REDUCTION OF CARBON DIOXIDE IN PUBLIC UTILITY JEEPNEY EXHAUST PIPES USING A MULTI-STEP FILTERING SYSTEM

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ABSTRACT *- Carbon dioxide (CO_2) is a critical gas that traps heat in the atmosphere to keep the earth warm and helps the human body in oxygen transport and nerve stabilization. However, a gradual increase in CO_2 concentrations may drive global warming and poses adverse effects on human health. In the Philippines, public utility vehicle known as jeepneys is the most common land transportation, which emitted smoke that gives a significant source of CO_2 emissions. The jeepney has no device to measure the quantity or filter the release of the content of the CO_2 to monitor the release of critical gas in the atmosphere. This study aimed to develop a filtering system device that will be attached to the jeepney's exhaust pipe to capture the concentration of CO_2. The study adopted the air filtration method which covered three stages: (1) pre-filter process, (2) HEPA process, and (3) filter and activated carbon process. The hardware system read analog data from the concentration of pollutants using a MQ-135 sensor device and outputted it in digital form using an LCD device.*

Keywords: Carbon Dioxide (CO_2), Exhaust, Filtering System, Smoke

INTRODUCTION

Carbon dioxide (CO_2) is the principal greenhouse gas which is not only harmful to the environment, but it also has an adverse effect on human health; by blocking the supply of oxygen to vital organs such as the brain, heart, and lungs and worst of all, it can cause death [1, 2, 3]. CO_2 is a crucial gas that retains heat in the atmosphere to keep the earth warm and helps the human body carry oxygen. It also helps plants create oxygen to maintain life. It calms nerves, but because of human activities like burning fossil fuels and other industrial processes, CO_2 has become increasingly prevalent. [4, 5]. According to a collaborative study by Blacksmith Institute and Clean Air Asia, jeepneys are the most popular mode of land transportation in the Philippines they are normally powered by old and dilapidated diesel engines such as Isuzu 4BC2; they produce pollutants that directly impact the health of citizens, such as particulate matter (PM), Carbon Monoxide (CO), Oxides of Nitrogen (NOx), Sulphur Oxides (SOx) and climate-relevant pollutants such as Carbon Dioxide (CO_2) [6] From the Proceedings of the 17th Annual Conference of the Transportation Science Society of the Philippines (2009) on the topic CO_2 Emissions from the Land Transport Sector in the Philippines: Estimates and Policy Implications stated that carbon dioxide (CO_2) emissions from the transport sector accounted for 38% of the total from fuel combustion in year 2000. The transport sector in the Philippines comprises various motor vehicles such as buses, private cars, jeepneys, and others. However, jeepneys travel more than other motor vehicles on the road. According to data from 2005, jeepneys account for 80% of the total passenger kilometer travel. As of June 30, 2016, the Land Transportation Franchising and Regulatory Board (LTFRB) in Region 10 recorded a total of 9,237 PUJs (jeepneys, with multicabs making up only a small number) which is quite numerous compared to other public vehicles. Previous data and studies conducted in the Philippines show that the estimated carbon dioxide emissions in the Philippines totaled 30 million tons in 2008[8].

There are several solutions that have been developed to reduce CO_2 emissions from vehicles such as hybrid cars, electric cars, and vehicles that run on alternative energy sources such as water and electricity. Air filtration is another technique that can help reduce air pollution by purifying the air through the use of efficient air filters like activated carbon can trap pollutants like CO_2 and particulate matter emitted from the exhaust pipe. This research aims to address the issue of carbon dioxide (CO_2) emissions from jeepneys, a common form of transportation in the Philippines, by developing a filtering device that captures CO_2 from exhaust smoke using an air filtration technique.

The testing of this study will be conducted in Lapasan Highway area of Cagayan de Oro City and will take place over a period of 17 days. Given the high population of jeepneys in Cagayan de Oro City and the harmful smoke released from their exhaust, which affects both the environment and human health, it is crucial to lowering carbon dioxide levels to an acceptable level that does not harm the environment and human health.

