CHEMICAL ENGINEERING TRANSACTIONS

VOL. 113, 2024

A publication of AIDIC

The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Jeng Shiun Lim, Bohong Wang, Guo Ren Mong, Petar S. Varbanov

ISBN 979-12-81206-14-4; **ISSN** 2283-9216

DOI: 10.3303/CET24113097

Empowering Women in Engineering Education through undergraduate Research Projects

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Engineering students are frequently in the front of technological advancement and they can create innovative technology and approaches to tackle several challenges. Introducing undergraduate research projects (URP) in engineering programs can benefit students by empowering their knowledge and skills. Sustainable Development Goals (SDGs) set by the United Nations (UN) can be implemented successfully through the involvement of undergraduate research projects. The engagement of female students in undergraduate research projects can strengthen their knowledge and skills to excel in the industry and society. This project is associated with the UAEU-African Women Empowering Program related to sustainability and climate action. In this work, two undergraduate engineering women students were engaged to work on a URP on the topic of climate action to implement SDG 13. The students work on photocatalytic CO_2 conversion into useful products with the use of solid-waste-derived composite materials. The students were trained to learn basic understanding related to the project and the use of various equipment. The photocatalysts were derived from carbon fibre-reinforced polymers (CFRPs) to produce carbon fibers (CFs)/TiO_2 composites. Photocatalytic CO_2 reduction with H_2O over CFs/TiO_2 experiments were conducted to get knowledge and skills about the topic related to solid waste management and climate action. The CFs loaded TiO_2 was promising due to efficient charge carrier separation and higher visible light absorbance. The students were able to get a real knowledge of reaction engineering, photocatalysis and materials synthesis and their applications for CO_2 conversion to mitigate global warming. Thus, undergraduate engineering research projects can help students improve their problem-solving skills and active learning. Due to the involvement of multidisciplinary students, their skills were further enhanced and students were able to improve their problem-solving and communication skills.

1. Introduction

Undergraduate research projects (URPs) have gained significant traction in engineering institutions across the globe due to their impactful effects on student learning skills (Long et al., 2019). URPs have been identified as a high-impact practice in undergraduate education that supports deep learning and the standards of a high-quality education (Webber et al., 2012). To improve students' learning skills, it is imperative to find a balance between the demands of productive research scholarly teaching and inquiry-based learning (Wolf 2018). Numerous studies show how important undergraduate research projects are for active learning, developing problem-solving abilities, growing cognitively, deciding whether to pursue professional careers or postgraduate education and making career decisions. Although the number of teachers and students participating in URP is growing, not much research has been done on the benefits of URP for students or the outcomes of student participation (Ahmed et al., 2021). In a related study, California State University reported the significance of undergraduate research projects for Underrepresented Students (Donnell et al., 2015).

It is not only advantageous but also crucial to involve undergraduate engineering students in the global achievement of sustainable development increases (SDGs) for several reasons: Students studying engineering are frequently in the front of technological advancement. Through interdisciplinary collaboration, engineering students can offer comprehensive solutions that are both socially and technically acceptable. When engineering courses include projects and coursework related to the SDGs, students' comprehension of global challenges

Paper Received: 17 April 2024; Revised: 9 August 2024; Accepted: 2 November 2024

Please cite this article as: Tahir M., Alkaabi A., Ketbi M.A., 2024, Empowering Women in Engineering Education Through Undergraduate Research Projects, Chemical Engineering Transactions, 113, 577-582 DOI:10.3303/CET24113097

and the significance of SDGs. These include entrepreneurship, sustainability, the environment, and integrating new technology with old chemical processes to meet the world's growing demand for cleaner energy (Voronov et al., 2017). In the United Arab Emirates (UAE), the number of female students enrolled in engineering programs are much higher compared to male students. The UAE government is determined to implement the UN SDG plan for climate action. Involving undergraduate students in research projects would contribute significantly to achieving this target. In previous work, undergraduate woman students have worked on graduate research projects related to photocatalytic water splitting to produce green hydrogen with significant new outcomes (Tahir et al., 2023).

