

How to Combat Ocean Acidification?

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Citation: Gupta, A. (2025). How to Combat Ocean Acidification? International Journal of Global Research Innovations & Technology, 03(03), 120–130. <https://doi.org/10.62823/ijgrit/03.03.7929>

ABSTRACT

Ocean acidification is driven by rising atmospheric carbon dioxide from human activities and it is causing significant changes in ocean chemistry that threaten the marine ecosystems, particularly shell-forming organisms and the coral reefs. This project investigates an engineering-based solution inspired by natural coastal erosion, where the calcium carbonate from cliffs leeches into seawater therefore buffering acidity in the water. The paper proposes a device that is a boat-mounted pellet dispenser that gradually releases limestone (CaCO_3) pellets into the ocean thereby increasing its alkalinity and enhancing its capacity to absorb CO_2 . The dispenser machine will consist of three integrated components: a helix feed mechanism, a rotary drum, and a bevel gear system, which together will ensure a steady and evenly distributed release of pellets in proportion to the boat's speed. Prototype testing confirmed the basic functionality of each component, with potential for improvement through automated control systems, corrosion-resistant materials, and integrated pH sensors. By mitigating local acidification through a low-cost scalable method, adaptable to various vessel types, this approach aims to complement global CO_2 reduction efforts. The device represents a practical step toward protecting vulnerable marine habitats and demonstrates the role of bio-inspired engineering in addressing climate-related challenges, however further research is required to assess large-scale environmental impacts and optimize dissolution rates.

Keywords: Ocean Acidification, Calcium Carbonate, Helix Mechanism, Rotary Drum, Bevel Gear.

Introduction

With the rapid rise in human activities such as burning coal, oil, and natural gas the amount of greenhouse gases in the atmosphere has increased manifold. One of the main gases, carbon dioxide (CO_2), is now at its highest level in hundreds of thousands of years. This extra CO_2 doesn't just stay in the air — it also gets absorbed by the oceans. Since the start of the industrial revolution in the late 1700s, the surface ocean's acidity has increased by about 30 percent, which means the pH has dropped by 0.1, from roughly 8.2 to 8.1 (NOAA 2024). Because the pH scale is logarithmic, even this small change means the amount of hydrogen ions in seawater has gone up by around 26 percent (Zeebe and Wolf-Gladrow 2001).

About one quarter of all human-made CO_2 is taken up by the ocean every year (Oschlies et al. 2024). Most of this happens at the surface, where the water is in direct contact with the atmosphere. CO_2 moves into seawater when there's more of it in the air than in the water — like when air pressure pushes gas into a fizzy drink. Rainwater can also carry CO_2 into the ocean. When CO_2 mixes with rainwater, it forms a weak acid called carbonic acid, which can slowly dissolve rocks on land and release bicarbonate ions. These bicarbonate ions eventually flow into rivers and then into the sea. When CO_2 dissolves in seawater, it changes into carbonic acid, which then breaks apart into bicarbonate and hydrogen ions. More hydrogen ions make seawater more acidic and reduce the amount of carbonate ions. These carbonate ions are essential for many marine animals such as oysters, clams, corals, and some tiny plankton. These creatures need carbonate ions to build their shells and skeletons out of calcium

carbonate (CaCO_3). If carbonate ion levels drop too much, shell-building becomes harder, and in some cases, shells can even start to dissolve (NHM, UK)

This process doesn't just affect individual species; it impacts entire ecosystems. Many tiny shell-forming plankton, like coccolithophores and pteropods, are food for fish, which are then eaten by larger animals. If the base of the food web is weakened, the effects spread upward. Coral reefs, which are home to thousands of species and help protect coastlines from storms, are already under pressure. Scientists expect coral growth rates to fall by 10 to 30 percent by 2050 if CO_2 emissions stay high (NOAA 2023).