The study aims to design a monitoring device to analyze and display the concentration of CO_2 in real time. The research objectives are to develop a reusable filtering device that uses three types of air filters, prefilter, HEPA filter, and activated carbon, and a monitoring device that analyzes the concentration of carbon dioxide through the graph, and notifies when to clean the filters via an LCD. The research also aims to contribute to the efforts of reducing the negative impacts of CO_2 emissions.

METHODOLOGY

An experimental approach was employed in this study due to the need for hardware and software integration and testing of a prototype carbon dioxide filtering and monitoring device. In order to ensure accurate readings, the prototype's CO_2 measurements will be compared to those of an industry-standard hand-held CO_2 monitoring device, with a tolerance of less than 10% deviation. The design of the filtering device will incorporate filters based on those used in modern commercial air conditioning systems to ensure the thorough removal of carbon dioxide.

The system device development process is illustrated in the flow chart diagram in Figure 1

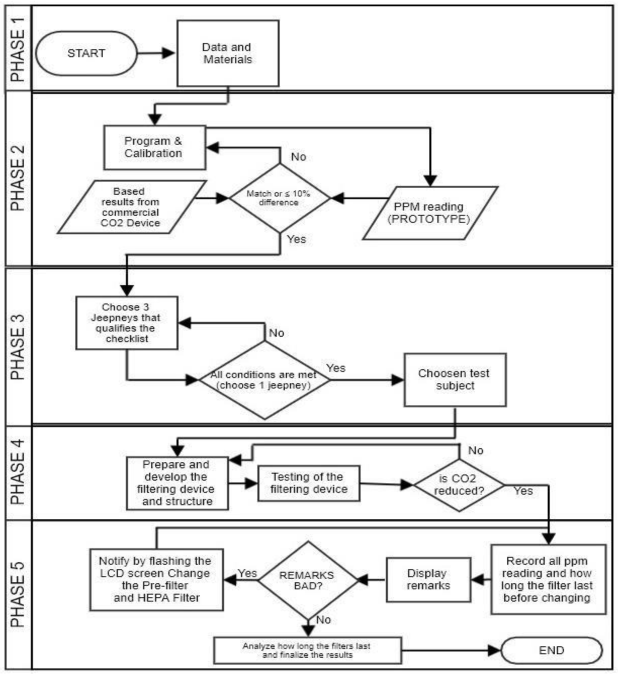


Figure 1. The Five Phases of the Development of the Device

Phase 1, Data & Materials Gathering, it began by gathering information on various aspects of the problem, such as air filtration methods, CO_2 monitoring standards, and the materials required to address the issue.

Phase 2, CO_2 Device Development, Calibration, and Testing, focused on the development of the prototype CO_2 monitoring device. Before deployment, the prototype was tested to ensure its accuracy in determining the concentration of CO_2 in the jeepney's smoke. This was done by comparing its readings with those of a gas analyzer at an emission testing center, with a tolerance of no more than a 10% difference in the readings.

Phase 3, Selection of Jeepney, outlined the process of selecting a jeepney to participate in the study. Three jeepneys along the Cagayan de Oro City highway were chosen based on criteria such as similar engine type, black smoke, and high CO_2 content. The jeepney with the highest CO_2 concentration was selected for the study using baseline data from initial emission test center results.

Phase 4, Filter Design Development and Testing, it aimed to lower the CO_2 concentration in the jeepney's exhaust smoke by developing and testing the design and structure of the filters. The effectiveness of the filter structure was evaluated using the prototype CO_2 monitoring device.

Phase 5, Deployment and Finalization of Results, evaluated the entire system after evaluating the filter's effectiveness. The device was installed on the chosen jeepney for 5-8 hours every day. If the device indicated that the filters needed cleaning, the researchers recorded each reading until that point and also checked how long the filters lasted between cleanings.

System Hardware Design Process

The filtration process is illustrated in Figure 2, it shows the process flow of the filtration system. The system is powered by a 12-volt battery from the jeepney and an 8-volt voltage regulator circuit is used.

