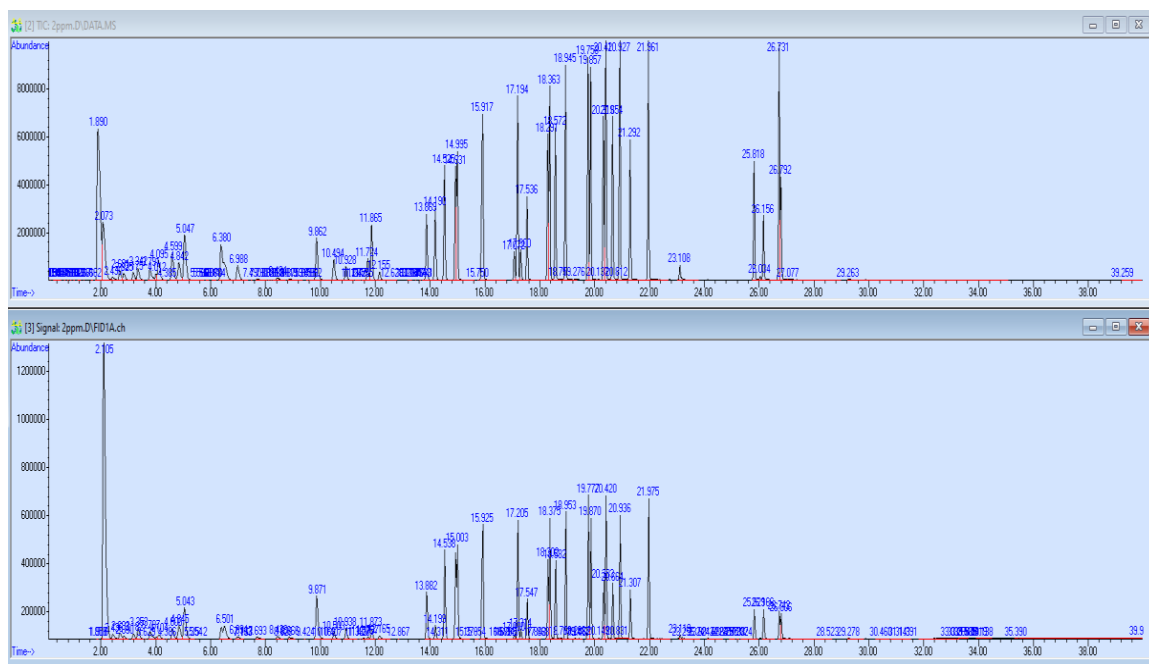


Figure 33: Chromatogram of a standard solution of VOCs.

Table 5: Chromatographic characteristics of the target compounds with retention time.

NO	Substance	Retention time (min)
1	Dichloroethene	2.6±0.05
2	Dichloroethylene	3.1±0.05
3	Trichloroethane	4.5±0.05
4	Dichloropropene	4.8±0.05
5	Carbon Tetrachloride	5.0±0.05
6	Toluene	9.8±0.05

7	Tetrachloroethylene	11.8±0.05
8	Ethylbenzene	14.5±0.05
9	O-Xylene	14.9±0.05
10	P&M-Xylene	14.9±0.05
11	Cumene	17.1±0.05
12	Chlorotoluene	18.2±0.05
13	Isocumene	18.3±0.05
14	Chlorotoluene	18.5±0.05
15	Mesitylene	18.9±0.05
16	Dimethylethylbenzene	19.7±0.05
17	Trimethylbenzene	19.8±0.05
18	Dichlorobenzene	20.3±0.05
19	Propyltoluene	20.4±0.05
20	Dichlorobenzene	20.6±0.05
21	Isopropyltoluene	20.9±0.05
22	Butylbenzene	21.9±0.05

21	Trichlorobenzene	25.8±0.05
23	Hexachlorobutadiene	26.7±0.05
24	Trichlorobenzene	26.8±0.05
25	Dichloroethene	2.6±0.05

To start the preparation, initial step preparation the concentrated stock standard with a concentration of 2000 ($\mu\text{g/ml}$) was diluted. First, it was mixed with milli-water to reach a concentration of 300 ($\mu\text{g/ml}$). Then, it was further diluted with 50 ml of milli-water to create a 2, 1, 0.5 and 0.25 ($\mu\text{g/ml}$) standards. For the polyacrylate-modified carbon. Experiment, a tube was filled with 1.0 g of polyacrylate-modified CNT and 50ml of water. After that, the appropriate concentration of the stock standard was added to the tube. The solution inside the tube was placed on a shaker, and at regular intervals, 10ml samples were taken for analysis using a high-sensitivity method.

The second step in preparing the concentrated stock standard involved diluting it with milli-water to achieve a concentration of 300 ($\mu\text{g/ml}$). This diluted solution was then further diluted with 50 ml of milli-water to create a 2, 1, 0.5 and 0.25 ($\mu\text{g/ml}$) standards. In the carbon experiment, a tube was filled with 1 g of polyacrylate-modified carbon and 50ml of water. The appropriate concentration of the stock standard was added to the tube. The solution in the tube was placed on a shaker, and at regular intervals, 10ml samples were taken for analysis using a GCMS.

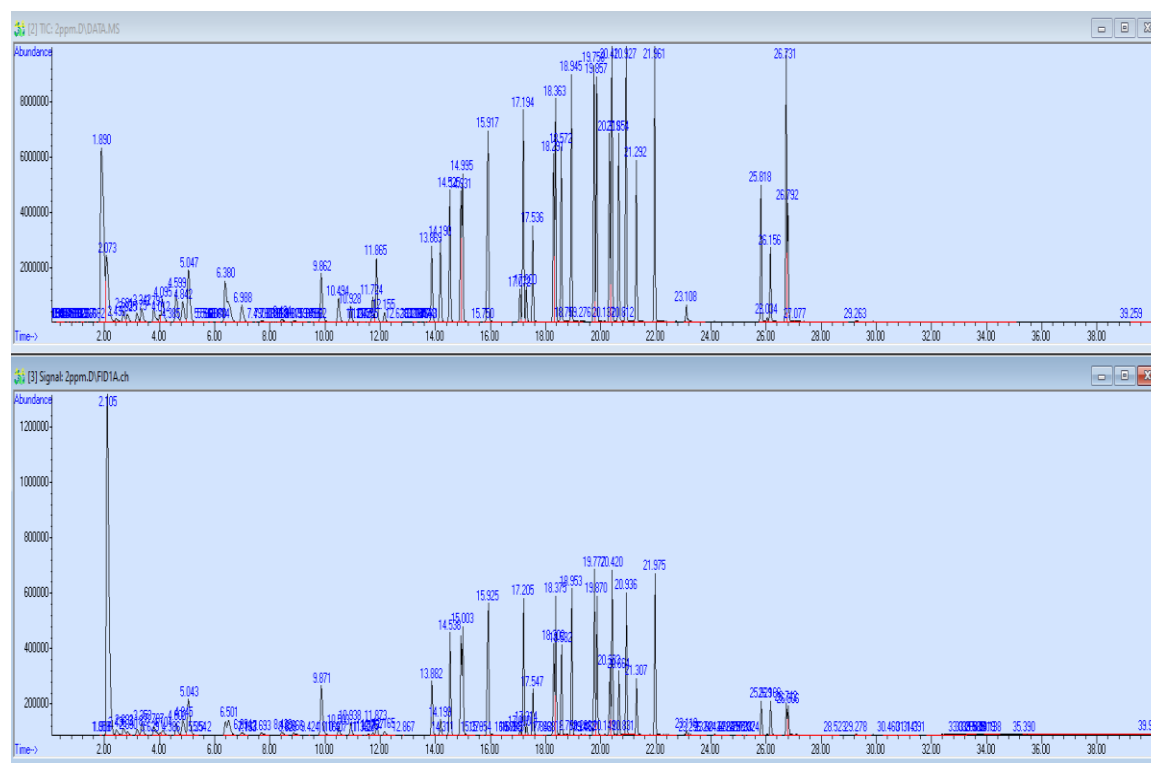


Figure 34: Chromatogram of a 2-ppm solution of VOCs.