Some parts of the world are at greater risk than others. Cold oceans, like the waters around Antarctica, naturally have fewer carbonate ions, so adding more CO_2 pushes them toward dangerous conditions faster. In certain areas like the Southern Ocean, parts of the water are already at times corrosive to organisms like pteropods. In the California Current along the U.S. West Coast, deep CO_2 -rich water sometimes rises to the surface (a process called upwelling), making local seawater so acidic that shellfish hatcheries have struggled to keep young oysters alive (Feely et al. 2008). As the climate warms, the ocean's ability to absorb CO_2 will decrease. Warm water holds less gas than cold water, and a warmer surface layer mixes less with deeper water, reducing the ocean's "breathing" capacity. This means more CO_2 will stay in the atmosphere, and acidification will continue to worsen.

Because ocean acidification is linked to both atmospheric CO_2 levels and the chemistry of seawater, the best solutions will combine cutting CO_2 emissions with methods to restore the ocean's natural balance. One possible approach is to add alkaline (basic) substances to seawater to help neutralize the extra acid. This idea is the basis for the engineering solution described in the next section.

The Solution

One natural process that helps keep ocean acidity in check is coastal erosion, which happens when waves wear away rocks along the shoreline. Many coastal cliffs are made of calcium carbonate (CaCO_3) rock, such as limestone or chalk. When these rocks are broken down by wave action, small particles of CaCO_3 enter the water. As they dissolve, they release carbonate ions that help balance acidity and keep the ocean's pH more stable (Kump et al. 2009). This works because calcium carbonate reacts with hydrogen ions in the water, reducing acidity and creating bicarbonate ions. This extra buffering capacity helps protect marine life from the harmful effects of ocean acidification. Inspired by this natural process, the proposed engineering solution aims to add alkaline material to seawater in a controlled way. The plan is to gradually release pellets made of calcium carbonate (limestone) into the ocean using a specially designed dispenser mounted at the back of a boat. By slowly increasing the ocean's alkalinity in the area where the boat travels, the system could make local waters better able to absorb CO_2 from the atmosphere while also reducing acidity.

Calcium carbonate is a good choice for this application because it is cheap, easy to obtain, and already naturally present in the marine environment. Its reaction in seawater follows a simple principle i.e. each molecule of CaCO_3 that dissolves increase the total alkalinity of the water by two equivalents, which can help push the pH slightly upward (Zeebe and Wolf-Gladrow 2001). In turn, this shift in chemistry makes it easier for the ocean to take up more CO_2 from the air. To ensure that calcium carbonate (limestone) pellets work, a small-scale experiment will be carried out to confirm the hypothesis that adding calcium carbonate in acidic water increase the alkalinity of water. The results will determine the efficacy of the pellets that could potentially be used in the product.

The Experiment

- Hypothesis**

It is hypothesized that adding a specific quantity (2 grams) of calcium carbonate pellets to 1 litre of acidic water will increase the pH level of the water by reducing acidity.

- Variables**

Table 1: Independent and Dependent Variables

Experiment Variables	Named Variables	Methods	Why to control?	How to control?
Independent	Calcium carbonate pellets	Adding 2 grams of pellets to 1 litre water of water in 5 sampling bottles	To avoid over-correction (by adding more than required amount)	By measuring pellets on a weighing scale to ensure uniformity

Dependent	The change in pH level of water	By recording the pH level through a pH meter	To assess the use of calcium carbonate pellets as a solution for reducing ocean acidification	By recording the pH level of slightly acidic water before and after adding calcium carbonate pellets
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- **Materials Required**

- Calcium Carbonate Pellets or Granules sourced online or from a lab
- 5 litres of neutral tap water
- 5 sample water collection bottles (capacity at least 1 litre)
- Weighing scale
- Small spoon and two plastic dish (one deep and one flat)
- pH level meter from a lab
- A silicone dropper
- Two lemons

- **Procedure**

- Collect 1 litre of tap water in every sampling bottle and label them.
- Measure and record the pH level of all five tap water samples in the bottles.
- Squeeze the juice of a whole lemon in the deep plastic dish.
- Using a dropper add 8 drops of lemon juice in each of the 5 water samples and shake the bottles gently.
- Measure and record the pH level of all five tap water samples in the bottles after waiting 5 minutes.
- On the weighing scale, place the plastic dish and press the tare button to ensure a zero-gram reading
- Remove calcium carbonate pellets from its container using a small spoon and place it on the plastic dish, add till the reading says 2 grams
- Add the pellets from the plastic dish to sample bottle 1 using the small spoon carefully, ensuring that it does not spill
- Repeat the steps 6-8 and add an equal quantity of calcium carbonate pellets in each water sample bottle.
- Shake the sample bottles gently to ensure the pellets dissolve completely.
- Let the water samples sit for 15 minutes.
- Measure and record the pH level of the water samples in the bottles.

