

PREPARATION, REGENERATION AND CYCLIC CO₂ CAPTURE PERFORMANCE OF CUTTLEBONEDERIVED CaO IN A SLURRY BUBBLE COLUMN REACTOR

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Abstract

Atmospheric CO₂ concentration has presently exceeded 420 ppm, while global CO₂ emissions have crossed nearly 37 billion tonnes annually due to fossil fuel combustion and industrial activities. Cuttlebone contains nearly 85–90% calcium carbonate and possesses a naturally porous biomorphic structure favorable for gas adsorption and was utilized as a sustainable precursor for preparing calcium oxide (CaO) sorbents for cyclic CO₂ capture applications through calcination. The synthesized cuttlebone derived CaO was characterized using FTIR, PSA, XRD, and SEM analyses. The material exhibited submicron particle size with a Z-average diameter of nearly 410 nm and dominant particle distribution around 338 nm. SEM analysis revealed highly porous and irregular morphology with interconnected cavities, while XRD confirmed the formation of crystalline CaO phase. CO₂ capture experiments were conducted in a slurry bubble column reactor using chimney flue gas containing approximately 9500–10500 ppm CO₂ from burning coconut shells and leaves. Different Cuttlebone-derived CaO slurry concentrations ranging from 1 wt% to 10 wt% were investigated to identify the optimum operating condition. The optimum performance was achieved at 8 wt% slurry concentration with nearly 70% removal efficiency and a maximum uptake capacity of 0.70 g CO₂/g sorbent. Regeneration studies showed that the sorbent retained nearly 75.36% uptake capacity even after three carbonation–calcination cycles, demonstrating appreciable cyclic stability and lower deactivation behaviour.

Keywords: Carbon capture; Calcium oxide; Cuttlebone; Slurry bubble column reactor; Regeneration; Calcium looping

1. Introduction

Climate change has emerged as a top contender in the list of environmental problems confronting us as we head into the 21st century because of the combination of exponentially increasing industrialization, urbanization, and our ongoing reliance on fossil fuel-based energy systems. The vast amounts of coal, oil and natural gas that we burn all use up tremendous resources and produce very large amounts of greenhouse gases (GHGs). Coal, oil and natural gas emits greenhouse gases when burned, resulting in global warming and increased climate instability. Of all of the GHGs produced by human activities, CO₂ is the most abundant and has the longest-lasting effects on climate because of the high level of concentration over a

significant length of time. The amount of CO₂ in earth's atmosphere prior to industrialization was about 280 parts per million (ppm). As of January 2024, CO₂ is measured at over 420 ppm, which represents a nearly 50 % increase since prior to the beginning of the industrial era. [1]. The International Energy Agency (IEA) also reported that global energy-related CO₂ emissions crossed nearly 37.4 Gt in 2024 due to continued reliance on fossil fuels for industrial and energy production [2].

Industrial industries contribute more than any other sector to global greenhouse gas emissions. Coal-fired thermal power plants contribute nearly 30–35% of CO₂ emissions from around the world and emit approximately 0.8–1.1 kg CO₂ per kWh produced [3]. Cement industries produce roughly 7–8% of anthropogenic CO₂ emissions globally, primarily from calcining limestone and burning fossil fuels to create clinker.

Carbon capture and storage (CCS) technologies have resurfaced as promising approaches to reduce industrial greenhouse gas emissions. Different CO₂ capture strategies, such as pre-combustion capture, post-combustion capture, oxy-fuel combustion, and direct air capture, have been extensively investigated for large-scale carbon mitigation applications [4]. Among these, post-combustion carbon capture offers great advantages in that it can be retrofitted to existing thermal power plants and industrial facilities without major modifications to the processes involved [5]. A variety of separation processes for post-combustion capture have been investigated in literature including but not limited to chemical absorption, physical absorption, adsorption, membrane separation, and cryogenic separation [6].

Amine-based solvents like monoethanolamine (MEA) that chemically absorb carbon dioxide are commonly used commercially because their capture efficiency can exceed 85-90% under optimised conditions. However, solvent degradation, equipment corrosion, volatility/toxicity, and the high thermal regeneration energy requirement (3.5-4.5 GJ/tonne of captured CO₂) significantly limit the large-scale sustainability of amine-based systems [7]. For these reasons, solid sorbents have begun to receive much more attention in research due to the comparatively lower operational complexity, better thermal stability, and reduced energy requirements associated with solid sorbent-based carbon capture technologies[8] [9].

Of the many different solid sorbents studied for CO₂ capture, calcium oxide (CaO) is of particular interest to researchers because of its high theoretical CO₂ adsorption capability; fast reaction rates during carbonation; and low cost, and abundance of material [10]. The calcium looping process is an example of reversible carbonation/calcination reactions that are based on using calcium oxide (CaO) and calcium carbonate (CaCO₃).

Carbonation reaction: $\text{CaO} + \text{CO}_2 \rightarrow \text{CaCO}_3$

Regeneration reaction: $\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$

Under ideal operating conditions, the theoretical carbon capture potential for pure CaO (i.e., calcium oxide) is around 0.785g CO₂ per gram of CaO; however, carbonation is generally most effective between 600°C and 700°C, while regeneration of active CaO requires calcination via heating to approximately 800°C to 900°C. Calcium looping systems can achieve greater than 90% efficiency in their ability to capture CO₂ in theory[4]. but limestone-based CaO sorbents

that abide by traditional methods will often experience a rapid decrease in effective adsorption capacity after multiple cycles of carbonation-calcination due to pore blockage, sintering, and/or structural failure [11]. Previous research has indicated that commercial limestone-based sorbents may exhibit a 50% to 70% loss of their original CO₂ capture capabilities after just 10-20 cycles of regeneration [12].