Table 6: Chromatographic characteristics of a 2-ppm solution of VOCs

NO	Substance	Retention time (min)	Concentration
1	Dichloroethene	2.6±0.05	2-ppm
2	Dichloroethylene	3.1±0.05	2-ppm
3	Trichloroethane	4.5±0.05	2-ppm
4	Dichloropropene	4.8±0.05	2-ppm
5	Carbon Tetrachloride	5.0±0.05	2-ppm
6	Toluene	9.8±0.05	2-ppm
7	Tetrachloroethylene	11.8±0.05	2-ppm

8	Ethylbenzene	14.5±0.05	2-ppm
9	O-Xylene	14.9±0.05	2-ppm
10	P&M-Xylene	14.9±0.05	2-ppm
11	Cumene	17.1±0.05	2-ppm
12	Chlorotoluene	18.2±0.05	2-ppm
13	Isocumene	18.3±0.05	2-ppm
14	Chlorotoluene	18.5±0.05	2-ppm
15	Mesitylene	18.9±0.05	2-ppm
16	Dimethylethylbenzene	19.7±0.05	2-ppm
17	Trimethylbenzene	19.8±0.05	2-ppm
18	Dichlorobenzene	20.3±0.05	2-ppm
19	Propyltoluene	20.4±0.05	2-ppm
20	Dichlorobenzene	20.6±0.05	2-ppm
21	Isopropyltoluene	20.9±0.05	2-ppm
22	Butylbenzene	21.9±0.05	2-ppm
21	Trichlorobenzene	25.8±0.05	2-ppm
23	Hexachlorobutadiene	26.7±0.05	2-ppm
24	Trichlorobenzene	26.8±0.05	2-ppm
25	Dichloroethene	2.6±0.05	2-ppm

After that the solution inside the tube was placed on a shaker, and after 15 minute intervals, 10ml samples were taken for analysis using a high-sensitivity method. When evaluating the properties of an adsorbent for monitoring purposes, the ability to recover the adsorbed substances is an important factor to consider.

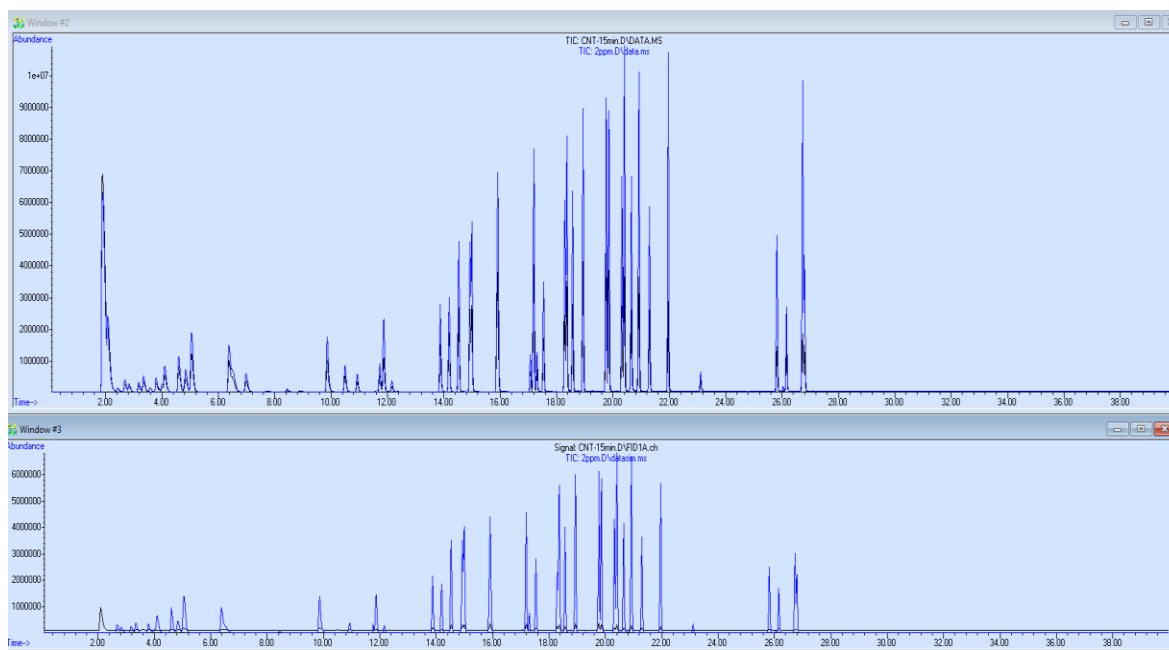


Figure 35: Chromatogram of a 2-ppm solution of VOCs after 15 min with polyacrylate-modified CNT

Following this, the solution within the tube was transferred onto a shaker, where it was subjected to agitation. Subsequently, at 15, 30, 60 and 90-minute intervals, aliquots of 10ml were extracted from the solution to undergo analysis utilizing a high-sensitivity technique

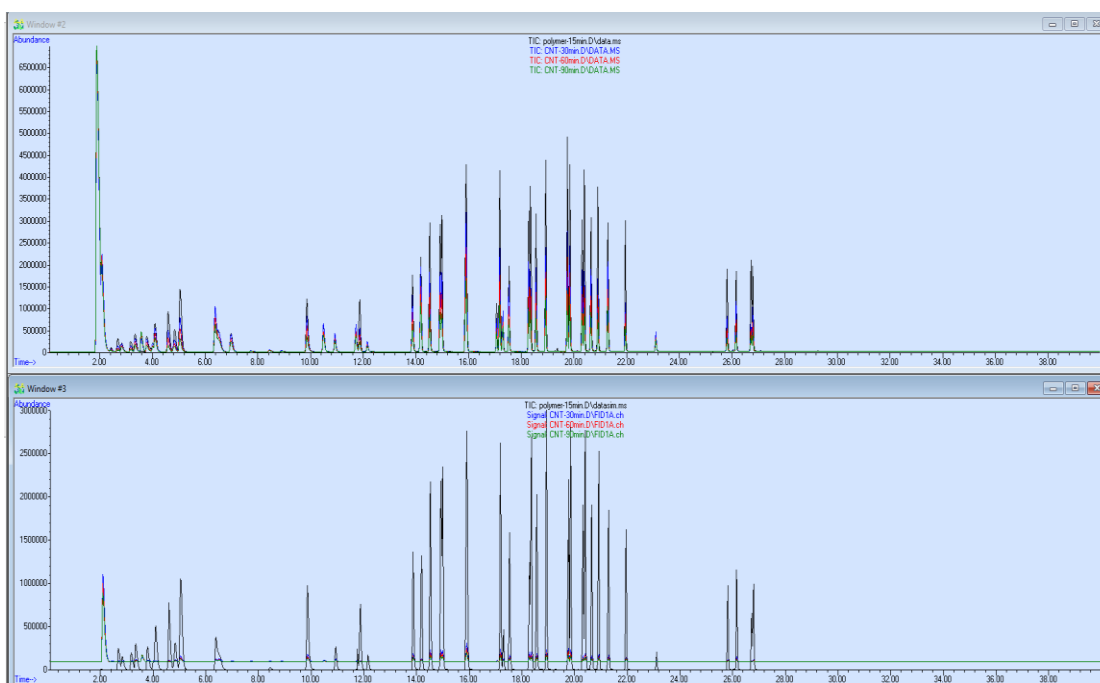


Figure 36: Chromatogram of a 2-ppm solution of VOCs after 30, 60 and 90 min with polyacrylate-modified CNT

Table 7: Chromatographic characteristics of a 2-ppm solution after 15, 30, 60 and 90 min with polyacrylate-modified CNT

NO	Substance	Retention time (min)	Concentration after 15 min	Concentration after 30 min	Concentration after 60 min	Concentration after 90 min	Recovery %
1	Dichloroethene	2.6±0.05	1.25	0.65	0.42	0.31	75%
2	Dichloroethylene	3.1±0.05	1.20	0.86	0.65	0.36	70%
4	Dichloropropene	4.8±0.05	1.09	0.82	0.61	0.42	61%
5	Carbon Tetrachloride	5.0±0.05	1.22	0.98	0.75	0.52	58%
6	Toluene	9.8±0.05	1.18	0.94	0.71	0.48	59%
7	Tetrachloroethylene	11.8±0.05	0.74	0.52	0.35	0.28	62%
8	Ethylbenzene	14.5±0.05	1.09	0.73	0.55	0.37	67%

9	O-Xylene	14.9±0.05	1.06	0.71	0.53	0.36	66%
10	P&M-Xylene	14.9±0.05	1.05	0.70	0.53	0.36	66%
11	Cumene	17.1±0.05	1.00	0.56	0.43	0.28	72%
12	Chlorotoluene	18.2±0.05	0.89	0.64	0.47	0.33	63%
13	Isocumene	18.3±0.05	0.78	0.41	0.33	0.23	71%
14	Chlorotoluene	18.5±0.05	0.86	0.60	0.44	0.31	64%
15	Mesitylene	18.9±0.05	0.86	0.51	0.39	0.28	68%
16	Dimethylethylbenzene	19.7±0.05	0.90	0.32	0.39	0.26	71%
17	Trimethylbenzene	19.8±0.05	0.87	0.16	0.42	0.29	66%
18	Dichlorobenzene	20.3±0.05	0.77	0.55	0.39	0.28	63%
19	Propyltoluene	20.4±0.05	0.69	0.31	0.25	0.17	75%
20	Dichlorobenzene	20.6±0.05	0.77	0.57	0.40	0.29	62%
21	Isopropyltoluene	20.9±0.05	0.67	0.31	0.24	0.17	74%
22	Butylbenzene	21.9±0.05	0.47	0.19	0.15	0.11	77%
21	Trichlorobenzene	25.8±0.05	0.64	0.42	0.30	0.21	67%
23	Hexachlorobutadiene	26.7±0.05	0.36	0.13	0.09	0.08	79%
24	Trichlorobenzene	26.8±0.05	0.76	0.57	0.38	0.27	65%

