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Title

Analytical Study of some Materials used to Reduce Carbon Dioxide "CO_2" Emissions

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Summary:

Dedication

Praise be to God, and prayers and peace be upon the messenger of God.

By the grace of God, we have completed this scientific treatise, which dream to the dearest people to my heart, my Mother, my heaven, and my dear Father.

And my Brothers and my Sisters, each in his name.

And to my little princess Nadjma, and the little chick Nazim.

And to my life companion Boukhalfa Soufiane, you gave me a beautiful thing that does not end.

And to all Khellou family, and also de not forget my frineds, colleagues, teachers, and everyone who supported me in my university career.

In the end, I ask God to complete the conclusion.

KHELLOU IKRAM

Dedication

Praise be to God who helped us in our university journey, of which only a few remained.

Here we are today about to end our academic journey after great effort and fatigue.

On this beautiful day, I dedicate this graduation to my beloved: my mother Madani Talia and my father Rahmania Abd ERrhmane.

To my brother Abd Elhalim, for he is my support in life.

To my sisters Aisha, Elyamina, Mobaraka, Zaineb, Ahlam, Yousra.

And to my soul mate Ayoub Rachad, and to my second mother Mariem Bassasi.

To all my friends especially my beloved Khellou Ikram, and to every teacher who taught me a letter and did not skimp on me with information.

In conclusion, I ask God to bless us in our work and make us happy.

RAHMANIA RAYANE

إهداء

الحمد هلل وكفى والصالة والسالم على الحبيب المصطفى وأهله ومن

وفي أما بعد:

هلل الذي وفقنا لتثمين هذه الخطوة في مسيرتنا الدراسية لمذكرتنا الجهد والنجاح بفضله

تعالى مهداة إلى الوالدين الكريمين الحمد هذه ثمرة

حفظهما هللا وأدامهما نورا ودربا لي.

لكل العائلة الكريمة التي ساندتني وال تزال من إخوتي ورفيقاتي. وال ينبغي أن أنسى

أساتذتي ممن كان لهم الدور األكبر في مساندتي ومدى المعلومات القيمة. وإلى كل

من كان لهم أثر في حياتي، وإلى

كل من أحبهم من قلبي.

وداعية المولى عز وجل أن يطيل في أعمارهم ويرزقهم الصحة

والعافية.

بالرمضان حسناء

إهداء

الحمد هلل الذي بنعمته تتم الصالحات الحمد هلل ما تم جهد وال ختم سعى إال

بفضله وما تخطى العبد من عقبات وصعوبات إال بتوفيق

من هللا أتممت مسيرتي الجامعية.

أهدي تخرجي هذا إلى من كان سببا في تحقيق هذا النجاح والدي العزيز

أطال هللا في عمره إلى أمي الغالية التي كانت دعواتها ترافقني طوال هذا

المشوار حفظها هللا ورعاها إلى إخوتي السند الدائم مريم منية عبد السالم بسملة

صديقاتي وإلى كل من دعمني ماديا ونفسيا وإلى كل زميالتي لتحقيق هذا النجاح

نجاحي هذا لكم

شطي شاهيناز

إهداء

ما بين قَد أُوتِيت » سُ ُ سوبَ َ جَ رَ » خَاَ
وَلِك َ م فِقَدْ عَ ِ
يا لهَ ّ
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ي

الحمد هلل الذي يسر لي البدايات وأكمل لي النهايات إلى من بلغ الرسالة وأدى

األمانة الى نبينا محمد صلى هلال عليه وسلم أهدي ختام مسيرتي:

ت، ولك أبي العظيم بعينيك رأيت قد زرعك أمي هذا أمي ثم أمي ثم إلى الحياة

لكم يا أفراد أسرتي الصغيرة صالح، نريمان وإسالم دمتم لي عونا وسندا

وفقكم هلال وحفظكم محظوظة بكم حقا ومن كان السند والداعم النفسي إلى من جمعني هلال به على

شرعه وسنته خطيبي طاهر

وألخت التي منحني هلال إياها وهانت معها السنوات مريم ومن كانت أخت بالروح وفقك

هلال ورعاك آمة هلال إليكم من سهرنا معا وتكبدنا لذة هذه النهاية يا من تعثرنا معا

شاهيناز وحسناء وأمال لطالما تمنيتك معنا في هذه اللحظات وأنت يا نعمة الزميلة

والرفيقة فاطمة وفردوس تلك التي رافقت الخمس سنوات بمرحها

دعمني وساهم ولو بكلمة طيبة او إبتسامة زميالتي شكرا لكم كثيرا أهدي إلى كل من

ورفيقاتي وأساتذتي

◇فالحمد هلل على حسن التمام والختام◇

شطي فطيمة زهرة

Thanks

Praise and thanks be to God first and foremost, who helped us finish this scientific thesis.

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We would like to thank everyone who is with us today.

Finally, thank you for listening and following up.

General Introduction

The synthesis of materials using dry methods has emerged as an intriguing area of research in the field of materials science and engineering. Dry synthesis techniques involve the preparation of new materials without the use of solvents or liquids, primarily relying on powders or solid precursors. These methods offer several advantages such as energy efficiency, environmental friendliness, and the ability to enhance material properties.[1]

One significant driver behind the exploration of dry synthesis methods is the need to reduce carbon dioxide (CO_2) emissions and mitigate the adverse effects of climate change. CO_2 emissions primarily result from human activities such as burning fossil fuels for energy, industrial processes, and deforestation. The accumulation of CO_2 in the atmosphere leads to the greenhouse effect, causing global warming, rising temperatures, sea level rise, and extreme weather conditions.[2]

In this context, the development of new materials through dry synthesis methods offers promising opportunities. Various techniques can be employed in dry materials synthesis, including mechanical milling, solid-state reactions, vapor deposition, and thermal treatments. Mechanical milling involves grinding powders to reduce particle size and enhance chemical reactivity. Solid-state reactions facilitate direct interactions between two or more solids, leading to the formation of novel compounds. Vapor deposition techniques, such as physical vapor deposition (PVD) and chemical vapor deposition (CVD), enable the deposition of thin material films onto substrates. Thermal treatments involve heating solids to induce chemical reactions and structural transformations.[3]

Various techniques are used to analyze synthesized materials and understand their properties. XRD determines crystal structure and identifies impurities. SEM reveals material morphology and microstructure. FTIR and Raman spectroscopy identify chemical compositions and functional groups. This study focuses on the thermal treatment of calcium acetate to obtain pure calcium oxide, highlighting the importance of dry methods in producing crucial materials for multiple industries. Characterization through XRD, FTIR, and SEM analysis provides insights into the material's composition, structure, and morphology.[4] And from here, we raise the question: How is locally available calcium used to absorb carbon dioxide from the air?

Chapter 1

Generalities on CO_2 emissions and ways to reduce them (Carbon Capture Methods)

Introduction

Carbon dioxide (CO_2) emission refers to the release of carbon dioxide gas into the atmosphere, usually as a result of human activities such as burning fossil fuels (coal, oil, and gas) for energy, deforestation, and industrial processes. CO_2 is a greenhouse gas, which means it traps heat in the Earth's atmosphere, leading to a warming effect commonly referred to as the "greenhouse effect."]5[

The increase in CO_2 emissions has been linked to climate change, as rising temperatures and sea levels, extreme weather conditions, and other environmental impacts are becoming more prevalent around the world. Governments, businesses, and individuals are taking steps to reduce CO_2 emissions through various means such as using renewable energy sources, improving energy efficiency, and adopting low-carbon lifestyles. There are also international efforts to limit global CO_2 emissions, such as the Paris Agreement, which aims to limit global warming to well below 2 degrees Celsius above pre-industrial levels.[6]

1) Understanding CO_2 Emissions: The Basics:

Carbon dioxide (CO_2) is a chemical compound that is naturally present in the Earth's atmosphere increased the concentration of CO_2 in the atmosphere, leading to a range of environmental and social impacts. Understanding CO_2 emissions is essential to tackling the issue of climate change and its consequences.[7]

Its core, CO_2 emissions refer to the release of carbon dioxide into the atmosphere as a result of human activities. These emissions come from a variety of sources, including power generation, transportation, industrial processes, and agriculture. The burning of fossil fuels such as coal, oil, and natural gas is the primary source of CO_2 emissions, accounting for approximately 75% of all emissions globally.[8]

The impacts of CO_2 emissions are vast and far-reaching. CO_2 is a greenhouse gas, which means that it traps heat in the Earth's atmosphere, leading to global warming and climate change. The consequences of climate change include rising sea levels, increased frequency and severity of extreme weather events, and damage to ecosystems and biodiversity.[9]

Reducing CO_2 emissions is therefore a critical step in mitigating the effects of climate change. A variety of strategies can be employed to reduce emissions, including transitioning to renewable energy sources such as solar and wind power, improving energy efficiency, and adopting low-carbon transportation options. In addition, carbon offsetting programs and carbon capture and storage technologies can help to offset and remove CO_2 emissions from the atmosphere.[10]

Policy and regulatory measures also play a crucial role in reducing CO_2 emissions. Governments can implement policies such as carbon taxes, emissions trading schemes, and regulations that mandate emissions reductions from specific industries or sectors. These measures can provide economic incentives for companies to reduce their emissions, while also promoting innovation and the development of new technologies.[11]

2) The Chemistry of CO_2: A Comprehensive Overview

Carbon dioxide (CO_2) is a colorless, odorless gas that is naturally present in the Earth's atmosphere. It is composed of one carbon atom and two oxygen atoms Figure (1), and is a critical component in many natural processes, including photosynthesis and respiration. Despite its importance in nature, carbon dioxide has become a major concern in recent years due to its impact on the environment and climate change. In this article, we will provide a comprehensive overview of the chemistry of CO_2, including its properties, sources, and reactions.[12]

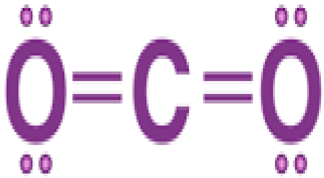

Figure 1: Carbon dioxide (CO_2)

❖ Properties of CO_2

Carbon dioxide is a non-polar molecule with a linear shape, meaning it has no overall electrical charge and its atoms are arranged in a straight line. It has a molecular weight of 44.01 g/mol and a density of 1.98 kg/m³ at standard temperature and pressure (STP), which is 0°C and 1 atm. CO_2 is highly soluble in water, forming carbonic acid, and can also be easily liquefied under high pressure.[13]

❖ Sources of CO_2

Carbon dioxide is produced naturally by many biological and geological processes, including the respiration of living organisms, decay of organic matter, volcanic activity, and the dissolution of carbonate rocks. However, human activities such as burning fossil fuels, deforestation, and industrial processes have significantly increased the concentration of CO_2 in the atmosphere, leading to concerns about climate change and global warming.[14]

❖ Reactions of CO_2

Carbon dioxide is a highly reactive compound that participates in a variety of chemical reactions. In the atmosphere, it reacts with water vapor to form carbonic acid, which can further react with other substances to form carbonate and bicarbonate ions. CO_2 can also participate in photosynthesis, where it is converted into organic compounds by plants and algae.[15]

One of the most important reactions involving CO_2 is its reaction with water to form carbonic acid, which plays a critical role in regulating the pH of many natural systems, including oceans, lakes, and rivers. In addition, carbon dioxide can react with a variety of metal oxides to form metal carbonates, which are used in many industrial processes, such as the production of cement and glass.[16]

Another important reaction involving carbon dioxide is its role as a greenhouse gas. CO_2 and other greenhouse gases trap heat in the atmosphere, leading to global warming and climate change. This has led to efforts to reduce greenhouse gas emissions and find alternative sources of energy.[17]

3) What are carbon emission?

Carbon emissions are the release of carbon dioxide (CO_2) and other greenhouse gases into the atmosphere. Carbon emissions are produced by a variety of human activities, including the burning of fossil fuels such as coal, oil, and natural gas, as well as industrial processes and deforestation.[18]

Carbon dioxide is a colorless, odorless gas that is naturally present in the Earth's atmosphere. It plays an important role in regulating the Earth's temperature by trapping heat from the sun and preventing it from escaping into space. However, when carbon emissions increase, they can trap too much heat in the atmosphere, leading to a phenomenon known as global warming.[19]

The burning of fossil fuels is the largest source of carbon emissions, accounting for around 75% of global greenhouse gas emissions. When fossil fuels are burned, they release carbon dioxide into the atmosphere, which then contributes to global warming.[20] This process is often referred to as the "greenhouse effect″.

In addition to carbon dioxide, other greenhouse gases, such as methane and nitrous oxide, also contribute to global warming. These gases are produced by agricultural practices, such as livestock farming, as well as industrial processes, such as the production of cement and other building materials.[21]

The consequences of carbon emissions and global warming are significant and wide-ranging. Rising temperatures can lead to more frequent and severe weather events, such as droughts, floods, and hurricanes. They can also cause sea levels to rise, threatening low-lying coastal communities and islands. In addition, global warming can have negative impacts on wildlife and ecosystems, leading to habitat loss and biodiversity decline.[22]

To address the problem of carbon emissions and global warming, many countries and organizations have adopted policies and strategies to reduce greenhouse gas emissions. This includes the development of renewable energy sources, such as solar and wind power, as well as improving energy efficiency in buildings and transportation. In addition, initiatives such as reforestation and sustainable agriculture practices can help to sequester carbon and reduce emission.[23]

4) Sources of CO_2 Emissions: An In-Depth Analysis:

Carbon dioxide (CO_2) emissions are a significant contributor to global warming and climate change. They result from a variety of human activities, including the burning of fossil fuels, deforestation, industrial processes, and agricultural practices. Understanding the sources of CO_2 emissions is crucial in formulating effective policies and strategies to mitigate their impact on the environment. In this article, we will take an in-depth look at the various sources of CO_2 emission.[2]

- Fossil fuel combustion:

Fossil fuels, including coal, oil, and natural gas Figure (2), are the primary source of energy for many human activities, including transportation, electricity generation, and heating. When these fuels are burned, they release CO_2 into the atmosphere. According to the International Energy Agency (IEA), the combustion of fossil fuels accounted for approximately 33 gigatons of CO_2 emissions in 2020, making it the largest contributor to global emission.[24]

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Figure 2: Carbon emission from fossil fuel

- Deforestation and land-use changes:

According to the International Energy Agency (IEA), the combustion of fossil fuels Accounted for approximately 33 gigatons of CO_2 emissions in 2020, making it the largest contributor to global emissions. Deforestation and land-use changes accounted for approximately 10% of global CO_2 emissions in 2020, according to the Global Carbon Project.[25]

- Industrial processes:

Industrial processes, such as cement production and steelmaking, also contribute to CO_2 emissions. Cement production, in particular, is a significant contributor, accounting for approximately 7% of global emissions in 2020, according to the IEA.[26]

- Agricultural practices:

Agriculture is a significant contributor to CO_2 emissions, primarily through livestock production and fertilizer use. Livestock produce methane, a potent greenhouse gas that contributes to global warming, while fertilizer use releases nitrous oxide, another potent greenhouse gas. According to the Food and Agriculture Organization of the United Nations, agriculture accounted for approximately 10% of global greenhouse gas emissions in 2018. [27]

- Transportation:

Transportation, including cars, trucks, ships, and airplanes, is a significant source of CO_2 emissions. According to the IEA, the transportation sector accounted for approximately 24% of global energy-related CO_2 emissions in 2020. [28]

5) How the Carbon emission effect the planet:

