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Developing Graphitic Carbon Nitride for Effective Treatment of Organic Pollutants in Industrial Water

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ABSTRACT
Organic pollutants, including pesticides and industrial waste, have become a significant environmental challenge due to their persistence and difficulty in decomposition, posing serious threats to both environmental health and water quality. This issue is particularly pressing in regions like Penang, where rapid industrial development and urbanization have exacerbated water pollution. In response, various research efforts have explored potential solutions, with graphite emerging as an effective adsorbent for removing toxic compounds from water. Building on this, our study focuses on the synthesis of graphitic carbon nitride (g-C3N4), a material recognized for its high-performance photocatalytic properties. g-C3N4's unique structure and ability to harness solar energy make it a promising candidate for catalyzing the breakdown of organic pollutants into less harmful molecules. Our project aims to develop a cost-effective and scalable method for producing g-C3N4 using readily available materials, with the goal of mitigating organic pollution in Penang. Through a straightforward synthesis process, we seek to make this technology accessible for widespread adoption in water treatment practices. The successful synthesis of g-C3N4 has already been demonstrated, with the process being effectively shared with students from the School of Chemical Science at USM. While further refinements are needed to maximize results, our findings suggest that g-C3N4 can play a crucial role in reducing organic pollution and improving water quality, contributing to the long-term sustainability of Penang's environment.

Keyword: Environment, Graphitic Carbon Nitride, Organic Pollutant, Water Pollution.

1. Introduction

Organic pollutants have emerged as a significant environmental challenge in recent times [1]. These pollutants, including toxic components such as pesticides and industrial waste, are notoriously difficult to break down, posing a serious threat to both environmental health and water quality. The persistence of these pollutants in ecosystems can lead to long-term detrimental effects, making it a critical issue that requires immediate attention. Among the many affected regions, Penang stands out as one of the cities grappling with the impact of organic pollution [2]. Water pollution, in particular, has attracted growing interest due to rapid industrial development and an expanding population [3]. As industries grow and urban areas expand, the volume of pollutants released into water bodies increases, exacerbating the issue of water contamination. This intensifying pollution not only affects aquatic ecosystems but also poses serious risks to public health and the environment.

In response to this pressing problem, various experiments and research studies have been conducted to explore potential solutions. One promising approach that has gained attention is the use of graphite as an adsorbent material in water treatment. Graphite has demonstrated significant effectiveness in absorbing and removing toxic compounds from water [4], making it a valuable tool in the fight against organic pollution [5]. Building on these findings, we propose a novel solution that involves the production of g-C3N4, a graphitic carbon nitride material, through a simple and accessible method. This approach not only leverages the beneficial properties of graphite but also aims to provide a cost-effective and scalable solution for addressing the pollution issues in Penang.

In recent years, graphitic carbon nitride (g-C3N4) has become an attractive research hotspot in the exploration of high-performance photocatalysts [6], [7]. Its unique structure and properties, combined with its ability to harness solar energy for photocatalytic reactions, have made g-C3N4 a key material in the development of advanced environmental remediation technologies [8]. Researchers are particularly interested in its potential to catalyze the breakdown of organic pollutants, transforming them into simpler, less harmful compounds.

The primary objective of this project is to contribute to the mitigation of organic pollution in Penang by developing and utilizing g-C3N4. Our approach involves synthesizing g-C3N4 using readily available materials, ensuring that the production process is both efficient and sustainable [9]. By focusing on a straightforward synthesis method, we aim to make this technology accessible to a broader audience, potentially leading to widespread adoption in water treatment practices.

The potential benefits of g-C3N4 extend beyond its use as an adsorbent material [10]. By harnessing solar energy, g-C3N4 can catalyze the oxidation of organic compounds into simpler, less harmful molecules [11]. This photocatalytic process represents a significant advancement in the field of environmental remediation, offering a sustainable and energy-efficient solution for reducing organic pollution. The implementation of this technology involves several key steps, including the optimization of the synthesis process, integration into existing water treatment systems, establishment of process parameters, and ongoing monitoring of performance.

Moreover, continued research and development are essential to further enhance the effectiveness of g-C3N4 and explore new applications for this versatile material. By investing in the ongoing study of g-C3N4, we can unlock additional potential uses and refine the technology to address a wider range of environmental challenges.

In conclusion, the production and utilization of g-C3N4 represent a promising approach to tackling organic pollution in Penang. We believe that this project can make a meaningful contribution to improving water quality and protecting environmental health. Furthermore, by enhancing the economic value of g-C3N4 through innovative applications, we can create new opportunities for sustainable development in the region. Ultimately, our goal is to provide a practical and effective solution that not only addresses the immediate problem of organic pollution but also contributes to the long-term sustainability of Penang's environment.