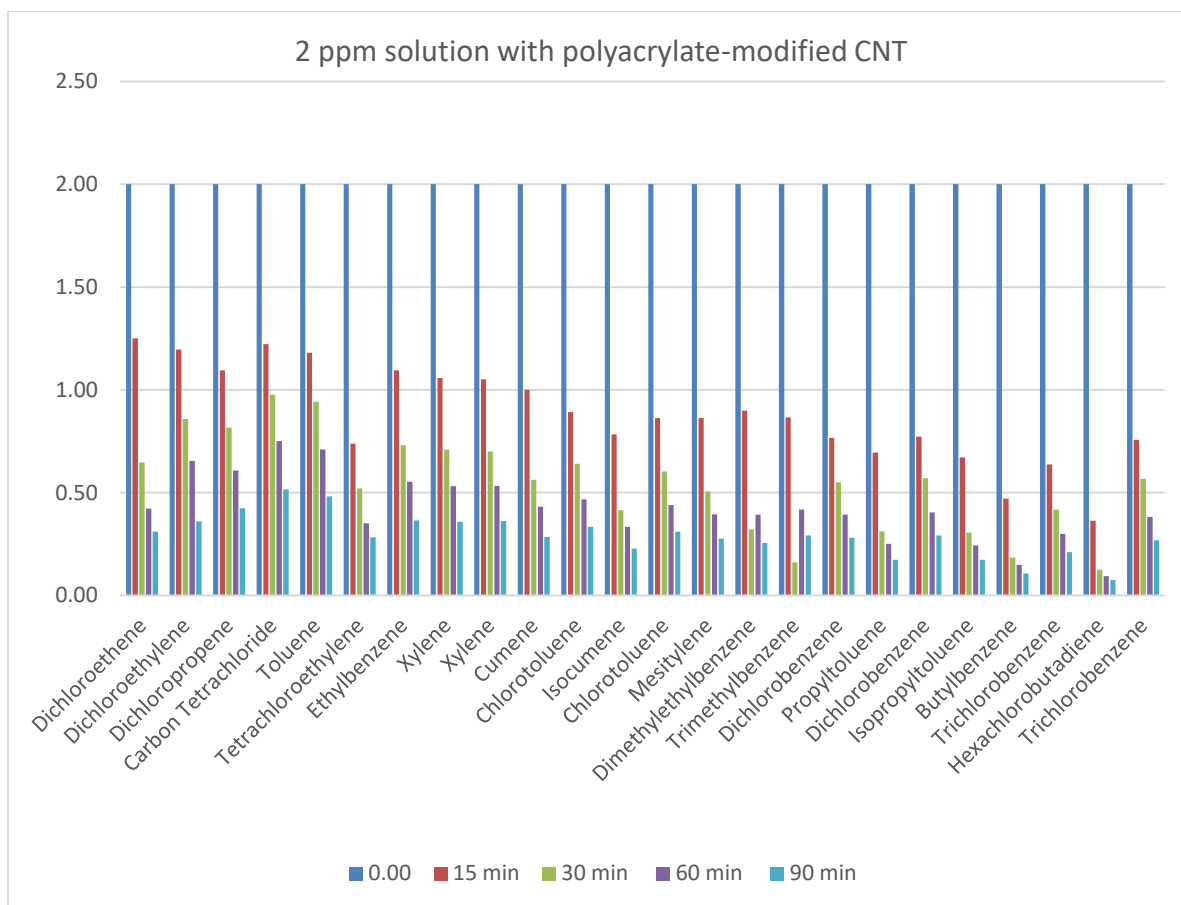


Figure 37: Adsorption of a 2-ppm solution after 15, 30, 60 and 90 min with polyacrylate-modified CNT

The compounds that were tested on polyacrylate-modified CNT showed excellent desorption recoveries. When studying the recovery rates for 2 ppm volatile organic compounds (VOCs) in water using polyacrylate-modified CNT, it was discovered that the recovery rates ranged from 58% to 78% over a 90-minute period. Further analysis indicated that certain VOCs had higher recovery rates compared to others. This observation suggests that the adsorption of VOCs onto polyacrylate-modified CNT is influenced by their chemical properties, molecular structures, and concentration

For the polyacrylate-modified carbon:

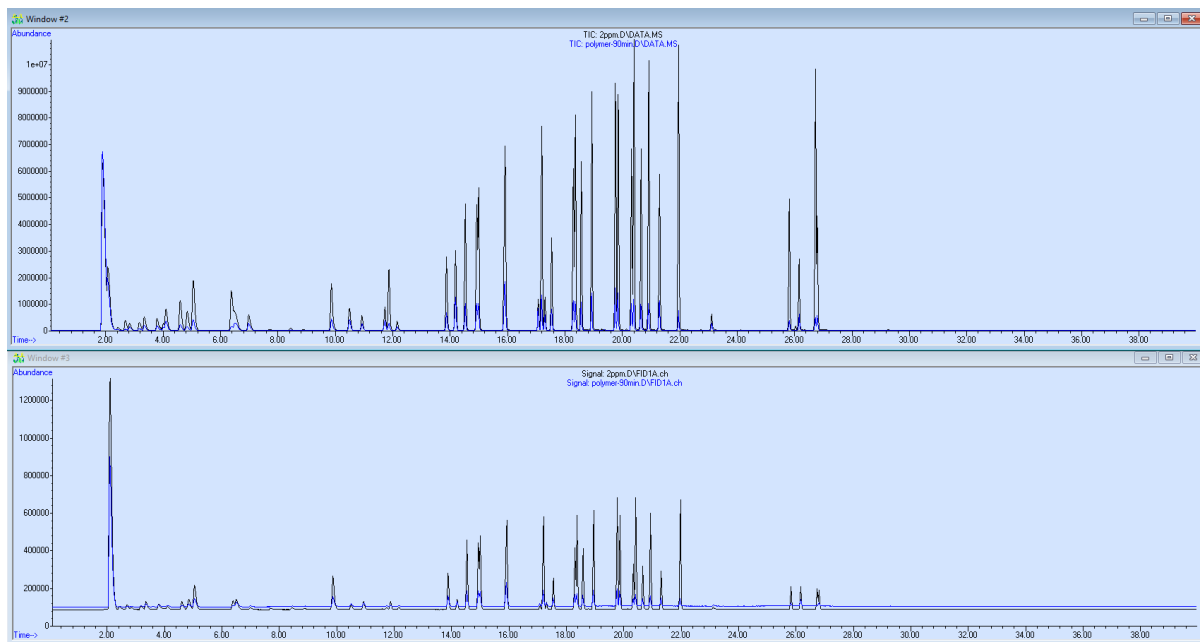


Figure 38: Chromatogram of a 2-ppm solution of VOCs after 90 min with polyacrylate-modified carbon.

Table 8: Chromatographic characteristics of a 2-ppm solution of VOCs after 15, 30, 60 and 90 min with polyacrylate-modified carbon

NO	Substance	Retention time (min)	Concentration after 15 min	Concentration after 30 min	Concentration after 60 min	Concentration after 90 min	Recovery
1	Dichloroethene	2.6±0.05	1.49	1.13	0.72	0.35	83%
2	Dichloroethylene	3.1±0.05	1.55	1.29	0.99	0.55	73%
4	Dichloropropene	4.8±0.05	1.37	0.95	0.84	0.55	72%
5	Carbon Tetrachloride	5.0±0.05	1.50	1.26	1.07	0.69	66%
6	Toluene	9.8±0.05	1.42	1.12	0.07	0.06	97%

7	Tetrachloroethylene	11.8±0.05	0.80	0.68	0.28	0.28	86%
8	Ethylbenzene	14.5±0.05	1.25	0.91	0.71	0.44	78%
9	O-Xylene	14.9±0.05	1.18	0.83	0.65	0.42	79%
10	P&M-Xylene	14.9±0.05	1.23	0.88	0.69	0.44	78%
11	Cumene	17.1±0.05	1.08	0.73	0.54	0.34	83%
12	Chlorotoluene	18.2±0.05	0.98	0.71	0.57	0.37	81%
13	Isocumene	18.3±0.05	0.92	0.57	0.42	0.27	86%
14	Chlorotoluene	18.5±0.05	1.00	0.67	0.55	0.36	82%
15	Mesitylene	18.9±0.05	0.95	0.62	0.48	0.32	84%
16	Dimethylethylbenzene	19.7±0.05	0.93	0.64	0.44	0.29	86%
17	Trimethylbenzene	19.8±0.05	0.96	0.62	0.50	0.33	83%
18	Dichlorobenzene	20.3±0.05	0.91	0.58	0.49	0.33	84%
19	Propyltoluene	20.4±0.05	0.72	0.43	0.31	0.21	89%
20	Dichlorobenzene	20.6±0.05	0.92	0.60	0.50	0.34	83%
21	Isopropyltoluene	20.9±0.05	0.71	0.41	0.30	0.21	90%
22	Butylbenzene	21.9±0.05	0.50	0.26	0.20	0.14	93%
21	Trichlorobenzene	25.8±0.05	0.83	0.46	0.38	0.26	87%
23	Hexachlorobutadiene	26.7±0.05	1.45	0.98	0.89	0.62	69%
24	Trichlorobenzene	26.8±0.05	0.98	0.57	0.52	0.37	82%