Carbon emissions, primarily in the form of carbon dioxide, have a significant impact on the growth and survival of plants. While plants require carbon dioxide for photosynthesis, excessive amounts of this gas in the atmosphere can lead to a range of negative effects, including changes in plant physiology, growth, and reproduction. In this article, we will explore how carbon emissions affect plants and their ability to thrive.[29]

Carbon emissions result from a range of human activities, including the burning of fossil fuels and deforestation. The concentration of carbon dioxide in the Earth's atmosphere has been steadily increasing since the Industrial Revolution, reaching levels not seen for millions of years. This increase in atmospheric carbon dioxide has already begun to affect the growth and health of many plant species, and the effects are likely to become more pronounced in the coming decades.[30]

One of the primary ways in which carbon emissions affect plants is through their impact on photosynthesis. Photosynthesis is the process by which plants use sunlight to convert carbon dioxide and water into glucose and oxygen. As atmospheric carbon dioxide levels increase, plants initially experience a boost in photosynthesis, as more carbon dioxide is available for them to use. However, this boost is often short-lived, as the plant's ability to process the additional carbon dioxide is limited by other factors, such as the availability of water and nutrients.[31]

As a result, long-term exposure to high levels of atmospheric carbon dioxide can actually reduce the rate of photosynthesis in many plant species. This reduction in photosynthesis can lead to a decrease in plant growth, as less energy is available for the plant to use. In addition, high levels of atmospheric carbon dioxide can cause changes in the timing of plant growth and development, which can disrupt the natural timing of ecosystem processes.[32]

Carbon emissions can also have negative effects on the reproductive success of plants. For example, studies have shown that high levels of atmospheric carbon dioxide can lead to a decrease in the production of pollen and seed, which can impact the survival of many plant species. Additionally, changes in plant growth and development can lead to shifts in the timing of flowering and fruiting, which can impact the ability of pollinators and seed dispersers to interact with the plant.[33]

6) Global carbon emission and their economic cost:

Global carbon emissions are one of the greatest challenges facing our world today, with a significant impact on our economies and societies. The burning of fossil fuels for energy, transportation, and industrial processes is the primary source of carbon emissions, and the consequences of these emissions are felt around the world. In this article, we will explore the economic costs of global carbon emissions and the challenges of transitioning to a low-carbon economy.[34]

The economic costs of global carbon emissions are significant and are projected to rise in the coming years. The Intergovernmental Panel on Climate Change (IPCC) estimates that the cost of damage caused by global warming could amount to as much as 10% of global GDP by the end of the century. These costs arise from a range of factors, including more frequent and severe natural disasters, damage to infrastructure, and loss of productivity due to rising temperatures.[35]

The economic impact of carbon emissions is not limited to the costs of damage caused by climate change Table (01): global carbon emissions and their economic costs based on data available as of my knowledge cutoff (2021). The costs of transitioning to a low-carbon economy are also significant. The shift away from fossil fuels and towards renewable energy sources, for example, requires significant investments in new infrastructure and technologies, which can be expensive. Additionally, the costs of reducing carbon emissions can be unevenly distributed, with some sectors of the economy, such as coal and oil, facing significant economic disruption.[36]

Table 1: global carbon emissions and their economic costs based on data available as of my knowledge cutoff (2021).

Year	Global Carbon Emissions (CO_2 e, in gigatons)	Economic Cost (in trillions of USD)
1990	22.7	-
2000	26.5	-
2010	31.6	0.87
2015	35.7	1.50
2016	36.3	1.56
2017	36.4	1.79
2018	37.1	2.28
2019	38.0	2.52
2020	34.0*	-

Despite the economic challenges of transitioning to a low-carbon economy, many experts argue that the costs of inaction are far greater. Climate change threatens to disrupt economic systems and social structures around the world, leading to widespread social and economic upheaval. The IPCC has warned that the costs of inaction could be catastrophic, with a loss of productivity, human life, and biodiversity that far outweighs the costs of action.[37]

To mitigate the economic costs of global carbon emissions, many countries are implementing policies and regulations to reduce carbon emissions and promote renewable energy sources Table (2). These policies include carbon taxes, emissions trading schemes, and regulations on emissions from industry and transportation. Additionally, many businesses and organizations are investing in renewable energy and other low-carbon technologies, recognizing the potential economic benefits of transitioning to a low-carbon economy.[38]

Table 2: global carbon emission and their economic cost by country.

Country	Carbon Emissions (CO_2 e, in megatons)	Economic Cost (in billions of USD)
United States	5,140	350
China	10,540	250
European Union	3,480	200
India	3,240	100
Russia	1,640	60
Japan	1,120	50
South Korea	660	20
Canada	580	20
Iran	590	30
Saudi Arabia	610	35
Rest of the World	18,930	365

7) The evolution of carbon dioxide emission in Algeria:

Algeria, like many other countries in the world, is facing the challenge of reducing its carbon dioxide emissions. As a signatory of the Paris Agreement, Algeria has committed to reducing its greenhouse gas emissions in order to limit global warming to well below 2 degrees Celsius. In this article, we will explore the evolution of carbon dioxide emissions in Algeria over the years.[39]

According to the Global Carbon Atlas, Algeria's carbon dioxide emissions have been steadily increasing since the early 2000s. In 2000, the country emitted approximately 80 million metric tons of CO_2. By 2018 Figure (3), this number had risen to approximately 157 million metric tons of CO_2.[40]

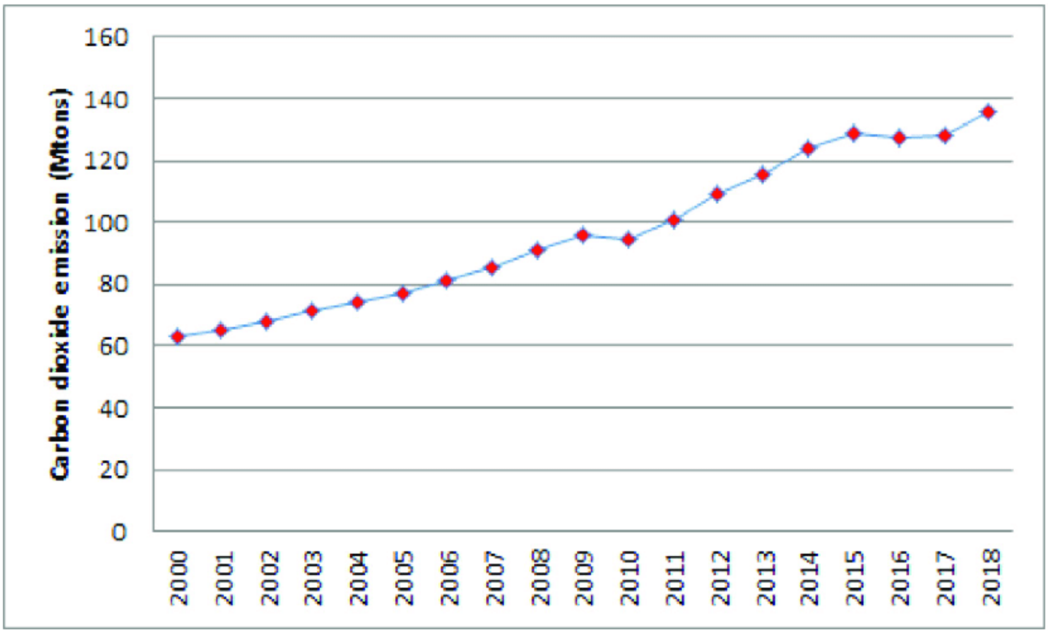


Figure 3: Evolution of CO_2 emission in Algeria (2000-2018)

One of the primary drivers of Algeria's carbon dioxide emissions is the country's reliance on fossil fuels. Algeria is one of the largest producers of oil and natural gas in Africa, and these fuels account for a significant portion of the country's energy mix. In addition, Algeria has a large industrial sector that is also heavily reliant on fossil fuels, particularly natural gas.[41]

Another factor contributing to Algeria's rising carbon dioxide emissions is the country's growing population and economy. As the population and economy grow, so does the demand for energy and resources, which in turn leads to increased emissions.

Despite the challenges posed by rising emissions, Algeria has taken some steps towards reducing its carbon footprint. The country has invested in renewable energy sources, particularly solar and wind power, and has set a target of producing 27% of its electricity from renewable sources by2030.[42] In addition, the government has implemented policies to promote energy efficiency and has launched public awareness campaigns to encourage individuals and businesses to adopt more sustainable practices.[43]

However, there is still much work to be done if Algeria is to meet its commitments under the Paris Agreement. The country will need to continue to invest in renewable energy sources and promote energy efficiency, while also finding ways to reduce emissions from its industrial and transportation sectors. In addition, international cooperation and financial support will be essential to help Algeria transition to a low-carbon economy.[44]

Algeria's growing carbon dioxide emissions have significant implications for both the country and the global community. Climate change, driven in part by rising greenhouse gas emissions, poses a threat to the world's ecosystems, human health, and economy. Algeria, as a country highly vulnerable to climate change impacts, must take action to reduce its emissions and adapt to the changing climate.[45]

One of the primary impacts of climate change on Algeria is the risk of desertification. The country is already one of the driest in the world, and rising temperatures and changing rainfall patterns could lead to further desertification and degradation of the country's ecosystems. This, in turn, could have significant impacts on agriculture, food security, and the livelihoods of rural communities.[45]

In addition, rising temperatures and more frequent extreme weather events, such as heat waves and droughts, could have significant impacts on public health. Algeria, like many other countries in the world, has already seen an increase in heat-related illnesses and deaths in recent years, and this trend is likely to continue if emissions are not reduced.[46]

Despite these challenges, Algeria has the potential to become a leader in the transition to a low-carbon economy. The country has significant solar and wind power potential, and with the right policies and investments, could become a major producer and exporter of renewable energy. In addition, reducing emissions from the industrial and transportation sectors through increased energy efficiency and the adoption of cleaner technologies could help to reduce Algeria's carbon footprint while also promoting economic growth and job creation.[47]

8) Reducing CO_2 Emissions: Strategies and Solutions: [48]

As concerns about climate change and global warming continue to rise, reducing carbon dioxide (CO_2) emissions has become a top priority for governments, businesses, and individuals around the world. CO_2 is a major contributor to the greenhouse effect, which causes the Earth's atmosphere to trap heat and leads to rising temperatures and other negative effects.

Reducing CO_2 emissions requires a multi-pronged approach that involves a range of strategies and solutions. Here are some of the most effective ways to cut down on CO_2 emissions:

- Energy Efficiency: One of the most effective ways to reduce CO_2 emissions is to improve energy efficiency in homes, businesses, and other buildings. This can be achieved through measures such as upgrading insulation, installing energy-efficient appliances and lighting, and using smart thermostats that automatically adjust heating and cooling based on occupancy.
- Renewable Energy: Another key strategy for reducing CO_2 emissions is to shift away from fossil fuels and toward renewable energy sources such as solar, wind, and hydro power. Governments and businesses can encourage the adoption of renewable energy through

policies and incentives that promote investment in renewable infrastructure and technologies.

- Carbon Capture and Storage: Carbon capture and storage (CCS) technologies can also help reduce CO_2 emissions by capturing carbon from power plants and other industrial sources and storing it underground or in other long-term storage facilities.
- Sustainable Transportation: Transportation is a major source of CO_2 emissions, and reducing emissions in this sector requires a range of solutions, including improving public transportation systems, promoting electric and hybrid vehicles, and encouraging the use of biking and walking.
- Circular Economy: A circular economy, in which waste is reduced and materials are recycled or repurposed, can also help reduce CO_2 emissions by cutting down on the need for new materials and reducing the energy required to produce and transport them.

Reducing CO_2 emissions is not just an environmental imperative, it is also an economic opportunity. Many of the strategies and solutions outlined above can create jobs and stimulate economic growth, while also protecting the environment and promoting sustainable development.

Governments, businesses, and individuals all have a role to play in reducing CO_2 emissions. By working together and adopting a range of strategies and solutions, we can help mitigate the worst effects of climate change and create a more sustainable future for all.

❖ Here are some additional strategies and solutions for reducing CO_2 emissions:[49]

- ✓ Sustainable Agriculture: Agriculture is responsible for a significant portion of global greenhouse gas emissions, mainly from the production of livestock and fertilizer use. Sustainable agriculture practices, such as reducing meat consumption, using natural fertilizers, and planting cover crops, can help reduce these emissions.
- ✓ Forest Conservation: Forests absorb and store carbon, making them important for mitigating the effects of climate change. Conserving and restoring forests, as well as promoting sustainable forestry practices, can help reduce CO_2 emissions and protect biodiversity.
- ✓ Carbon Pricing: Carbon pricing is a policy mechanism that puts a price on carbon emissions, either through a carbon tax or a cap-and-trade system. By putting a price

on carbon, this approach encourages businesses and individuals to reduce their emissions and invest in low-carbon technologies.

- ✓ Green Buildings: Buildings account for a significant portion of global energy use and greenhouse gas emissions. Green building practices, such as using sustainable materials, designing for energy efficiency, and using renewable energy sources, can help reduce these emissions.

By educating individuals and communities about the causes and consequences of climate change, as well as the solutions available to address it, we can build a more informed and engaged society that is committed to reducing emissions and creating a more sustainable future. Reducing CO_2 emissions is a complex challenge that requires a range of strategies and solutions. By adopting a holistic approach that includes energy efficiency, renewable energy, carbon capture and storage, sustainable transportation and agriculture, forest conservation, carbon pricing, green buildings, and public education and awareness, we can make significant progress toward a more sustainable future.

9) The technological and economic prospects for CO_2 utilization and removal:

The economic prospects for CO_2 utilization are mixed. While there is potential for significant cost savings and revenue generation, the technology is still in its early stages, and the market for CO_2-based products is relatively small. Additionally, there are concerns about the scalability of these technologies and their ability to compete with traditional products on price.[50]

❖ CO_2 Removal:

CO_2 removal, also known as negative emissions, refers to the process of removing CO_2 from the atmosphere and storing it underground. There are several approaches to CO_2 removal, including afforestation (planting trees), bioenergy with carbon capture and storage (BECCS), and direct air capture (DAC).[51]

Afforestation involves planting trees to absorb CO_2 from the atmosphere. While this approach is relatively low-tech, it is also relatively slow and requires large amounts of land.[51]

BECCS involves using biomass (such as agricultural waste) to produce energy and capturing the CO_2 emissions. This approach has the potential to be carbon negative, meaning it can remove more CO_2 from the atmosphere than it produces. However, it requires large amounts of land and biomass, and there are concerns about the environmental impact of large-scale biomass production.