SDG 13 addresses climate change and extreme weather brought on by excessive carbon dioxide release and it requires to address to reduce CO_2 level in the atmosphere (Tahir et al., 2021). It is possible to reduce the concentration of CO_2 by converting it into a variety of useful chemicals and fuels (Tahir et al., 2021). Photocatalytic conversion of CO_2 with the use of semiconductor materials would be a promising approach as it utilizes only CO_2 and solar energy in the presence of photocatalysts and the outcomes are promising. In previous years, titanium dioxide (TiO_2) with various metals and semiconductors was explored and the process was not efficient. Composite materials made of carbon fibres incorporated into a polymer matrix—typically epoxy resin—are known as carbon fibre-reinforced polymers or CFRPs. CFRPs are widely used in a variety of industries such as automotive, and aerospace sectors due to their lot of advantages such as high strength, low density, and corrosion resistance (Zhang et al., 2023). Although recycling systems for CFRPs have made significant headway, they have not yet been extensively employed on an industrial basis. (Deng et al., 2020). Solid CFRP waste can be converted into pure carbon fibers (CFs), which are highly conductive materials for semiconducting applications (Akbar et al., 2020). Using CFs, a metal-free source, electrons can be trapped and moved inside semiconductors. Because of their cheap cost, high electrical conductivity, and huge surface area, they can also be used as cocatalysts. Therefore, CFs can be added to TiO2 as a cocatalyst to increase their photocatalytic stability and efficiency (Sahani et al., 2022).

The main objective of this paper is to enhance the education and learning skills of engineering students which build critical and creative thinking abilities while promoting learning. Through the undergraduate research project, this work employed a student-centered learning approach involving female Engineering undergraduate students. Students from multidisciplinary backgrounds were involved in developing methods and approaches for CO2 recycling through photocatalysis for climate action to achieve SDGs. The students worked on creating various solid waste TiO2 composites and tested their photoactivity to convert CO2 to green fuels using solar energy. This helps them to gain more practical experience, combine it with project-based learning, and learn critical thinking and knowledge to generate new concepts and thinking skills.

2. Research Methodology

2.1 Sustainable Development Goals (SDGs) Program

To raise awareness of the United Nations Sustainable Development Goals (UN-SDGs) among university students, the Research Office of UAE University initiated the SDGs Research Program. The undergraduate students can apply for the SDGs Research Program, which is yearly and focuses on particular sustainable development goals. Recently, a new initiative was launched under the UAEU-African Women Empowering Program, selecting two women from Haramaya University in Egypt and two women from UAE University. SDG 13 (Climate Action), which was acquired from the United Arab Emirates University, is the subject of the current research. The participating students must have information about climate change issues and the SDGs of the UN. The project involves faculty members and full-time students. To work on this research, two female undergraduate engineering students were chosen from the College of Engineering, one from Mechanical Engineering and one from Chemical Engineering.

2.2 Research Design and Procedure

The research project was developed with a focus on two key areas: recycling solid waste and repurposing greenhouse gas CO_2 to generate green fuels using solar energy. Students are actively involved, enabling them to gain a deeper understanding of local waste resources and the abundant solar energy available, to contribute to climate action and sustainability. Additionally, the project provides students with hands-on experience with various analytical techniques and engineering equipment, which will be valuable for their future careers. The project emphasizes project management, teamwork, enhancing engineering skills, and decision-making, all of which are crucial for their career development.

Working on an SDGs project, two students from the chemical and mechanical engineering departments aimed to combat climate change by converting CO_2 through photocatalysis into more valuable products. Recycled carbon fibre-reinforced polymers, or CFRPs, were gathered for this project from the nearby industry to produce carbon fibers. Students received a complete plan that included a monthly detailed outline, the scope of work, and the expected takes and deliverables, following the authorized proposal. The students were trained in conventional operating procedures, laboratory equipment use, and reading safety instructions. Initially, the students received training on how to operate various laboratory apparatus, including gas chromatography, ball mills, centrifuges, furnaces, ovens, and photocatalytic reactors. Providing a lab orientation is a crucial educational step for first-time study participants as it provides them with crucial knowledge about the lab and its potentially hazardous equipment. Students who participate in this effort learn about laboratory safety, equipment upkeep, time management between courses and research, decision-making and, confidence-building.

