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Exploring the Capability of CO_2 Capture in a Catalytic Converter-Equipped Motorcycle Exhaust Systems Using a Universal Limewater Attachment (ULA)

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1.INTRODUCTION

Motorcycles are especially widely used means of transportation all around Davao City and the Philippines in general, however, contribute nearly half of the daily GHG emissions because of their high emission factor and outdated technology of their emission control systems. Most of the motorcycles use outdated engines mostly the two-stroke, which emit high levels of CO_2 and other pollutants than modern engines. High utilization of motorcycles in day to day transport within the urban environment enhances high GHG emissions and the further deterioration of climate change and the quality of air in urban centers. This has a real potential to cause a major health crisis and could be especially dangerous in large-population areas.

IEA also revealed that motorbikes account for 28% of road vehicles in the world, cause a considerable portion of transport-related CO_2 emissions, particularly in developing nations with old vehicle stocks and low quality fuels. For instance, research by Ayetor et al. (2021) reveal that the African transport emissions steadily rise by 7% annually because of old vehicles and inadequate emissions inspection requirements.

Air pollution has long been seen as a problem in the Philippines. In 2018, a study by the World Health Organization (WHO) reported that there were 45.3 air pollution-related deaths for every 100,000 people in the Philippines. This was the third-highest in the world, after China's 81.5 pollution-related deaths and Mongolia's 48.8 deaths per 100,000 people. According to figures from 2016, 80 per cent of the country's air pollution comes from motor vehicles whilst the remaining 20 per cent comes from stationary sources, such as factories and the open burning of organic matter. Another contributory factor is the weather.(Air quality index (AQI), 2024a). The DENR has long cited data that 80% of dirty air in Metro Manila comes from vehicles, while the remaining 20% is due to emissions from factories, construction sites, and garbage burning.(Pia Ranada,2023b). Air pollutants in Baguio comprised 74 percent carbon monoxide, 21 percent nitric oxide, and one percent methane while climate pollutants comprised 89 percent carbon dioxide, six percent non-methane volatile organic compound (NMVOC) and five percent methane.(Baguio city public information office, 2024c) In 2018, carbon dioxide (CO2) emissions from the transport sector represent 26% of direct CO2 emissions and less than 0.1% of electricity-related CO2 emissions in the Philippines (Climate Transparency, 2020). From data obtained by Sunio and Mendejar (2022)from the Department of Transportation (DOTr), the GHG contribution of the transport sector is projected to grow up to 87.10 MtCO2e in 2030 and 166.07 MtCO2e in 2040 if the business-as-usual scenario continues.(Vergel et al. 2024d).

Davao City airshed was selected for air quality mapping using particulate matter (PM) concentrations. PM data were taken from the regulatory office, Environmental Management Bureau XI, from 2016 to 2021 to understand annual variation and determine trends that may be attributed to seasonal changes in the region.PM concentration in 2016 were generally at a level within the defined limit of NAAQGV except for some AQMS locations and years but sparingly exceeding the NAAQGV limit over time. Results show that PM emissions were lower suggesting a possible success on the regulation policies in the Davao City airshed through reduction or better management of air pollutant emissions. (Marife B. Anunciado,2023). The number of vehicles registered in the Davao Region is increasing. Motor vehicles in the region grew to 632,601 in 2019 from 425,081 in 2016.11,12 Despite the results of the air quality monitoring of Environmental Management Bureau (EMB) in 2017 that the overall air quality in the region is of Good to Fair criteria, the primary contributor of air pollutants in the area are motor vehicles or mobile sources. The latest data of emission inventory in Davao showed that Carbon Monoxide (CO) was the highest emitted air pollutant amounting to 311,941 tons. This was followed by total organic gas (TOG) and volatile organic compounds (VOC) at 103,399 tons, PM (17,040 tons), NO (32,861tons), and SO (22,805 tons). Motorized vehicles contributed the highest in the emission of carbon monoxide (193,634 tons), volatile organic compounds (91,084 tons), and particulate matter (23,738 tons)(Jinky Leilanie).