Given these limitations, significant research has been performed in order to find more stable solid sorbents with high CO₂ capturing efficiencies that are composed of either naturally occurring or waste-derived calcium rich biomaterials. Marine-derived wastes (such as eggs, oyster, shellfish, etc.) are excellent example wastes that contain large amounts of calcium carbonate (> 90-95% wt.) and contain unique microstructures that make them ideal for use as sorbents [13]. Using these types of biomaterials for sorbent production provides the added benefits of sustainable waste management and a supporting circular economy.

A number of studies have shown that biogenic CaO materials were significantly superior to conventional lime-stone based sorbents for gas diffusion and cyclic stability [15]. Luo et al. [15] showed that the CaO sorbents derived from shells maintained almost 65%-75% of their original carbonation capacity after repeatedly being regenerated due to their naturally interconnected porous structure. Also, many of the cuttlefish/discal waste products generated in seafood processing and fishmarket industries create waste disposal problems in coastal areas of the world.

The cuttlebone is a type of internal shell that comes from marine cephalopods of the Sepia kind. The cuttlebone is a primarily aragonitic form of calcium carbonate along with a small amount of organic material and trace minerals. The internal structure of the material has a highly ordered, porous lamellar architecture with chambers linked together with vertically oriented support pillars. The porosity of cuttlebone ranges from 85% to 93%, which results in its being a very light weight, highly porous biomaterial [14]. Due to the naturally porous structure of cuttlebone, it is a very promising candidate for the making of high surface area calcium oxide (CaO) sorbents for cyclic carbonation applications.

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A Slurry Bubble Column Reactor (SBCR) is an effective component used to create contact between gases, solids, and liquids in multiphase reactions. The amount of gas present in bubble column reactors will vary based on conditions and will typically range between 0.1 and 0.4, which provides a large enough amount of useable area between the gas phase and liquid phase

for a typical carbonation reactions [17]. The utilization of Slurry Bubble Column Reactors to capture CO_2 by providing appropriate contact between gaseous CO_2 and suspended CaO are expected to improve the overall efficiency of carbonation processes.

Calcium oxide produced from the cuttlebone, was created and used for cyclic capture of CO_2 in a slurry bubble column reactor. The spent sorbent was removed from the slurry via filtration after carbonation and regenerated by applying heat for future cycles of carbonation. The performance of the produced sorbent regarding cyclic carbonation/regeneration was characterized to assess the regeneration potential of the sorbent and the structural integrity of the sorbent through many cycles of adsorption/desorption.

2. Materials and Methods

2.1. Materials

Cuttlebone was obtained from fish markets and manually cleaned by removing the attached tissue. The cuttlebone was thoroughly rinsed with both tap and distilled water to reduce the amount of organic materials and salts that could affect the cuttlebone during subsequent processing. After the cuttlebone pieces were cleaned, they were air dried, and then dried in an oven at a low temperature to assure all the remaining moisture was removed before further processing could occur.

2.2. Preparation of cuttlebone-derived CaO

The Procedure for producing CaO from dried cuttlebone began with breaking dried cuttlebones into smaller pieces by hand and then grinding them into a coarse powder in a laboratory ball mill. The coarse powder was then passed through a sieve system to achieve a uniform particle

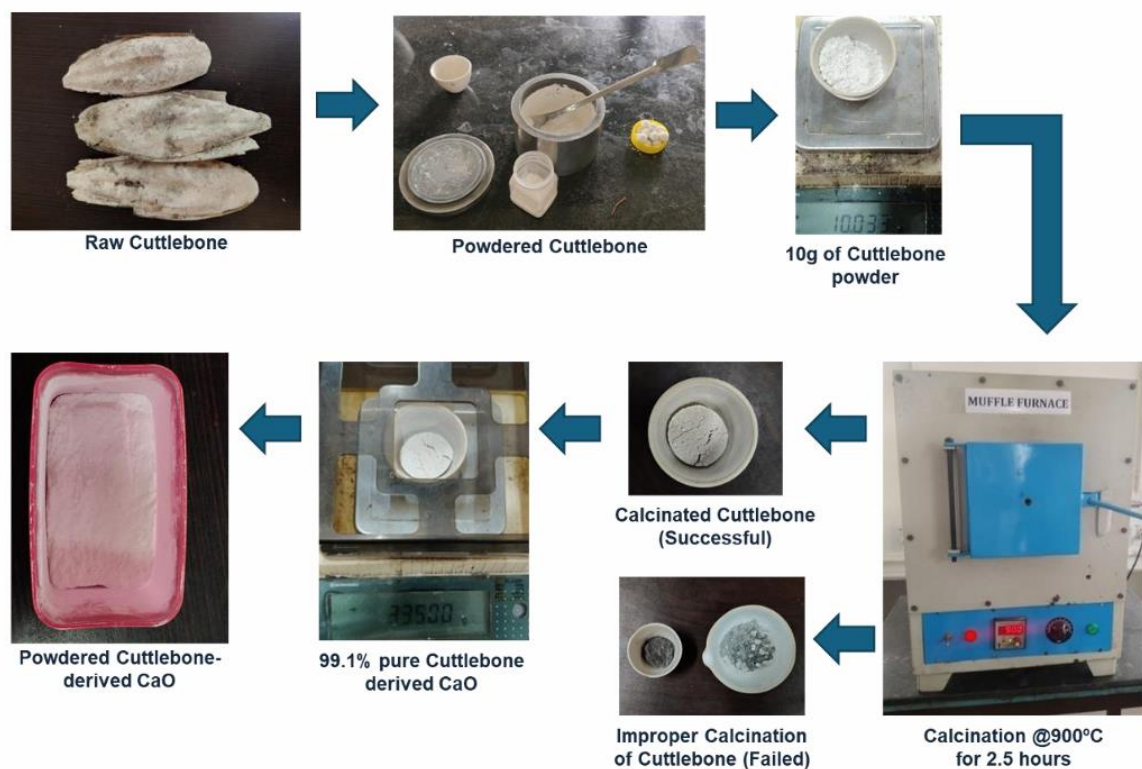


Fig.1. Preparation of cuttlebone-derived CaO

size distribution for slurry processing and being suspended in the bubble column. Most of the powder from the sieving process consisted of aragonitic CaCO_3 and was calcined in a muffle furnace to form CaO at a temperature of $\sim 900^\circ\text{C}$ and held for approximately 2.5 - 3.0 hours. This procedure for producing CaO from cuttlebone is similar to those that have been previously reported for other biogenic sources used to produce CaO from marine waste.