2.3 Synthesis of Carbon Fibers (CFs) from Recycled Carbon Fibre-Reinforced Polymers (CFRPs)

The students were engaged in preparing the pure carbon fibers and their composites based on the available literature and their new learning skills. Thermal decomposition was used to produce carbon fibers (CFs) from recycled carbon fiber-reinforced polymers (CFRPs). Different heating conditions led to the production of three different types of carbon fibers. In the first instance, samples were created without heating, and Figure 1a displays the systematic approach. First, CFRPs were cut into small pieces. The CFRPs were further ground using the ball mills, and the product obtained was a combination of CFs and epoxy resins, which can be named CFRP powder. The CFs were obtained by heating CFRPs at 500 and 700 °C and the results are shown in Figure 1b. In this case, small pieces of CRPs were placed in a ceramic crucible, covered with aluminium foil and were placed in a muffle furnace and heated at two different temperatures. The product obtained at 500 °C was not fully converted to CFs. Using the temperature of 700 °C, a complete conversion of CFRPs into CFs was obtained. The CF material obtained after heating was further ground using the ball mill and was converted into CF powder. After preparing CF materials, students were able to learn about recycling different types of solid wastes and how they can be converted into various useful products such as carbon fibers with the use of thermal treatment methods.

Figure 1: (a) Schematic illustration of the carbon fibres powder obtained from CFRPs without heating, (b) Schematic illustration of the CFs obtained from CFRPs by heating at 500 and 700 °C for 2 h

2.4 Synthesis of CFs/TiO_2 Composite

The students were further involved in preparing composite materials. The self-assembly method was used to prepare the TiO_2 composite loaded with CF. Stirring a specific amount of TiO_2 distributed in methanol typically took two hours. In a separate step, CFs were dispersed in methanol for uniform dispersion and the CFs suspension was added to the TiO_2 mixture. After that, CFs added to TiO_2 suspension were stirred for another 2 h using a magnetic stirrer at normal temperature. Finally, the slurry was oven-dried at 100 °C under airflow, overnight and the product obtained was named CFs/TiO_2 composite.

2.5 Photoactivity Test for CO_2 Conversion

A continuous flow photoreactor system linked to an online GC for product analysis was used to examine the performance of the CFs, TiO_2, and CFs/TiO_2 composite. The main light source, a 35 W Xenon lamp placed above the reactor glass window, emitted light with an intensity of 20 mW/cm^2. For every experiment, 150 mg of powder catalyst was employed, and the catalyst was evenly spread around the bottom surface of the reactor. The mass flow controllers (MFC) were used to control the CO_2 flow rate, which was flowing at 15 mL/min. The CO_2 first flows through the water saturator before entering the reactor to carry water vapours (H_2O). Every product was examined using online micro-GC Fusion (INFICON).

3. Results and Discussion

3.1 Materials Characterization

The students were further engaged to understand the properties of materials through different characterization techniques. Figure 2a shows XRD analysis of CFs, TiO_2 and CFs/TiO_2 composites. XRD patterns of the CFs exhibits a distinct peak observed at 2θ of 25.96°, which corresponds to the (002) plane of the carbon structure. This characteristic peak confirms the successful removal of the polymer layer during the heating process (Zhou et al., 2022). The anatase phase TiO_2 is confirmed by the many peaks in the TiO_2 XRD patterns, which are connected to the (101), (004), (200), (105), (211), and (204) facets (Han et al. 2020). When CFs were added to TiO_2, only the TiO_2 peaks were obtained. Furthermore, because of their overlap with TiO_2 peaks and the amorphous nature of CFs inside the CFs/TiO_2 composite structure, peaks belonging to CFs were not found.
Figure 2b shows a UV-visible analysis of TiO_2, CFs, and CFs/TiO_2 composite samples. Pure CFs have a large absorption capacity for visible light (Huang et al., 2023). In contrast, TiO_2 shows absorption of light in the ultraviolet spectrum. When CFs were added to TiO_2, visible light absorbance was increased. These findings suggest that adding CFs to TiO_2 may increase light absorption efficiency (Cheng et al., 2021). There are similar works reported in the literature. It was demonstrated that the addition of CF caused the band gap energy of TiO_2 to drop from 3.1 to 2.76 eV. (Nguyen et al., 2022). In a different study, C/Ag/TiO_2 has the most visible light absorption and C/Ag loading reduced TiO_2 band gap energy from 2.79 eV to 2.21 eV (Yuan et al., 2023). Scanning electron microscopy (SEM) was used to evaluate the morphology of the CFs and CFs/TiO_2 samples and the results are shown in Figure 3. The shape of CFs is depicted in Figure 3a–b, where uniform-size carbon fibers are seen. The morphology of CFs/TiO_2 is depicted in Figure 3c, where the attachment of TiO_2 particles to CF validates their uniform distribution and interaction.