2. Implementation Methods

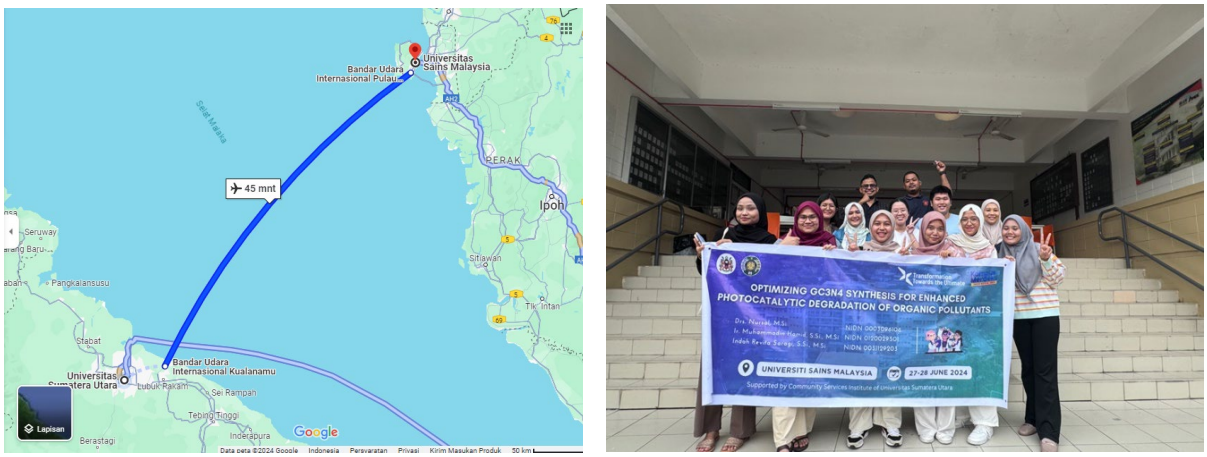
2.1. Tools and Materials

The tools used in the synthesis of graphitic carbon nitride (g-C3N4) include beaker glasses, spatulas, mortars and pestles, crucibles, furnaces, and sample pots. These tools are essential to ensure the precision and success of the synthesis process. The materials used for the synthesis of graphitic carbon nitride (g-C3N4) are primarily melamine and ammonium chloride. These compounds are selected due to their ability to form g-C3N4 through thermal polymerization, which is a critical step in achieving the desired photocatalytic properties. To guarantee the quality of the materials, they were obtained from certified suppliers and were prepared with strict adherence to safety and procedural guidelines.

2.2. Community Service Location

The community service activities were conducted at the School of Chemical Sciences, Universiti Sains Malaysia, Gelugor, Penang, Malaysia. The location is situated 1,529 km from the Universitas Sumatera Utara, with a travel time of approximately 45 minutes by plane. Figure 1 illustrates the geographical location of the community service implementation.

This partnership location was chosen due to its advanced research facilities, which align with the objectives of synthesizing and applying g-C3N4 for environmental solutions. The strategic collaboration is aimed at fostering mutual knowledge exchange and enhancing the application of cutting-edge photocatalytic materials.



(a) (b)

Figure 1. (a) Location map of the partner network of Universitas Sumatera Utara; (b) School of Chemical Science, Universiti Sains Malaysia.

2.3. Implementation Process

The implementation method for international service activities with partners from the Chemistry Study Program of Universiti Sains Malaysia was conducted through three key phases:

1. Socialization and Counseling Activities
   Socialization and counseling activities focused on providing foundational knowledge about the synthesis of g-C3N4 and its role in improving the photocatalytic degradation of organic pollutants. This phase was conducted in both lecture-style sessions and interactive discussions, ensuring that partners grasped the theoretical framework and the significance of the material in addressing environmental challenges.
2. Training and Workshop Activities
   Training sessions included hands-on workshops designed to familiarize partners with the tools and materials needed for g-C3N4 synthesis. Step-by-step demonstrations of the synthesis process were conducted, starting from material preparation to thermal polymerization and characterization of the final product. Emphasis was placed on safety protocols, accuracy in measurements, and monitoring during the synthesis process.
3. Assistance and Monitoring Activities
   Assistance was provided during the practical application phase, where partners utilized g-C3N4 for photocatalytic experiments. Monitoring sessions ensured that the procedures were followed correctly, and troubleshooting support was offered for any challenges faced. Regular feedback was collected to adapt and improve the learning process during the implementation period.

To address partner challenges effectively, two approaches were employed:

1. Classical Approach
   This involved formal delivery of material in a structured format, such as lectures and presentations. Partners were encouraged to engage through Q&A sessions to clarify concepts and theoretical foundations.
2. Individual Approach
   During the hands-on workshops, individual mentoring was provided to guide partners through the synthesis and application process. This personalized approach helped address specific questions and ensured a deeper understanding of the practical aspects of g-C3N4 synthesis and application.

The implementation of these activities is expected to result in the following outcomes:

- Enhanced knowledge and skills among partners in synthesizing and applying g-C3N4.
- Development of locally applicable strategies for utilizing g-C3N4 in photocatalytic degradation of organic pollutants.
- Strengthened collaboration between Universitas Sumatera Utara and Universiti Sains Malaysia, paving the way for future research and service projects.