- **Data Collection and Processing**

Table 2: Water pH levels at different stages

	Sample 1 pH level	Sample 2 pH level	Sample 3 pH level	Sample 4 pH level	Sample 5 pH level	Average (rounded off)
Tap water	7.4	7.4	7.3	7.4	7.4	7.4
Water with added lemon juice	7.0	6.9	6.8	6.8	6.8	6.9
Water after adding calcium carbonate pellets	7.3	7.5	7.2	7.2	7.4	7.3

- **Result Analysis**

Table 1 shows that the pH level of tap water decreased when lemon juice was added. This decrease in pH level makes the water slightly acidic. The average pH level dropped from 7.4 to 6.9. 2 grams of calcium carbonate pellets were added in the acidic water which increased the pH level of the

water samples in all cases. The average pH level of water with lemon juice increased from 6.9 to 7.3. The introduction of calcium carbonate to acidic water increased the pH level and was able to stabilize it. The hypothesis that calcium carbonate pellets when added in acidic water increases the alkalinity in water is proven.

The experiment could be improved upon by replicating the experiment using real world conditions such as ocean water instead of tap water and increasing the sample size while also taking water from different parts of the ocean.

Furthermore, for this method to work well in real life conditions, the pellets need to dissolve efficiently in the surface layer of the ocean — the zone that is in direct contact with the atmosphere. If the pellets sink too quickly, they may reach deeper water before they dissolve, reducing their ability to affect surface pH. Factors like pellet size, water temperature, and mixing from waves or boat movement all influence the rate of dissolution. Studies on “alkalinity enhancement”, the technical term for adding base minerals to seawater show that small particle sizes, high turbulence, and slightly warmer water tend to speed up dissolution (Renforth and Henderson 2017).

Another important consideration is environmental safety. While calcium carbonate itself is non-toxic and naturally occurring, adding too much in one place could raise local pH above natural ranges, which might stress marine organisms adapted to stable conditions. Therefore, the design includes a controlled-release system to avoid dumping large amounts in a single spot. The device also takes advantage of the boat’s movement to spread pellets over a wide area, reducing the chance of harmful local pH over-correction spikes.

The key challenge to this promising solution is to balance effectiveness, releasing enough CaCO_3 to make a measurable difference while also focusing on safety and practicality in real-world marine environments. The next section will explain in detail how the product’s design works in order to fulfil this requirement.

The Product

The product is designed as a three-part mechanical system that can be attached to the back of a boat. It is designed to store, move, and then release calcium carbonate (CaCO_3) pellets into the ocean in a steady and controlled way. By using the movement of the boat and an efficient feeding mechanism, the system can spread pellets over a large area of ocean.

The three main components are:

- **Helix Mechanism**

The helix mechanism works like a screw conveyor or Archimedes screw. It is placed inside the storage hopper, a container that holds the pellets before they are released. When the helix rotates, it pushes pellets along its spiral shape towards a small opening at the bottom. This design allows the pellets to be fed at a steady rate into the next part of the system.

Testing showed that the number of turns in the helix affects how quickly pellets move through it. A single-turn helix turned out to be the most efficient because it moved pellets to the opening with less resistance, using the same amount of motor power as more complex designs. However, in the current design the helix motor is separate from the other moving parts. This means the speed must be controlled manually and may need adjusting depending on the boat’s speed and the number of pellets left in the hopper. If the helix moves too fast, pellets could build up in the next stage, causing uneven release. One possible improvement would be to link the helix rotation to the rotation of the next component which is the rotary drum so that both always work in sync.

Because the helix is in constant contact with the pellets, which are slightly abrasive, it should be made from a material that is resistant to wear and safe for the marine environment. For the prototype, Polylactic Acid (PLA), a biodegradable polymer, was used. PLA is moisture-tolerant and environmentally friendly, but for long-term durability in saltwater, other materials such as reinforced plastics or corrosion-resistant metals could be explored.