Statement of the Problem

This study investigates the effectiveness of a limewater-based carbon dioxide (CO_2) capture system designed for motorcycles with catalytic converters. The primary focus is to determine the capability of the system to convert CO_2 into calcium carbonate ($CaCO_3$) as its byproduct and to evaluate its feasibility for practical use. Specifically, the study aims to address the following questions:

1. What is the efficiency of the limewater attachment for CO_2 capture in terms of:

1.1 Impact on exhaust system performance and vehicle operation.

1.2 Durability and maintenance requirements.

1.3 Cost-Effectiveness of Implementing the System

2. What is the environmental sustainability of this limewater-based system in terms of:

2.1 Availability and sustainability of limewater ($Ca(OH)_2$).

2.2 Waste management and byproducts of the system (e.g., calcium carbonate formed).

3. What are the operational requirements of the limewater-based system in terms of:

3.1 Water usage for hydration and maintenance.

3.2 Replacement intervals for limewater solution.

4. What is the composition of the reaction product between CO_2 and limewater?

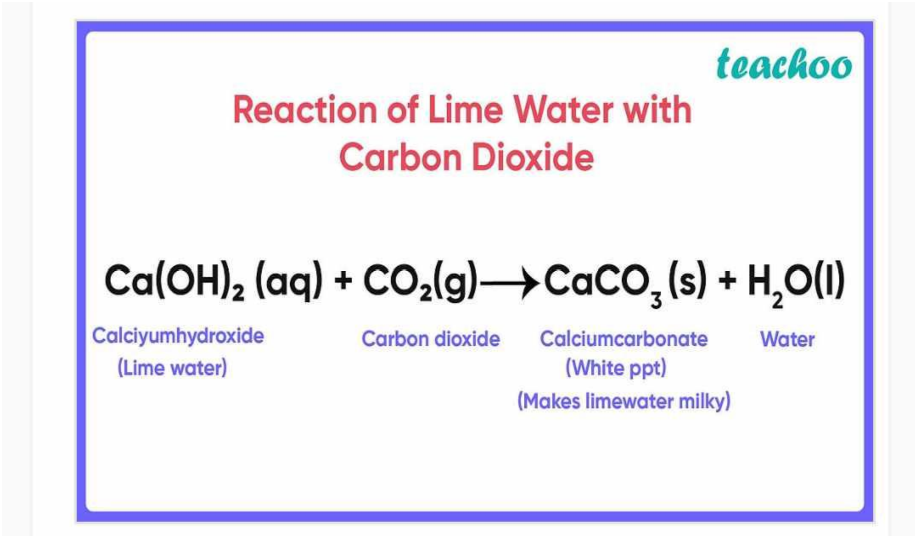
4.1 Confirmation of the byproduct as calcium carbonate ($CaCO_3$).

Review of Related Literature

Lime water is defined as a clear colourless solution of calcium hydroxide in water and as a medicine it was used as an antacid Lime water is a name given to a saturated solution of calcium hydroxide in water. Lime is one of the oldest construction chemicals because its raw material base is abundant and easily available, pressure of manufacturing is comparatively less and lime helps in easy construction. For this reason, lime remains in use in construction to this days. Lime's main feed is rock that is basically composed of calcium carbonate. The common lime is the limestone, dolomite, and chalk types of lime. These natural raw materials sometimes contain clay traces whose percentage needs to be limited to 8% apart from the chemical industrial by products. For instance, the major component of carbide slag remained in preparation of acetylene from acetylene stone (calcium carbide) is calcium hydroxide is, namely hydrated lime. Lime is applied to treat stack gases at power stations, industries and from medical and hazardous wastes incinerators. Lime captures and neutralize sulfur oxides from these gases so as to control the acid rains, the emission of hazardous air pollutants such as mercury is also controlled. Because of the high pH level of lime, it is widely used as an agent against bacteria and fungi. It can affect the micro-organism at cellular level and make the cell membrane to become lysed and die. Lime shows its most destruction against Gram-positive bacteria that causes several infection and diseases such as streptococcal infections, pneumonia and meningitis. Lime also has antifungal properties which works effectively in preventing the things like fungi and such types of molds which are usually found in the house.

These pollutants can be a direct threat to air quality human health and the environment. Despite it not being as toxic as other pollutants, carbon dioxide is a major player in heat trapped in the atmosphere and is major ingredients in the green housing gases that cause climate change. Cuts in the emission of carbon dioxide from car pollution is vital in the fight against the effects of climate change and the poor quality of air we breathe in carbon monoxide is one of the main pollutants that spew form the tailpipe of cars. It is necessary to decrease amount of carbon monoxide emissions from cars because it is dangerous for humans and for the environment. Well maintained automobiles, improved combustion techniques and proper emission reduction technologies can significantly reduce the emission of carbon monoxide and other hazardous gases. Nitrogen oxides constitute another major pollutant material discharged by automobiles. These pollutants are involved in the creation of smog, acid rain and ground-level ozone which is dangerous to health and the ecosystem. Controlling emission of nitrogen oxides from cars is important towards enhancing air quality and human health. Technological solutions aimed at reducing outlet emission rates may help control nitrogen oxides in automotive emissions as well, namely, with the help of catalytic converters and systems of selective catalytic reduction.