DAC involves using machines to directly capture CO_2 from the atmosphere. This approach is still in the experimental stage, but several companies, including Carbon Engineering and Clime works, are developing DAC technology. While this approach has the potential to be highly effective, it is also likely to be expensive and energy-intensive.[52]

The economic prospects for CO_2 removal are also mixed. While there is potential for significant revenue generation, the technology is still in its early stages, and there are concerns about the scalability and cost-effectiveness of these technologies.[53]

10) Policy and Regulatory Measures to Control CO_2 Emissions:

Carbon dioxide (CO_2) emissions are a major contributor to climate change and global warming. To address this problem, governments around the world have implemented policy and regulatory measures to control CO_2 emissions.[54]

- Carbon Pricing:

Carbon pricing is a policy that puts a price on the carbon content of fossil fuels, such as coal, oil, and gas. This can take the form of a carbon tax or a cap-and-trade system, where companies are given a limit on how much CO_2 they can emit and can buy or sell emissions allowances. Carbon pricing incentivizes companies to reduce their emissions and invest in clean energy technologies. Countries such as Canada, the European Union, and China have implemented carbon pricing policies, with varying levels of success.[55]

- Renewable Energy Targets:

Renewable energy targets are policies that require a certain percentage of a country's energy to come from renewable sources, such as wind, solar, and hydropower. These policies encourage investment in clean energy technologies and reduce reliance on fossil fuels. Countries such as Germany, India, and the United Kingdom have set ambitious renewable energy targets, with some countries aiming to generate 100% of their electricity from renewable sources by 2050.[10]

- Fuel Economy Standards:

Fuel economy standards are regulations that require automakers to produce vehicles that meet certain fuel efficiency standards. These standards reduce the amount of CO_2 emitted by vehicles and encourage the development of cleaner technologies, such as electric and hybrid vehicles. Countries such as the United States, Canada, and Japan have implemented fuel economy standards, with some countries setting targets for zero-emission vehicles.[56]

- Building Codes:

Building codes are regulations that require buildings to meet certain energy efficiency standards. This includes standards for insulation, lighting, and heating and cooling systems. Building codes reduce the energy consumption of buildings and encourage the use of renewable energy sources. Countries such as the United States, Canada, and the European Union have implemented building codes, with some countries setting targets for net-zero buildings.[57]

- International Agreements:

International agreements are agreements between countries to work together to reduce global CO_2 emissions. The most significant international agreement on climate change is the Paris Agreement, which was signed in 2015 by 196 countries. The Paris Agreement aims to limit global warming to well below 2 degrees Celsius above pre-industrial levels and pursue efforts to limit the temperature increase to 1.5 degrees Celsius. The agreement includes commitments by countries to reduce their CO_2 emissions and increase their use of renewable energy.[58]

While these policy and regulatory measures are effective in controlling CO_2 emissions, there are challenges to their implementation. Some of these challenges include political opposition, lack of public support, and difficulties in measuring emissions. Additionally, the effectiveness of these policies depends on their implementation and enforcement. However, with continued innovation and political will, these measures have the potential to significantly reduce CO_2 emissions and mitigate the impacts of climate change.[59]

11) Study of the effecting some factors and the precipitate calcium ions from produced water:

Produced water is a byproduct of oil and gas production that contains high levels of calcium ions. These ions can cause scaling and other problems in production equipment and pipelines, leading to reduced efficiency and increased costs. As a result, it is important to study the factors that affect the precipitation of calcium ions from produced water.[60]

One factor that affects the precipitation of calcium ions is PH. When the pH of the produced water is high, calcium ions tend to stay in solution, while at low pH levels, they tend to precipitate out of solution. Therefore, adjusting the pH of the produced water can help to control the precipitation of calcium ions.

Another factor that affects the precipitation of calcium ions is temperature. As the temperature of the produced water increases, the solubility of calcium ions decreases, which leads to their precipitation. Therefore, controlling the temperature of the produced water can help to reduce the precipitation of calcium ions.[61]

The presence of other ions in the produced water can also affect the precipitation of calcium ions. For example, sulfate ions can form insoluble calcium sulfate, which can lead to scaling in production equipment. Therefore, it is important to consider the concentration and type of other ions present in the produced water when studying the precipitation of calcium ions.[62]

There are several methods for precipitating calcium ions from produced water, including chemical precipitation, ion exchange, and reverse osmosis. Chemical precipitation involves adding a chemical agent, such as lime or soda ash, to the produced water to cause the precipitation of calcium ions. Ion exchange involves passing the produced water through a resin bed that selectively removes calcium ions.

Reverse osmosis involves passing the produced water through a membrane that selectively removes calcium ions In addition to the methods mentioned above, there are other methods for precipitating calcium ions from produced water, such as electrocoagulation and membrane filtration. Electrocoagulation involves the use of an electric current to destabilize and aggregate the calcium ions, which then settle out of the produced water. Membrane filtration involves passing the produced water through a membrane that selectively removes calcium ions based on their size and charge.[63]

It is also important to consider the environmental impact of the methods used for precipitating calcium ions from produced water. Chemical precipitation can lead to the generation of sludge, which can be difficult to dispose of and may contain other contaminants. Ion exchange and reverse osmosis require the use of energy and may generate wastewater that requires treatment before disposal. Therefore, it is important to consider the overall sustainability and environmental impact of the methods used for precipitating calcium ions from produced water.[64]

Moreover, it is worth noting that the production of oil and gas generates a large amount of produced water, which can be a significant source of pollution if not properly managed. In addition to the precipitation of calcium ions, it is important to consider other methods for treating and managing produced water, such as recycling and reuse, evaporation and crystallization, and injection into deep wells. These methods can help to reduce the environmental impact of produced water and minimize the amount of waste generated.[65]

12) What is gross domestic product GDP and its types?

Gross Domestic Product (GDP) is a measure of the economic output of a country, which includes the value of all goods and services produced within a country's borders over a given period. However, as the world is grappling with the challenge of climate change, there has been increasing interest in measuring the carbon footprint of a country's economy. This has given rise to the concept of the Gross Domestic Product of carbon dioxide (CO_2).]66[

The GDP of CO_2 is a measure of the total amount of CO_2 emissions generated by a country's economic activity. It provides an estimate of the carbon footprint of a country's economy and has become increasingly important in the context of global efforts to mitigate climate change.

To calculate the GDP of CO_2, one needs to quantify the amount of CO_2 emissions generated by different sectors of the economy, such as energy production, manufacturing, transportation, and other industries figure (4). The emissions are typically measured in metric tons of CO_2 equivalent ($_{CO2e}$), which includes not only CO_2 emissions but also other greenhouse gases, such as methane and nitrous oxide that have a higher global warming potential than CO_2.[67]

There are two main approaches to measuring the GDP of CO_2: production-based and consumption-based. Production-based GDP of CO_2 measures the emissions generated within a country's borders as a result of economic activity, including energy production, manufacturing, transportation, and other industries. This approach assigns the responsibility for emissions to the country where they are produced, regardless of whether the goods and services produced are Consumed domestically or exported.[68]

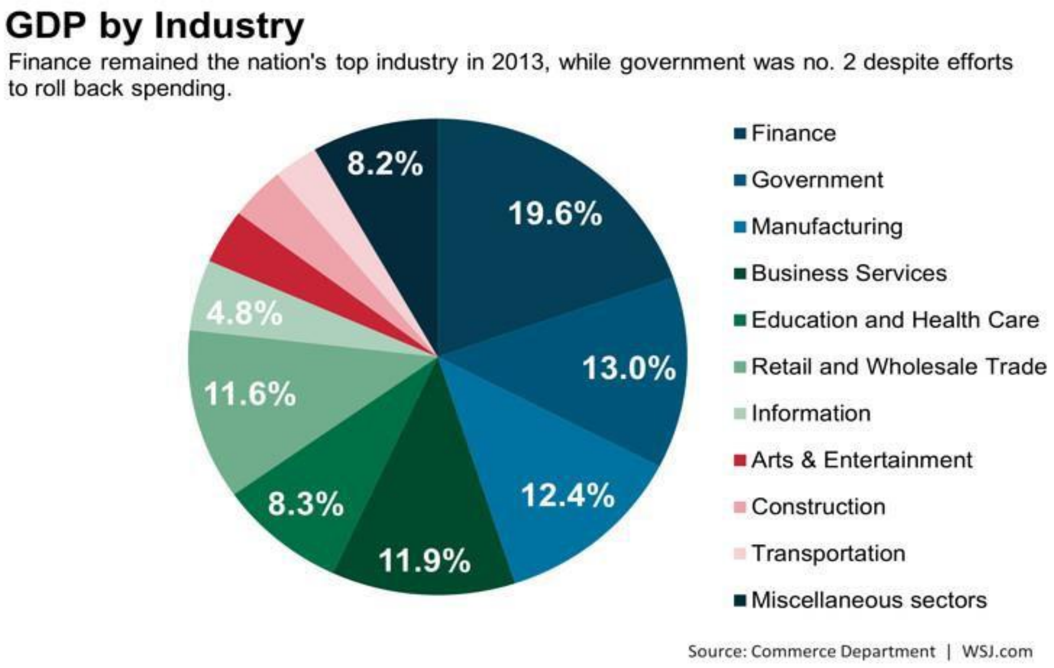


Figure 4: GPD by industry

Consumption-based GDP of CO_2, on the other hand, takes into account the emissions embedded in the goods and services that a country consumes, regardless of where they were produced. This approach reflects the idea that the responsibility for emissions should be shared between producers and consumers, as both play a role in driving demand for emissions-intensive goods and services.

While both approaches provide useful information, they have different implications for policy and action. Production-based GDP of CO_2 is often used to set emissions reduction targets and track progress, as it focuses on a country's domestic emissions. Consumption-based GDP of CO_2, on the other hand, highlights the role of international trade and can inform policies such as carbon tariffs or border adjustments.[69]

It is important to note that the GDP of CO_2 is not a perfect measure of the carbon footprint of a country's economy. It does not capture all greenhouse gases, nor does it account for the environmental impacts of economic activity beyond greenhouse gas emissions. Nevertheless, it provides a useful indicator of the carbon footprint of a nation's economy and can help inform policies to reduce emissions and combat climate change.[70]

13) There are two main types of the Gross Domestic Product of carbon dioxide (CO_2):

Within a country's borders as a result of economic activity, including energy production, manufacturing, transportation, and other industries. This approach assigns the responsibility for emissions to the country where they are produced, regardless of whether the goods and services produced are consumed domestically or exported. Production-based GDP of CO_2 is often used to set emissions reduction targets and track progress, as it focuses on a country's domestic emissions.[71]

Consumption-based GDP of CO_2: This approach takes into account the CO_2 emissions embedded in the goods and services that a country consumes, regardless of where they were produced. This approach reflects the idea that the responsibility for emissions should be shared between producers and consumers, as both play a role in driving demand for emissions-intensive goods and services. Consumption-based GDP of CO_2 highlights the role of international trade and can inform policies such as carbon tariffs or border adjustments.[72]

Both types of GDP of CO_2 provide useful information for policymakers and researchers interested in reducing greenhouse gas emissions and mitigating the impacts of climate change. However, they have different implications for policy and action, and the choice of approach depends on the specific objectives of the analysis or policy.

As the world works to address the impacts of climate change and transition to a low-carbon economy, the challenges and opportunities for businesses, governments, and individuals are becoming increasingly clear. Adapting to a low-carbon future is essential to mitigate the worst effects of climate change and ensure a sustainable future for all.[73]

❖ Here are ten challenges and opportunities for adapting to a low-carbon future:[74]

- ✓ Reducing greenhouse gas emissions: The most fundamental challenge of adapting to a low-carbon future is to reduce greenhouse gas emissions across all sectors of the economy. This requires a transition away from fossil fuels and towards renewable energy sources, such as solar, wind, and hydropower.
- ✓ Decarbonizing transportation: Transportation is one of the largest sources of greenhouse gas emissions worldwide. Adapting to a low-carbon future requires the decarbonization of the transportation sector, through the electrification of vehicles, the development of low-carbon fuels, and the promotion of public transportation.
- ✓ Building energy-efficient buildings: Buildings are a significant source of greenhouse gas emissions, primarily through their energy consumption. Adapting to a low-carbon future requires the construction of energy-efficient buildings, the use of renewable energy sources, and the integration of smart technologies to optimize energy consumption.
- ✓ Promoting circular economy: The linear economy model of "take-make-dispose" is a significant source of greenhouse gas emissions. Adapting to a low-carbon future requires the promotion of a circular economy, where waste is minimized, and resources are reused and recycled.
- ✓ Investing in sustainable infrastructure: The transition to a low-carbon future requires significant investments in sustainable infrastructure, such as renewable energy systems, public transportation, and green buildings.
- ✓ Developing low-carbon industries: The shift towards a low-carbon future offers opportunities for the development of new low-carbon industries, such as renewable energy technologies, energy-efficient products, and sustainable agriculture.
- ✓ Addressing social and environmental justice: The transition to a low-carbon future must be inclusive and address social and environmental justice issues. This

includes ensuring access to clean energy and sustainable infrastructure for all communities, particularly those that have been historically marginalized.

- ✓ Promoting carbon pricing and regulation: Adapting to a low-carbon future requires the implementation of policies and regulations that promote carbon pricing, and discourage the use of fossil fuels.
- ✓ Increasing public awareness and engagement: Adapting to a low-carbon future requires the engagement and participation of individuals and communities. Increasing public awareness and understanding of the impacts of climate change, and the benefits of a low-carbon future is essential to drive change.
- ✓ Collaboration and partnership: Adapting to a low-carbon future requires collaboration and partnership across sectors and borders. Public-private partnerships, cross-sectoral collaboration, and international cooperation are critical to accelerating the transition to a low-carbon future.

14) Materials that store carbon and help reduce greenhouse gas emissions:

Carbon dioxide (CO_2) is the primary greenhouse gas responsible for global warming and climate change. To combat the effects of climate change, it is crucial to reduce the amount of CO_2 released into the atmosphere. One of the most effective ways to achieve this is through carbon capture and storage (CCS) technology. CCS involves capturing CO_2 emissions from power plants and other industrial sources, transporting the gas, and storing it in a safe and permanent manner.[75]

There are several materials that store carbon and help reduce greenhouse gas emissions. These materials fall into two categories: natural and engineered.

Natural materials include trees and other plants that absorb CO_2 during photosynthesis. Trees store carbon in their trunks, branches, and leaves, and this carbon is only released when the tree dies or decays. Therefore, planting more trees and preserving forests is an essential strategy for reducing greenhouse gas emissions. In addition to their carbon storage capacity, trees also provide many other environmental benefits, including air and water purification, soil conservation, and biodiversity.[76]

Engineered materials are designed specifically to capture and store CO_2 emissions. One such material is carbon capture and storage (CCS) technology, which captures CO_2 from power plants and other industrial sources and stores it underground or in other storage facilities. CCS technology has the potential to significantly reduce greenhouse gas emissions from industrial processes.[77]

Another engineered material that stores carbon is biochar. Biochar is a type of charcoal made from organic material such as wood chips, crop waste, or animal manure. When added to soil, biochar can improve soil fertility and water retention while also storing carbon for hundreds or even thousands of years. Biochar is considered a promising technology for mitigating climate change and promoting sustainable agriculture.[78]

Carbon-negative concrete is another engineered material that has the potential to reduce greenhouse gas emissions. Traditional concrete production is responsible for a significant amount of CO_2 emissions. However, carbon-negative concrete is designed to absorb CO_2 from the atmosphere during the curing process, effectively storing carbon in the material. This technology has the potential to revolutionize the construction industry by reducing its carbon footprint.[7]

Finally, carbon-negative plastics are an emerging class of materials that have the potential to reduce greenhouse gas emissions. These plastics are made from renewable sources such as plants, and they have a negative carbon footprint because they absorb more CO_2 during production than they release. Carbon-negative plastics have the potential to replace traditional plastics made from fossil fuels, which are a significant source of greenhouse gas emissions.[79]

15) Carbon capture:

Carbon capture is a technology that has the potential to reduce greenhouse gas emissions and mitigate the effects of climate change. It involves capturing carbon dioxide (CO_2) from power plants, industrial processes, and other sources, and then storing or reusing it instead of releasing it into the atmosphere.