Table 2.1 – Synthesis of Cuttlebone-derived CaO

Description	Value
Empty Crucible Weight	27.95 g
Amount of Cuttlebone Powder	10 g
Calcination Parameter	900°C for 2.5 hours
Amount of Calcinated Cuttlebone Powder	33.50 g
Molar weight of CaO to be obtained	5.6 g
Efficiency of Conversion	$\frac{5.55}{5.6} * 100 = 99.1\%$

2.3.Characterization

The characterization of cuttlebone-derived calcium oxide (CaO) confirms the successful synthesis of a reactive and structurally suitable sorbent for gas absorption.

2.3.1. Particle size analysis

It is inferred from particle size analysis that a Z-average diameter of 410 nm with a single dominant intensity peak around 338 nm accounted for 100% of the distribution. This unimodal distribution indicates no substantial agglomeration or secondary particle populations. The

Results

	Size (d.n...	% Intensity:	St Dev (d.n...
Z-Average (d.nm): 410.0	Peak 1: 338.2	100.0	90.59
Pdl: 0.407	Peak 2: 0.000	0.0	0.000
Intercept: 0.793	Peak 3: 0.000	0.0	0.000
Result quality	Refer to quality report		

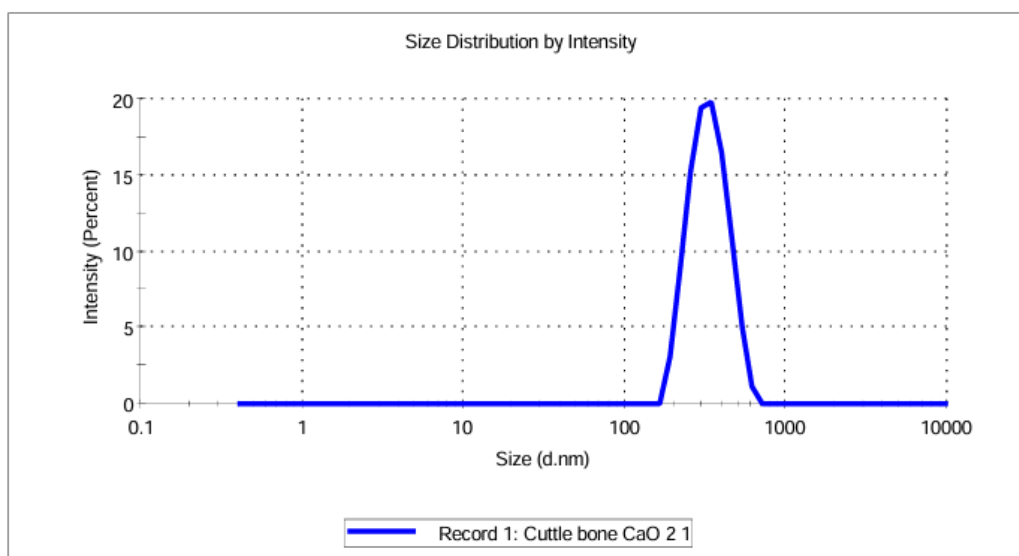


Fig.2. Particle Size Analysis of Cuttlebone derived CaO

polydispersity index of 0.407 indicates midrange uniformity, which is acceptable for heterogeneous sorbents. The submicron particle size is very advantageous since it provides for a high specific surface area, as well as improved gas–solid interaction kinetics during the adsorption process.

2.3.2. X-ray diffraction

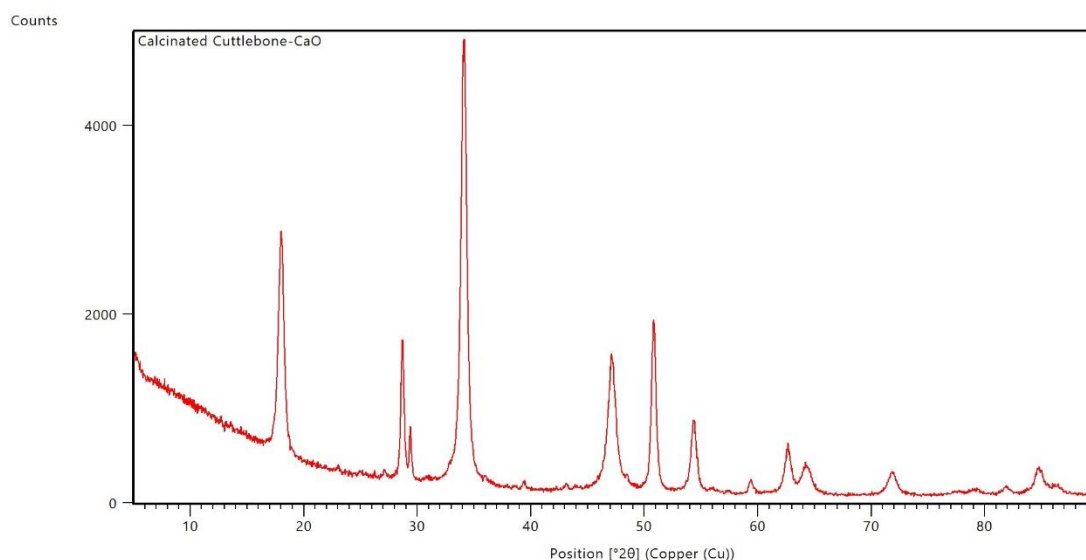


Fig.3. XRD Analysis of Cuttlebone derived CaO

The X-ray diffraction (XRD) pattern, proving the formation of crystalline CaO, has distinct, sharp peaks at about $2\theta = 32^\circ$, 37° , 54° , and 64° , which correspond to the expected lattice planes of cubic CaO. The intensity of the peak and its narrow width suggest high crystallinity and phase purity. In particular, absent of some peaks belonging to calcium carbonate (CaCO_3), it supports the claim that calcination almost completely carried out the thermal decomposition. The small elevation of the basal line at low angles may be related to either some small amounts of amorphous phase or residual impurities, which nevertheless do not notably affect the dominant crystalline CaO phase. XRD analysis results confirm the efficiency of the calcination process for transforming biogenic CaCO_3 into CaO.