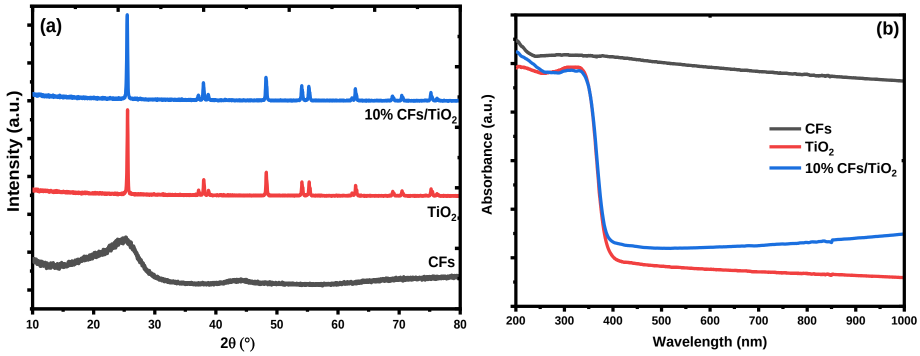

Figure 2: (a) XRD analysis of CFs, TiO_2 and CFs/TiO_2 composite. (b) UV visible analysis of CFs, TiO_2 and CFs/TiO_2 composite

After completing all the characterization analysis and their discussion, students were able to understand the properties of different materials. The outcomes of all the materials were linked to their different courses such as catalysts, size and shape of materials and others for their better understanding. Mechanical engineering student excels more in understanding the operation of different machines and chemical engineering students gain knowledge and understanding about the properties of the materials and their relation in their different courses. The students empower their knowledge by sharing knowledge.

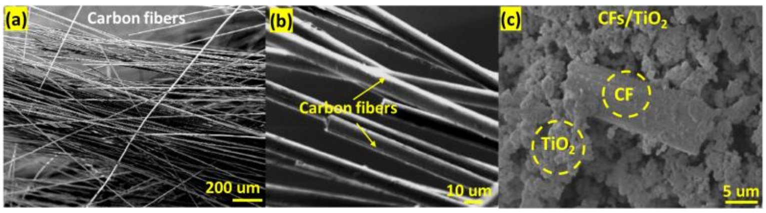

Figure 3: SEM analysis of (a-b) CFs, (b) CFs/TiO_2 composite

3.2 Photocatalytic CO_2 Reduction for Climate Action

As an interdisciplinary research project, the students were fully involved in discussing their results linked with different characterization techniques and applying their interdisciplinary knowledge, learning skills an innovation.

A continuous flow photoreactor system was used to test the CO_2 reduction effectiveness of both pure and composite photocatalysts, with a gas flow rate of 15 mL/min. The generation of CO and CH_4 over TiO_2 and CFs/TiO_2 composites at varying irradiation periods is depicted in Figure 4a. Throughout the whole irradiation period, CO and CH_4 were continuously created in all of the samples. Due to decreased visible light absorbance and increased charge recombination inside the TiO_2 structure, a tiny amount of CO and CH_4 were formed while using TiO_2. On the other hand, when CFs were added to TiO_2 to CFs/TiO_2 composites, the photocatalytic efficiency was significantly increased. Using CFs/TiO_2, the highest CO production of 38 µmol g^{-1} was produced, which was 15 folds more than using pure TiO_2. On the other hand, the production of CH_4 was also increased with CFs/TiO_2 composite and the composite was more beneficial for CO formation. The increase in CFs/TiO_2 composite photoactivity was due to the efficient separation of charge carriers and higher visible light absorbance. The schematic illustration for the production of CO and CH_4 over CFs/TiO_2 composite is shown in Figure 4b. During the photocatalytic process, electrons produced over TiO_2 were trapped by CFs, which resulted in their efficient separation. The electrons were used to produce CO and holes were used to oxide water. After going through the use of different tools of material characterizations and comparative analysis of the experimental results, the students would be able to build creative and thinking skills.