The need for carbon capture arises from the fact that the burning of fossil fuels, such as coal, oil, and natural gas, for energy production is one of the largest sources of greenhouse gas emissions. These emissions trap heat in the atmosphere, leading to global warming and other environmental problems.[80]

Carbon capture works by using a variety of techniques to separate CO_2 from other gases in the emissions stream. The most common method is called post-combustion capture, which involves using solvents or other chemicals to absorb CO_2 from the flue gas produced by power plants or other industrial processes. The captured CO_2 can then be compressed and transported to a storage site, such as an underground geological formation, where it can be stored permanently.[81]

Another type of carbon capture is pre-combustion capture, which involves removing carbon from fossil fuels before they are burned. This process is often used in conjunction with a gasification process, where the fuel is converted into a gas before it is burned. The resulting CO_2 can then be captured and stored as described above.

A third type of carbon capture is called oxy-fuel combustion, which involves burning fuel in pure oxygen instead of air. This produces a concentrated stream of CO_2 that can be captured and stored.[82]

Carbon capture has the potential to reduce greenhouse gas emissions from power plants and other industrial sources by up to 90%. However, the technology is still in its early stages and faces several challenges, including high costs and the need for large-scale infrastructure.[83]

Despite these challenges, carbon capture is seen as an important tool in the fight against climate change. It can help to bridge the gap between fossil fuels and renewable energy sources by reducing emissions from existing fossil fuel infrastructure. It can also be used in conjunction with other technologies, such as renewable energy and energy storage, to create a more sustainable energy system.

Carbon capture is not only important for reducing emissions from power plants and industrial processes, but it can also be used in other sectors such as transportation and agriculture. For example, carbon capture technology can be applied to capture CO_2 emissions from vehicles, airplanes, and ships. Additionally, it can be used to capture carbon dioxide from agricultural processes, such as livestock farming and crop cultivation.[84]

Furthermore, carbon capture can also be used to produce a range of valuable products, such as chemicals, fuels, and building materials. This process is known as carbon capture and utilization (CCU), which involves converting captured CO_2 into useful products instead of simply storing it. For example, captured CO_2 can be used to produce synthetic fuels, plastics, and cement, which can help to reduce the carbon footprint of these industries.[85]

In other words, CCU there is also a concept called carbon capture and storage (CCS), which involves capturing CO_2 emissions and storing them underground in geological formations. This approach is sometimes referred to as "carbon sequestration" and is seen as a way to permanently remove CO_2 from the atmosphere. However, there are concerns about the safety and long-term viability of CCS, and it is important to ensure that stored CO_2 does not leak back into the atmosphere.[86]

16) Methods of carbon capture:

Carbon capture is an important process that has been developed to mitigate the effects of climate change by reducing the amount of carbon dioxide released into the atmosphere. Carbon capture methods are designed to capture carbon dioxide from various sources such as power plants, industrial processes, and transportation. The captured carbon dioxide can then be transported and stored safely in geological formations, such as deep saline aquifers or depleted oil and gas reservoirs, or used in industrial applications.[87]

There are various methods of carbon capture that have been developed, and each has its own unique advantages and disadvantages.

- Post-Combustion Capture:

Post-combustion capture is the most commonly used carbon capture method. This method involves capturing carbon dioxide after it has been produced by a combustion process, such as in a power plant or industrial process. The carbon dioxide is separated from other gases, such as nitrogen and oxygen, using a solvent or adsorbent material. The captured carbon dioxide can then be compressed and transported for storage or use.

The advantages of post-combustion capture are that it can be added to existing plants and processes with relatively low capital costs. However, it requires significant energy inputs and can reduce the efficiency of the power plant or industrial process.[81]

- Pre-Combustion Capture:

Pre-combustion capture involves capturing carbon dioxide before it is produced by a combustion process. This method is commonly used in gasification processes, where coal or other fuels are converted into a gas. The carbon dioxide is separated from the gas using a solvent or adsorbent material before the gas is combusted to produce energy.

Pre-combustion capture can be more efficient than post-combustion capture because it captures a purer stream of carbon dioxide. However, it requires a separate gasification process, which can increase capital costs.[88]

- Oxy-Fuel Combustion:

  Oxy-fuel combustion is a process where fuel is burned in a mixture of oxygen and recycled flue gas. This creates a high concentration of carbon dioxide, which can be captured using a solvent or adsorbent material. The captured carbon dioxide can then be compressed and transported for storage or use.

  Oxy-fuel combustion is a promising technology because it can be retrofitted to existing power plants. However, it requires significant energy inputs to generate the oxygen needed for combustion.[89]

- Carbonate Looping:

  Carbonate looping is a process where carbon dioxide reacts with a metal oxide, such as calcium oxide, to form a metal carbonate. The metal carbonate is then heated to release the carbon dioxide and regenerate the metal oxide, which can be used again.

  Carbonate looping has the potential to be more efficient than other carbon capture methods because it produces a stream of pure carbon dioxide. However, it requires a separate chemical process, which can increase capital costs. Carbon capture is an essential process for reducing greenhouse gas emissions and mitigating climate change. The captured carbon dioxide can be stored safely underground, preventing it from entering the atmosphere, or used in industrial applications, such as enhanced oil recovery.

However, carbon capture is not a silver bullet solution to climate change. It is an expensive and energy-intensive process, and it does not address the root cause of climate change, which is the burning of fossil fuels. Additionally, the transportation and storage of captured carbon dioxide figure (5) come with their own risks and challenges, such as leakage and cost.[90]

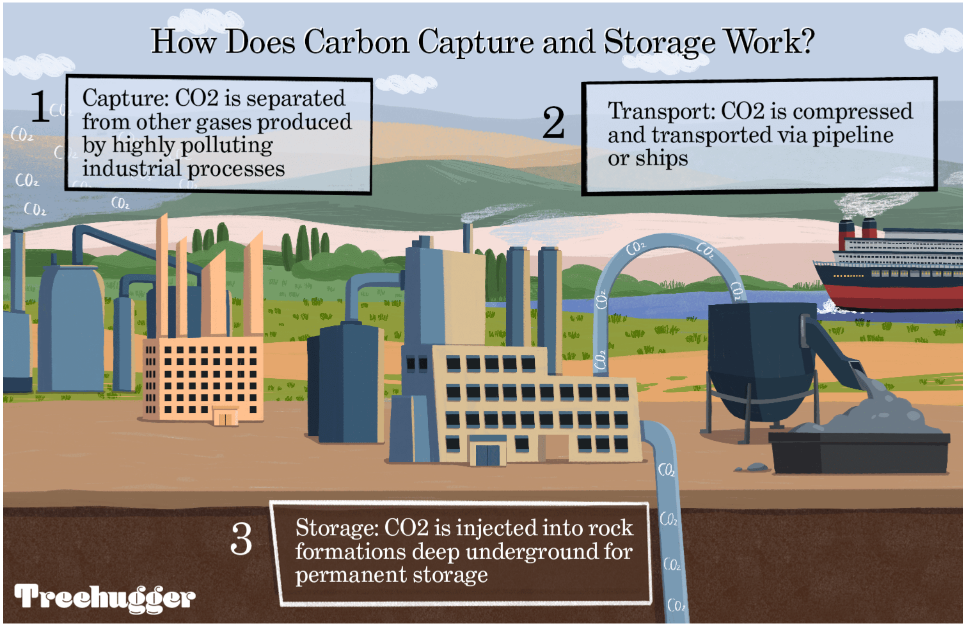


Figure 5: How does capture and storage work

To make carbon capture more feasible, governments and industries need to invest in research and development to reduce costs and increase efficiency. Policies such as carbon pricing and tax credits can also incentivize industries to adopt carbon capture technologies.

Furthermore, it is important to recognize that carbon capture is only one of many solutions needed to address climate change. We also need to focus on reducing our reliance on fossil fuels, promoting renewable energy, and improving energy efficiency.[91]

17) How to store CO_2 yet capture: [92]

As the world continues to grapple with the challenge of reducing greenhouse gas emissions to combat climate change, carbon capture and storage (CCS) technology has emerged as a promising solution to address the issue of carbon dioxide (CO_2) emissions. CCS is a process that involves capturing CO_2 from industrial processes or power plants, transporting it to a storage site, and storing it underground in a safe and secure manner.

The need for CCS technology has become more urgent in recent years, with the concentration of CO_2 in the atmosphere reaching unprecedented levels, leading to a rise in global temperatures and catastrophic weather events. According to the International Energy Agency (IEA), CCS technology could help reduce global CO_2 emissions by up to 15% by 2050.

So how does CCS technology work, and what are the steps involved in storing CO_2? Let's take a closer look:

- CO_2 capture:

  The first step in the CCS process is capturing CO_2 from industrial processes or power plants. This can be done through various technologies such as absorption, adsorption, and membrane separation. The captured CO_2 is then compressed and transported to a storage site.

- Transportation:

  Once the CO_2 has been captured, it needs to be transported to a storage site. This can be done via pipelines, ships, or trucks. The transportation method chosen will depend on the distance between the capture site and the storage site.

- Storage:

  The final step in the CCS process is storing the CO_2 in a safe and secure manner. This can be done through various methods such as geological storage, ocean storage, and mineralization. Geological storage is the most common method used for CCS, which involves injecting the CO_2 into deep underground rock formations such as depleted oil and gas reservoirs, saline aquifers, and coal seams.

  Geological storage is considered to be a safe and effective method of storing CO_2 as it involves injecting the gas into rock formations that are impermeable and geologically stable. Once injected, the CO_2 is trapped underground and held in place by the pressure of the surrounding rock.

- Monitoring:

  To ensure that the stored CO_2 remains secure and does not leak into the atmosphere, it is important to monitor the storage site regularly. This can be done through various methods such as seismic imaging, pressure monitoring, and gas sampling. By monitoring the storage site, any potential leaks can be detected early and addressed before they become a problem.

Conclusion

Based on scientific research and data analysis, it is clear that carbon dioxide (CO_2) emissions from human activities, such as burning fossil fuels and deforestation, are contributing to climate change and global warming. The increase in atmospheric CO_2 levels is causing a range of negative impacts on the environment, including rising sea levels, more frequent and severe weather events, and the loss of biodiversity.[93]

To address the issue of CO_2 emissions, it is necessary to implement measures to reduce and eventually eliminate the use of fossil fuels, promote the adoption of renewable energy sources, improve energy efficiency, and encourage sustainable land use practices. Such actions will require international cooperation and a shift in societal attitudes towards environmental responsibility and sustainability. It is crucial to act quickly and decisively to address CO_2 emissions and mitigate the effects of climate change before irreparable damage is done to our planet and its ecosystems.[94]

Chapter 2

Generalities about the preparation of materials by the dry method liquid solutions and methods of analysis

Introduction

Materials synthesis using dry methods involves the preparation of new materials through the use of powders or solid precursors without the addition of any solvents or liquids. This process can be accomplished through various techniques such as mechanical milling, solid-state reactions, vapor deposition, and thermal treatments.[95]

Mechanical milling is a widely used technique that involves the grinding of powders to reduce their particle size and promote chemical reactivity. Solid-state reactions involve the direct reaction of two or more solids to produce a new compound. Vapor deposition techniques such as physical vapor deposition (PVD) and chemical vapor deposition (CVD) are used to deposit thin films of materials onto a substrate. Thermal treatments involve the heating of solids to promote chemical reactions and transformations.[96]

To analyze the synthesized materials, various techniques can be employed such as X-ray diffraction (XRD), scanning electron microscopy (SEM), Fourier-transform infrared spectroscopy (FTIR), and Raman spectroscopy…etc. XRD is used to determine the crystal structure of the material and the presence of impurities. SEM provide information on the morphology and microstructure of the material. FTIR and Raman spectroscopy are used to determine the chemical composition and functional groups present in the material.[97]

1) General information about preparing materials by dry and hydrothermal methods:

- Dry method:

❖ Materials synthesis using dry method**:**

➢ Definition:

Materials synthesis refers to the process of creating new materials with desired properties and structures using various techniques and methods. It involves combining different chemical elements or compounds to form a new material, or modifying existing materials to improve their properties. The goal of materials synthesis is to produce materials with specific physical, chemical, and mechanical properties that can be used in various applications, such as electronics, medicine, energy, and transportation. Materials synthesis is a key area of research in materials science, chemistry, and engineering, and it plays a crucial role in advancing technology and addressing societal challenges.[98]

Dry methods of materials synthesis involve the preparation of materials in the absence of solvents or liquids. This technique is useful for producing materials that are insoluble or unstable in solvents, or for creating materials with specific physical and chemical properties.[99]

❖ Here are some examples of materials synthesis using dry methods:[100]

✓ Solid-state reaction: This is the most common method for synthesizing materials in a dry environment**.** In this method, the reactants are mixed and ground together to form a homogeneous powder, which is then heated at high temperatures to initiate a chemical reaction. The products of the reaction are usually obtained as a solid powder.

✓ Vapor phase deposition: This method involves the deposition of materials from the vapor phase onto a substrate. The most common technique is chemical vapor deposition (CVD), where a reactant gas is introduced into a chamber and reacts on a heated substrate to form a thin film.

✓ Spray pyrolysis: This technique involves spraying a solution of the precursor onto a hot substrate, which decomposes to form the desired material. This method is commonly used for the synthesis of metal oxides and sulfides.

- ✓ Sol-gel method: This is a wet-chemical method that can be adapted for dry synthesis. In the dry sol-gel method, a mixture of metal alkoxides is ground together to form a powder, which is then heated to form the desired material. This method is commonly used for the synthesis of ceramics and glasses.
- ✓ Mechanical alloying: This method involves the mixing of powders of different metals or alloys, which are then mechanically milled together to form a homogeneous powder. This process leads to the formation of alloys with unique properties that cannot be obtained through conventional casting methods.
- ✓ Flame spray pyrolysis: This method involves the combustion of a mixture of fuel and oxidizer to form a flame, which is then used to spray a precursor solution onto a substrate. The precursor decomposes in the flame to form the desired material, which is deposited onto the substrate.
- ✓ Laser ablation: In this method, a laser beam is used to vaporize a target material, which then condenses onto a substrate to form a thin film. This technique is commonly used for the synthesis of metal and semiconductor thin films.
- ✓ High-pressure high-temperature (HPHT) synthesis: This method involves the application of high pressure and temperature to reactants to initiate a chemical reaction. This method is commonly used for the synthesis of diamonds, superconducting materials, and other high-performance materials.
- ✓ Freeze drying: This method involves the removal of water from a frozen solution or suspension by sublimation under vacuum. This process is commonly used for the synthesis of porous materials, such as aerogels and xerogels.
- ✓ Electrospinning: This method involves the use of an electric field to spin a polymer solution or melt into nanofibers, which are then collected onto a substrate to form a mat or film. This method is commonly used for the synthesis of Nano fiber-based materials, such as filters and scaffolds for tissue engineering.

Preparing materials by dry method refers to a process of creating a substance or product by using dry powders or solid components that are mixed and blended together without the use of a solvent or liquid binder. This method is commonly used in industries such as pharmaceuticals, food processing, and ceramics, among others.

- The process of preparing materials by dry method involves several steps, including:[95]
  - ✓ Weighing and measuring the solid components: The first step involves accurately weighing and measuring the different solid components of the product to ensure that the final mixture is of the desired quality and consistency.
  - ✓ Mixing the components: The solid components are then mixed together thoroughly in a dry mixing apparatus such as a blender or a ball mill. The mixing process ensures that the individual components are evenly distributed throughout the mixture.
  - ✓ Granulation: In some cases, the mixture may need to be granulated to create larger particles or aggregates that are easier to handle and process. This is typically done by adding a small amount of liquid binder to the mixture, which is then dried and sieved to create the desired particle size.
  - ✓ Compaction: In some cases, the mixture may be compressed or compacted into a solid shape using a press or a compactor.
  - ✓ Final processing: The final product may require additional processing steps, such as milling or sieving, to ensure that it meets the required specifications.