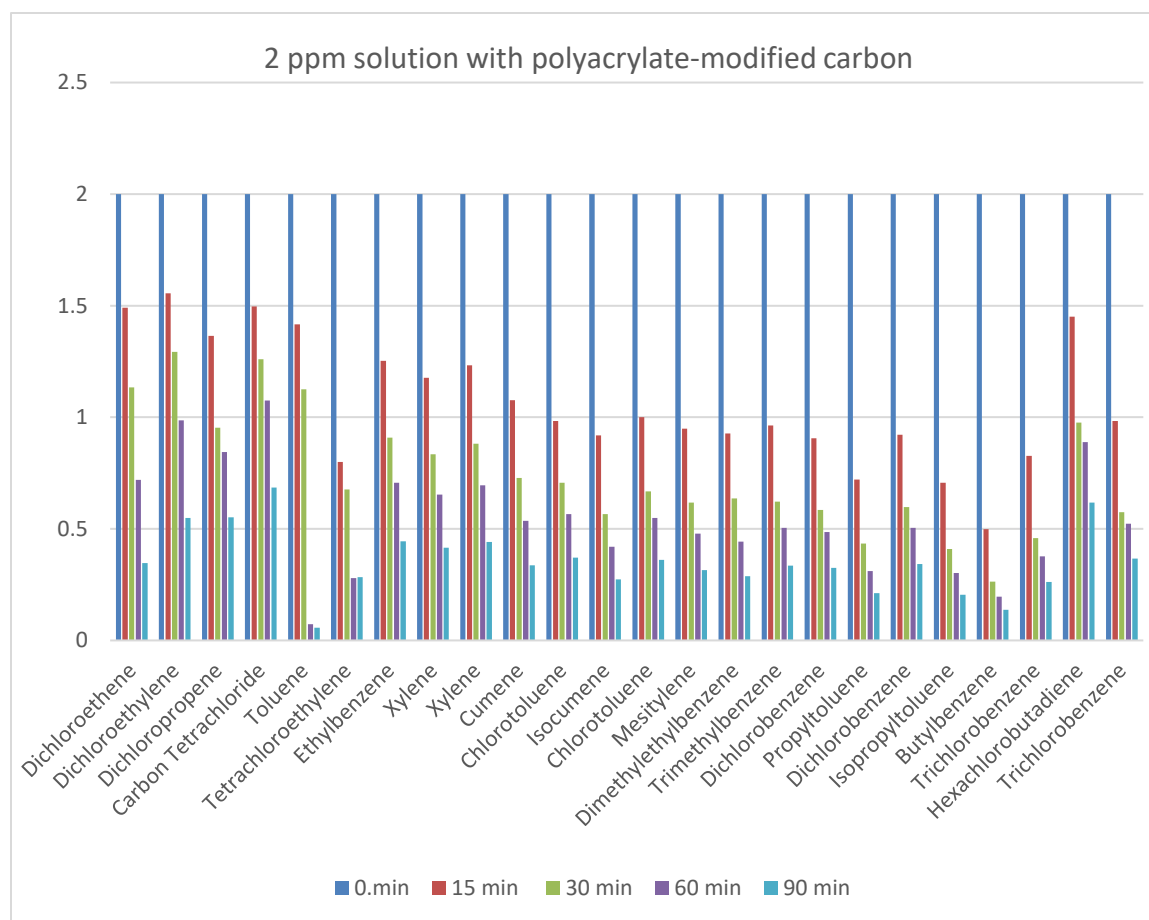


Figure 39: Adsorption of a 2-ppm solution of VOCs after 90 min with polyacrylate-modified carbon

The compounds tested on polyacrylate-modified carbon showed excellent results in terms of desorption recoveries. When studying the recovery rates of volatile organic compounds (VOCs) in water using polyacrylate-modified carbon, it was discovered that recovery rates varied from 72% to 93% over a 90-minute period.

Table 9: Chromatographic characteristics of a 1ppm solution after 15, 30, 60 and 90 min with polyacrylate-modified carbon

NO	Substance	Retention time (min)	Concentration after 15 min	Concentration after 30 min	Concentration after 60 min	Concentration after 90 min	Recovery %
1	Dichloroethene	2.6±0.05	0.88	0.21	0.09	0.03	97%
2	Dichloroethylene	3.1±0.05	0.89	0.50	0.43	0.14	86%
4	Dichloropropene	4.8±0.05	0.90	0.66	0.25	0.08	92%
5	Carbon Tetrachloride	5.0±0.05	0.89	0.71	0.56	0.17	83%
6	Toluene	9.8±0.05	0.85	0.66	0.55	0.17	83%
7	Tetrachloroethylene	11.8±0.05	0.72	0.44	0.26	0.08	92%
8	Ethylbenzene	14.5±0.05	0.82	0.58	0.48	0.15	85%
9	O-Xylene	14.9±0.05	0.79	0.54	0.47	0.15	85%
10	P&M-Xylene	14.9±0.05	0.80	0.55	0.46	0.15	85%
11	Cumene	17.1±0.05	0.72	0.49	0.40	0.13	87%
12	Chlorotoluene	18.2±0.05	0.74	0.50	0.46	0.14	86%
13	Isocumene	18.3±0.05	0.62	0.40	0.35	0.11	89%
14	Chlorotoluene	18.5±0.05	0.72	0.48	0.44	0.14	86%
15	Mesitylene	18.9±0.05	0.63	0.42	0.39	0.12	88%
16	Dimethylethylbenzene	19.7±0.05	0.62	0.43	0.37	0.12	88%
17	Trimethylbenzene	19.8±0.05	0.63	0.43	0.40	0.13	87%
18	Dichlorobenzene	20.3±0.05	0.69	0.44	0.42	0.13	87%
19	Propyltoluene	20.4±0.05	0.52	0.35	0.30	0.09	91%
20	Dichlorobenzene	20.6±0.05	0.70	0.45	0.44	0.14	86%

21	Isopropyltoluene	20.9±0.05	0.48	0.32	0.29	0.09	91%
22	Butylbenzene	21.9±0.05	0.35	0.23	0.22	0.07	93%
21	Trichlorobenzene	25.8±0.05	0.39	0.23	0.12	0.04	96%
23	Hexachlorobutadiene	26.7±0.05	0.93	0.63	0.32	0.10	90%
24	Trichlorobenzene	26.8±0.05	0.43	0.26	0.13	0.04	96%

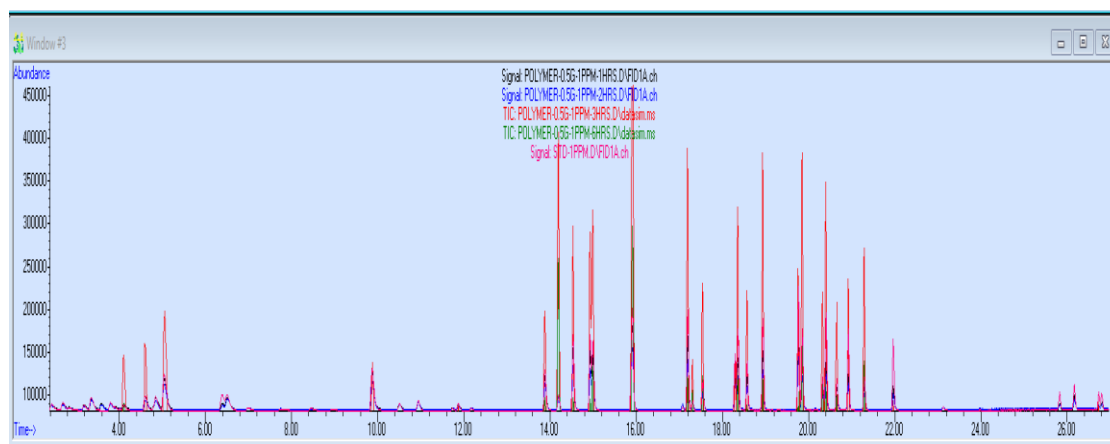


Figure 40: Chromatogram of a 2-ppm solution of VOCs after 90 min with polyacrylate-modified carbon.

