Fabrication of CO_2 Capture and Conversion Filter from Local Material

Bayan Al Dabdoub[1], Reem Al Balushi[1], Abdullah Al Jabri[1], Muna Al Hinai[1] and Tahereh Jafary[1#]

[1]International Maritime College of Oman, Oman
[#]Advisor

ABSTRACT

Carbon dioxide emissions have recently become a global concern because of the industrial revolution and growing urbanization activities. By increasing the global population and the requirement for industrial growth to support economies and meet human needs, greenhouse gases, and CO_2 emissions CO_2 are rising. Emissions and their influence on global warming compel governments and companies to develop new technologies to decrease stress on ecosystems. Photocatalysis is one of the most promising technologies in water treatment and environmental remediation. This research project focuses on the development of an eco-friendly photocatalysis technique for capturing CO_2 from industrial plants and safely converting it to methanol. This project's invention is based on the use of local sand to produce a unique sand filter modified with ZnO nanoparticles that is promising for photocatalytic CO_2 capture and conversion into methanol. The effect of sand modification on CO_2 capture will be investigated using a variety of characterization methods such as chemical composition, morphology, physiochemical properties, X-ray diffraction (XRD), Energy Dispersive Spectroscopy (EDS), and Fourier Transform Infrared (FTIR). The morphology of the sand and the modified sand will be studied using scanning electron spectroscopy (SEM). This project aims to improve the environmental performance and global innovation indexes of Oman Vision 2040 by identifying pathways for an eco-friendly, sustainable, science-based economy.

Introduction

In recent years, many developing countries have been concerned about the environmental harm caused by uncontrolled CO_2 emissions into the atmosphere. Industrial activities have increased CO_2 emissions into the atmosphere due to increased urbanization and industrialization in many developing countries. This has caused a significant rise in the atmospheric concentration of greenhouse gases produced by humans, such as CO_2, which has aided in climate change and global warming. A decline in global agricultural output is a result of climate change, which also causes seasonal changes, low rainfall, and rising temperatures. Carbon dioxide is generated by the burning of solid waste, biological substances, fossil fuels, and trees. It is known to produce UV and thermal infrared radiation and reduces heat transfer to space. CO_2 has an impact on both the environment and human existence, with short-term impacts from inhaling high amounts of carbon dioxide quickly, whereas long-term consequences result from inhaling little amounts on a regular basis. Global greenhouse gas emissions have increased since the turn of the century, primarily due to rising CO_2 emissions from India, China, and other developing countries. The latest projections show that this trend continued in 2019, with worldwide anthropogenic fossil carbon dioxide emissions. As can be seen from Table 1.1, CO_2 emissions have risen over time. As a result, Oman must reduce its reliance on fossil fuels, and expand the use of renewable energy resources. To put it another way, increased use of fossil fuels will not only have the risk of depleted energy resources in the near future but will also lead to increased carbon emissions.

Table 1. Growth rates of Oman, 2010-2018 (Panigrahi et al., 2020)

Year	Oman Energy Consumption	CO2 Emission
2010	5521.2	15.5
2011	584.0	16.62
2012	6176.9	16.91
2013	6207.	16.30
2014	6445.6	15.19
2015	6703.4	17.86
2016	7231.9	19.87
2017	7556.4	20.76
2018	7858.3	21.7

COVID-19 has changed the world by lowering human activity on a large scale and having a considerable influence on many national economies. As a result of the lockdowns, industrial production, and energy consumption have been curtailed, resulting in a significant reduction in CO_2 emissions (Liu et al., 2020). Because of the significant harm and emissions caused by this gas, nations and people must seek measures to decrease it. Green energy (Perathoner & Centi, 2014), smart homes, and recycling and reusing are some of the ways to reduce CO_2 emissions. Photocatalysis is a potential green technology in environmental treatment sectors. This project's approach is to use natural resources modified with semiconductor nanoparticles having photocatalytic activity.