2.3.3. Fourier Transform Infrared (FTIR)

FTIR has demonstrated the complete creation of calcium oxide (CaO) produced by the synthesis of cuttlebone with its active surface functional groups. The strong absorption peaks at approximately 1479 cm^{-1} and 1144 cm^{-1} are indicative of the presence of Ca–O lattice vibrations and thus confirm the formation of CaO. The broad absorption band observed near 3640 cm^{-1} may be attributed to O–H stretching associated with the presence of surface moisture or hydroxyl groups. The hydroxyl groups are expected due to the hygroscopic properties of calcium oxide (CaO). The minor peak located at approximately 874 cm^{-1} may indicate the presence of trace carbonate species, which may have been introduced as a result of atmospheric carbon dioxide or residual CaCO_3 from the original cuttlebone used in the synthesis. The

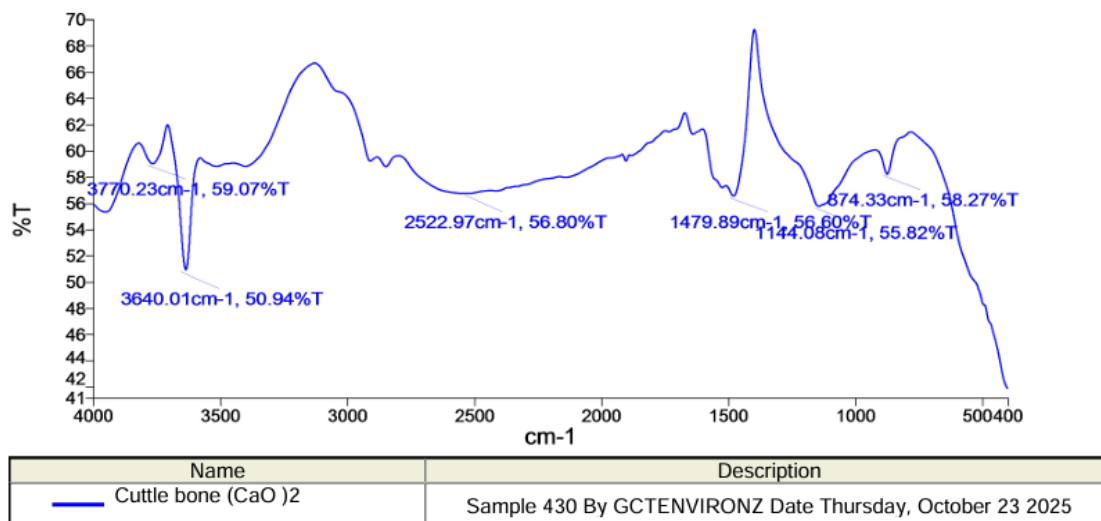


Fig.4. FTIR Analysis of Cuttlebone derived CaO

relative weak intensity of the peak at 2522 cm^{-1} may also suggest residual organic matter from the biogenic precursor used in the synthesis.

2.3.4. SEM Analysis

The CaO derived from cuttlebone (synthesized by SBM's method) had an extremely porous and irregular surface morphology, with loose agglomerated clusters of particles. The SEM photos show that there were mostly flaky or plate-shaped structures with rough surfaces and interconnected voids, as well as non-uniform pore distributions. This porous morphology

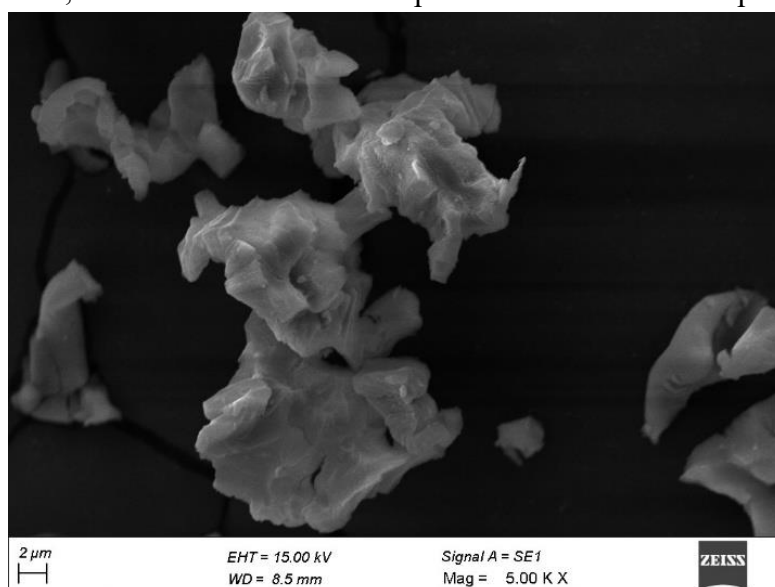


Fig.5. Cuttlebone-derived CaO (SEM-1)

formed during calcination of CaCO_3 to CaO through thermal decomposition with the production of CO_2 . The formation of CO_2 during this reaction generated both voids inside the sorbent matrix and surface defects throughout the structure. The majority of the particles had a sub-micron size; this results in a large surface area relative to their volume and increased accessibility of active carbonation sites on the carbonated product. Higher magnification