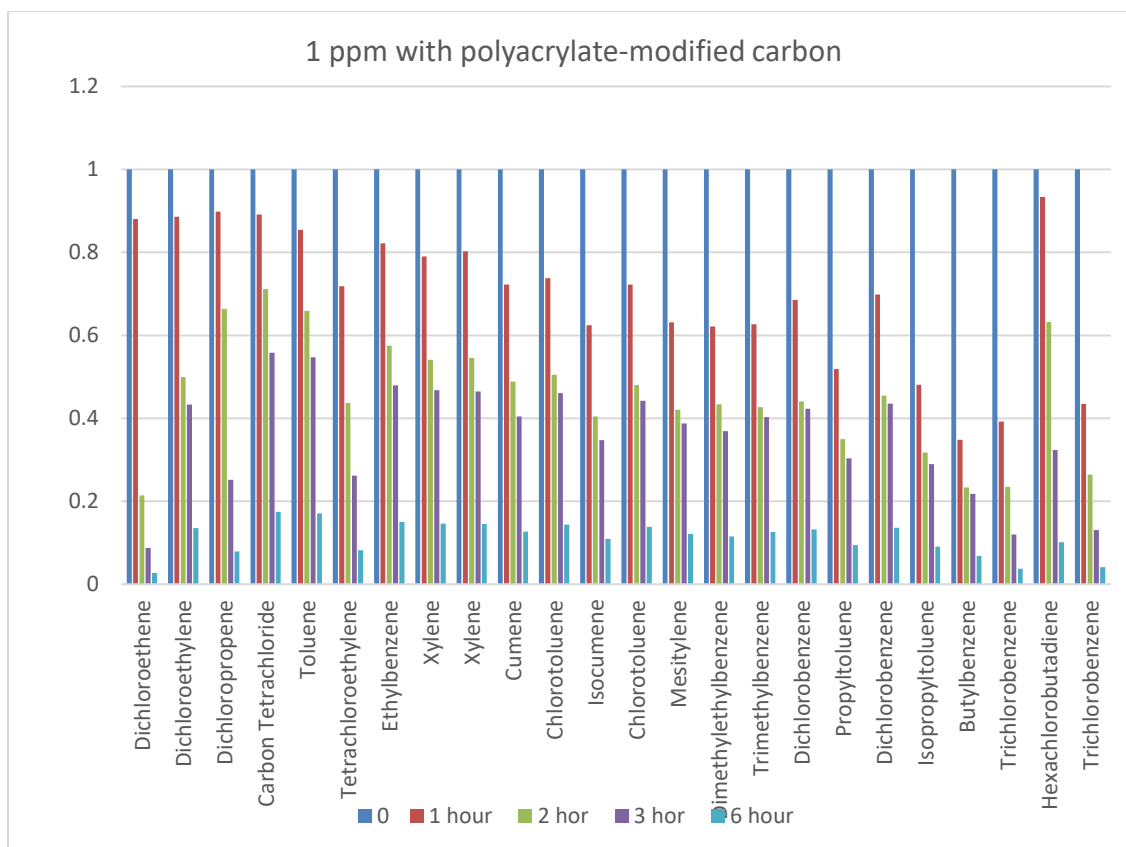


Figure 41: Adsorption of a 1 ppm solution of VOCs after 90 min with general polyacrylate-modified carbon.

In terms of desorption recoveries, the 1 ppm tested on 50 ml with 1 gram of polyacrylate-modified carbon yielded outstanding results. When the recovery rates of volatile organic compounds (VOCs) in water were studied using conventional polyacrylate-modified carbon, the recovery rates ranged from 83% to 97% during a 90 min period. In a study involving 24 compounds, it was found that 22 of them were absorbed by more than 85 percent. This indicates a high level of absorption for many of the compounds tested. These findings suggest that the absorption rate of these compounds is quite efficient and may have important implications in various fields such as medicine, agriculture, or environmental science.

Table 10: Chromatographic characteristics of a 0.5 ppm solution after 15, 30,60 and 90 min with polyacrylate-modified carbon

NO	Substance	Retention time (min)	Concentration after 15 min	Concentration after 30 min	Concentration after 60 min	Concentration after 90 min	Recovery
1	Dichloroethene	2.6±0.05	0.05	0.05	0.02	0.00	99%
2	Dichloroethylene	3.1±0.05	0.16	0.12	0.10	0.05	89%
4	Dichloropropene	4.8±0.05	0.19	0.14	0.04	0.03	95%
5	Carbon Tetrachloride	5.0±0.05	0.21	0.17	0.08	0.05	90%
6	Toluene	9.8±0.05	0.20	0.15	0.12	0.09	82%
7	Tetrachloroethylene	11.8±0.05	0.04	0.03	0.02	0.01	98%
8	Ethylbenzene	14.5±0.05	0.18	0.14	0.10	0.08	84%
9	O-Xylene	14.9±0.05	0.17	0.13	0.10	0.08	85%
10	P&M-Xylene	14.9±0.05	0.17	0.13	0.10	0.08	84%
11	Cumene	17.1±0.05	0.16	0.12	0.09	0.07	87%
12	Chlorotoluene	18.2±0.05	0.15	0.12	0.09	0.08	84%
13	Isocumene	18.3±0.05	0.12	0.09	0.07	0.06	89%
14	Chlorotoluene	18.5±0.05	0.14	0.11	0.09	0.07	85%
15	Mesitylene	18.9±0.05	0.14	0.10	0.08	0.07	87%

16	Dimethylethylbenzene	19.7±0.05	0.14	0.10	0.08	0.06	88%
17	Trimethylbenzene	19.8±0.05	0.13	0.10	0.08	0.07	86%
18	Dichlorobenzene	20.3±0.05	0.13	0.10	0.08	0.07	86%
19	Propyltoluene	20.4±0.05	0.10	0.07	0.06	0.05	91%
20	Dichlorobenzene	20.6±0.05	0.13	0.10	0.08	0.07	86%
21	Isopropyltoluene	20.9±0.05	0.10	0.07	0.05	0.05	91%
22	Butylbenzene	21.9±0.05	0.07	0.05	0.04	0.03	94%
21	Trichlorobenzene	25.8±0.05	0.05	0.04	0.04	0.02	96%
23	Hexachlorobutadiene	26.7±0.05	0.35	0.11	0.00	0.00	99%
24	Trichlorobenzene	26.8±0.05	0.02	0.06	0.06	0.06	88%

UDL= Under detection limit

In terms of desorption recoveries, the tested concentration of 0.5 ppm on 50 ml with 1 gram of polyacrylate-modified carbon produced exceptional results. The recovery rates for volatile organic compounds (VOCs) in water using conventional activated carbon were from 83% to 99% during a 90 min period. However, it is important to note that some of these compounds started to disappear within 60 min of the study.

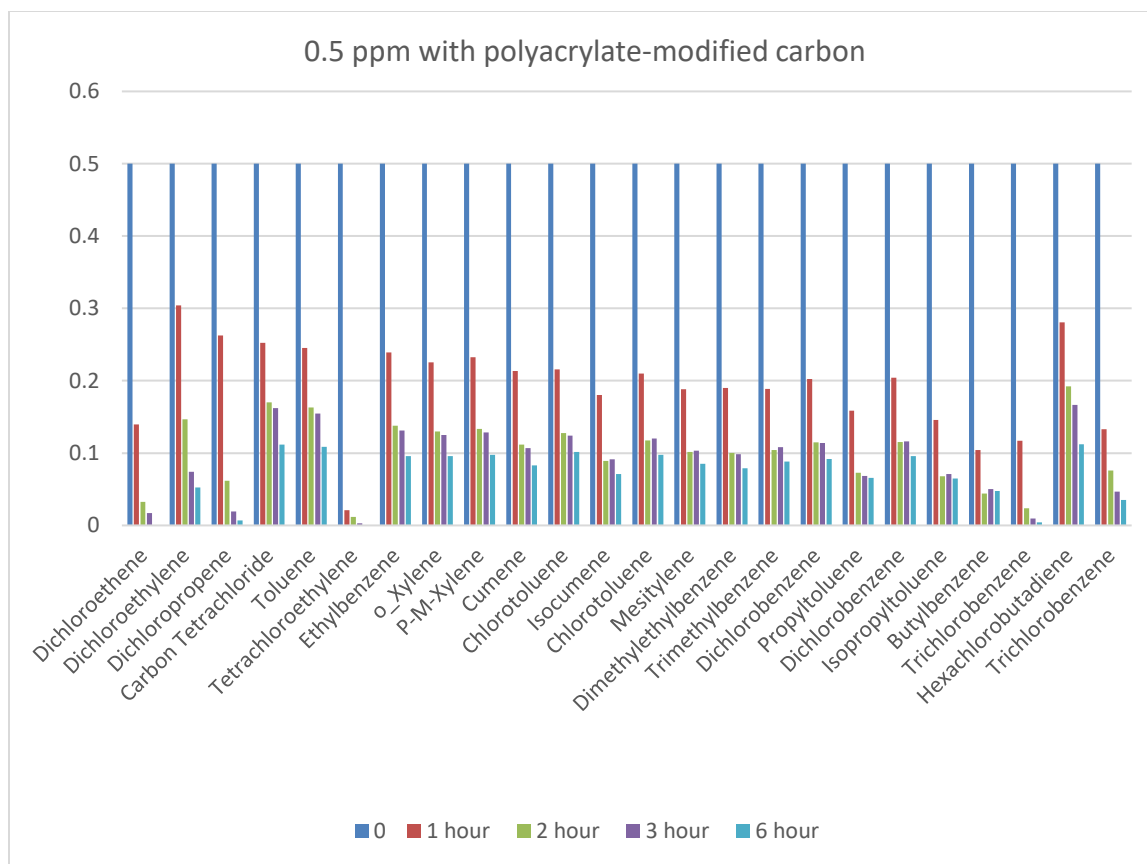


Figure 42: Adsorption of a 0.5-ppm solution of VOCs after 90 min with general polyacrylate-modified carbon