Photocatalysis and Recent Advancement in Photocatalyst

In last years, various technologies have been developed to reduce the amount of carbon dioxide in the atmosphere. If artificial photosynthesis techniques can be applied, scientists will be able to convert carbon dioxide to other products. Since the amount of carbon dioxide on Earth is immense, it is necessary to develop new photocatalysts that are made with only the elements that can be found on Earth. Photocatalyst is phrase made up of two parts: photo, which refers to a photon, and catalyst, which refers to a material that speeds up the process. As a result, photocatalysts are materials that, when exposed to light with the help of semiconductor which generates an electron-hole pair, modify the efficiency of a chemical reaction. Photocatalysis is the term for this occurrence. The value of photocatalysis comes from the fact that it creates both an oxidation-reduction environment, all at the same time. Moreover, low resistivity, optical transmittance, mechanical hardness, uniformity, piezoelectric behavior, and heat treatment stability (Ameta et al., 2018) are the attractive features that made scholars and the world turn to it. Photocatalysts are made of semiconductors. This process can be used for conservation, antifouling, air purification, deodorization, sterilization, wastewater treatment, and self-cleaning.

Semiconductors can conduct electricity in the presence of light even at room temperature, making them photocatalysts. Due to their electrical structure, semiconductors operate as photo redox sensitizers. Many organic contaminants, such as dyes, aromatics, insecticides, halo hydrocarbons, surfactants, and herbicides, can be photocatalyzed to full mineralization. (Ameta et al., 2018). Much research has been done in recent years, and it has been proven that using sunlight as an energy source can help reduce carbon dioxide. However, the remaining tasks are still necessary to successfully implement this strategy. Several highly active photocatalysts containing precious metals such as ruthenium, rhenium and tantalum were used. The reduction of CO_2 to other products can be done by artificial photosynthesis or hydrogeneration process. Artificial photosynthesis is a process that involves the use of solar light, H_2O as a reducing agent, and a photocatalyst. On the other hand, in addition to H_2O, H_2 from renewable sources rather than fossil fuels is used to achieve carbon neutrality and is used as a source of electrons and protons for photocatalytic CO_2 reduction.

Sand Characteristics

Sand is one of the natural materials resulting from the disintegration of rocks and minerals, due to the natural factors that the rock passes through, an example of that is rain and wind...etc. To divide the sand, many organizations divide the sand based on several factors, one of which is because of the sand component and the other because of the size of the sand. There are two types of sand, the first is silica sand, which is pure sand that contains a high percentage of silica SiO2, where silica constitutes 99% of its components, which consists of the mineral quartz, and this type of sand is characterized by a small percentage of impurities, which constitute 0.1%. As for the other type, which is glass sand, it is characterized by chemical and physical characteristics that helped it to be used in many industries, including the glass industry, due to the size of the particles that range between (100-500) microns and the percentage of iron oxides that are less than 0.05%. On the other hand, the International Organization for International Standards classified sand according to its size, as sand that ranges between (0.063mm-0.2mm) is considered fine sand, or sand that ranges between (0.2mm-0.63mm) is considered medium sand, which is (0.63mm-2mm) is considered coarse sand. (Mathis,2022)

Sand is characterized by many chemicals, physical and hydrological properties. In terms of physical properties, the bulk density is high, due to the high content of sand particles. It is also characterized by different porosity ratios, ranging between 36%-46%. It is also distinguished by its ability to pass water and at the same time with the passage of water the sand was able to retain all other impurities and thus perform the work of the filter. As for the chemical properties, sand is considered a fire-resistant material, as the temperature reaches 550 degrees Celsius and does not change. At the same time, it is considered one of the frost-resistant materials, as the same material appears without any change at low temperatures. One of the hydrological properties is that the soil has a low capacity to retain moisture due to the large size of the pores. In addition, the hydraulic conductivity of the soil is highly variable in relation to the density of the sand. It can be in the range of 300-30000 cm / day (Wei Gong, Hao, 2015).