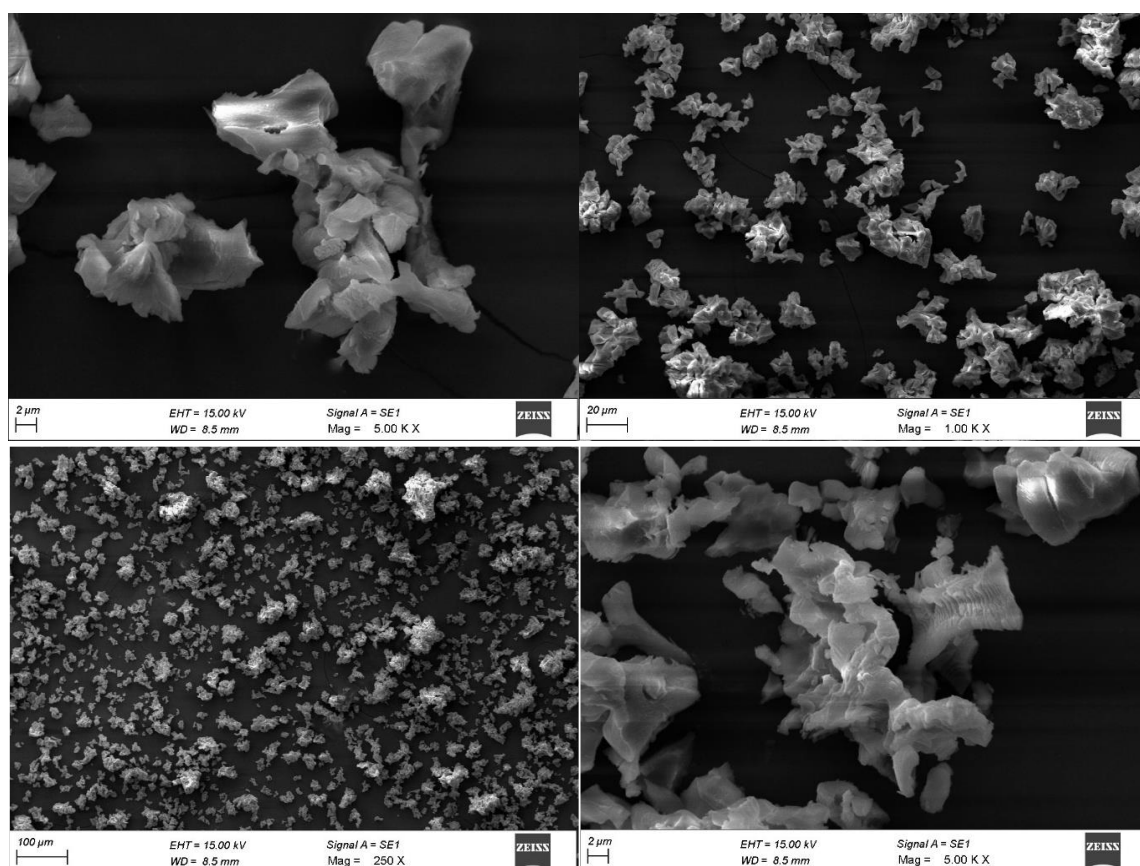


Fig.6. Cuttlebone-derived CaO (SEM-2)

images of the cuttlebone-derived CaO showed that there were extensive wrinkles, layers, and folds on the surface (edge and surface defects) along with micro-pores all over the surface. These structured irregularities increase pore access and promote CO₂ diffusion into the sorbent structure. The lack of substantial amounts of sintering or densification in the prepared composite indicates that the calcination process preserved the biogenic porous structure of the cuttlebone-derived calcium carbonate, resulting in high surface reactivity and favourable adsorption properties for all carbonated products.

2.4.Experimental setup

The chimney discharges the flue gas and connects to a flexible silicone tube to transfer the gas to the reactor. The gas goes through a CO₂ (carbon dioxide) sensor located near the inlet to get the initial concentration value prior to entering the reactor; therefore, we can monitor the input conditions regarding gas composition. The gas flows into the bubble column reactor at the bottom of the reactor. The gases from the flue (the chimney) will be atomized into small fine air bubbles within the slurry that contains the CaO (Calcium Oxide) made from cuttlebones. The gas/gas interaction, while the bubble is rising in the liquid (the slurry), increases how effectively the gas will be absorbed. The increase in gas contact area and the amount of time the gas is exposed to the liquid in the reactor increases the probability of gas absorption into the liquid. After flowing through the reactor, the gas exits through the side of the reactor at the top through a silicone outlet pipe and is measured from a second CO₂ gas sensor. At this point, we will be able to establish a measurable difference between the inlet and outlet gas



Fig.7. Bubble Column Experimental Setup

concentration values to calculate the overall removal efficiency. Throughout the experiment, a vacuum pump pulls the gas through the entire flow system and provides a constant and regulated flow rate. The compact, leak-proof design of the system makes it ideal for performing laboratory-scale experiments using consistent, dependable operation.

2.5.Cyclic CO₂ Capture Performance

Through a series of tests involving repeated use of synthesized CaO sorbents and same experiments were performed multiple times on cuttlebone-derived CaO Sorbents as a means to evaluate reusability and cyclic stability of that sorbent. Following each test, the used sorbent would be regenerated via Calcination, and then used in following tests. The series of tests were performed to evaluate the structural stability, effectiveness of regeneration, and retention characteristics related to the synthesized material. Decreased CO₂ removal efficiency (or amount of CO₂ sorbed) as a result of repeated testing occurs as a result of pore blockages, sintering and structural densification of CaO particles.