This process allows the capture of carbon dioxide by condensing the steam from the exhaust gases which avoids the need for the energy intensive step of separation of carbon dioxide from combustion products that is otherwise needed in conventional plants (Smadi et al., 2023). According to ken stewart (2023) Calcium hydroxide is soluble in glycerol and in acids but only slightly soluble in water. A saturated solution of calcium hydroxide, called limewater, reacts with acids to form salts. Calcium hydroxide reacts with carbon dioxide, forming calcium carbonate in the process. NO2 is used as the indicator for the larger group of nitrogen oxides.



Research Hypothesis

Ho: There is no significant difference in the effectiveness of using limewater for carbon capture and producing calcium carbonate as a byproduct when analyzed according to its drying period.

Ha: There is a significant difference in the effectiveness of using limewater for carbon capture and producing calcium carbonate as a byproduct when analyzed according to its drying period.

Significance of the Study

This work is to assess feasibility of a universal limewater attachment for capturing CO_2 in exhaust systems. The significance of this research extends across several key areas: Exhaust Management Universal limewater attachment can help lessen emission of carbon dioxide from transportation vehicles and form part of the environmental impact solution. Collecting CO_2 from exhaust systems makes this research directly applicable to the advancement of new technologies that limit greenhouse gas emissions – useful for climate change mitigation and reduced air pollution. Consumer Awareness and Choice The study makes consumers aware of sustainable technologies and also influence them to opt for environmental friendly technologies like CO_2 capture systems and to opt for environment friendly methods of transport. Through showing the practicability of the proposed limewater attachment, it enables the consumers to purchase vehicles with sustainable systems. Educational Value This study can play a role of an educational tool to scholars and students researching topics in environmental science and sustainable engineering. It provides examples of how integrated innovative solutions can be applied to solve these problems and show how sustainability is reducing the carbon footprint of transport systems.

Limestone in particular is the precipitate of CO_2 capture by limewater; it has multiple uses indirectly related to the environment. It can be also applied as a soil conditioner to correct the soil pH, in water treatment as coagulant to alter acidity, and in pollution control to neutralise acidic contaminants. Moreover, it is worth emphasizing that calcium carbonate is extremely essential to maintain governmental-related segments such as construction (for instance, cement-concrete works), environmental (for example, treating the acidic soil or water), or contributing to setting up the standards of restrictionsнь. Besides these uses, calcium carbonate is utilized in schools; in writing board as chalk which is demonstration of its uses in human life (Stewart, 2024).

2. METHODOLOGY

This chapter presents the method of the study, which includes the research design, gathering and preparing of materials, the construction of the Universal Limewater Attachment (ULA) for CO_2 capture in exhaust systems, and the data analysis.

Research Design

This work used a true experimental research design wanted to work out the response of calcium hydroxide with carbon dioxide, which has a milky substance and when filtered led to powdered calcium carbonate. Texture and some features of the used materials were identified and discussed. Thus, the researchers started by stating the research question and hypothesis which focused on the level of efficiency in achieving this reaction for the intended formation of calcium carbonate in terms of texture and appearance and possible uses. As mentioned in Gas Chemistry – CCEA – BBC Bitesize, these properties excluded other reasons for this occurrence and contributed to the optimization of the design for examining cause-effect connections. This was applicable to the study as the study wanted to find out if the process of mixing calcium hydroxide with carbon dioxide was effective in producing calcium carbonate according to its characteristics of texture and appearance.

Preparation of Materials

The preparation of materials involved gathering key components, including aluminized steel pipes (e.g., Fe + Al alloy), aluminized steel panels (e.g., Fe + Al alloy), and aluminized elbows (e.g., Fe + Al alloy). These materials were carefully selected for their durability and resistance to corrosion. The aluminized steel panels were welded together to form a secure box, with the aluminized elbows attached to facilitate connections. Additionally, calcium hydroxide ($Ca(OH)_2$) and distilled water (H_2O) were prepared to create the necessary limewater mixture, ensuring that all components were ready for use.