Table 11: Chromatographic characteristics of a 0.25 ppm solution after 15, 30, 60 and 90 min with polyacrylate-modified carbon

NO	Substance	Retention time (min)	Concentration after 15 min	Concentration after 30 min	Concentration after 60 min	Concentration after 90 min	Recovery
1	Dichloroethene	2.6±0.05	0.18	0.13	UDL	UDL	99%
2	Dichloroethylene	3.1±0.05	0.16	0.15	0.06	UDL	99%
4	Dichloropropene	4.8±0.05	0.12	0.07	0.03	UDL	99%
5	Carbon Tetrachloride	5.0±0.05	0.21	0.18	0.07	UDL	99%
6	Toluene	9.8±0.05	0.20	0.16	0.11	UDL	99%

7	Tetrachloroethylene	11.8±0.05	0.11	0.10	UDL	UDL	99%
8	Ethylbenzene	14.5±0.05	0.23	0.04	0.03	UDL	99%
9	O-Xylene	14.9±0.05	0.21	0.17	0.10	UDL	99%
10	P&M-Xylene	14.9±0.05	0.23	0.15	0.09	UDL	99%
11	Cumene	17.1±0.05	0.23	0.14	0.10	UDL	99%
12	Chlorotoluene	18.2±0.05	0.19	0.12	0.09	UDL	99%
13	Isocumene	18.3±0.05	0.20	0.11	0.08	UDL	99%
14	Chlorotoluene	18.5±0.05	0.17	0.12	0.08	UDL	99%
15	Mesitylene	18.9±0.05	0.18	0.11	0.08	UDL	99%
16	Dimethylethylbenzene	19.7±0.05	0.21	0.13	0.09	UDL	99%
17	Trimethylbenzene	19.8±0.05	0.17	0.10	0.07	UDL	99%
18	Dichlorobenzene	20.3±0.05	0.15	0.09	0.06	UDL	99%
19	Propyltoluene	20.4±0.05	0.18	0.10	0.07	UDL	99%
20	Dichlorobenzene	20.6±0.05	0.15	0.08	0.03	UDL	99%
21	Isopropyltoluene	20.9±0.05	0.15	0.08	0.06	UDL	99%
22	Butylbenzene	21.9±0.05	0.11	0.05	0.01	UDL	99%
21	Trichlorobenzene	25.8±0.05	0.03	0.00	UDL	UDL	99%
23	Hexachlorobutadiene	26.7±0.05	0.17	0.07	0.06	UDL	99%
24	Trichlorobenzene	26.8±0.05	0.07	0.01	UDL	UDL	99%

UDL: Under detection limit

The desorption recovery tests showed exceptional results when using 1 gram of polyacrylate-modified carbon and 50 ml of water with a concentration of 0.25 ppm. The volatile organic compounds (VOCs) had consistent recovery rates of 99% when using conventional polyacrylate-modified carbon over 90 min. However, it is noteworthy that some of these compounds began to dissipate within 60 min of the experiment.

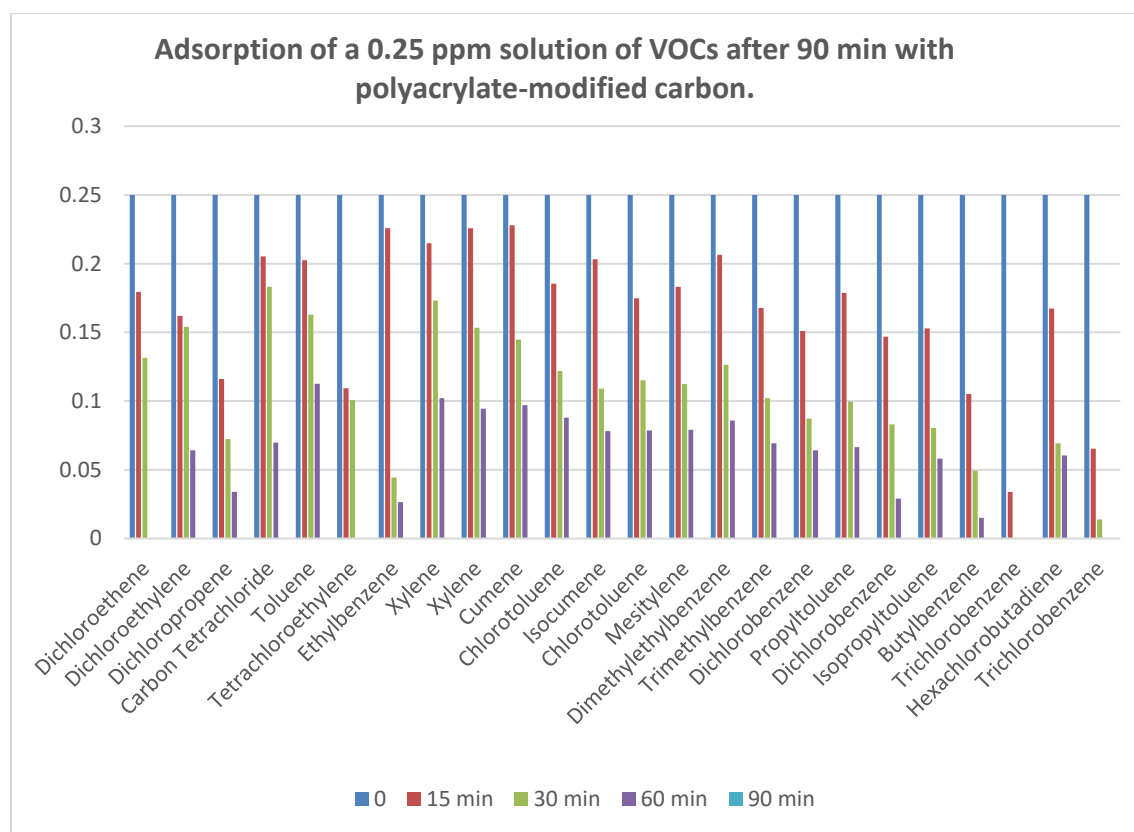


Figure 43: Adsorption of a 0.25 ppm solution of VOCs after 90 min with polyacrylate-modified carbon.

Table 12: Chromatographic characteristics of a 1ppm solution after 15, 30,60 and 90 min with polyacrylate-modified CNT

NO	Substance	Retention time (min)	Concentration after 15 min	Concentration after 30 min	Concentration after 60 min	Concentration after 90 min	Recovery
1	Dichloroethene	2.6±0.05	3	4	5	6	89%
2	Dichloroethylene	3.1±0.05	0.9	0.6	0.4	0.1	94%
4	Dichloropropene	4.8±0.05	0.6	0.6	0.6	0.1	52%
5	Carbon Tetrachloride	5.0±0.05	0.9	0.8	0.6	0.5	47%
6	Toluene	9.8±0.05	1.0	0.9	0.7	0.5	49%
7	Tetrachloroethylene	11.8±0.05	1.0	0.8	0.6	0.5	73%
8	Ethylbenzene	14.5±0.05	0.6	0.4	0.2	0.3	58%
9	O-Xylene	14.9±0.05	0.9	0.6	0.5	0.4	58%
10	P&M-Xylene	14.9±0.05	0.8	0.6	0.5	0.4	57%
11	Cumene	17.1±0.05	0.9	0.6	0.5	0.4	65%
12	Chlorotoluene	18.2±0.05	0.7	0.5	0.4	0.4	56%
13	Isocumene	18.3±0.05	0.7	0.6	0.5	0.4	68%
14	Chlorotoluene	18.5±0.05	0.6	0.4	0.3	0.3	57%
15	Mesitylene	18.9±0.05	0.8	0.6	0.4	0.4	63%
16	Dimethylethylbenzene	19.7±0.05	0.7	0.5	0.4	0.4	68%
17	Trimethylbenzene	19.8±0.05	0.6	0.5	0.4	0.3	61%
18	Dichlorobenzene	20.3±0.05	0.7	0.5	0.4	0.4	63%
19	Propyltoluene	20.4±0.05	0.7	0.5	0.4	0.4	74%