3. Results and Discussion

3.1. CO₂ Removal Performance at Different Slurry Concentrations

In order to evaluate the efficiency and performance of CaO slurries as adsorbents for the removal of CO₂ gases, a series of carbon dioxide absorption experimental trials were conducted in which CaO slurries derived from cuttlebone were used as adsorbent materials with a concentration range of 1 wt% to 10 wt%. The concentration level of CO₂ entering the reactor system from the combustion of coconut shells was approximately 9500 to 10500 ppm, with typical fluctuations for a biomass-derived flue gas stream.

Table 3.1. CO₂ Removal Performance at Different Slurry Concentrations

Slurry	Trial	CO ₂ Inlet (ppm)	CO ₂ Outlet (ppm)	Removal Efficiency (%)	CO ₂ Uptake Capacity (g CO ₂ /g sorbent)
1 wt% CaO	1	9684	6417	33.73	0.18
	2	10472	7093	32.26	0.17
	3	9516	6038	36.56	0.19
2 wt% CaO	1	10038	4936	50.83	0.31
	2	9487	4369	53.95	0.33
	3	10366	5127	50.54	0.30

5 wt% CaO	1	9879	3274	66.85	0.56
	2	10128	3016	70.22	0.59
	3	9623	2897	69.89	0.58
8 wt% CaO	1	9728	3021	68.95	0.68
	2	10354	3186	69.22	0.69
	3	9592	2875	70.01	0.70
10 wt% CaO	1	9816	3348	65.89	0.63
	2	10092	3527	65.05	0.62
	3	9476	3196	66.27	0.64

At 1 wt% concentration of the CaO slurries, the CO₂ removal efficiency of 32% to 36% was observed. The decreased carbonation performance of the CaO slurries at this low concentration was due to insufficient amounts of CaO available for adsorption of the CO₂ molecules that were generated in the reactor system. Adequate mixing and gas-liquid interface development resulted from continued gas bubbling during the carbonation process, but the limited amount of calcium oxide available restricted the overall carbonation holding capacity of the reactor.

As the slurry concentration was increased to 2 wt%, an increase in carbonation efficiency was achieved with an approximately 50-54% removal efficiency. The improvement shows that more active CaO sites are available as well as the increased alkalinity of the slurry phase allows for better CO₂ absorption behaviour. The increase in performance was also gradual, implying the development of moderate gas – liquid mass-transfer limitations within the reactor.

When the slurry concentration is further increased to 5 wt%, the performance of the reactor increased substantially achieving a removal efficiency of almost 67-70%. At this slurry concentration, the reactor had good characteristics for gas – liquid -solid interactions and good dispersion of gas bubbles in the slurry phase. The availability of a greater amount of sorbent and stable hydrodynamic conditions contributed to improved kinetics of carbonation of the CO₂ within the CaO sorbent.

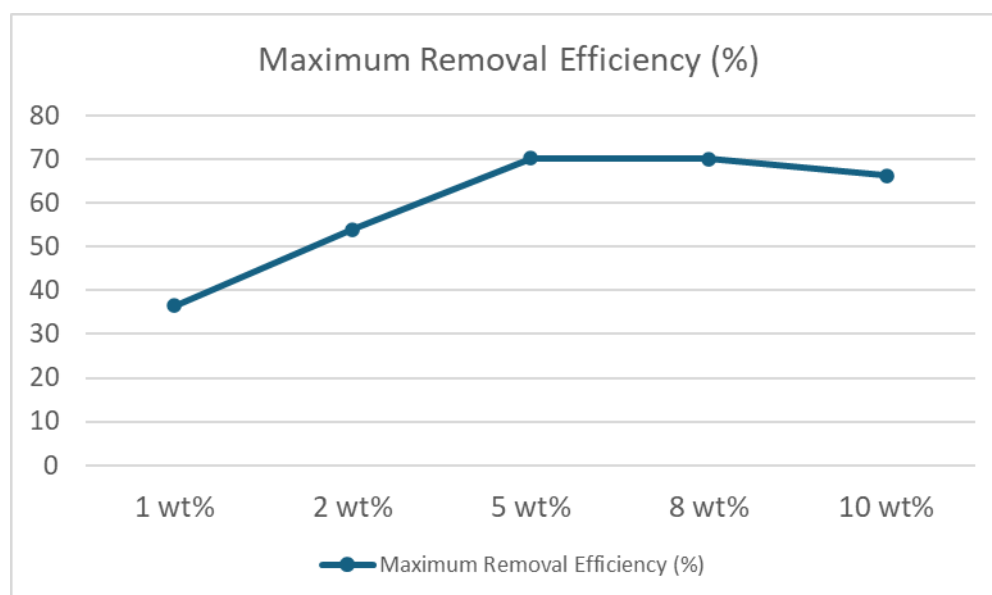


Fig.8. Maximum removal efficiency

The 8% CaO slurry produced the best overall and most constant CO₂ absorption results compared to the other slurries tested between 0–10% concentration by weight. Over time, the CO₂ absorption efficiency stayed relatively constant between 69–70%, with the maximum CO₂ absorption capacity at ~0.70 gCO₂/gsorbent. The improvement in carbonation characteristics is linked to the increased amount of reactive surface area, gas-solid interaction, and naturally porous structure of the calcium oxide from cuttlebone-derived sources, which has a unique pore