  Preparing materials by dry method has several advantages, including reduced processing time, lower energy costs, and the ability to produce products with a high degree of purity and consistency. However, this method may not be suitable for all types of materials, and it may require specialized equipment and expertise to achieve the desired results.

- Benefits of preparing materials by the dry method:[101]
  - ✓ Reduced processing time: Compared to wet methods, dry methods usually require less processing time because there is no need to wait for the solvent to evaporate or for chemical reactions to take place.
  - ✓ Lower energy costs: Dry methods typically use less energy than wet methods because there is no need to heat or cool solvents or other liquids. This can result in significant cost savings over time.
  - ✓ High degree of purity and consistency: Dry methods can produce products with a high degree of purity and consistency because there is no risk of contamination from solvents or other liquids.

- ✓ Improved handling and storage: Dry materials are generally easier to handle and store than wet materials because they are less prone to spoilage, mold, or bacterial growth.
- ✓ Flexibility in product design: Dry methods offer a great degree of flexibility in product design because the solid components can be easily mixed, blended, and granulated to create the desired particle size, shape, and texture.

▪ Hydrothermal method:

❖ Definition:

The hydrothermal method is a chemical synthesis technique that involves the use of high-pressure and high-temperature conditions to facilitate the formation of materials. It is commonly used to synthesize materials that are difficult to prepare by other methods, such as nanoparticles, zeolites, and metal-organic frameworks. In this method, a precursor solution is placed inside a closed vessel and heated to temperatures above the boiling point of water (100°C) under pressure, typically ranging from 1 to 100 atm. The high pressure and temperature create a supercritical fluid environment, which can dissolve and react with the precursor to form the desired material. The process can take place over several hours or days, depending on the material being synthesized. Once the process is complete, the vessel is cooled down slowly to prevent the material from cracking or degrading. The hydrothermal method is widely used in materials science, chemistry, and geology.[102]

❖ Materials synthesis using hydrothermal method: [103]

The hydrothermal method can be used to synthesize a wide range of materials, including:

- ✓ Nanoparticles: The hydrothermal method can be used to synthesize nanoparticles of various materials such as metal oxides, semiconductors, and magnetic materials. The method allows precise control of particle size and shape, making it useful for applications such as catalysis, drug delivery, and imaging.
- ✓ Zeolites: Zeolites are a class of microporous materials with a wide range of applications, including adsorption, catalysis, and ion exchange. The hydrothermal method is commonly used to synthesize zeolites, as it allows for precise control over the crystal structure and porosity.
- ✓ Metal-Organic Frameworks (MOFs): MOFs are a class of porous materials made up of metal ions or clusters linked by organic ligands. The hydrothermal method is often

used to synthesize MOFs, as it allows for precise control over the structure and porosity of the material.

- ✓ Ceramic materials: The hydrothermal method can also be used to synthesize ceramic materials such as hydroxyapatite, a calcium phosphate ceramic used in bone grafts, and zirconia, a ceramic used in dental implants and catalysis.

❖ General steps the preparation of a materials using the hydrothermal method:[104]

- ✓ Prepare the precursor solution: The precursor solution is typically a mixture of metal salts or organic compounds that will react to form the desired material. The solution should be carefully prepared to ensure the correct stoichiometry and concentration of the components.
- ✓ Transfer the precursor solution to a closed vessel: The precursor solution is then transferred to a closed vessel, such as a Teflon-lined autoclave or a stainless-steel vessel. The vessel is typically designed to withstand high pressure and temperature conditions.
- ✓ Heat the vessel: The vessel is then heated to a specific temperature and pressure using an appropriate heating source, such as an oven or hotplate. The temperature and pressure conditions are critical for controlling the synthesis process, as they determine the solubility and reactivity of the precursor solution.
- ✓ Allow the reaction to occur: Once the vessel has reached the desired temperature and pressure, the precursor solution is allowed to react for a specific period of time. The length of the reaction time depends on the material being synthesized and can range from a few hours to several days.
- ✓ Cool the vessel: After the reaction is complete, the vessel is slowly cooled down to room temperature to prevent cracking or degradation of the material. The cooling rate is also critical for controlling the properties of the synthesized material.
- ✓ Collect the synthesized material: The synthesized material is then collected and typically washed with a suitable solvent to remove any impurities or by-products. The material is then characterized using various analytical techniques to determine its properties, such as crystal structure, particle size, and surface area.

2) Differences between dry and hydrothermal methods: advantages and disadvantages:

The two methods you mentioned, the sol-gel method and the hydrothermal method, are both used for the synthesis of materials, but they have some differences in terms of their advantages and disadvantages.

The sol-gel method involves the synthesis of materials from precursor solutions that undergo gelation to form a solid matrix. On the other hand, the hydrothermal method involves the use of high-pressure and high-temperature conditions to facilitate the formation of materials.[105]

❖ Advantages:

Dry method	Hydrothermal method
1) The sol-gel method is relatively simple and can be performed at low temperatures, making it suitable for the synthesis of a wide range of materials. 2) The method allows for precise control of the chemical composition, porosity, and morphology of the synthesized materials. 3) The sol-gel method can produce materials with high purity and uniformity.	1) The hydrothermal method can produce materials with high purity and uniformity, even at high temperatures and pressures. 2) The hydrothermal method allows for precise control over the crystal structure, particle size, and surface area of the synthesized materials. 3) The hydrothermal method can be used to synthesize a wide range of materials, including nanoparticles, zeolites, and metal-organic frameworks.

❖ Disadvantages:

Dry method	Hydrothermal method
1) The sol-gel method requires a longer reaction time than the hydrothermal method, which can lead to higher costs and lower throughput. 2) The sol-gel method can produce materials with low mechanical strength, which can limit their applications in certain fields. 3) The sol-gel method may require the use of toxic solvents or catalysts, which can pose a health hazard to workers and the environment.	1) The hydrothermal method requires specialized equipment that can withstand high temperatures and pressures, which can increase the cost of the synthesis process. 2) The hydrothermal method can be challenging to scale up, as it requires careful control of the synthesis conditions to produce high-quality materials. 3) The hydrothermal method can produce materials with non-uniform properties, especially if the synthesis conditions are not optimized.

3) Generalities about analysis methods:

❖ FTIR Analysis:

➢ Definitions:

FTIR (Fourier Transform Infrared) analysis is a technique used to obtain information about the chemical composition of a sample based on the absorption or transmission of infrared light. In this technique, a beam of infrared light is passed through a sample, and the amount of light absorbed or transmitted is measured at different frequencies. This information is then used to determine the chemical bonds and functional groups present in the sample.[106]

FTIR analysis is widely used in many fields, including chemistry, materials science, pharmaceuticals, and food science. It can be used to analyze a wide range of sample types, including liquids, solids, and gases.[107]

➢ Objective of FTIR:

The objective of FTIR (Fourier Transform Infrared Spectroscopy) is to identify and analyze the chemical composition of a sample by measuring the absorption of infrared radiation as a function of frequency or wavelength. FTIR is a powerful analytical technique that can be used to determine the functional groups present in a sample, as well as the presence of impurities and contaminants. It is widely used in many fields, including chemistry, biology, materials science, and environmental science, among others. Some common applications of FTIR include the analysis of polymers, proteins, pharmaceuticals, and environmental samples.[108]

Figure 6: FTIR Thermo SCIENTIFIC

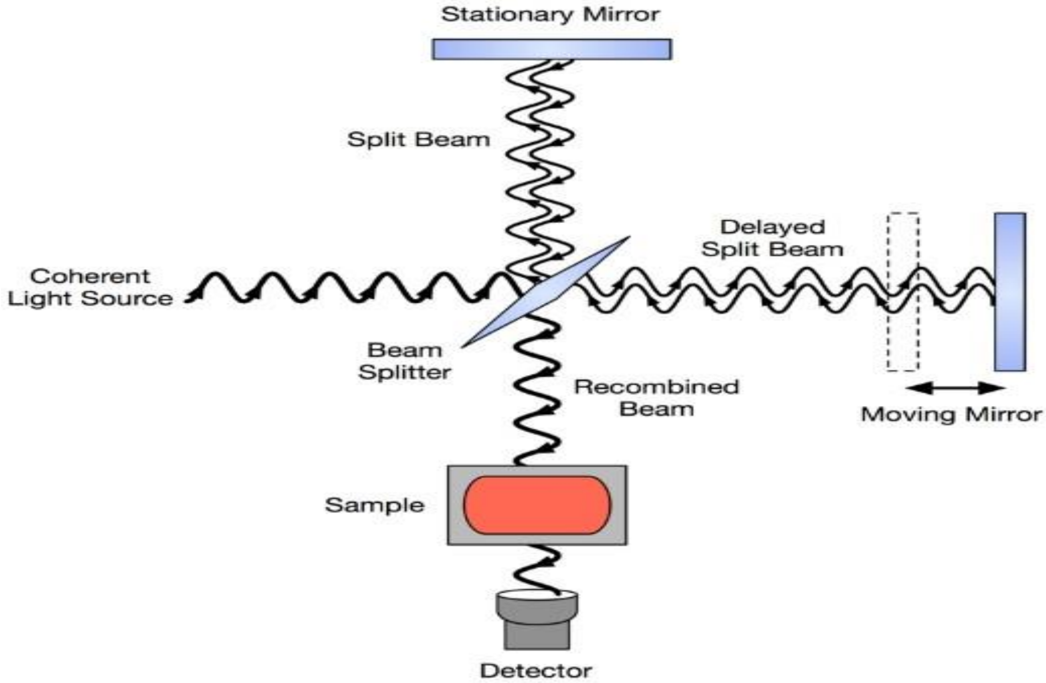


Figure 7: Schematic diagram of a Michelson interferometer, configured for FTIR

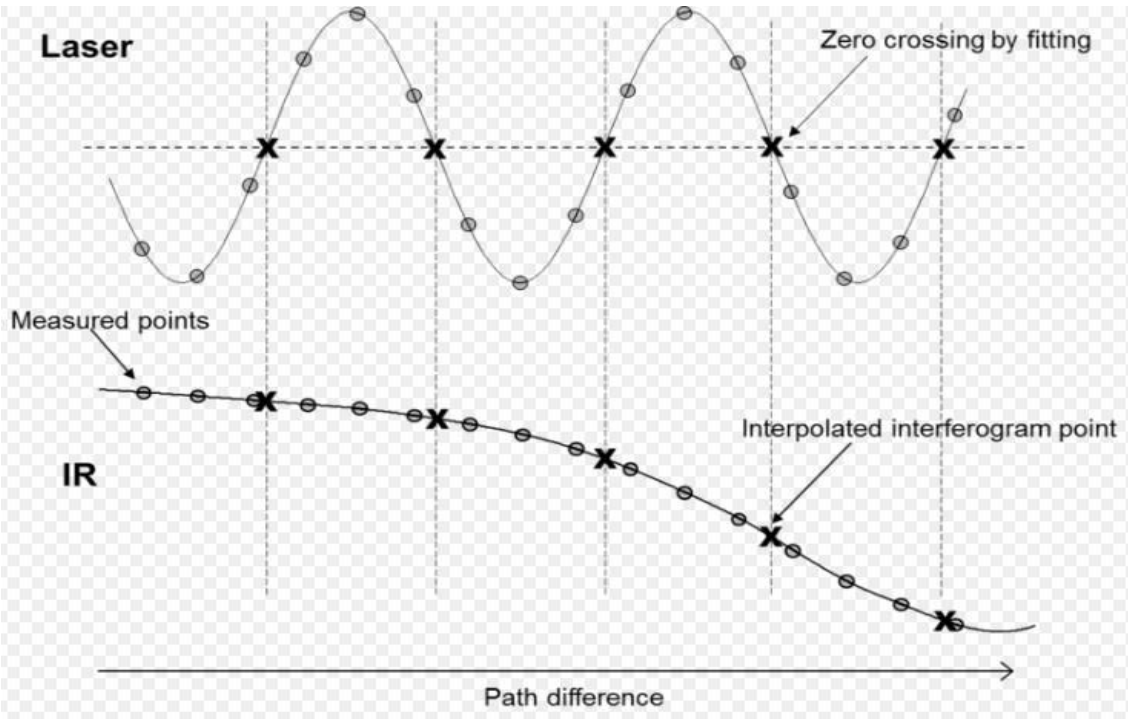


Figure 8: values of the interferogram at times corresponding to zero crossings of the Laser signal are found by interpolation.

❖ XRD Analysis:

➢ Definitions:[109]

XRD (X-ray Diffraction) analysis is a technique used to determine the crystal structure of a material by analyzing the diffraction pattern of X-rays that are scattered by the atoms in the crystal lattice. This technique is widely used in materials science, chemistry, geology, and other fields to study the structure and properties of crystalline materials.

The basic principle of XRD analysis is that when a beam of X-rays is directed towards a crystalline material, the X-rays will be scattered by the atoms in the crystal lattice, producing a diffraction pattern on a detector. The diffraction pattern is a series of spots or lines that correspond to the angles at which the X-rays are diffracted by the crystal lattice.

By analyzing the diffraction pattern, it is possible to determine the crystal structure of the material, including the unit cell dimensions, the arrangement of atoms within the unit cell, and the symmetry of the crystal lattice. This information can be used to understand the physical and chemical properties of the material, such as its mechanical, optical, and electronic properties.

XRD analysis typically involves the use of a specialized instrument called an X-ray diffractometer, which consists of an X-ray source, a sample holder, and a detector.

The X-ray source generates a beam of X-rays, which is directed towards the sample holder. The sample is rotated while the X-ray beam is directed at it, producing a diffraction pattern that is recorded by the detector.

XRD analysis is a powerful tool for studying the crystal structure and properties of materials. It is widely used in materials science, metallurgy, geology, and other fields to study the structure of metals, minerals, ceramics, and other crystalline materials.

➢ Objective of XRD:[110]

The objective of XRD (X-ray diffraction) is to analyze the crystal structure of a material by measuring the diffraction pattern produced when X-rays interact with the material. XRD is a powerful analytical technique that can be used to determine the atomic and molecular arrangement within a crystalline material, as well as its crystallographic orientation, lattice parameters, and other structural properties. It is widely used in many fields, including materials science, chemistry, geology, and physics, among others. Some common applications of XRD include the analysis of minerals, metals, ceramics, and pharmaceuticals, among others. By understanding the crystal structure of a material, scientists can gain insights into its properties, behavior, and potential applications.

Figure 9: device Benchtop XRD Diffraction.

Figure 10: DustTrak^{TM} DRX Aerosol Monitor 8533

❖ BET Analyses:

➢ Definition: [111]

BET analyses, or Brunauer-Emmett-Teller analyses, are a type of physical adsorption measurement used to determine the specific surface area of a solid material. This technique involves the measurement of the amount of gas adsorbed onto the surface of a solid material as a function of pressure or relative humidity. The data is then analyzed using the BET equation, which describes the relationship between the amount of gas adsorbed and the surface area of the material. The BET equation assumes that the adsorption occurs in a monolayer and that the surface is homogeneous and uniform. BET analyses are commonly used in materials science and engineering, as well as in the fields of chemistry, biology, and environmental science, to characterize the properties of various materials, including catalysts, porous materials, and nanoparticles.