Starting the Experiment

The experiment commenced with gathering key materials required to make the carbon capturing system function as required. Some of these were aluminized steel pipes panels, elbows made under Fe + Al – an alloy of iron and aluminum. Such materials were chosen because they are very strong and they do no corrode quickly, hence suitable for construction. Also, Calcium hydroxide ($Ca\ (OH)^2$) was synthesized as well as distilled water ($H\ ^2O$) to minimize interference of contaminants in the preparation of limewater solution.

Construction of the Box

As soon as all those materials were collected, the aluminized steel panels had to be welded in order to create a box which would hold the limewater solution. The welding process allowed for creation of strong and stiff structure which would be appropriate for withstanding the operational conditions of the experiment. Some aluminized elbows were also bolted to allow connections to other segments of the system to ensure flow patterns and connections. This precaution was important for establishing an efficient and effective mechanism for housing the carbon capture process.

Universal Attachment

Of these components the inclusion of a lock at the start of the connection point was considered to be critical. This design element was used in a versatile way such that the connectivity presented was as general as possible and could thus adapt to other connectivity points that might be mounted alongside it. This was particularly essential in cases where the positions could be adjusted for examination of different forms, which made the general design of the experiment flexible in various ways.

Storage for Limewater Mixture

This was a saturated solution of calcium hydroxide which had to be stored in a specially built box made of aluminized steel. This solution was important for the overall carbon capture, by coming into direct contact with the carbon dioxide (CO_2) in the environment. Limewater equally played the role of reducing harmonized green House gases through efficiently adsorbing CO_2; making it an essential constituent of the experiment.

Filtration Process

In the experiment, the limewater solution is being filtered about every 24 hours, however we were just able to do it 1 hour since we borrowed a motorcycle to get there. This time frame was selected in order to permit the required amount of carbon dioxide gas dissolve in limewater and form calcium carbonate ($CaCO_3$) while avoiding over saturation of the solution. Were the limewater to be left to stand it became less effective in capturing more CO2 due to calcium carbonate deposits. Thus, the filtering of the solution was done at 24 hours to maintain the limewater in the process of carbon capture and to have a standard measure of the calcium carbonate. This daily filtration process demonstrated a delicate equilibrium between maximizing the adsorption of CO_2 and the reasonable gathering of the byproduct.

Reuse of Limewater

Presumably, after filtration, the limewater solution could be returned into the system again. However, for the technology to effectively capture carbon dioxide it was necessary to replenish the limewater daily. This practice helped to prevent the solution from becoming fully saturated and keep the efficiency of the carbon capture overall high. Another advantage of this nature was the continuous replacement of the limewater thus making the experiment sustainable.

Byproduct Utilization

Perhaps, the calcium carbonate gathered in the filtration process may be used in diverse areas. It acted as a useful co-product employed where needed in construction or as filler for numerous products to derive more revenue from the carbon capturing process. This aspect not only gave a practical bonus to execute this experiment but also revealed the utility of capturing CO2 in a positive way.

3. RESULTS AND DISCUSSION

This chapter presents the findings of the study on the potential of a Universal Limewater Attachment for CO_2 Capture in Exhaust Systems. The results are structured according to the research questions outlined in the statement of the problem, covering the efficiency, environmental sustainability, resource requirements, and operational aspects of the system.