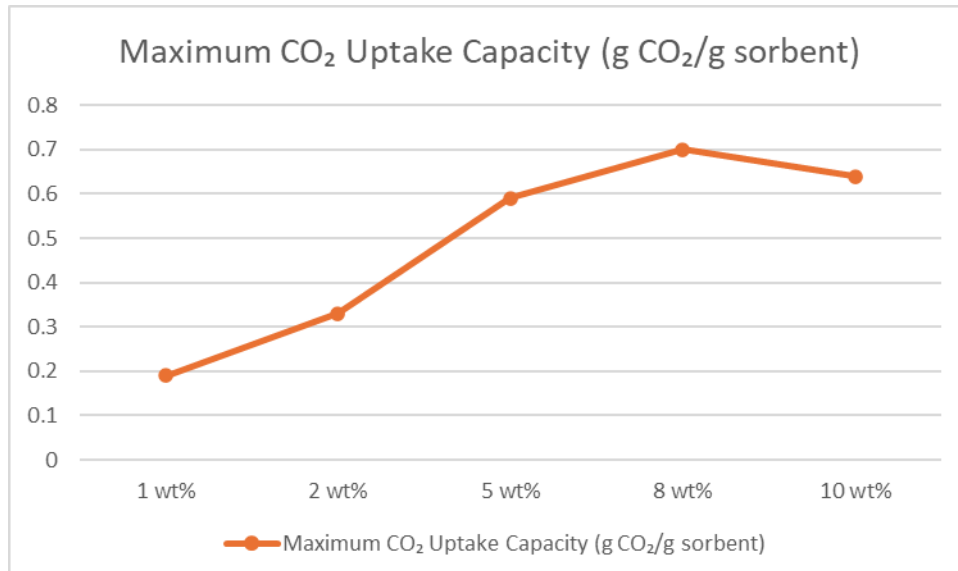


Fig.9. Maximum CO₂ Uptake Capacity (g CO₂/g sorbent)

structure that makes it porous. Therefore, the incorporation of hierarchical porous structures through cuttlebone likely facilitated increased diffusion of CO₂ toward active adsorption sites within the calcium oxide.

Beyond the optimal level of 8% slurry concentration, there was a slight decrease in the carbonation efficiency with a 10% concentration producing an absorption efficiency of approximately 65–66%. This decrease in carbonation efficiency can potentially be associated with increased viscosity of the slurry that inhibits the movement of bubbles and dispersal of gas inside the reactor. In addition, a higher density of the slurry could facilitate the coalescence of bubbles and decrease the effective interfacial area for gas and liquid, thereby reducing the overall efficiency of mass transfer.

3.2.Reusability of Regenerated 8 wt% CaO Slurry

After performing preliminary experiments to test carbon dioxide absorption through carbonating a waste product of the cuttlefish shell called cuttlebone, we found that, when tested at the same weight (8 wt%) for mass, the cuttlebone-derived calcium oxide demonstrated superior performance in terms of both the efficiency in absorbing carbon dioxide and stability. Based on this result, we selected the cuttlebone-derived calcium oxide for testing its ability to be reused as an absorbent through multiple cycles of use. After each experiment, sorbent is recovered by calcining it. The absorbent was then reused to allow us to determine how well the absorbent would work in repeated use as it underwent a total of three cycles of absorption and calcination. The results showed that the regenerated cuttlebone-derived calcium oxide retained significant.

Table 3.2. Reusability of Regenerated 8 wt% CaO Slurry

Sorbent Condition	Trial	CO₂ Inlet (ppm)	CO₂ Outlet (ppm)	Removal Efficiency (%)	CO₂ Uptake Capacity (g CO₂/g sorbent)
Fresh 8 wt% CaO	1	9728	3021	68.95	0.68
	2	10354	3186	69.22	0.69
	3	9592	2875	70.01	0.70
Regenerated Cycle 1	1	10042	3462	65.52	0.63
	2	9835	3347	65.97	0.64
	3	10218	3521	65.54	0.63
Regenerated Cycle 2	1	9916	3874	60.93	0.58
	2	10406	4095	60.65	0.57
	3	9638	3761	60.98	0.58
Regenerated Cycle 3	1	10126	4463	55.92	0.52
	2	9784	4317	55.88	0.51
	3	10352	4582	55.74	0.52

After going through their first regeneration period, their average CO₂ removal efficiencies ranged from approximately 69–70% to almost 65-66%. This small drop in performance suggests that a significant number of available CaO active adsorbent sites were available for continued thermal regeneration. Because of its naturally porous morphology from the cuttlebone structure, it is likely that sufficient pathways for gas diffusion and reactive surface areas were available throughout multiple cycles of operation to provide suitable reaction conditions. When the sorbent was regenerated extensively, consistently and replicatively through future experiments after it had been regenerated multiple times, it continued to demonstrate stable repeatability in the carbonation behaviours of these compounds.

After their second regeneration cycle, their removal efficiencies further dropped down to approximately 60–61%. Continuing the trend of diminishing returns/cycles for performance, largely due to thermal sintering of the CaO particles from having undergone calcinations at elevated temperatures over so much time, has decreased both the pore volumes and effective surface areas for all of the available adsorbent sites.

Table 3.3. Uptake Retention over Regeneration Cycles

Sorbent Condition	CO₂ Uptake Capacity (g CO₂/g sorbent)	Uptake Retention (%)
Fresh 8 wt% CaO	0.69	100
Regenerated Cycle 1	0.63	91.30
Regenerated Cycle 2	0.58	84.06
Regenerated Cycle 3	0.52	75.36

During the third regeneration cycle, the average carbonation efficiency further decreased to approximately 55–56%. Although the regenerated sorbent retained noticeable carbonation activity, the reduction in CO₂ uptake capacity indicates gradual deactivation of the sorbent material. The uptake capacity decreased from approximately 0.70 g CO₂/g sorbent for fresh CaO to nearly 0.52 g CO₂/g sorbent after the third cycle.