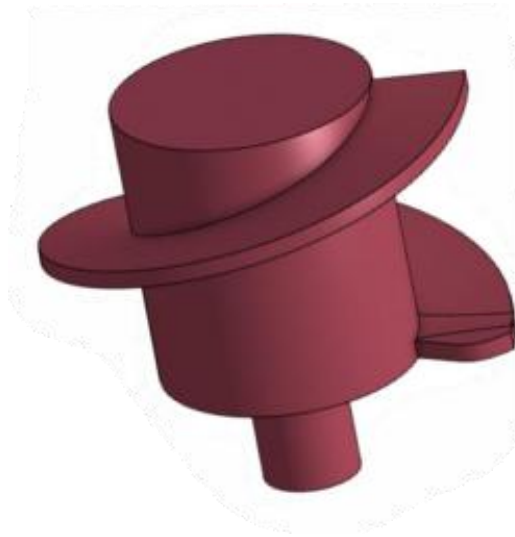


Figure 1: Helix mechanism

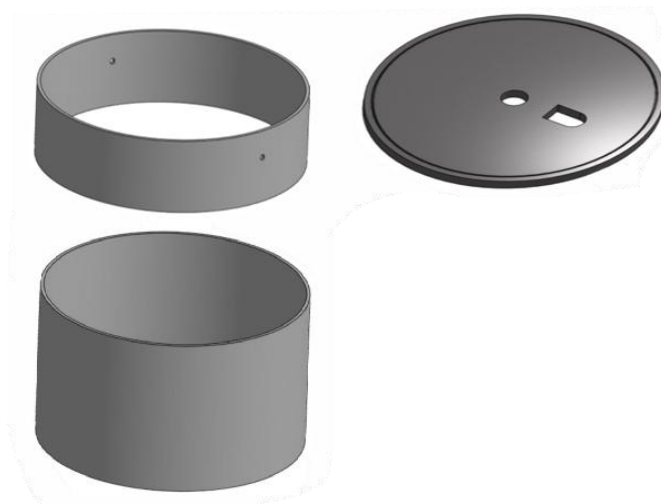


Figure 2: Pellet Storage Container

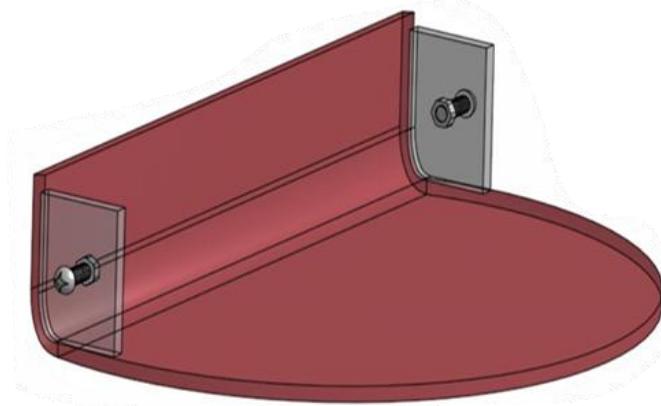


Figure 3: Motor and Battery Holder with clasp fixed with steel bolts and nuts



Figure 4: Assembled helix mechanism

- **Rotary Drum Mechanism**

The rotary drum is the main part of the system responsible for actually throwing pellets into the ocean. It is mounted just above the water's surface and spins around a central pivot connected to a power source. As the drum rotates, centrifugal force pushes the pellets outward from the centre towards openings in its sides. This force comes from inertia: as the drum spins, anything inside it wants to move in a straight line, but the walls of the drum push it outward instead.

The pellets exit through these openings at speed, ensuring they land in the water in a spread pattern instead of clumping together. This controlled ejection is important for even distribution in the ocean, helping to prevent sudden high concentrations of CaCO_3 in one place. The drum in the prototype was made from curved aluminium plates, shaped using a jig and mounted on a central spacer with a hollow shaft for the axle. Aluminium is strong and lightweight, but like the helix, long-term exposure to seawater may require a more corrosion-resistant metal or coating.