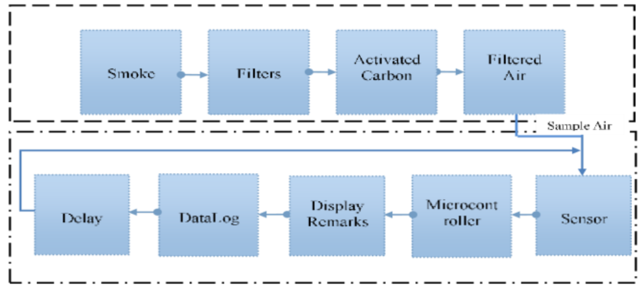


Figure 2. Block Diagram for Filtering Process

Each block in the flowchart has a specific role. The first line block includes (1) Smoke, which originates from the jeepney's exhaust pipe, (2) Filters, which consist of a pre-filter and a HEPA filter that remove dust and other pollutants, (3) Filtered Air (sampling), which uses a small amount of filtered air to read the results from a sensor circuit, and (4) Filtered Air, which is the actual output of the block, with minimal pollutants and contaminants.

The monitoring process is carried out in the second line block, which includes the following components: (1) Sensor: An MQ-135 air quality sensor is used to measure the concentration of pollutants in smoke and sends an analog signal output, which is used as input by the microcontroller system; (2) Microcontroller: This board is programmed to interpret the analog signal to evaluate the air quality and determine the number of pollutants present, and sends a digital signal output. (3) Display Remarks: This block, composed of an LCD and a speaker, will display and announce the CO_2 result calculated by the microcontroller system via the sensors. (4) Datalog: This block stores logs of the CO_2 concentration and time in .txt file format. (5) Delay: This block determines when to read the CO_2 concentration.. Figure 3 illustrates the prototype perspective, visualizing each block of the hardware design process.

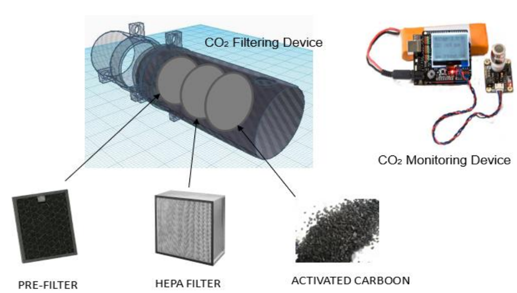


Figure 3. Prototype perspective

Figure 4 below illustrates the design of the exhaust filtering device. It has a total height of 9.45 inches and a width of 1.9 inches at the bottom and 2.0 inches at the top. The device is designed to be inserted into the exhaust pipe of the Jeepney.

The monitoring device includes the following components: (1) LCD, (2) Power plug 7-12 Volts, DC, (3) USB Type B Port, (4) USB type A port for Sensor Circuit, (5) Sensor Circuit. The sensor circuit is placed in the location where samples are collected, and the LCD is positioned in the driver's line of sight on the dashboard. The microcontroller will store the outcome displayed on the LCD, and the log files in .txt format can be manually downloaded onto a computer or laptop.

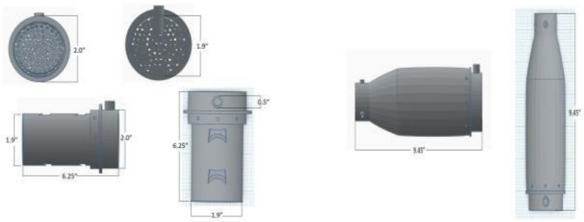


Figure 4. The Design of the Exhaust Filtering Device

Monitoring Device

The monitoring device includes the following components: (1) LCD, (2) Power plug 7-12 Volts, DC, (3) USB Type B Port, (4) USB type A port for Sensor Circuit, (5) Sensor Circuit. The sensor circuit is placed where the samples are collected, and the