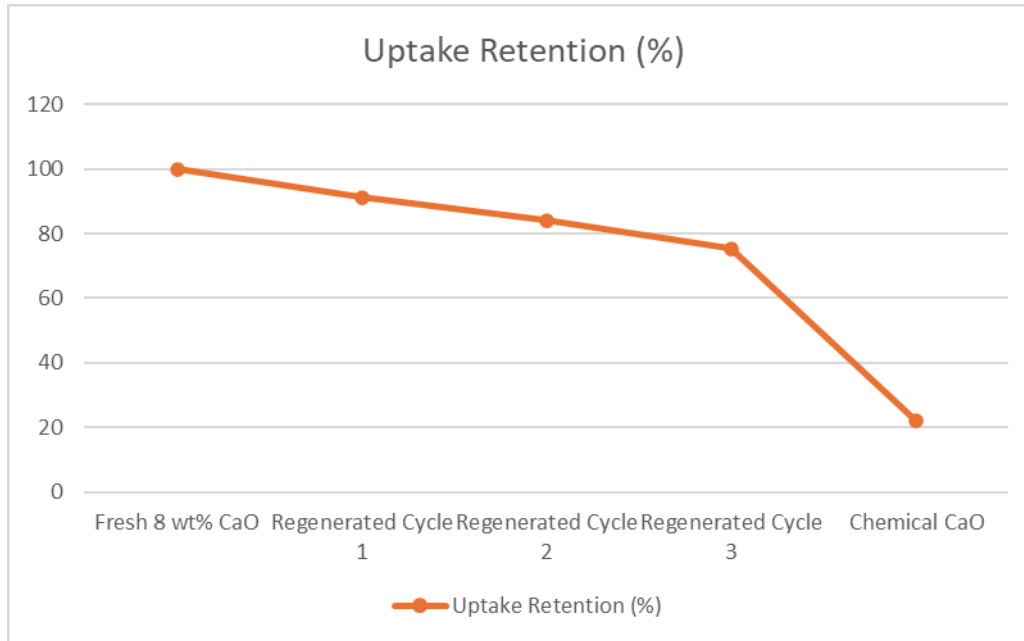


Fig.10. Uptake retention (%)

3.3.Comparison of Initial and Final CO₂ Uptake Capacity

According to research, the calcium oxide obtained from cuttlebone is capable of capturing CO₂ at a significantly higher rate than traditional chemical CaO in multiple cycles of regeneration. The current investigation shows that CO₂ uptake capacity in CaO decreased from 0.69 g CO₂/g sorbent (fresh) after the third cycle of regeneration to approximately 0.52 g CO₂/g sorbent for the same sorbent, indicating a deactivation of approximately 24.64%. In contrast, conventional dense chemical CaO as shown by Afandi et al. [2] has significantly less uptake capacity, going from approximately 0.45 g CO₂/g sorbent to approximately 0.10/g CO₂/g sorbent after multiple carbonation-calcination cycles, or 77.78% deactivation.

Table 3.4. Comparison of Initial and Final CO₂ Uptake Capacity

Sorbent Type	Sorbent Condition	CO ₂ Uptake Capacity (g CO ₂ /g sorbent)	Uptake Retention (%)	Sorbent Deactivation (%)
Cuttlebone-derived CaO	Fresh 8 wt% CaO	0.69	100	0
	Regenerated Cycle 1	0.63	91.30	8.70
	Regenerated Cycle 2	0.58	84.06	15.94
	Regenerated Cycle 3	0.52	75.36	24.64
Conventional Chemical CaO [16]	Initial Cycle	0.45	100	0
	Final Regeneration Cycle	0.10	22.22	77.78

The superior cyclic stability of CaO from cuttlebone is likely due to its porous and inter-connected natural biomorphic structure, which provides gas diffusion pathways and prevents

pathway blockage due to sintering at high temperatures during multiple regeneration cycles. The natural cuttlefish bone structure's complex hierarchical pore arrangements provide for stability of structure and minimal collapse of pores during cyclic carbonation-calcination operation.

4. Conclusion

The work described in this paper evaluated the ability of calcium oxide (CaO) produced from cuttlebone waste to be prepared, regenerated, and used for cyclic CO₂ capture in a slurry bubble column reactor. The waste cuttlebone material was thermally calcined into a porous form and subsequently tested for its ability to be cycled through carbonation. The results show that the porous biomorphic structure of the cuttlebone-derived CaO played an important role in increasing the interaction between gas and solid, resulting in greater stability during carbonation tests. The main conclusions from the study are

- As slurry concentration was increased, the CO₂ removal efficiency increased, resulting in more available reaction sites for carbonation
- The highest CO₂ removal efficiency of 70%, corresponding to an approximately 0.70 g CO₂/g sorbent maximum uptake, occurred at the optimal CaO slurry concentration of 8 wt%
- When slurry concentrations exceeded the optimal concentration, carbonation efficiency decreased slightly because of increased viscosity of the slurries, bubble coalescence, and limitations on gas dispersion
- The slurry bubble column reactor provided good interaction between gas, liquid, and solid as well as stable hydrodynamics, and as a result, was a good candidate for use in carbonation applications under ambient conditions.
- Cuttlebone-derived CaO derived from regeneration has shown significant carbonation activity after many carbonation and calcinations, demonstrating that it can be reused and cycled with good stability.
- After 3 cycles of batch regeneration CaO from cuttlebone retained roughly 75 % of its originally retained weight, which shows less deactivation behaviour compared to other CaO sorbents from dense chemicals owned.
- Cuttlebone has a naturally porous, interconnecting pore network and was preserved through multiple cycles of being regenerated, resulting in increased gas diffusion from and reduced pure structural failure of cuttlebone CaO through multiple cycles of regeneration.

The results indicate that CaO is a viable, environmentally-friendly and low-cost waste product for successive capture; therefore, this also serves as a foundation for further studies of CO₂ capture techniques such as the use of marine biowastes as an environmentally sustainable way of developing calcium looping systems for carbon capture after combustion, and provides a basis for future studies related to mechanical flue gas disposal from an engineering perspective, large-scale batch slurry reactors and long-term carbon sequestration studies for greenhouse gas reduction technologies.

DECLARATIONS

Ethics approval and consent to participate: Not applicable

Consent for publication: Not applicable

Availability of data and materials: It is available with the corresponding author

Competing interests: The authors declare that they have no competing interests.

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