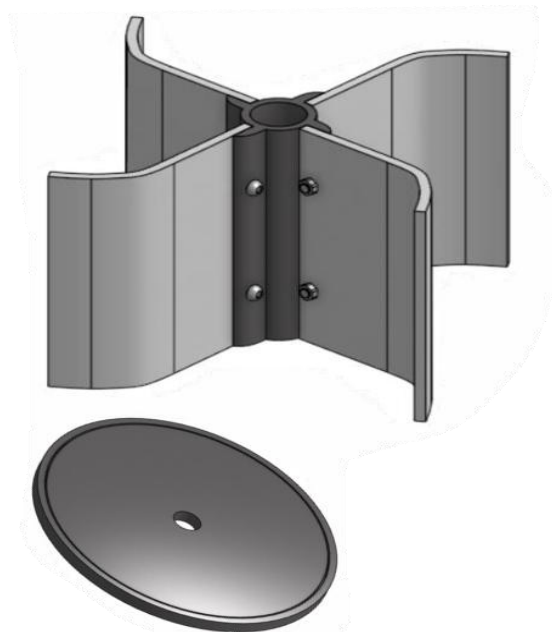


Figure 5: PLA mechanism with aluminium rotary wings fixed with steel bolts, and acrylic base

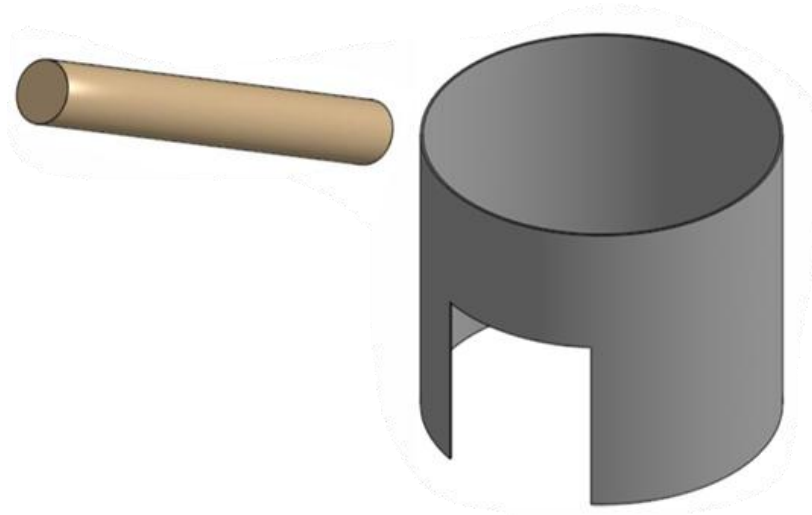


Figure 6: Pine Dowel and Outer PVC Shell

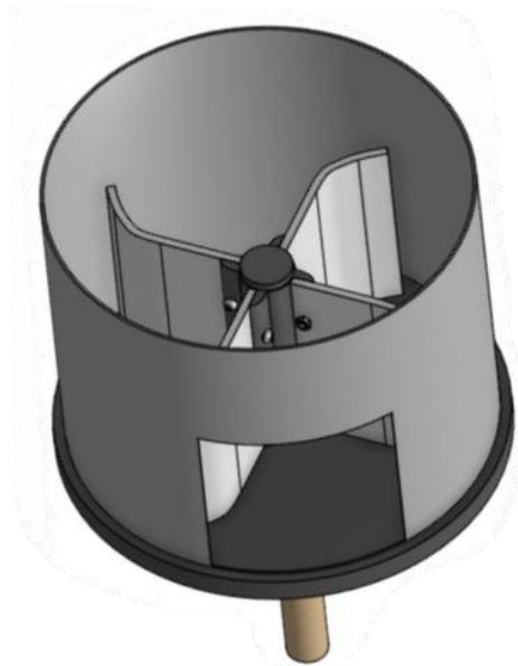


Figure 7: Assembled Rotary Drum

- **Bevel Gear Mechanism**

The bevel gear mechanism connects the boat's motor to the rotary drum and changes the direction of rotation by 90 degrees so the drum can spin horizontally. Bevel gears have angled teeth arranged along a cone, allowing them to transfer motion between shafts that aren't parallel. The type used here are mitre gears, which are the same size and transfer rotation without changing speed.