Sand in the Field of Photocatalysis

Since the beginning of the twentieth century, silica has been used in the production of optical fibers, electromagnetic materials, and photocatalytic materials, which in turn convert light energy derived from sunlight into electrical energy, as silica compounds contain photocatalytic properties. And in order to reduce the costs of materials used for photocatalysis, silica is used instead of using other materials, for example titania, not only that, but when it is replaced with silica, the durability increases, and it can also be used in photocatalytic applications that require high temperature photocatalysis as Silica has high mechanical and thermal stability. It is also used in photocatalysis because it can absorb some pollutants and intermediates for a longer period due to its large specific surface area. (Bansal, 2017)

Sand in Oman

Sand and stony deserts represent approximately 82% of the Sultanate of Oman's total area. Given this high percentage, it is critical to consider strategies to utilize this sand in modern industries rather than wasting it. The Sultanate of Oman was named one of the top exporters of silica sand in 2021. This suggests that the country has a big supply of sand. The Wahiba Sands are a desert in the Sultanate of Oman's Eastern Province that covers 12,500 square kilometers. Different minerals were detected in samples taken from the northern and southern Wahiba dunes.

Table 2. Comparison between average percentages of heavy minerals in Wahiba (Gheith et al., 2021).

Heavy minerals	Northern Wahiba	Southern Wahiba
Opaques	30	29.3
Augite	30.5	20.9
Hornblende	7.5	7.8
Actinolite	3	0.8
Tremolite	1.9	0.9
Anthophyllite	2.6	2.7
Epidote	4.2	2.0
Chlorite	0.7	0.6
Biotite	1.0	2.3
Zircon	4.5	6.0
Tourmaline	3	1.5
Rutile	1.3	0.9
Garnet	3.2	6.1
Kyanite	1.1	0.7
Staurolite	1.1	3
Olivine	1.9	2.4
Weathered minerals	22.6	28.9

Methods

In this research investigation, the experiment of CO_2 capture and conversion from local material will be conducted in five phases as shown in Figure 3.

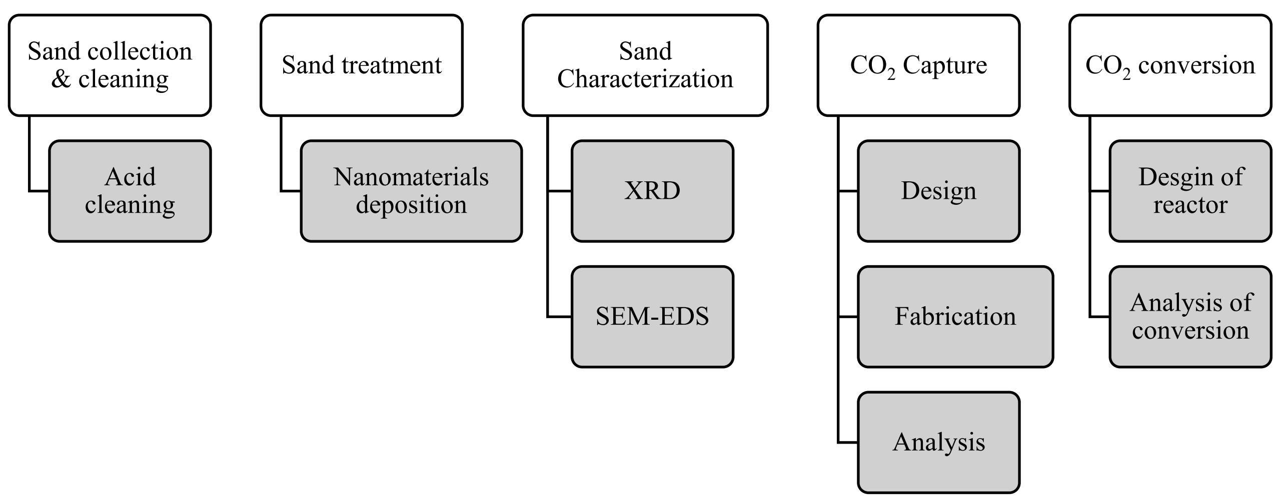

Figure 1. Fabrication for CO_2 capture and conversion from local material

Materials

The sand was collected from Wahiba Sand, Al-Sharqia. Acetone (58.08 g/mol, 99%), zine acetate dehydrates (219.51 g/mol, 99%), Hexamethylenetetramine (140.19 g/mol,99%) were purchases from Sigma-Aldrich from Germany. Absolute Ethanol (46.07g/mol) was obtained from Suprlco from Germany. Zinc nitrate hexahydrate (297.47 g/mol, 98% and obtained from Daejung from China). Hydrochloric Acid (36.460 g/mol, 99%, obtained from J.T.Baker , China), Oxalic Acid (126.07 g/mol,99.6%) from Zhengzhou, China and Acetic acid (60.05 g/mol,99.8%) from RANKEM from India were used to for chemical washing of the sand. Deionized water machine was used for cleaning and washing porpoises and it was filtered in VEOLIA.