Calibration Test of Sensor

The calibration and limit of the CO_2 monitoring device were limited only to a unit of measurement of parts per million (ppm) since the Philippine standard for vehicle emission limit uses a different unit of measurement gram per kilometer (g/km) which was not possible to convert to its equivalent ppm and since the MQ-135 sensor has a limited range of 1000 ppm instead the researchers would adhere to the international standards set by Occupational Safety and Health Administration. The MQ-135 sensor is sensitive to the following gasses namely ammonia, sulphide, benzene, and carbon dioxide. The air quality sensor is calibrated by adjusting the potentiometer to calibrate the sensor's sensitivity to CO_2 and must be 24 hours on before that gives accurate data. Also, the sensor must have a heater circuit that gives a constant supply of power in order to improve the sensor's accuracy in reading the concentration of CO_2 since the sensor's accuracy is affected by cold weather.

Equation 1 is the formula for converting the percentage (%) of gas to parts per million(ppm).

$$1\% = 10{,}000ppm\ x\ (ppm) = 10{,}000\ (x\%) \qquad (1)$$

Table 1 Equivalent percentage (%) to PPM

Percent (%) CO2	PPM CO2	Remarks
0 – 0.045	0 - 450	Good
0.0451 – 0.06	451 - 600	Fair
0.0601 – 0.1	601 - 1000	Bad

The percent and ppm carbon dioxide is set to 1000 since the MQ-135 has a limited range of 1000 ppm only. The "Good" remarks imply that the concentration of CO_2 is at a suitable level, while the "Fair" remarks indicate that the concentration of CO_2 is tolerable to healthy persons but not to persons with lung-related concerns. Lastly, the "Bad" remarks imply that the concentration of CO_2 is not good for health or hazardous. To verify the result after the testing, the jeepney would be sent to the Smoke Emission Test Center.

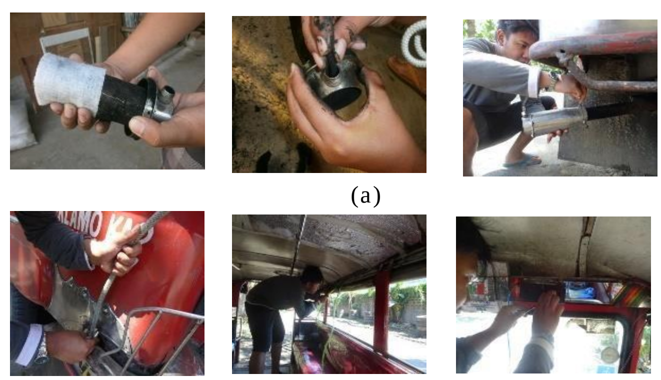
RESULTS AND FINDINGS

Installation Process

The Exhaust filtering device and the monitoring device will be installed on the public utility jeepney to monitor its CO_2 status. The jeepney should have an engine type 4BA1 ISUZU since most of them have the same exhaust pipe diameter.

Exhaust filtering device installation: For the Exhaust Filtering Device, it needs to wrap the muffler structure with the pre-filter and HEPA filter and insert the 20grams of activated carbon into the small hole of the muffler structure located at the tip so that it will be easy to screw tightly when the adapter inserted to the jeepney's exhaust pipe. After the adapter is inserted, connect the sampling tube to the tip of the adapter. Make sure not to bend the sampling tube for this will affect the sensor reading. Then place the sampling tube from the exhaust adapter to the dashboard where the monitoring device is located. Lastly, connect the sampling tube to one of the holes of the sensor circuit for its monitoring.

Monitoring device installation: For the monitoring device, it needs to peel the double-sided tape located at the back cover. Then install the monitoring device on the dashboard. The sensor circuit is installed beside the monitoring device and plugs the USB of the sensor circuit is into the USB port of the monitoring device. The USB will be plugged to the serial connector to the serial port of the monitoring device while the USB is connected to a power source or portable charger. Then power ON the sensor circuit and leave it for 24 hours before using. The sensor circuit must be supplied with power for 24 hours so it gives correct reading results. Figure 5 illustrates how it was installed.