In the prototype, the gears were 82 mm in diameter with 36 teeth and a 65-degree slant. PLA was used for initial testing because it is easy to work with, but for real marine use, stainless steel such as 316L would be better due to its high corrosion resistance. The gears also ensure that when the boat travels faster, the drum rotates faster, increasing pellet release to match the area being covered. This prevents too much material from being released in one spot if the boat is stationary and instead spreads it evenly over the water's surface.

Together the three-part design allows the efficient spread of calcium carbonate in open water. For further improvements, integrating sensors to automatically adjust pellet release based on boat speed, water pH, or hopper capacity can be explored. These modifications could make the system more adaptable and reduce the need for manual adjustments during operation.



Figure 8: Pine rotating shafts

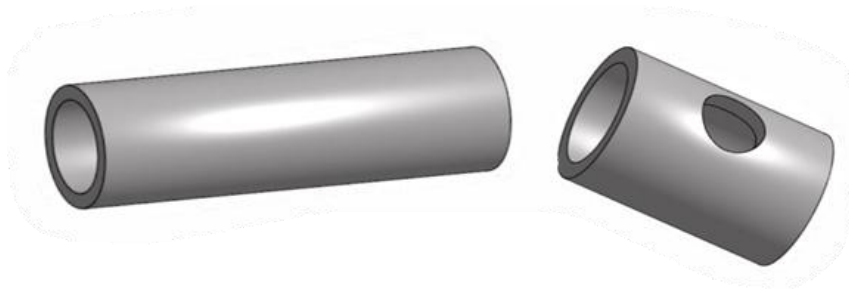


Figure 9: Acrylic pine shaft sleeve/holder

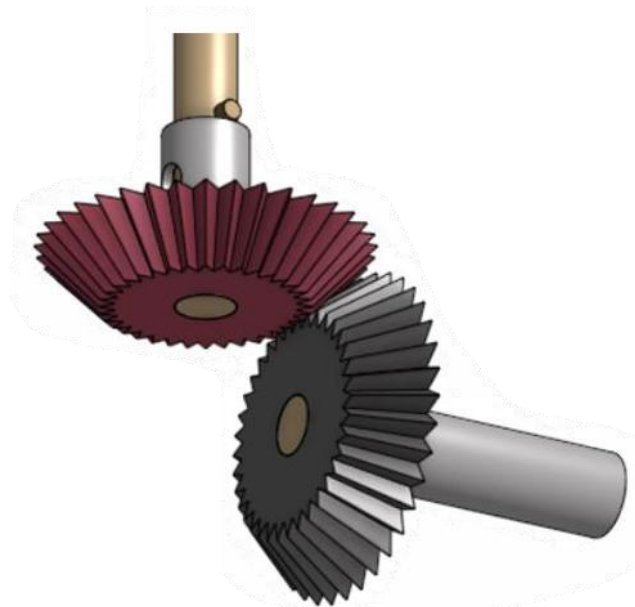


Figure 10: PLA bevel gears attached with pine shafts and acrylic holder fixed in place with stainless steel screws