Objective of BET:

The main objective of the Brunauer-Emmett-Teller (BET) analysis is to determine the specific surface area of a solid material. This parameter is an important characteristic of many materials, including catalysts, porous materials, and nanoparticles, because it influences their performance in various applications. Specifically, the BET analysis provides a quantitative measurement of the surface area of a solid material by analyzing the amount of gas adsorbed onto its surface. The specific surface area is a measure of the total surface area per unit mass of the material, and it is an important parameter that influences the material's reactivity, selectivity, and adsorption properties. The BET analysis is also used to determine the porosity of a material, including the pore volume and pore size distribution. These parameters are important for understanding the transport of fluids and molecules through the material, as well as its storage capacity.[112]

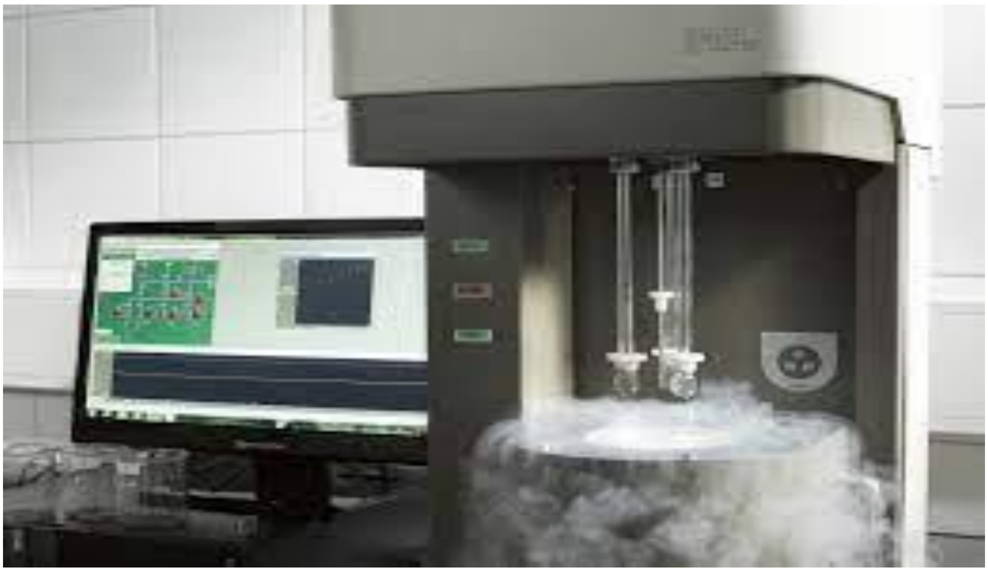


Figure 11: BET Analyses

❖ SEM Analysis:

➢ Definitions:[113]

SEM stands for Scanning Electron Microscopy, which is a type of microscopy used to investigate the surface morphology and composition of a material at high resolution. It uses a beam of high-energy electrons that are scanned across the surface of a sample, and the resulting signal is used to generate an image of the sample.

In SEM analysis, the electrons interact with the atoms on the surface of the sample, causing the emission of secondary electrons and other signals, such as backscattered electrons and X-rays. These signals are detected and used to create a highly magnified image of the sample surface, which can reveal details such as surface features, topography, and composition.

SEM analysis is a valuable tool in materials science, engineering, and other fields where surface characterization is important. It is often used to investigate the surface properties of materials such as metals, ceramics, polymers, and composites, as well as biological samples such as cells and tissues. The technique is highly versatile and can be used to obtain both qualitative and quantitative information about the sample surface, such as the size and shape of particles, surface roughness, and elemental composition.

- Objective of SEM:[114]

The objective of Scanning Electron Microscopy (SEM) is to provide a high-resolution, three-dimensional image of the surface of a sample. SEM can provide information about the morphology, topography, and composition of a wide range of materials and samples.

Figure 12: SEM-EDX Phenom Prox

Cyclic voltammetry Analyses:

- definition:

Cyclic voltammetry (CV) is a powerful electrochemical technique that is commonly used to investigate the redox properties of electro active species in solution. It involves applying a series of voltage pulses to an electrochemical cell containing the species of interest, and measuring the resulting current as a function of the applied voltage.[115]

During a cyclic voltammetry experiment, the voltage is typically swept back and forth between two set values in a repeated cycle. As the voltage is increased, the electro active species will either gain or lose electrons, leading to an increase or decrease in current, respectively. By analyzing the shape of the resulting current-voltage curves, it is possible to extract important information about the thermodynamics and kinetics of the redox reaction, such as the standard potential, diffusion coefficient, and rate constant.[116]

Cyclic voltammetry is widely used in many fields, including electrochemistry, analytical chemistry, materials science, and biochemistry. It can be used to study a wide range of electro active species, including metal ions, organic compounds, and biomolecules.[117]

➢ Objective of cyclic voltammetry:

The objective of cyclic voltammetry is to study the redox properties of electro active species in solution. By applying a series of voltage pulses to an electrochemical cell and measuring the resulting current, cyclic voltammetry can provide important information about the thermodynamics and kinetics of redox reactions.[118]

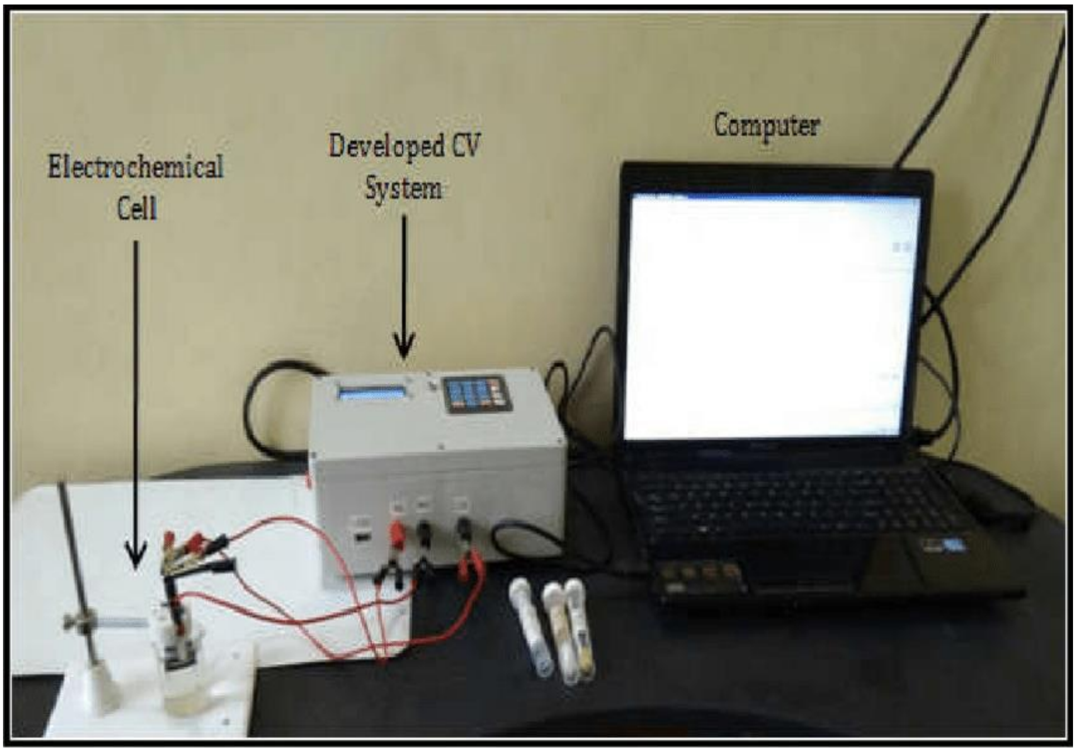


Figure 13: Cyclic voltammetry analyses

❖ Adsorption:

➢ Definition:[119]

Adsorption is a process in which molecules or particles from a substance adhere to the surface of another material. It is a surface phenomenon that occurs when the attractive forces between the adsorbate (the substance being adsorbed) and the adsorbent (the material onto which adsorption occurs) are stronger than the cohesive forces within the adsorbate itself. Adsorption can occur in various systems, including gases on solids, liquids on solids, or even liquids on liquids. The substance being adsorbed is typically referred to as the adsorbate, while the material onto which adsorption takes place is called the adsorbent. There are two main types of adsorption: physical adsorption (also known as physisorption) and chemical adsorption (also known as chemisorption).

Physical adsorption is characterized by weak van der Waals forces between the adsorbate and adsorbent, resulting in reversible adsorption. This type of adsorption is commonly observed at low temperatures and high pressures. Examples include the adsorption of gases on the surface of activated carbon or the adsorption of water vapor on silica gel.

Chemical adsorption involves the formation of chemical bonds between the adsorbate and adsorbent, resulting in stronger interactions and typically irreversible adsorption. This type of adsorption is often observed at higher temperatures and can involve reactions such as oxidation, reduction, or complex formation. Adsorption has numerous practical applications. In industrial processes, adsorption is widely used for gas separation, purification of liquids, and removal of contaminants from air or water. It is also employed in various technologies, such as activated carbon filters, chromatography, catalysis, and drug delivery systems.

Conclusion

In conclusion, the dry method and the thermal method are two different methods of use, each of them uses a different field from the other and has its own characteristics and components of the material to be studied, namely Fourier Transform Infrared (FTIR), X-ray diffraction (XRD), scanning electron microscopy (SEM), Brunauer-Emmett-Teller (BET), Cyclic voltammetry (CV). The use of dry methods in materials synthesis offers several advantages and potential applications. Continued research efforts in this field can lead development of new and improved material with various properties, applications, and contributions to the scientific understanding of materials science.

Chapter 3

Experimental and Methods

Introduction

Calcium oxide (CaO) is a fundamental material in various industries, where it is used in the production of cement, glass, paper, and other chemicals. However, to obtain pure and efficient calcium oxide, the process of thermal treatment of calcium acetate is used.

The thermal treatment of calcium acetate is carried out by exposing it to very high temperatures, which converts it into pure calcium oxide. This process is essential to obtain pure and efficient calcium oxide, as it ensures the removal of any impurities or other residues.

1) Heat treatment: [120]

Heat treatment is a process that involves heating a material, usually a metal or an alloy, to a specific temperature and holding it at that temperature for a specified period of time. Followed by controlled cooling. The aim of heat treatment is to alter the material's properties, such as its hardness, strength, ductility, and toughness, to make it suitable for a particular application.

There are several types of heat treatment, the most important of which is:

- Annealing: involves heating the material to a specific temperature and holding it at that temperature for a period of time, followed by controlled cooling. The purpose of annealing is to soften the material, reduce its hardness, and increase its ductility.
- Normalizing: is a heat treatment process similar to annealing, but the material is cooled in air instead of being controlled. The purpose of normalizing is to refine the grain structure of the material and improve its mechanical properties.
- Quenching: involves heating the material to a high temperature and then rapidly cooling it in a liquid, such as water or oil. The rapid cooling causes the material to harden and become brittle, but also increases its strength.
- Tempering: is a heat treatment process that involves heating the material to a specific temperature and holding it at that temperature for a period of time, followed by controlled cooling. The purpose of tempering is to reduce the brittleness of the material and increase its toughness and ductility.
- Case hardening: is a heat treatment process that involves adding a layer of hard material to the surface of the material, while keeping the core of the material soft and ductile. The purpose of case hardening is to increase the wear resistance of the material and make it suitable for applications where high wear resistance is required.

- The specific temperature and time for heat treatment depend on the material being treated and the desired outcome. For example, a high-carbon steel may need to be heated to a temperature of around 800-900°C for several hours during quenching, while a low-carbon steel may only need to be heated to 600-700°C for a shorter period of time.
- Heat treatment can also affect the material's microstructure, which can in turn affect its mechanical properties. For example, during annealing, the material's grain structure can become larger and more uniform, which can improve its ductility and toughness. During quenching, the material's microstructure can become more martensitic, which can increase its hardness and strength.

- Heat treatment can also cause undesirable effects, such as warping, cracking, or distortion. To minimize these effects, thermal method is often done in controlled environments, such as furnaces or kilns, with precise temperature and cooling controls.
- Heat treatment is commonly used in the manufacturing of various industrial products, such as metal parts for machinery, tools, and automotive components.
- Different materials may require different types of thermal method or a combination of heat treatments to achieve the desired properties. For example, a steel alloy may need to undergo quenching and tempering to achieve the desired hardness and toughness.
- Heat treatment is a critical process in metallurgy and materials science, and it requires careful consideration of factors such as the material's composition, microstructure, and intended use.

Figure 14: High temperature high treatment furnaces

Principle of operation:

The thermal treatment of calcium acetate to obtain calcium oxide involves the decomposition of the calcium acetate compound. When calcium acetate is heated to a high temperature, it decomposes into calcium oxide and acetic acid. The reaction can be represented by the following chemical equation:[121]

$$Ca(CH_3COO)_2 + O_2 \rightarrow CaO + CO_2 + 3H_2O$$

Or

$$Ca\,(CH_3COO)_2 + 4O_2 \rightarrow CaO + 2CO_2 + 3H_2O$$

The decomposition of calcium acetate is an endothermic reaction, which means it requires heat energy to occur. The decomposition temperature of calcium acetate depends on the purity of the compound and the heating rate. Generally, the thermal treatment of calcium acetate is carried out in a furnace or kiln at temperatures 500°C for 24 hours.

During the thermal treatment process, the calcium oxide produced is highly reactive and can react with impurities or other residues in the furnace or kiln, which can affect the purity of the final product. Therefore, the thermal treatment process should be carefully controlled to ensure the production of pure calcium oxide.[122]

2) Objective:

The main objective of the thermal treatment of calcium acetate is to obtain pure and efficient calcium oxide. The thermal treatment process ensures the removal of any impurities or residues in the calcium acetate compound, which can affect the purity and efficiency of the final product. The pure calcium oxide obtained from the thermal treatment process can be used as a raw material in various industries, including the production of cement, glass, paper, and other chemicals. The thermal treatment process is also important to ensure the safety of the workers involved in the production process. Calcium acetate is a hazardous substance that can release harmful gases when heated. Therefore, the thermal treatment process should be carried out in a well-ventilated area and with appropriate safety measures.[123]

3) Tools and used materials:

Tools	Used materials
✓ Balance ✓ Oven ✓ Crucible or ceramic dish ✓ Bunsen burner or other heat source ✓ Tongs or other heat-resistant tools	✓ Calcium acetate 15g

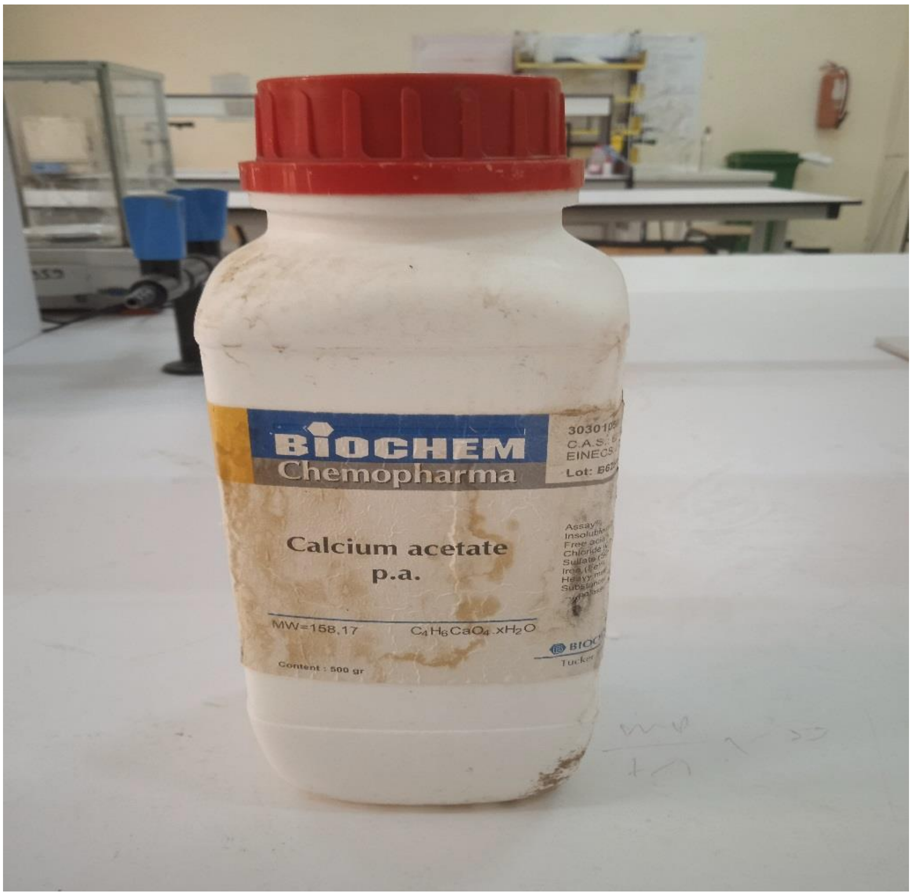


Figure 15: Calcium Acetate

4) Stages of experience:

- Calculation of the molecular mass of calcium acetate:

  $M_{Ca\,(CH3COO)\,2} = M_{Ca} + 2(M_C + 3\times M_H + M_C + M_O + M_O)$

  $M_{Ca\,(CH3COO)\,2} = 40 + 2(12 + 3\times 1 + 12 + 16 + 16)$

  $M_{Ca\,(CH3COO)\,2} = 158 g/mol$

- Enter calcium acetate for oven at 500C° temperature for 24h
- The thermal treatment of calcium acetate to obtain calcium oxide:

  Converting calcium acetate to calcium oxide through heat treatment involves a process called calcination. Here's how it can be done.