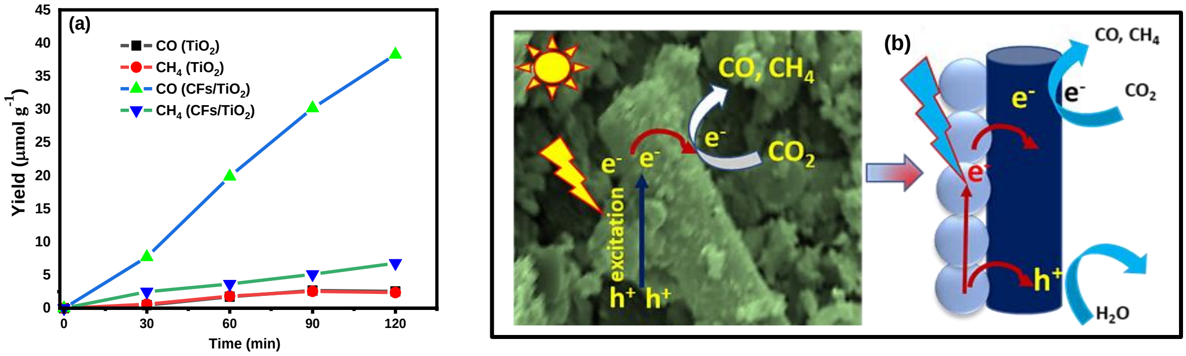

Figure 4: (a) Photocatalytic CO_2 reduction to CO and CH_4 over TiO_2 and CFs/TiO_2 composites, (b) Schematic illustration of the mechanism for photocatalysis process

3.3 Students Viewpoint and Belief

Participating in the SDG-13 research project empowered Asma, a chemical engineering student, by deepening her understanding of carbon fibers, photocatalysts, and sustainable methods. Initially expecting to focus on technical tasks, she soon recognized the importance of interdisciplinary teamwork in addressing climate change. This broadened her perspective, revealing that chemical engineering extends beyond processes and reactions to support global sustainability. The hands-on experience with photochemical reactors enhanced her grasp of reaction kinetics, material science, and thermodynamics, bridging the gap between theory and practice.
The project had a similarly profound impact on Maryam, a mechanical engineering student. Initially focused on machinery optimization, she discovered the crucial role her field plays in environmental sustainability. Learning to optimize equipment to reduce carbon emissions shifted her perspective and strengthened her commitment to climate action. This experience also deepened her understanding of thermodynamics, heat transfer, and material science, integrating theoretical concepts with real-world applications. Collaborating across disciplines enriched both students' understanding of how different engineering fields converge to address global challenges. The project also enhanced their problem-solving, decision-making, and communication skills, essential for successful engineering careers.

4. Conclusions

This paper focuses on the importance of undergraduate research projects and experimental learning and their contribution to developing critical thinking and knowledge to improve the quality of engineering education. The engineering female students were engaged in different research activities, which included, materials synthesis, testing of the photocatalysts for CO_2 reduction and reporting results. The students gained a fundamental understanding of recycling solid waste and repurposing greenhouse gas CO_2 to create valuable products using solar energy. By the end of the project, the students had significantly improved their skills in areas such as decision-making, converting waste into useful products, recycling materials, and understanding core concepts related to engineering programs and future career decisions. Given their diverse backgrounds in chemical and mechanical engineering, the students found this project particularly valuable for enhancing their multidisciplinary understanding, knowledge sharing, and professional skills. In summary, research can empower individuals in their field of study by equipping them with the necessary knowledge, skills, and expertise. Participating in research also strengthens communication, problem-solving abilities, and competitiveness in the job market.

Acknowledgements

This work is funded by United Arab Emirates University under Sustainable Development Goals (SDG, Grant # 3269).

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