3. Result and Discussion

3.1. Preparation and Discussion

The preparation and discussion stage served as a foundation for the successful execution of the community service program. During this phase, the service team held detailed discussions with partners to identify their specific needs, assess available resources, and determine the objectives of the program. A key aspect of this stage was the introduction of g-C3N4 as an innovative material for addressing environmental challenges. The potential applications of g-C3N4, particularly in photocatalytic degradation of organic pollutants, were thoroughly explained. This discussion emphasized its relevance in tackling water pollution in Penang, a significant issue caused by industrial discharge. Preparatory meetings also included an evaluation of the partner's equipment and laboratory facilities to ensure compatibility with the synthesis process. Collaborative planning ensured that all required tools and materials were prepared in advance, minimizing disruptions during implementation.

Figure 2. Captures the discussions and coordination during this stage, showcasing the active engagement of all stakeholders

3.2. Stages of Training

The training phase was designed to translate theoretical knowledge into practical expertise. It was divided into several key components to ensure comprehensive learning:

1. Introduction to Photocatalytic Materials
   Partners were introduced to the principles and significance of photocatalytic materials, focusing on the unique properties of g-C3N4.
2. Equipment Familiarization
   Training sessions included detailed instructions on the use of furnaces, crucibles, and other tools critical for the synthesis process. Emphasis was placed on proper handling techniques and safety measures.
3. Hands-On Workshops
   Under the supervision of the service team, partners were guided through the step-by-step synthesis process. This included material preparation, thermal polymerization, and product characterization using basic analytical methods.

The hands-on workshops also encouraged participants to ask questions and troubleshoot challenges during the synthesis process. Feedback from participants indicated a high level of satisfaction and confidence in their ability to replicate the procedures independently.

Figure 3. Illustrates the interactive and engaging nature of the training sessions.

3.3. Application of Technology

The application stage marked the culmination of the training and preparation efforts. Partners applied the synthesized g-C3N4 in controlled experiments aimed at degrading model organic pollutants in water. This phase included:

1. Demonstration of Photocatalytic Experiments
   Service team members demonstrated how to set up and conduct photocatalytic reactions using g-C3N4 under specific light conditions.
2. Optimization of Experimental Parameters
   Partners were guided on optimizing reaction parameters such as light intensity, pollutant concentration, and reaction time to achieve maximum efficiency.
3. Testing and Analysis
   Partners performed preliminary testing and analyzed the results to evaluate the material's effectiveness in degrading pollutants.

This stage also involved ensuring that the laboratory equipment functioned optimally, and minor adjustments were made to improve experimental outcomes. The results of graphitic carbon nitride (g-C3N4) synthesis that have been carried out in this service are quite good. There has also been a socialization and training on making g-C3N4 at USM which can be seen in Figure 4a. The activities carried out are expected to help partners to increase the economic value of g-c3n4 and can help reduce pollutants that are a problem in the surrounding environment. With this service, it is hoped that the problem of water pollution caused by organic pollutants in Penang caused by various industries can be helped. At the end of the socialization event, there was also a symbolic handover of souvenirs in the form of placards with one of the lecturers at USM, Prof. Dr. Noor Haida Binti Moh. Kaus which can be seen in Figure 4b.

(a) (b)

Figure 4. (a) Presenting and discussion about g-C3N4; (b) Giving a Plaque of gratitude.

Environmentally, the synthesized g-C3N4 showed promising results in degrading organic pollutants, offering a practical solution to mitigate water pollution problems in Penang. In terms of capacity building, the participants gained essential skills and knowledge, empowering them to independently synthesize and apply g-C3N4 in their future endeavors. The collaboration between Universitas Sumatera Utara and Universiti Sains Malaysia was also significantly strengthened, fostering a foundation for future joint research and community service initiatives. Economically, the program promoted the local synthesis and application of g-C3N4, creating opportunities to reduce costs and enhance its economic value. Looking ahead, the application of g-C3N4 can be expanded to tackle other environmental challenges, such as air pollution and industrial waste management. Further research is encouraged to improve the efficiency and scalability of g-C3N4 synthesis, ensuring its broader and more impactful utilization.

4. Conclusion

The synthesis of graphitic carbon nitride (g-C3N4) has been successfully conducted at Universitas Sumatera Utara, demonstrating its potential as an innovative material for environmental remediation. The process of synthesizing g-C3N4 has also been effectively socialized to students from the School of Chemical Sciences, Universiti Sains Malaysia, through training and collaborative activities. While there are areas that require further refinement to optimize the synthesis process and enhance its results, the program has already showcased g-C3N4's promise as a viable solution for reducing organic pollution, particularly in water. This initiative not only addresses pressing environmental issues but also strengthens cross-institutional collaboration and empowers participants with the knowledge and skills to contribute to sustainable environmental practices.

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