5) Action steps:

1. Place the calcium acetate in a crucible or ceramic dish.
2. Heat the crucible or dish over a Bunsen burner or other heat source. Begin with a low flame and gradually increase the heat.
3. Continue heating until the calcium acetate melts and starts to decompose. This will release acetic acid and produce calcium carbonate.
4. Keep heating until the calcium carbonate decomposes further, releasing carbon dioxide and leaving calcium oxide (also known as quicklime).
5. Turn off the heat source and allow the calcium oxide to cool.
   - Caution: Calcium oxide is a strongly alkaline substance that can cause burns and eye damage. Handle it with care and wear protective gloves and goggles.
   - Note: The exact temperature and duration of the heating process will depend on the amount of calcium acetate being used and the heat source being used. It is important to monitor the process closely and adjust the heat as needed to avoid overheating or underheating.
   - Calcination is a process that involves heating a substance to a high temperature in the absence of air or with limited air. The process is used to drive off volatile compounds and to promote chemical reactions that lead to the formation of a desired product. In the case of calcium acetate, calcination leads to the production of calcium oxide.[124]
   - Calcium oxide is a white or grayish-white powder that is widely used in industry, particularly in the production of cement and steel. It is also used as a desiccant (drying agent) and as an ingredient in some fertilizers. Calcium oxide is highly reactive with

water and can produce a significant amount of heat when it reacts, so it must be handled with care.[125]

- Calcination is an important process in many industries, including metallurgy, ceramics, and chemical manufacturing.[126]
- In addition to producing calcium oxide from calcium acetate, calcination can also be used to produce a wide range of other materials, such as metal oxides, ceramics, and pigments.[100]

  The process of calcination involves heating a substance to a high temperature in a controlled environment. This can be done in a variety of ways, including in a furnace, a kiln, or a retort. The temperature and duration of the calcination process can vary depending on the properties of the material being processed and the desired outcome.[127]

6) The chemicals reactions: [128]

The chemical reaction that occurs during the calcination of calcium acetate to produce calcium oxide can be represented by the following equation:

$$Ca\,(CH_3COO)_2 \rightarrow CaCO_3 + CH_3COOH$$

This reaction shows that when calcium acetate is heated, it decomposes to form calcium carbonate and acetic acid. The calcium carbonate is further decomposed at higher temperatures to produce calcium oxide and carbon dioxide:

$$CaCO_3 \rightarrow CaO + CO_2$$

Therefore, the overall reaction that occurs during the calcination of calcium acetate to produce calcium oxide is:

$$Ca\,(CH_3COO)_2 \rightarrow CaO + CO_2 + CH_3COOH$$

This reaction is endothermic, meaning that it requires the input of heat to occur. The exact temperature and duration of the calcination process can vary depending on the amount of calcium acetate being used and the heat source being used.

Calcium acetate is a white crystalline solid that is soluble in water and organic solvents. It is commonly used as a food additive, as a medication for hyperphosphatemia (excess phosphates in the blood), and as a precursor for the production of other calcium compounds.

When calcium acetate is heated, it undergoes a decomposition reaction, as shown in the equation above. This reaction occurs because the heat energy breaks the chemical bonds between the atoms in the calcium acetate molecule, causing it to break down into its constituent elements.

Calcium carbonate is produced as an intermediate product during the decomposition of calcium acetate. It is a white crystalline solid that is commonly found in rocks and shells and is used in a variety of industrial applications, such as in the production of cement and as a filler in paper, plastics, and paints.

Calcium oxide, also known as quicklime, is produced as the final product of the calcination process. It is a white or grayish-white powder that is highly reactive with water and can produce a significant amount of heat when it reacts. Calcium oxide is commonly used in a variety of industrial applications, including in the production of cement, steel, and chemicals. It is also used as a desiccant and as an ingredient in some fertilizers.

Figure 16: Calcium acetate powder after firing

7) Yield:

R = R��������� �a����ia� w�igh� / I�i�ia� ��������� w�igh� × 100

$$\mathbf{R} = \frac{9.15}{15} \times 100$$

$$\mathbf{R} = 0.61 \times 100$$

$$\mathbf{R} = 61\%$$

Conclusion

In conclusion, the thermal treatment of calcium acetate to obtain calcium oxide is a crucial process in many industrial applications. The analysis of the resulting carbon dioxide using FTIR, XRD, BET, SEM, and Cyclic Voltammetry provides critical information on the properties of the oxide, including its chemical composition, physical properties, surface area, crystal structure, three-dimensional image, and electrical properties.[129]

The information obtained from the analysis of the carbon dioxide can be used to improve and develop the uses of calcium oxide in various industrial applications, such as in the production of cement, ceramics, and glass. Therefore, it is important to continue exploring and improving the process of thermal treatment of calcium acetate to obtain high-quality calcium oxide, and to use analytical techniques to understand the properties of the resulting oxide.[130]

Chapter 4

Results and discussion

Introduction

In this study, we performed X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), and scanning electron microscopy (SEM) analyses on a powder sample composed of calcium, carbon, and oxygen. The goal of the study was to characterize the structural and chemical properties of the sample and identify the phases present.

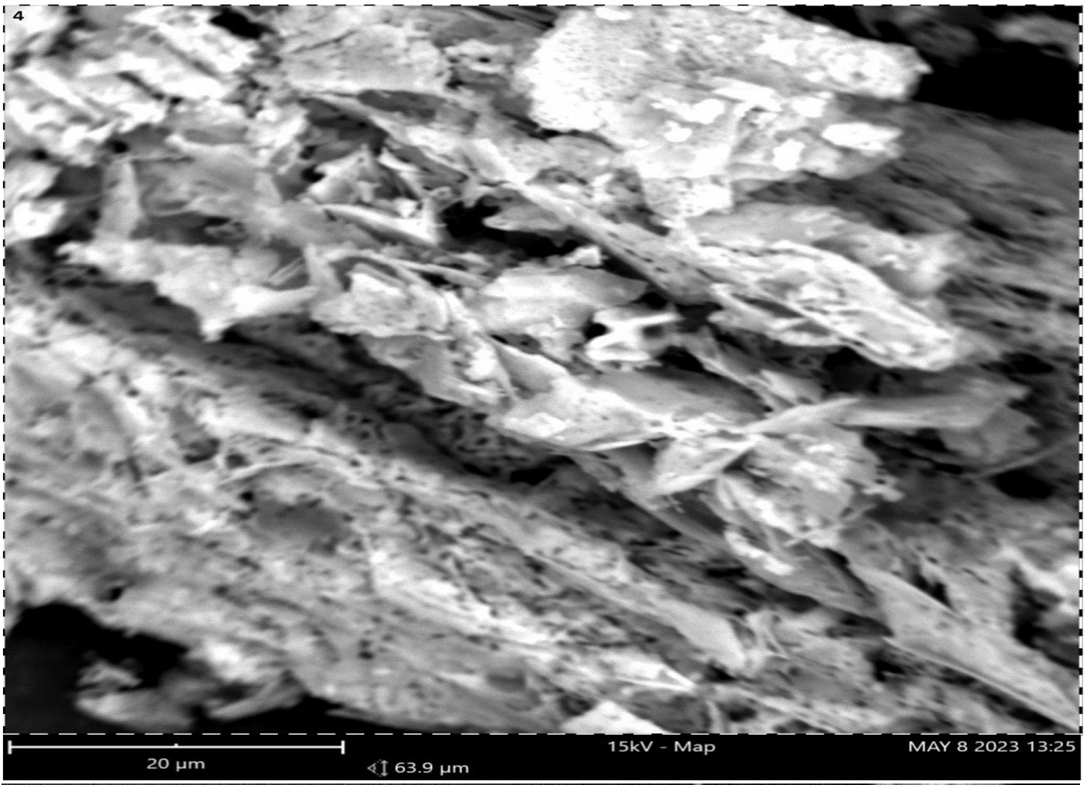
XRD analysis showed several peaks, indicating the presence of multiple crystalline phases. The diffraction pattern revealed sharp peaks at 2θ values of 29.4°, 44.5°, and 65.3°, which correspond to the (104), (200), and (116) planes of the calcium carbonate (CaCO3) crystal structure. Additionally, there were peaks at 2θ values of 26.3° and 43.3°, indicating the presence of calcium oxide (CaO). The XRD results indicate the presence of both CaCO3 and CaO phases in the sample.

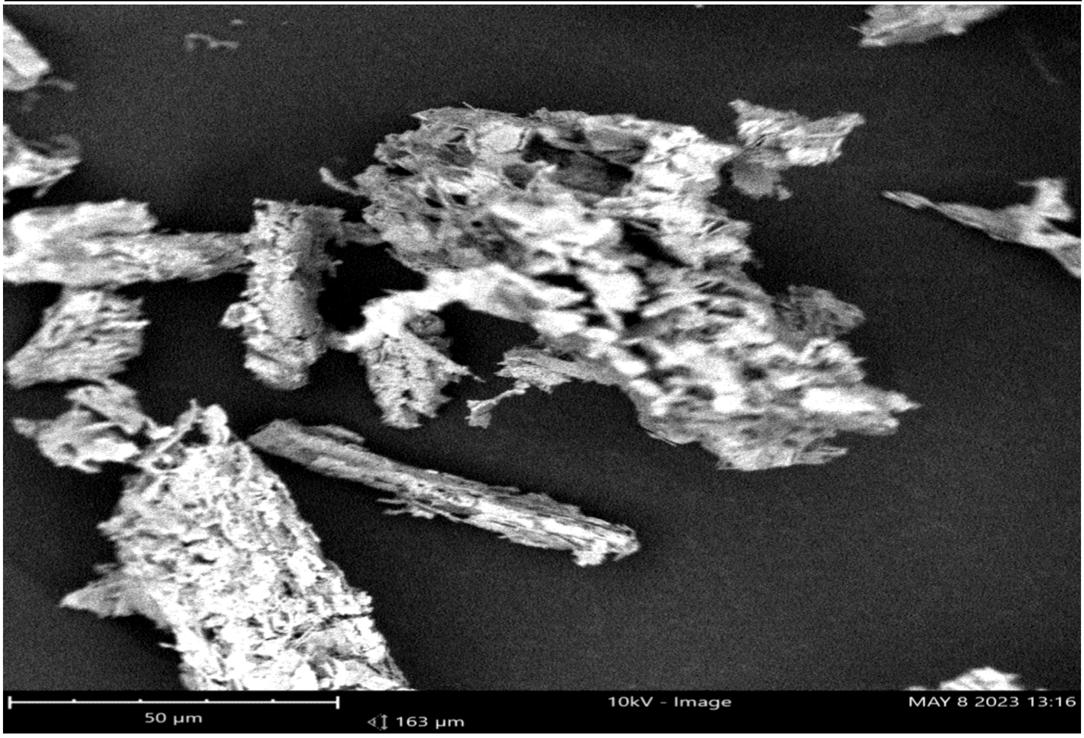
FTIR analysis was used to investigate the functional groups present in the sample. The FTIR spectrum showed a strong peak at 1413 cm^-1, indicating the presence of carbonate (CO3^-2) groups. This is consistent with the XRD results, which identified the presence of CaCO3. There was also a broad peak centered at 3420 cm^-1, indicating the presence of hydroxyl (OH^-) groups, which are common in metal hydroxides and oxides.

SEM analysis was used to examine the morphology and microstructure of the sample. The SEM images showed irregularly shaped particles with varying sizes and rough surfaces. The microstructure of the sample appeared to be composed of aggregates of smaller particles. This observation is consistent with the XRD results, which indicated the presence of multiple phases in the sample.

The XRD results suggest that the sample is composed of both calcium oxide and calcium carbonate phases. This could be due to incomplete combustion of the starting material, resulting in a mixture of different products. The FTIR results support the XRD results by confirming the presence of carbonate groups in the sample. The SEM images show that the sample is composed of irregularly shaped particles with rough surfaces and aggregates of smaller particles, indicating a heterogeneous structure.

1) SEM Image:





FOV: 63.9 µm, Mode: 15kV - Map, Detector: BSD Full, Time: MAY 8 2023 13:25

Figure 17: image of the powder obtained after burning under a scanning electron microscope

In order to analyse the image of the material under a scanning electron microscope, we used the ImageJ software tool to measure the size of the particles. The first image showed particles that appeared as a cluster resembling a calcareous stone, which made it difficult to measure the size of each individual particle. To overcome this limitation, we used the second image, which showed the particles separated to some extent, allowing us to obtain a more accurate measurement of each particle's size. The process involved opening the image in ImageJ, adjusting the scale to match the magnification of the microscope, and then using the measurement tools to draw a line or select an area to calculate the size of the particles. This was repeated for multiple particles to obtain a representative sample size. The resulting data can then be used to analyze the characteristics of the material, such as particle size distribution, morphology, and composition.

2) EDS Results:

The table (Table 3) presents the results of an elemental analysis of a material, showing the presence of three elements: oxygen (O), calcium (Ca), and carbon (C). For each element, the table provides the element's symbol, name, atomic concentration, and weight concentration. The atomic concentration represents the number of atoms of the element per unit volume of the material, while the weight concentration represents the mass of the element per unit mass of the material.

According to the table, oxygen has the highest atomic concentration of 55.48 and weight concentration of 50.73, indicating that it is the most abundant element in the material. This is not surprising since oxygen is a common element found in many compounds, and it is essential for many chemical reactions. Calcium has an atomic concentration of 11.67 and weight concentration of 26.73, indicating that it is present in the material but not as abundant as oxygen. Calcium is also a common element found in many minerals and compounds, and it plays an important role in many biological processes such as muscle contraction and bone formation.

Table 3: of Elemental Composition of a Substance Containing Oxygen, Calcium, and Carbon"

Element Number of device	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
8	O	Oxygen	55.48	50.73
20	Ca	Calcium	11.67	26.73
6	C	Carbon	32.85	22.54

Based on the table results, the main species that exist in the sample are likely to be a combination of oxygen, calcium, and carbon. Oxygen has the highest atomic and weight concentrations in the material, indicating that it is the most abundant element. Calcium is also present in the material, but not as abundant as oxygen. Carbon has a relatively high atomic and weight concentration, indicating that it is present in significant amounts in the material.