(a)

(b)

Figure 5 Installation of (a) Exhaust filtering device (b) Monitoring Device

The precision and the operational aspects of the designed system device would be determined by its results from the sensor circuit. The system device was tested on three (3) public utility jeepneys that passed the checklist without the exhaust filtering device. The average PPM was computed after reading the concentration of CO_2 from the exhaust smoke of the jeepneys for 20 seconds. The average result from three jeepneys was compared, and the jeepney with the highest average ppm was selected to participate in the testing process using the exhaust filtering device. Figure 6 shows the results of the three Jeepneys.

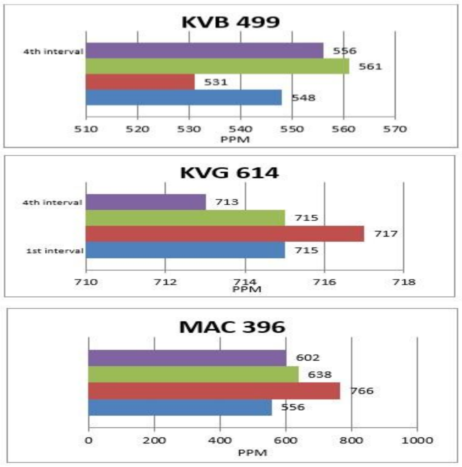


Figure 6. Graph PPM result of three jeepneys using the exhaust filtering device

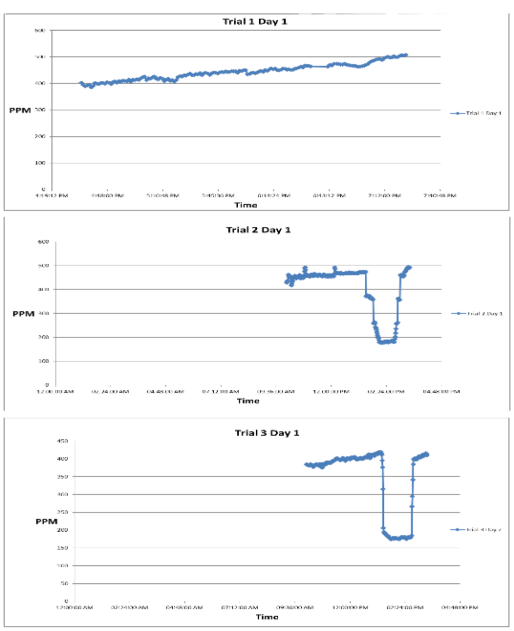
As shown in Table 2, the jeepney with plate number KVG 614 had the highest average concentration of CO_2 in PPM. Thus, the said jeepney was utilized for the subsequent testing.

Table 2. Average Concentration of CO_2 of Three Jeepneys

Plate No.	Average CO_2 PPM
KVB 499	549
KVG 614	715
MAC 396	640.5

Trial Testing of Exhaust Filtering Device

The testing was conducted for three days at different time intervals to test if the exhaust filtering device was working well under different environmental conditions. The sensors were calibrated after every test conducted before it is placed on the exhaust pipe of the jeepney. The result taken from the microcontroller was converted into graph form and calculated the average PPM for all the testing results per trial. The succeeding figures showed the graphs during testing.