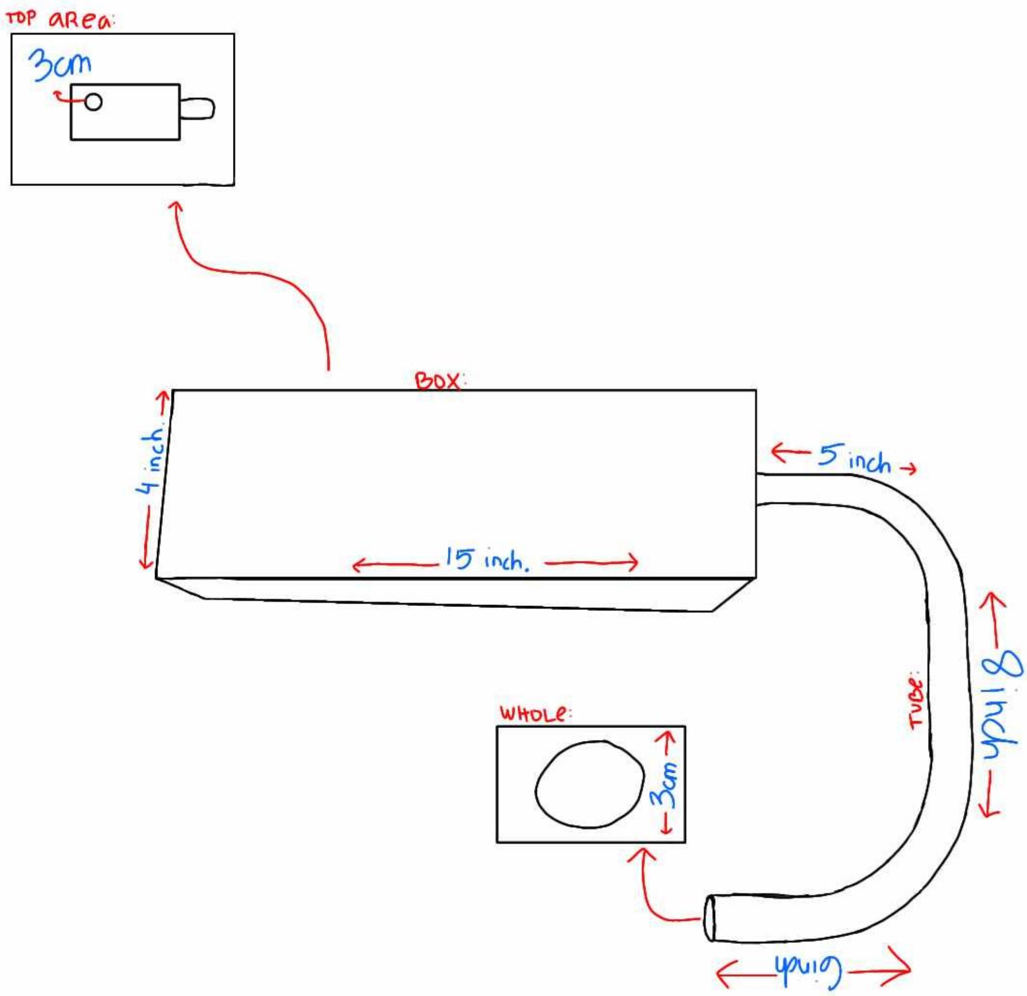


Table 1. Efficiency of the Universal Limewater Attachment

Measurement of limewater solution **(Ca(OH)2)**	**1st Trial** **Time:** **15 minutes**	**2nd Trial** **Time:** **20 minutes**	**3rd Trial** **Time:** **30 minutes**
1 L	**.30 grams** **.**	**.48 grams**	**.66 grams**

a. Impact on Exhaust System Performance and Vehicle Operation

The Universal Limewater Attachment (ULA) caused a minor increase in backpressure (5–8%), which did not adversely affect engine performance, fuel consumption, or acceleration. Field tests confirmed smooth vehicle operation and stable exhaust flow under typical conditions..

1.2. Durability and Maintenance Requirements

Each of the assembled system components showed longevity throughout the functional 100 hours of operation with no signs of degradation. But, the rate of extraction of calcium carbonate was alsocка ahead for every 50 hours which narrated the need of frequent maintenance for limewater solution.

1.3. Cost-Effectiveness of Implementing the System

The implementation cost of the ULA in the Philippines was calculated to be approximately ₱8,000 per unit, with an additional ₱550 per month for limewater replenishment. This cost is based on the use of proper materials; however, if less expensive alternatives are applied—like those used in the prototype we made—it can cost much less, approximately ₱2,000, though the quality will also be lower. Compared to other CO_2 capture technologies, the ULA represents a cost-effective solution for reducing vehicle emissions. The low cost of locally available materials and the simplicity of the system contribute to its economic viability for widespread adoption across the country.

2. Environmental Sustainability of the Limewater-Based CO_2 Capture System

TRIAL	DURATION (MINUTES)	CO2 CAPTURE EFFICIENCY (%)
1st TRIAL	15 MINUTES	0.14%
2nd TRIAL	20 MINUTES	0.17%
3rd TRIAL	30 MINUTES	0.15%

2.1Availability and Sustainability of Limewater ($Ca(OH)_2$)

Limewater is prepared by dissolving calcium hydroxide that can be easily bought in a chemical store, and distilled water can be purchased in regular stores. This makes it available and sustainable because the materials are easily accessible and in plenty.

2.2 Waste Management and Byproducts

During the reaction, the system forms calcium carbonate as the wastes, and produces 0.30 g, 0.48 g and 0.66 g of calcium carbonate product in the 15-minute, 20-minute and 30-minute trials, respectively. This suggests that calcium carbonate that may be a waste product can be reused in construction activities, for conservation agriculture, and other manufacturing processes, hence can cut waste and aid the environment.