Sand Collection and Cleaning

The sand was collected from Wahiba and treated and cleaned to remove contaminants by water and chemicals.

Sand Cleaning with Deionized Water

It is important to get rid of the impurities that natural sand contains. Multiple modern techniques have been improved to clean the sand. Deionized water is used to wash the water- dissolved impurities including minerals. Sand was washed with water at 50 °C, filtered using vacuum filtration and then dried.

Cleaning the sand with Chemicals

Sand washing was carried out to remove carbonates derived from organic contaminants and Fe-containing minerals. To dissolve the current carbonates, sand was washed in multi acidic solution with the sonication for 15 minutes, then the acid was decanted, and the sand was extensively washed with DW while vacuum filtration was conducted. The sand was dried in a 70°C oven overnight.

Sieving Sand Analysis

Sand sieving analysis separates sand particles based on part size, thus obtaining sand particles of equal size. The washed sand was sieved using the sieve shaker (UTEST) for 5 minutes at atmospheric temperature and pressure. Sand will be separated based on their size. After that will take the weight of each part. For the first sieve which was 150 μm the percentage from the total sand was 5.8-7.3%, for 75 μm was 68.2- 86.3% and for 63 μm 2.7-3.4%.

Deposition of ZnO Nanomaterial

At a temperature of 250 °C, ZnO nanoparticles were seeded on the sand surface using a 1:1 molar ratio of zinc acetate: zinc nitrate solution. The sand-ZnO surface area was increased by the hydrothermal development of ZnO nanodisks in zinc nitrate solution.

Characterization of Sand and Modified Sand

The surface shape, chemical compositions, surface area, and band gap studies of sand and ZnO-modified sand will be studied. The surface morphology of the sand and ZnO-modified sand particles will be studied using a scanning electron microscope (SEM-EDS) with elemental analysis. The elemental composition of the photocatalyst will be investigated using electron dispersive spectroscopy (EDS). X-ray diffraction (XRD) will be used to examine the crystal structure of the sand and ZnO-modified sand. Fluorescence spectroscopy will be used to calculate and estimate the band gap of ZnO-modified sand. Through the measurement of N_2 gas adsorption, the surface area of sand and ZnO-modified sand will be investigated and determined using the Brunauer-Emmet- Teller (BET) method.

Fabrication of CO_2 Sand Capture and Converter

A customized 3D-printed reaction tank will be created to catch CO_2 and convert it to methanol at the ZnO-modified sand particles. The vessel cell will be designed using SolidWorks software. To replicate sunlight, a Xenon lamp will be used for light irradiation. Every 30 minutes, a gas sample will be tested for CO_2 and generated methanol using Gas Chromatography- MsS with mass spectrometry (GC-MS).

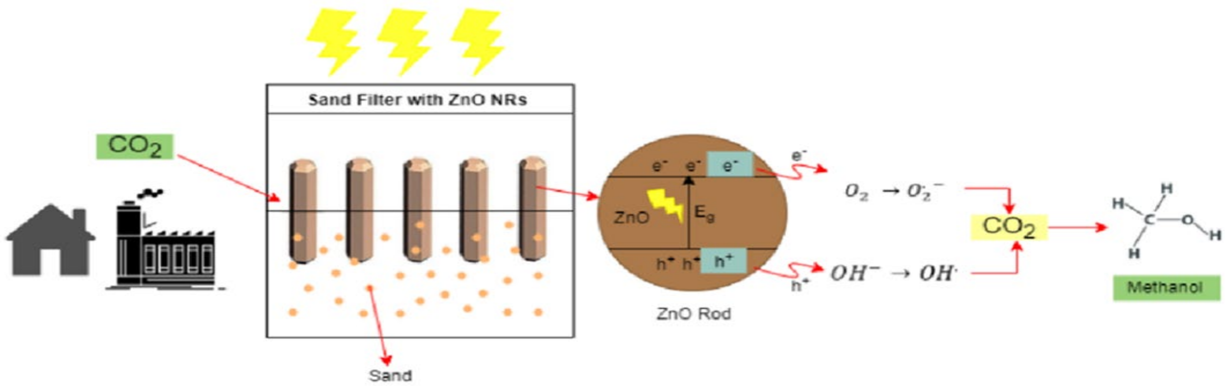

Figure 2. Scheme of modified sand used in photocatalysis for CO2 conversion into methanol