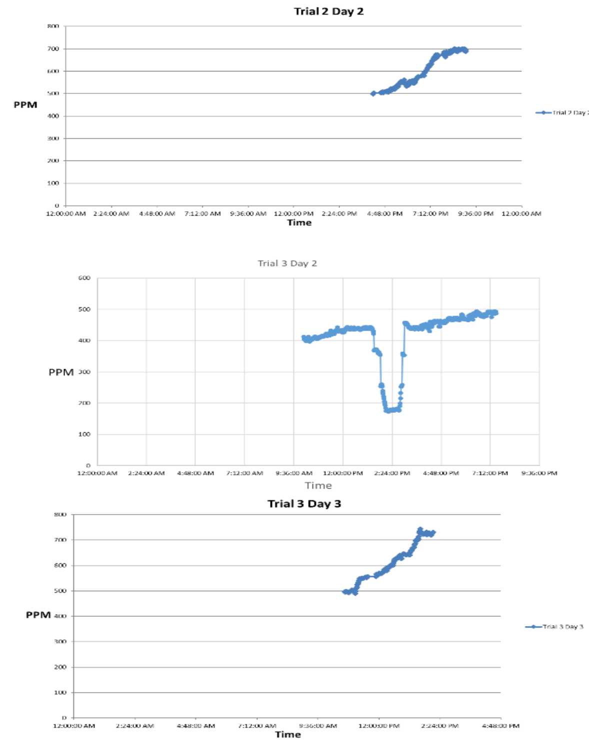


Figure 7 Output from testing converted into graph form

Table 3 Average ppm of 1st, 2nd, 3rd trial on each day

Interior Structure	Volume of Activated Carbon (grams)	Trial No.	Day 1 (average ppm)	Day 2 (average ppm)	Day 3 (average ppm)
No interior structure	10	1	443		
No interior structure	10	2	464.24	589	
Muffler interior structure	20	3	412	543	618

Table 3 described the average ppm of the second and third trials on each day showing the different conditions which affect the lifespan and efficiency of the filter. In the second trial, the average ppm reading of the device increases from 464.24 ppm to 589 ppm which means that the filter slowly becomes dirty. On the third trial which lasted for three days, the average ppm reading on the first day is 402 PPM quite smaller compared to the second trial because the exhaust filtering device contains more activated carbon and filters are doubled compared to the previous and the exhaust pipe exhaust was designed similarly to a muffler.

Table 4 Summary of results using exhaust filtering device

Trial	Average PPM	Testing Duration	Overall average PPM	Efficiency (%)
1	Failed			
2	526.62	10hrs, 15mins	526.62	24.77%
3	491	18hrs ,6 mins	491	29.86%

Table 4 showed the summary of results from trials 1,2 & 3. The percent (%) efficiency of the exhaust filtering device was computed by adding the average ppm of trials 2 & 3 minus 700 ppm (smoke emission test [SET] result) divided by 700 multiplied by 100. Equation 2 below showed how the efficiency of the exhaust filtering device was computed, having 29.86% efficiency in filtering CO_2 from the smoke of the jeepneys exhaust.

$$Efficiency = \frac{Overall\ average\ of\ trial - results\ [SET]}{results\ [SET]} \quad (2)$$

CONCLUSIONS

The effectiveness of the exhaust filtering device was relative to the HEPA filters used and how it is placed inside, while the monitoring device accuracy particularly the MQ-135 sensor depends on whether the sensor was preheated for over 24 hours, and away from any liquids and concussion. The calibration of the MQ-135 sensor corresponded to the results from the smoke emission test center. The calibration was conducted in order to give a precise result in calculating the concentration of CO_2 from the jeepney exhaust smoke. The percentage error kept the reading down to $\pm$2.14% by adding a heater circuit which will give a constant supply of power to the sensor. The heater circuit helps the MQ-135 sensor in power on the state since the sensor needs to be pre-heated for 24 hours before giving precise results. The internal structure of the exhaust pipe adapter was based on a muffler that helps in leading the smoke to pass through the three filters allowing the filters to capture the carbon dioxide from the smoke before leaving the adopter and release the rate of CO_2 released into graph form.

A multi-step air filtration system requires two or more filters. In this filtration method consists of a coarse type or a pre-filter and the main filter has fine fibers compared to the prefilter. Multi-step filtration and two-step air filtration process are recommended for higher filtration efficiency and economical in long period of use. Since the prefilter protects the main filter from odor-causing particles. The lifespan of a filter used depends on the concentration of CO_2 and the volume of other pollutants present in the smoke released from the jeepneys exhaust. The two filters capture large particles from the smoke emitted while the activated carbon captures the CO_2 gas.

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