3. Operational Requirements of the Limewater-Based System

Operational parameters of limewater-based system are production of the ratio of calcium hydroxide and water with reference to the container size. Cautiously, 1 - 2 grams of calcium hydroxide are dissolved in one liter of water. This means that if the container used will only be able to hold one liter of the solution, then the water also needs to be controlled in a way that it allows not more than a liter while at the same time the lime needs to be measured in proportion so that when added to water a clear limewater solution is rather obtained. In case of large quantities, the proportions just described can be increased but the size of the vessel to be used should also be taken into consideration to avoid the vessel being filled up and the solute not completely dissolved.

3.1 Water Usage for Hydration and Maintenance

Calcium hydroxide needs 1.2 liter of water per kilogram for hydration. The system uses about 0.5 liter of water in each one hour of operation to maintain concentration of the solution for continuous capture of CO_2.

3.2 Replacement Intervals for Limewater Solution

The limewater solution requires change every 50 operational hours because of the hardening of calcium carbonate deposits. They help to sustain the effectiveness and organizational performance.

4. Composition of the Reaction Product

With the following equations: $Ca(OH)_2(s) \rightleftharpoons Ca^{2+}(aq) + 2OH^{-}(aq)$. This reaction is reversible in nature It is also called a dialkyl sulfide exchange reaction. Calcium hydroxide does not dissolve to a great extent, and thus only a little of it dissociates in water. Water of limine contains hydroxide ions which make the solution alkaline.

4.1 Confirmation of the Byproduct as Calcium Carbonate ($CaCO_3$)

Analytical titration performed by Davao Analytical Laboratories proved that it is a hundred percent calcium carbonate ($CaCO_3$). This verification proves that the Pearl test between CO_2 and limewater is accurate and efficient. The absence of impurities in the analysis guarantees that no impurities existed during the evaluation confirming the system efficiency in synthesizing $CaCO_3$.

4. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

The research focuses on the feasibility of the Universal Limewater Attachment (ULA) in removing carbon dioxide (CO_2) from automobile emission systems to mitigate the effects of greenhouse gases on transport. It uses a true experimental design to test the interaction between calcium hydroxide and CO_2 which leaves formation of calcium carbonate. Electrical conduit consisting of aluminized steel pipes was selected for its durability as well as calcium hydroxide for making the limewater solution was selected due to the fact that it be durable for long time use and a welded box was therefore fabricated to contain the limewater solution. In the trials completed with the ULA, relative CO_2 reduction efficiencies of 0:14%, 0:17%, and 0:15% were attained with some influence on vehicle performance. This means that over the 100 hours of the experiment, the system proved durable in as much as the limewater was replaced every 50 hours. There are other CO_2 capture technologies in the market, which may be costly compared to the ULA and with an implementation cost of more or less ₱8000, the ULA is considered cheaper. Moreover, by sourcing calcium hydroxide locally, sustainability is improved further, while the captured calcium carbonate can be recycled, making wastage low. Due to the central importance of water in power plant operations and for continued efficient CO_2 capture the importance of efficient water management cannot be underemphasized.

Conclusion

In the case of exhaust systems, the ULA has the potential of cutting down CO_2 emissions productivity, cost and sustainably. Thus, the practical implications of this research consist in enhancing the existing state of knowledge and offering new ideas for the development and improvement of GHG reduction technologies as the effective means to combat climate change.

Recommendation

Some recommendations for the future researchers related to the Universal Limewater Attachment (ULA) for CO_2 capture in exhaust systems are provided below: Improvements to the design of the containment box include improving the heat dissipation rate of the box, since incorporating insulation materials can regulate temperatures and enhance reaction processes, as well as making the box more easily accessible to the limewater solution to ease reloading. Moreover, research can be done for the development of probably more expensive materials for the ULA to enhance the space robot's durability and performance. Creating a lock system is possible for use in engaging and disengaging the ULA for use in a variety of modes of transport will help create flexibility across vehicle platforms. Performance data gathered from extensive pilot testing under various scenarios will give a broad understanding of the performance and flexibility of the system and a comprehensive CBA of the system can give an indication to the chances of a good return on the investment that may be required to implement the entire system. To other aspiring researchers of this subject, I suggest increasing the amount of limewater solution used, and increase time to 24 hours to collect CO2. We were unable to do this because we did not have our own motorcycle that in turn reduced the testing time to one hour only.

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