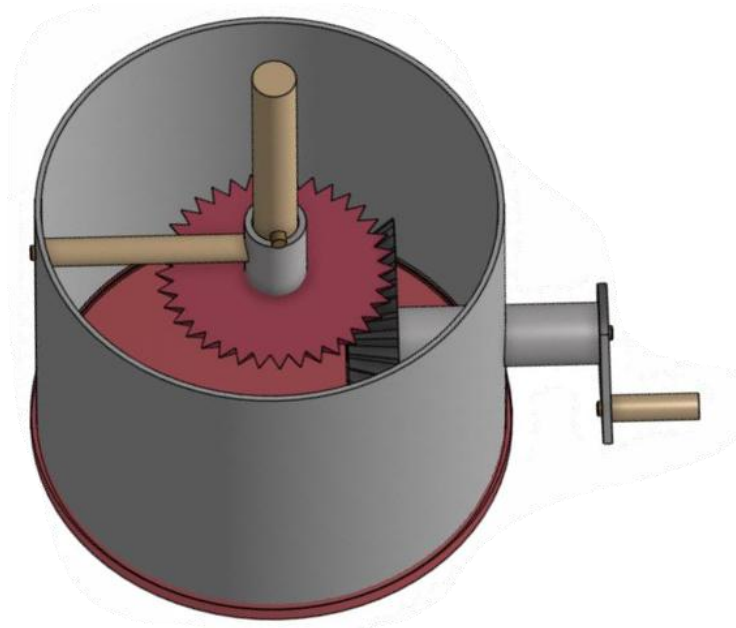


Figure 11: Assembled bevel gear mechanism with acrylic cranking mechanism and a brass handle

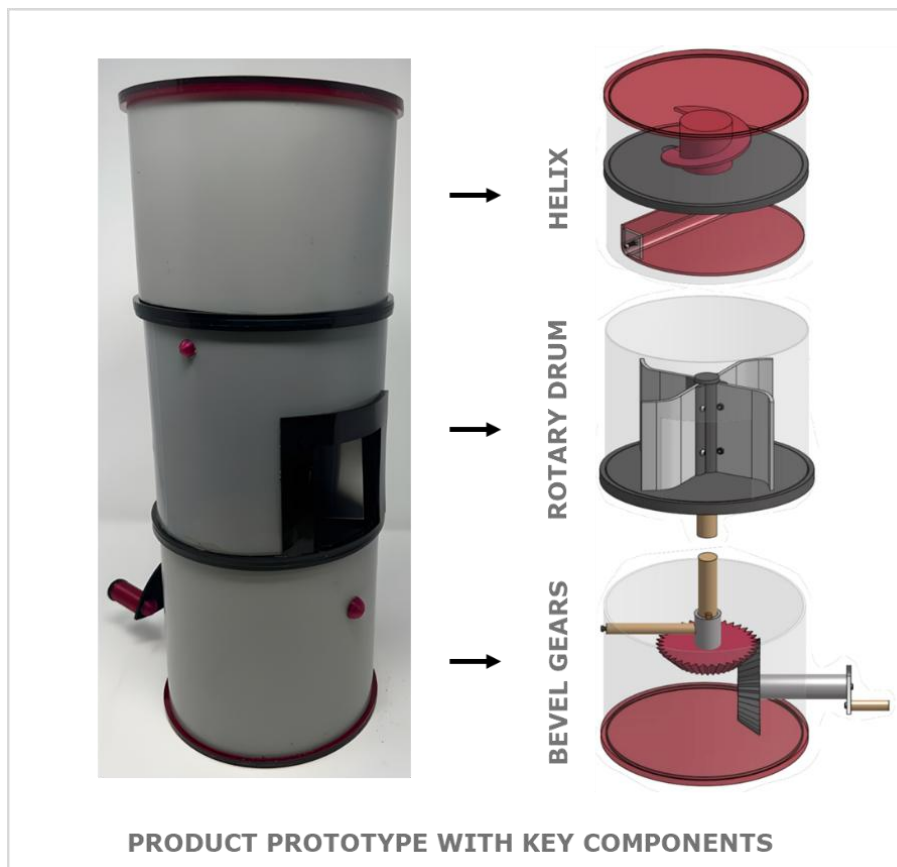


Figure 12: Complete product prototype with all three sections

Modifications and Recommendations

The prototype works as intended in releasing calcium carbonate pellets into the water, but its design can be improved upon in several ways to make it more reliable, efficient, and environmentally sustainable in real-world use.

One significant area for improvement is controlling the speed at which pellets are fed from the hopper into the rotary drum. In the current design, the helix speed is set manually, which means the rate of release does not automatically adjust to changes in boat speed. If the hopper is completely full and the boat is moving fast, for example, at 16 knots (about 18.4 miles per hour) the release rate could be much higher than intended, which will lead to unnecessary release of pellets and over-correction in certain areas. A better approach would be to connect the helix and drum so that they can work in a synchronised rotation. This could be done by mechanically linking them with gears or belts. It may also be accomplished by using an electronic control system where both motors are coordinated by the same controller. Such a system could automatically adjust the release rate to match both the boat's speed and the remaining pellet load in the hopper.