20	Dichlorobenzene	20.6±0.05	0.5	0.4	0.3	0.3	58%
21	Isopropyltoluene	20.9±0.05	0.7	0.5	0.4	0.4	74%
22	Butylbenzene	21.9±0.05	0.5	0.4	0.3	0.3	81%
21	Trichlorobenzene	25.8±0.05	0.3	0.2	0.2	0.2	71%
23	Hexachlorobutadiene	26.7±0.05	0.1	0.3	0.2	0.3	96%
24	Trichlorobenzene	26.8±0.05	0.4	0.2	0.1	0.1	89%

In terms of desorption recoveries, the 1 ppm test on 50 ml with 0.5 gram of polyacrylate-modified CNT produced exceptional results. The recovery rates of volatile organic compounds (VOCs) in water were tested using standard activated carbon and ranged from 47% to 96% during a 6-hour period.

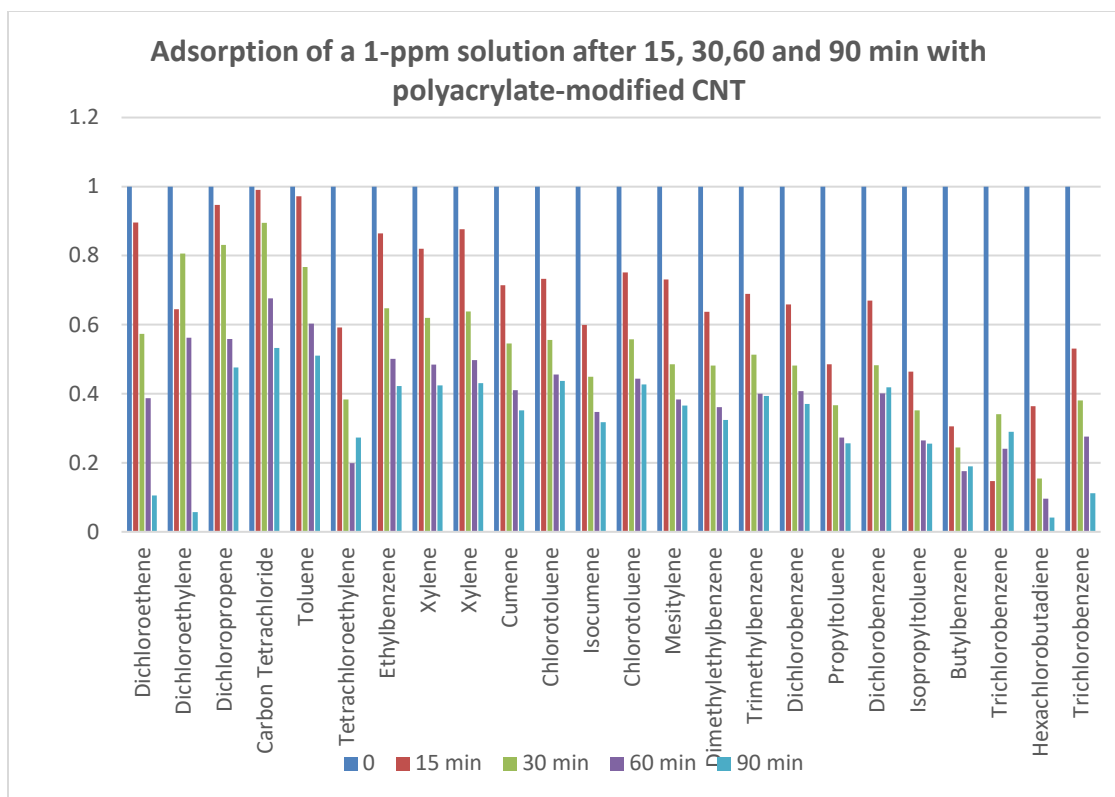


Figure 44: Adsorption of a 1-ppm solution after 15, 30, 60 and 90 min with polyacrylate-modified CNT

Table 13: Chromatographic characteristics of a 0.5 ppm solution after 15, 30, 60 and 90 min with polyacrylate-modified CNT

N O	Substance	Retention time (min)	Concentration after 15 min	Concentration after 30 min	Concentration after 60 min	Concentration after 90 min	Recovery
1	Dichloroethene	2.6±0.05	0.05	0.05	0.02	UDL	99%
2	Dichloroethylene	3.1±0.05	0.16	0.12	0.10	0.05	95%
4	Dichloropropene	4.8±0.05	0.19	0.14	0.04	0.03	90%
5	Carbon Tetrachloride	5.0±0.05	0.21	0.17	0.08	0.05	82%
6	Toluene	9.8±0.05	0.20	0.15	0.12	0.09	98%

7	Tetrachloroethylene	11.8±0.05	0.04	0.03	0.02	0.01	84%
8	Ethylbenzene	14.5±0.05	0.18	0.14	0.10	0.08	85%
9	O-Xylene	14.9±0.05	0.17	0.13	0.10	0.08	84%
10	P&M-Xylene	14.9±0.05	0.17	0.13	0.10	0.08	87%
11	Cumene	17.1±0.05	0.16	0.12	0.09	0.07	84%
12	Chlorotoluene	18.2±0.05	0.15	0.12	0.09	0.08	89%
13	Isocumene	18.3±0.05	0.12	0.09	0.07	0.06	85%
14	Chlorotoluene	18.5±0.05	0.14	0.11	0.09	0.07	87%
15	Mesitylene	18.9±0.05	0.14	0.10	0.08	0.07	88%
16	Dimethylethylbenzene	19.7±0.05	0.14	0.10	0.08	0.06	86%
17	Trimethylbenzene	19.8±0.05	0.13	0.10	0.08	0.07	86%
18	Dichlorobenzene	20.3±0.05	0.13	0.10	0.08	0.07	91%
19	Propyltoluene	20.4±0.05	0.10	0.07	0.06	0.05	86%
20	Dichlorobenzene	20.6±0.05	0.13	0.10	0.08	0.07	91%
21	Isopropyltoluene	20.9±0.05	0.10	0.07	0.05	0.05	94%
22	Butylbenzene	21.9±0.05	0.07	0.05	0.04	0.03	96%
21	Trichlorobenzene	25.8±0.05	0.05	0.04	0.04	0.02	96%
23	Hexachlorobutadiene	26.7±0.05	0.35	0.11	UDL	UDL	99%
24	Trichlorobenzene	26.8±0.05	0.02	0.06	0.06	0.06	89%

ULD: Under detection limit

The 0.5 ppm test on 50 ml water with 1.0 gram of polyacrylate-modified CNT achieved outstanding desorption recoveries, The recovery rates of volatile organic compounds (VOCs) in water ranged from 82% to 99% during a 90 min period.