Results

After conducting a series of tests, the following results were obtained. Figure 3 summarizes the distribution of cleaning of sand with distilled water and chemicals. As seen in figure 3A, the sample of sand collection from Wahiba. Figure 3B illustrates the sand after washed by distilled water. Figure 3B shows the sand that was washed with distilled water, and the materials attached to the sand and some of the existing sediments were removed, in addition to removing a percentage of the iron from the sand. Figure 3C shows a sample of sand after it was cleaned with chemicals. Magnesium, calcium and carbonite were removed. Furthermore, the figure 3D shows the sand after sieving 75 µm.

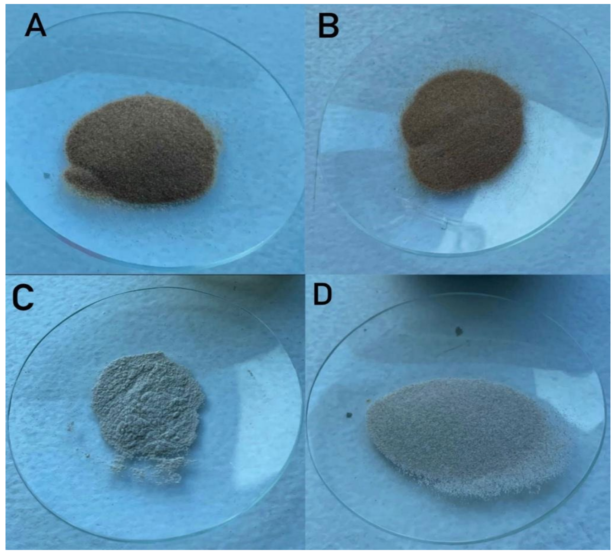

Figure 3. Sand samples at different washing and treatment stages. (A) sand as collected, (B) sand after DI water washing, (C) sand after acidic cleaning, (D) sand after nanoparticles deposition.

Discussion

The sand cleaning process was repeated first with distilled water and then cleaning with chemicals to ensure the removal of all sediment and that the sand used is clean and suitable for the carbon dioxide capture process. In addition, sand and modified sand characterization will be done to analyze the sand used in the experiment and know its properties as we mentioned in methodology of the experiment. Ultrasound technology is a good iron removal technique when processing natural silica sand. The effect of getting rid of iron reaches more than 50% within 10 minutes, which is superior to other techniques. In addition, the efficiency of the ultrasound technology can be increased by combining it with the chemicals in the solution due to their synergistic action.

Conclusion

This research project focuses on the development of an eco-friendly photocatalysis technique for capturing CO_2 from industrial plants and safely converting it to methanol. It is based on the use of local sand modified with ZnO nanoparticles. Sand cleaning is addressed to remove impurities and wash out materials that can interfere with the performance in CO_2 capturing. The effect of sand modification on CO_2 capture will be investigated using characterization methods such as chemical composition, morphology, physiochemical properties, X-ray diffraction, EDS, and FTIR. Gas analyzers will be used to test CO_2 capture and conversion. Approximately 82% of the total area of the Sultanate of Oman is covered by sandy and stony deserts. In view of this high percentage, it is necessary to think of ways to exploit this sand in modern industries and not to waste it. In 2021, the Sultanate of Oman was classified as one of the largest exporters of silica sand. This indicates the availability of large quantities of sand in the country (Garzanti, 2019).

Limitations

Searching for comprehensive analysis of sand and its application in CO_2 capture and photocatalysis is challenging. There are many research articles concerned utilizing sand in water treatment applications, however CO_2 capture is recently investigated. Designing a photocatalysis reactor will be limited to transparent materials to allow light penetration.

Acknowledgments

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