Another useful upgrade would be the addition of real-time sensors. For example, a pH sensor attached to the outside of the device could measure the acidity of the surrounding seawater. If the water is already close to the target pH, the system could slow down the release rate to avoid overshooting. Similarly, a level sensor inside the hopper could detect how many pellets are left and adjust the feed rate accordingly to make sure they last for the intended operating time.

The product could also be improved by considering materials and durability. While PLA and aluminium are suitable for prototyping, a full-scale system used in the open ocean will face harsh conditions: saltwater corrosion, constant motion, and long-term mechanical wear. For the helix and gears, stainless steel alloys like 316L would offer excellent corrosion resistance and longer life. For the drum, marine-grade aluminium or coated steel could provide both strength and resistance to seawater damage.

Finally, the environmental sustainability of the product itself should be considered. The design could follow the principles of the 6 R's: repair, reuse, recycle, rethink, refuse, and reduce. Making components modular and easy to replace would extend the product's life and make repairs simpler. Using recyclable or biodegradable materials where possible would reduce environmental impact if parts need to be discarded. Additionally, ensuring that manufacturing processes use minimal energy and materials would further align the product with its environmental goals.

By making these modifications, the dispenser could become more effective, more durable, and more sustainable, all of which would increase its chances of making a meaningful impact in reducing ocean acidification on a larger scale.

Conclusion

This project set out to address one of the less visible but highly damaging effects of climate change - ocean acidification. The primary objective was to design a practical, efficient, and sustainable method that can help restore the natural chemical balance of seawater by introducing alkaline substances such as calcium carbonate into the marine environment.

The solution proposed is a boat-mounted dispenser that releases the calcium carbonate in pellet form, following in the footsteps of natural coastal erosion where waves gradually wear down calcium carbonate-rich cliffs, releasing small particles into the ocean that dissolve and help buffer acidity. This project emulates that natural phenomena into a controlled and engineered system capable of delivering the same benefit in a more targeted and scalable manner. The dispenser works by slowly releasing calcium carbonate pellets as the vessel moves through the water, thereby making the water more resilient to further acidification while also improving its capacity to absorb atmospheric carbon dioxide.

Calcium Carbonate pellets were chosen as the alkaline agent as they proved successful in decreasing acidity in the water. The initial design of the device consists of three core mechanical components: a helix feed mechanism to transport pellets from the hopper, a rotary drum to disperse them evenly, and a bevel gear assembly that connects the device to the boat's motor and synchronizes the operational speed of the machine with the vessel speed. Testing of the prototype demonstrated that these components could function together as intended. The device can effectively use the boat's motion to adjust pellet release rates in proportion to speed, helping to prevent an excessive build-up of the pellets in any single location.

While the early results are promising, several areas for improvement remain. The most important next steps include developing an automatic control system to regulate the pellet feed based on real-time conditions, selecting materials that can withstand prolonged exposure to harsh marine environments, and refining the system's sustainability by making it easier to repair, recycle, or upgrade components. These refinements would improve reliability, extend the operational life of the dispenser, and reduce environmental impact.

If such advancements are implemented, the dispenser could be adapted for a variety of vessel types, from small fishing boats to large commercial cargo ships. This versatility would make it possible to deploy the technology on a large scale without requiring entirely new infrastructure. By integrating this method into broader climate action strategies, such as cutting greenhouse gas emissions at their source, the device could become a valuable tool for protecting marine life. Coral reefs, shell-forming plankton, and other sensitive species would particularly benefit from reduced acidity in their habitats.

Beyond its direct environmental impact, the project highlights the potential of combining engineering innovation with environmental science to address complex global challenges. Drawing on lessons from natural systems and applying them through mechanical design demonstrates that effective and responsible solutions can be created when technology and ecological principles are combined smoothly.

Ocean acidification is a complex problem that will not be eliminated by any single intervention. However, each effective step that slows its progression provides critical time for ecosystems to adapt and for global mitigation measures to take effect.

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