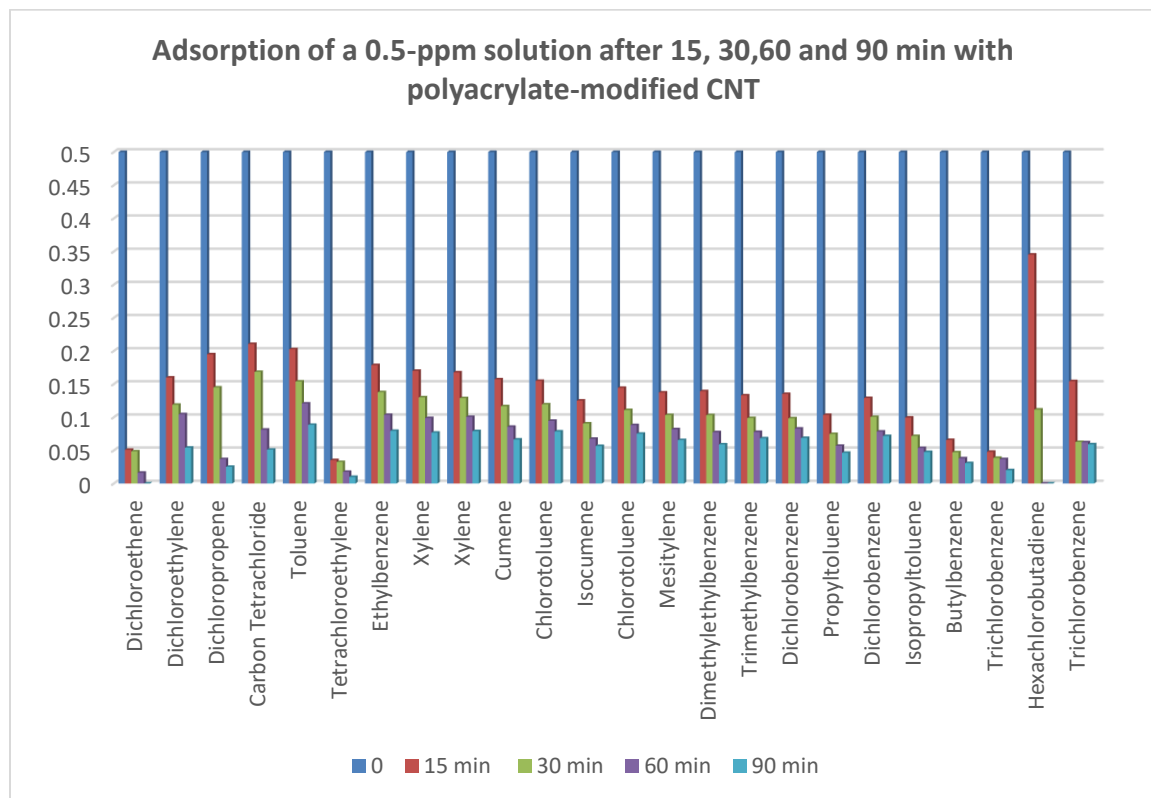


Figure 45: Adsorption of a 0.5-ppm solution after 15, 30, 60 and 90 min with polyacrylate-modified CNT

Table 14: Chromatographic characteristics of a 0.25 ppm solution after 15, 30,60 and 90 min with polyacrylate-modified CNT

NO	Substance	Retention time (min)	Concentration after 15 min	Concentration after 30 min	Concentration after 60 min	Concentration after 90 min	Recovery
1	Dichloroethene	2.6±0.05	0.18	0.13	ULD	ULD	99%
2	Dichloroethylene	3.1±0.05	0.16	0.15	ULD	ULD	99%
4	Dichloropropene	4.8±0.05	0.12	0.07	0.03	ULD	99%
5	Carbon Tetrachloride	5.0±0.05	0.21	0.18	0.07	ULD	99%
6	Toluene	9.8±0.05	0.20	0.16	0.11	ULD	99%
7	Tetrachloroethylene	11.8±0.05	0.11	0.10	ND	ULD	99%
8	Ethylbenzene	14.5±0.05	0.23	0.04	0.02	ULD	99%
9	O-Xylene	14.9±0.05	0.21	0.17	0.10	ULD	99%
10	P&M-Xylene	14.9±0.05	0.23	0.15	0.09	ULD	99%
11	Cumene	17.1±0.05	0.23	0.14	0.10	ULD	99%
12	Chlorotoluene	18.2±0.05	0.19	0.12	0.09	ULD	99%
13	Isocumene	18.3±0.05	0.20	0.11	0.08	ULD	99%
14	Chlorotoluene	18.5±0.05	0.17	0.12	0.08	ULD	99%
15	Mesitylene	18.9±0.05	0.18	0.11	0.08	ULD	99%
16	Dimethylethylbenzene	19.7±0.05	0.21	0.13	0.09	ULD	99%
17	Trimethylbenzene	19.8±0.05	0.17	0.10	0.07	ULD	99%
18	Dichlorobenzene	20.3±0.05	0.15	0.09	0.06	ULD	99%
19	Propyltoluene	20.4±0.05	0.18	0.10	0.07	ULD	99%

20	Dichlorobenzene	20.6±0.05	0.15	0.08	0.03	ULD	99%
21	Isopropyltoluene	20.9±0.05	0.15	0.08	0.06	ULD	99%
22	Butylbenzene	21.9±0.05	0.11	0.05	0.01	ULD	99%
21	Trichlorobenzene	25.8±0.05	0.03	ULD	ULD	ULD	99%
23	Hexachlorobutadiene	26.7±0.05	0.30	0.07	0.06	ULD	99%
24	Trichlorobenzene	26.8±0.05	0.07	0.01	ULD	ULD	99%

ULD: Under detection limit

When 1 gram of polyacrylate-modified CNT and 50 ml of water with a concentration of 0.25 ppm were used in the desorption recovery experiments, the results were outstanding. When employing standard activated carbon for 90 min, the volatile organic compounds (VOCs) achieved constant recovery rates of 99%. It is worth noting, however, that some of these chemicals began to evaporate within 60 min after the trial.

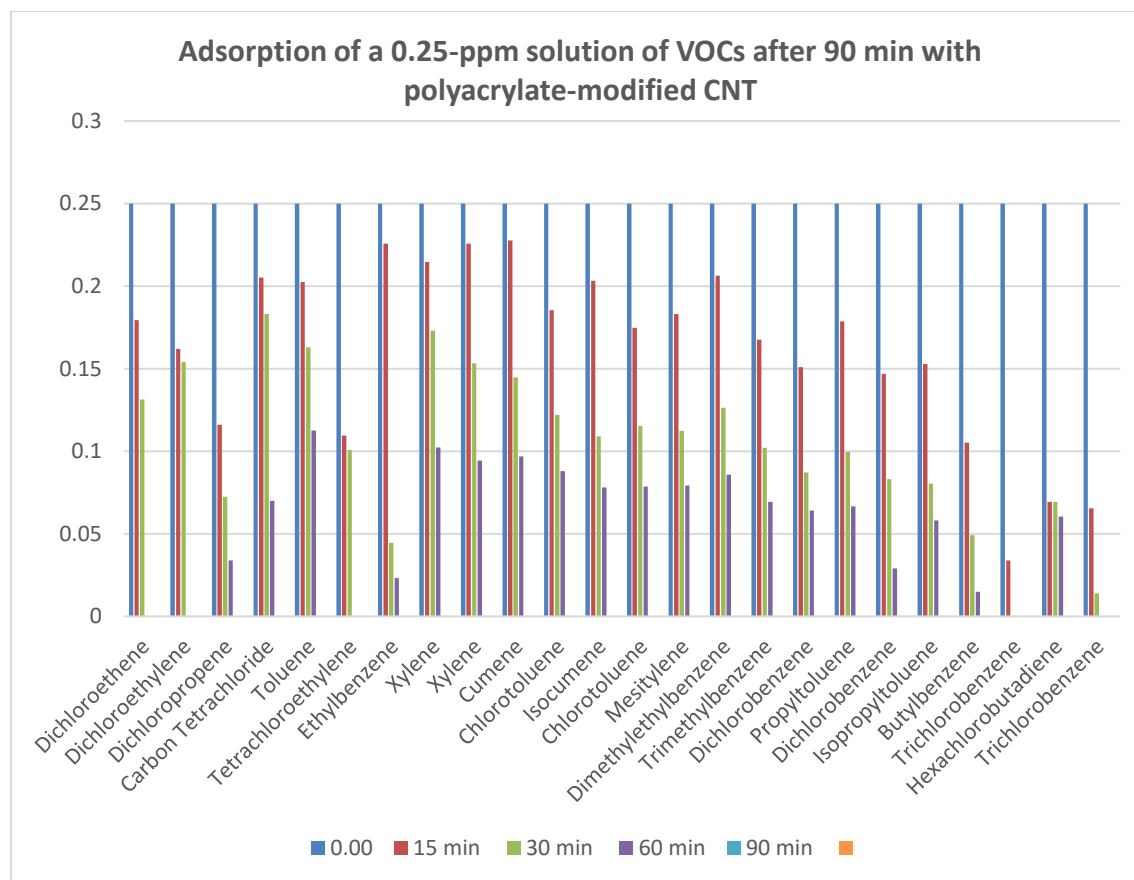


Figure 46: Adsorption of a 0.25-ppm solution after 15, 30, 60 and 90 min with polyacrylate-modified CNT.

CONCLUSION:

In this study, polyacrylate-modified activated carbon and polyacrylate-modified carbon nanotube materials were prepared and evaluated for the removal of the several volatile organic compounds (VOCs). In this study, headspace gas chromatography (HS-GC) with mass spectrometry (MS) was used to analyze residual VOCs in water, assessing the materials effectiveness and optimizing their adsorption capabilities. Several parameters related to the adsorption process were optimized. The polyacrylate-modified activated carbon showed better efficiency than the polyacrylate-modified carbon nanotubes in the

simultaneous removal of several VOCs. In general, polyacrylate-modified carbon synthesizes copolymer-modified carbon (PAMC) derived from palm shells showed good performance for most of the tested VOCs, in less contact time. This can be explained by the availability of more internal pores in the activated carbon's structure. Because activated carbon has a huge number of micropores and mesopores, pollutants can be absorbed on a vast surface area. As precise removal of pollutants is critical for monitoring environmental contamination and guaranteeing the safety of ecosystems and human health, copolymer-modified carbon can be recommended to be used for the removal of such pollutants.

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