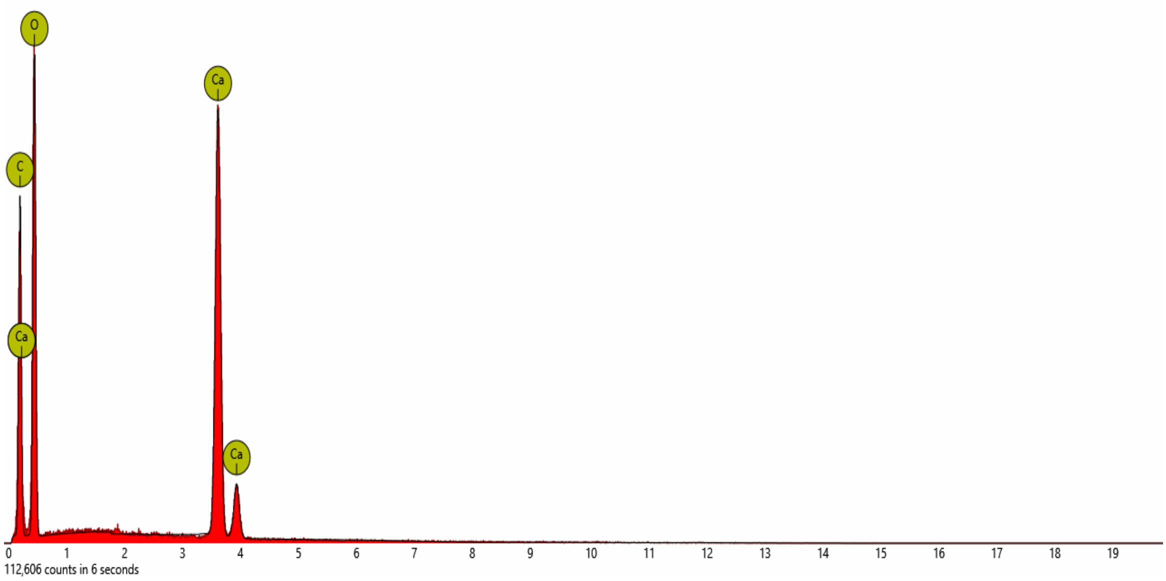


Figure 18: curve reflects the initial installation of the matter containing calcium, carbon and oxygen

Table 4**:** the table represents the sizes of the powder molecules obtained under the microscopic

	Area	Mean	Min	Max	Angle	Length
1	23.329	153.451	23	234.824	-179.326	44.274
2	50.456	157.365	70	255	-140.471	96.562
3	172.255	168.532	3.202	255	-48.389	330.192
4	58.594	184.445	89.385	255	-0.533	111.925
5	0.043	176.976	20	255	-27.799	4.11
6	0.008	160.98	28	255	-124.38	0.719
7	0.041	217.669	44.608	255	-69.708	3.965
8	0.02	217.424	108	255	22.989	1.867
9	0.024	182.169	87.715	255	-86.892	2.305
10	0.01	186.733	94.734	255	14.036	0.902

3) FTIR Image:

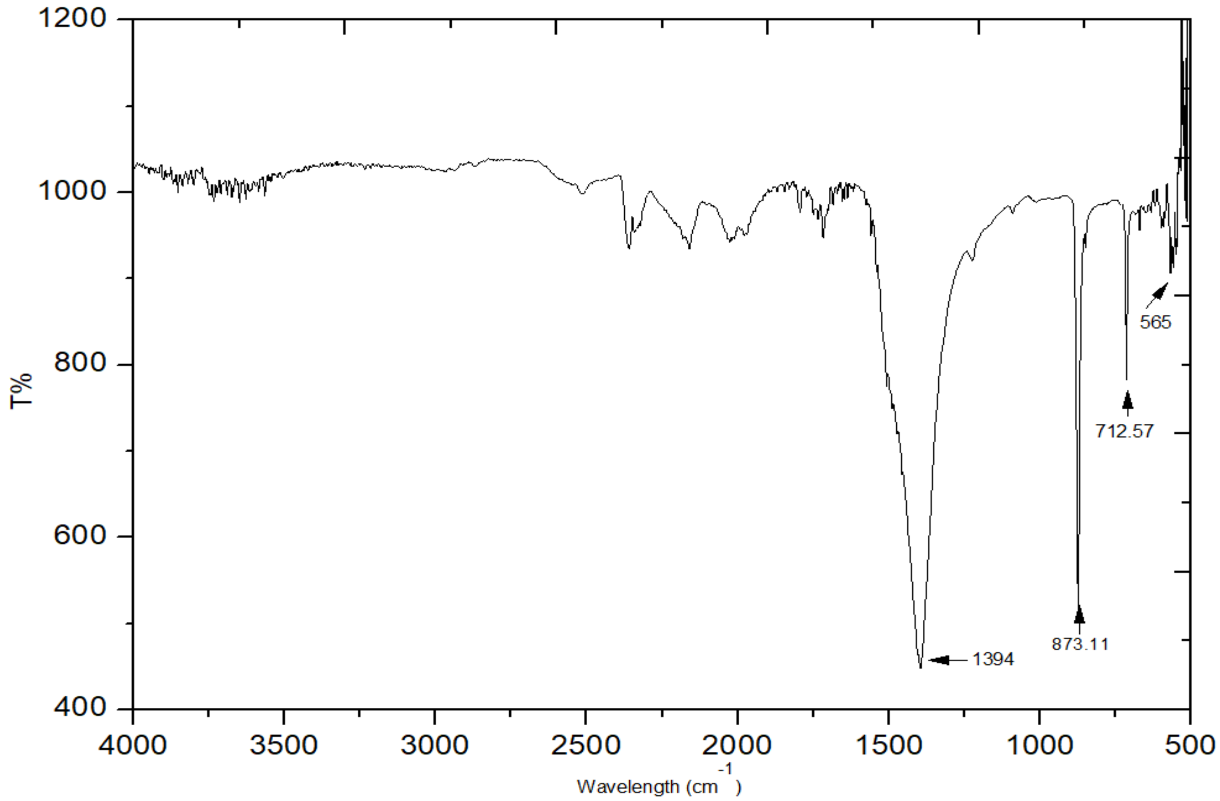


Figure 19: A graphic curve representing the results of FTIR analysis of the obtained powder**.**

During the infrared spectroscopic analysis (Figure19) of the inorganic material composed of calcium, oxygen, and carbon, distinct and sharp bands were observed. These bands were ordered in descending order of their wavenumbers, as follows:

- The largest band was observed at a wavelength of 1394 cm^{-1}.
- The second-largest band was observed at a wavelength of 873.11 cm^{-1}.
- The third-largest band was observed at a wavelength of 712.57 cm^{-1}.
- The smallest band was observed at a wavelength of 565 cm^{-1}.

Without specific information about the material's composition, it is challenging to determine the exact functional groups or compounds associated with these bands. However, based on the observed wavenumbers, we can make some general interpretations.

The band at 1394 cm^{-1} may correspond to vibrations of carbonate (CO_3^{2-}) or carboxylate (COO^- groups. The band at 873.11 cm^{-1} could be attributed to vibrations of calcium-oxygen (Ca-O) bonds or other calcium-related functional groups. The band at 712.57 cm^{-1} may be associated with vibrations of carbon-oxygen (C-O) bonds or other carbon-related functional groups. Finally, the band at 565 cm^{-1} may indicate vibrations of calcium-carbon (Ca-C) bonds or other calcium-related functional groups.

4) The XRD:

The XRD pattern suggests that the sample has well-crystallized characteristics. The presence of distinct diffraction peaks at various 2θ values indicates a regular arrangement of atoms within the crystal lattice. The pattern also indicates the presence of the calcite ($CaCO_3$) crystal phase. Calcite is a common polymorph of calcium carbonate (CaCO3) and is known for its characteristic XRD peaks: **23, 29.4, 31.5, 36, 39.5, 43.2, 47.5, 48.6, 56.6, 57.4, 61, 63, 64.9, 65.6, 69.2, 70.3, 72.9, 76.3,** and **77.3.**

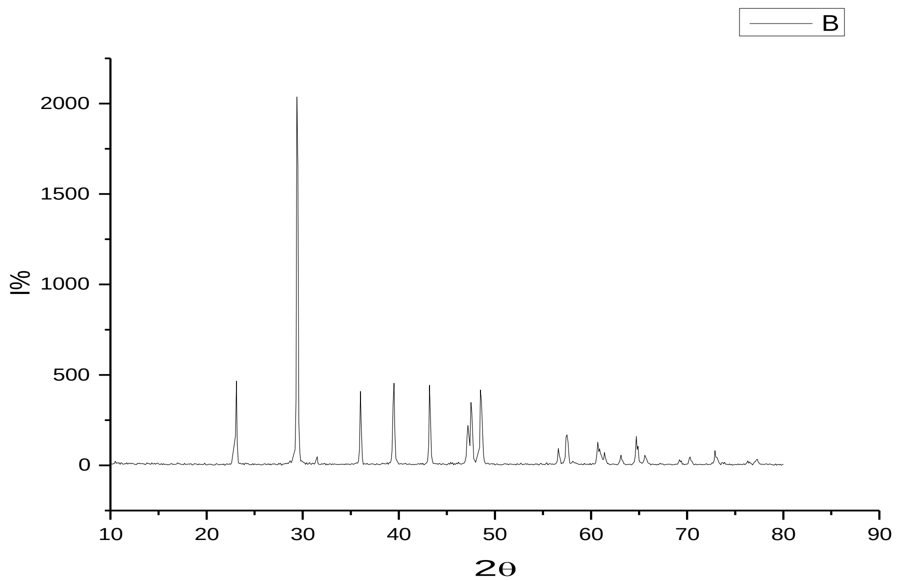


Figure 20: A graphic curve representing the results of XRD analysis

Conclusion

The analysis of the material under a scanning electron microscope (SEM) provided valuable insights into its characteristics. ImageJ software was utilized to measure the particle size, with the second image proving more suitable due to particles being separated. This allowed for more accurate measurements of individual particle sizes, enabling the assessment of particle size distribution, morphology, and composition.

The elemental analysis of the material using energy-dispersive X-ray spectroscopy (EDS) revealed the presence of three elements: oxygen (O), calcium (Ca), and carbon (C). Oxygen had the highest atomic and weight concentrations, indicating its abundance in the material. Calcium was present but less abundant than oxygen, while carbon was also present in significant amounts. These elements likely form the main species in the sample.

Further analysis was conducted using Fourier-transform infrared spectroscopy (FTIR) to identify functional groups or compounds in the material. Distinct and sharp bands were observed at specific wavenumbers. While specific identification of functional groups requires more detailed information, general interpretations based on wavenumbers were provided. These interpretations suggested the presence of carbonate or carboxylate groups, calcium-oxygen bonds, carbon-oxygen bonds, and calcium-carbon bonds or related functional groups.

The X-ray diffraction (XRD) pattern indicated well-crystallized characteristics of the sample and revealed the presence of the calcite ($CaCO_3$) crystal phase. The distinct diffraction peaks at various 2θ values confirmed the regular arrangement of atoms within the crystal lattice, consistent with the known XRD peaks of calcite.

General conclusion

The exploration of dry synthesis methods in materials science and engineering has gained significant interest due to their numerous advantages and potential for addressing environmental challenges. Dry synthesis techniques offer energy efficiency, environmental friendliness, and the ability to enhance material properties without the use of solvents or liquids. [98]

One of the driving factors behind the research in dry synthesis is the urgent need to reduce carbon dioxide (CO2) emissions and mitigate the impacts of climate change. CO2 emissions, primarily resulting from human activities, contribute to the greenhouse effect and global warming. By developing new materials through dry synthesis methods, researchers aim to contribute to reducing CO2 emissions and finding sustainable solutions. [6]

Different techniques can be employed in dry materials synthesis, including mechanical milling, solid-state reactions, vapor deposition, and thermal treatments. Each method offers unique advantages and enables the production of novel materials with tailored properties. Analytical techniques such as X-ray diffraction (XRD), scanning electron microscopy (SEM), Fourier-transform infrared spectroscopy (FTIR), and Raman spectroscopy are used to characterize and understand the synthesized materials' composition, structure, and morphology. [131]

This study specifically focuses on the thermal treatment of calcium acetate to obtain pure calcium oxide, highlighting the significance of dry methods in producing essential materials for various industries. By characterizing the synthesized material through XRD, FTIR, and SEM analysis, valuable insights are gained into its properties and potential applications.

Looking forward, a crucial question arises: How can locally available calcium be utilized to absorb carbon dioxide from the air? Exploring innovative approaches that harness calcium's properties and developing efficient CO2 capture and storage systems can contribute to mitigating climate change and achieving a more sustainable future.

In summary, the ongoing research in dry synthesis methods and the utilization of locally available resources hold great promise for advancing materials science, addressing environmental challenges, and promoting sustainable development. By continuing to explore and optimize these techniques, scientists and engineers can contribute to a more sustainable and environmentally conscious future.

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Abstract:

The proposal focuses on using calcium-based compounds to capture and store carbon dioxide (CO_2) from the atmosphere. This is crucial due to the rising CO_2 levels, which pose a significant climate challenge. The key objective is to find an effective and locally available method for this purpose. The proposal suggests identifying suitable calcium sources, developing efficient capture technologies, and implementing cost-effective storage strategies. Heat treatment is utilized to obtain pure and efficient calcium oxide from calcium and carbon, with oxygen being the most abundant element. Infrared spectroscopic (FTIR) analysis confirms the presence of calcium, oxygen, and carbon, while XRD patterns indicate the existence of well-crystallized calcite ($CaCO_3$). Utilizing calcium-based compounds offers a locally available and effective solution for capturing and storing CO_2, thereby mitigating the impacts of climate change. Continuous innovation, investment, and collaboration are essential for finding sustainable solutions to global challenges and preserving our planet for future generations.

Key words: carbon dioxide capture, calcium-based compounds, heat treatment, Infrared spectroscopic (FTIR), calcium acetate, XRD.

Résumé:

La proposition se concentre sur l'utilisation de composés à base de calcium pour capturer et stocker le dioxyde de carbone (CO_2) de l'atmosphère. Cela est crucial en raison de la hausse des niveaux de CO_2, qui constitue un défi climatique majeur. L'objectif principal est de trouve une méthode efficace et localement disponible à cet effet. La proposition suggère d'identifier des sources de calcium appropriées, de développer des technologies de capture efficaces et de mettre en œuvre des stratégies de stockage rentables. Le traitement thermique est utilisé pour obtenir de l'oxyde de calcium pur et efficace à partir du calcium et du carbone, l'oxygène étant l'élément le plus abondant. L'analyse spectroscopique infrarouge (FTIR) confirme la présence de calcium, d'oxygène et de carbone, tandis que les motifs de diffraction des rayons X indiquent l'existence de calcite bien cristallisée ($CaCO_3$). L'utilisation de composés base de calcium offre une solution efficace et localement disponible pour capturer et stocker le CO_2, atténuant ainsi les impacts du changement climatique. L'innovation continue, l'investissement et la collaboration sont essentiels pour trouver des solutions durables aux défis mondiaux et préserver notre planète pour les générations futures.

Mots clés: capture du dioxyde de carbone, composés à base de calcium, traitement thermique, spectroscopie infrarouge (FTIR), acétate de calcium, DRX.