Botanical Biofilter for Carbon Dioxide and Temperature Reduction of Diesel Exhaust

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Abstract. Diesel engines have high efficiency, durability, and reliability together with their low-operating cost. These important features make them the most preferred engines especially for heavy-duty vehicles. Corresponding to that increase rate of using diesel engines, the environmental pollution also increases caused by exhaust emissions. In this study, a new way of pollution control aims to minimize the growth of carbon dioxide (CO_2) emission. The diesel exhaust gas was directed to the botanical biofiltration system. This study aimed to assess the carbon dioxide absorption capabilities of the botanical biofilters namely Broadleaf Lady Palm, Snake Plants, Aloe Vera, Bermuda grass, Carabao grass, Results from the current investigation shows that all plants are capable of reducing carbon dioxide from diesel exhaust but not constant. The maximum removal efficiency and elimination capacity for each plants were obtained for Broadleaf Lady Palm (64.71%) and (0.00104922 CO_2/s), for Snake Plant (64.71%) and (0.001176 CO_2/s), for Aloe Vera (33.33%) and (0.00060017 CO_2/s), for Carabao grass (58.82%) and (0.000798 CO_2/s), for Bermuda Grass (70.59%) and (0.0005378 CO_2/s). In biological aspect, the change in chlorophyll content was obtained for Broadleaf Lady Palm (-7.18), for Snake plant (+3.16), for Aloe Vera (-1.76), for Bermuda Grass (-0.77), for Cararabao Grass (-4.44). Only Snake Plants have an increase amount of chlorophyll after the test.

1. Introduction

Combustion of fossil fuels has played a critical role in the development of our modern society that touch directly or indirectly nearly all aspects of our lives. The electronic devices we use are generally powered by fossil-fuel-fired power plants. The air craft we fly in use jet-fuel-powered turbine engines. Most of the materials we use have been made through some type of heating or melting process. And mostly our modern transportation systems are almost entirely dependent on the use of petroleum oil.

Along with this global development, air pollution became rampant and greenhouse gas (GHG) emission from combustion of fossil fuels is also increasing. As a result, more heat is “trapped” in the earth's atmosphere and global temperature rises.

According to the World Resources Institute Climate Analysis Indicators Tool (WRI CAIT), the Philippines’ GHG emissions in 2012 were dominated by the energy sector (54%), followed by agriculture (33%), industrial processes (IP) (8%), and waste (7%) [1].

Arising from the global necessity, there are many studies towards methods and techniques in air pollution control that reduces malodors, reduce amount of greenhouse gases disperse to the environment, reduce pollutants that can harm environment and humans from industrial combustion and internal combustion such as Biofiltration and Phytoremediation.

Basically, biofiltration process is a technology which uses a biofilter whose main function is to bring microorganism into contact with pollutants contained in an airstream [2].

Phytoremediation is the process using plants for cleaning large contaminated areas of soil and water in the outdoor environment [3]

This study is the combination of soil biofiltration and phytoremediation which will be the botanical biofilter that will use different plants which are considered as high absorber of carbon dioxide. This study will be conducted at the University of San Carlos at Takakura Area.

2. Theoretical Background and Literature Review

Carbon and hydrogen construct the origin of diesel fuel like most fossil fuels. For ideal thermodynamic equilibrium, the complete combustion of diesel fuel would only generate CO_2 and H_2O in combustion chambers of engine but there are other harmful products that are generated during combustion such as are CO, HC, NOx, and PM due to some reason such as the air– fuel ratio, ignition timing, turbulence in the combustion chamber, combustion form, air–fuel concentration, and combustion temperature [4].

According to Ziska, L. that ongoing increase in atmospheric carbon dioxide should stimulate net photosynthesis in plants by increasing the CO_2 concentration gradient from air to the leaf interior [5]. Equation (1) shows the equation of photosynthesis that relates carbon dioxide, water and sunlight.

$$6CO_2 \ + \ 6H_2O \xrightarrow{Light} C6H_{12}O_6 \ + \ 6O_2 \tag{1}$$

2.1 Basic Parameters for Biofilter Performance

The basic parameters of biofilters include its loading rate, elimination capacity, and removal efficiency [6].

2.1.1 Loading Rate

The loading rate of a biofilter (sometimes referred to as mass loading rate or the feeding rate) is defined as mass of contaminant entering the biofilter per unit volume of filter material and per unit time. It is often expressed as in terms of area or volume [6].

$$LR = \frac{Q}{V}\left(C_{g_{in}}\right) \tag{2}$$

2.1.2 Elimination Capacity

Elimination capacity (EC) is defined as the mass of contaminant degraded per unit volume of filter material per unit time [6].

$$EC = \frac{Q}{V}\left(C_{g_{in}} - C_{g_{out}}\right) \tag{3}$$

2.1.3 Removal Efficiency

Removal efficiency (RE) characterizes the fraction of contaminant degraded as a percentage. Removal efficiency is one of the biofilter parameters that describe the performance of the biofilter [6].

$$RE = 100\left(\frac{C_{g_{in}} - C_{g_{out}}}{C_{g_{in}}}\right) \tag{4}$$

Where

EC = the elimination capacity, (g/m^3-s)

Q = Volumetric gas flow rate, (m^3/s)

V = Packed Bed Volume, (m^3/s)

$C_{g_{in}}$ = Gas concentration at the Inlet, (g/m^3)

$C_{g_{in}}$= Gas concentration at the outlet, (g/m^3)

There are several studies in the past employing methods to reduce malodors, reduce amount of greenhouse gases disperse to the environment, reduce pollutants that can harm environment and humans from industrial combustion and internal combustion which includes the following:

S.B. Anit et al (2001) used filter material that serves as a breeding ground for the microorganisms which organic pollutants are diffused and undergone a process of biological degradation by oxidation [7].

M. Nelson et al (2011) used of soil bed reactor to control gases producing malodor in industrial processes. Soil biofilters use soil, peat or compost as media utilizing their high porosity and sorption capability to begin the degradation process [8].

G. Soreanu (2013) used of plants as indoor air pollution control. It was found out that this kind of green technology can be tailored for control of gaseous compounds with the aim to improve air quality in a variety of industrial and domestic settings [3].

3. Methodology

This study followed a systematic procedure that is applied to reduce the carbon dioxide and temperature of the exhaust of diesel engine which served as the driver of the shredding machine at Takakura Area at University of San Carlos. This study considered the biology aspect of the botanical biofilters in terms of chlorophyll content. The chlorophyll extraction was performed before and after biofiltration process to check the effect of direct exposure of plants to the diesel exhaust.

The design of the biofilter system was done through CAD software which is Solidworks. The botanical biofilter shown in Fig.2 served as the bioreactor in this study that was used to filter some gas pollutants from the exhaust of a diesel engine specifically carbon dioxide CO_2. This was a hybrid of an ordinary biofilration, a combination of soil biofiltration and botanical biofiltration. The main parts of this bioreactor were the plant assembly, grass assembly, plenum chamber assembly, and the two heat exchangers.

Fig. 1 Actual Design of Botanical Biofilter

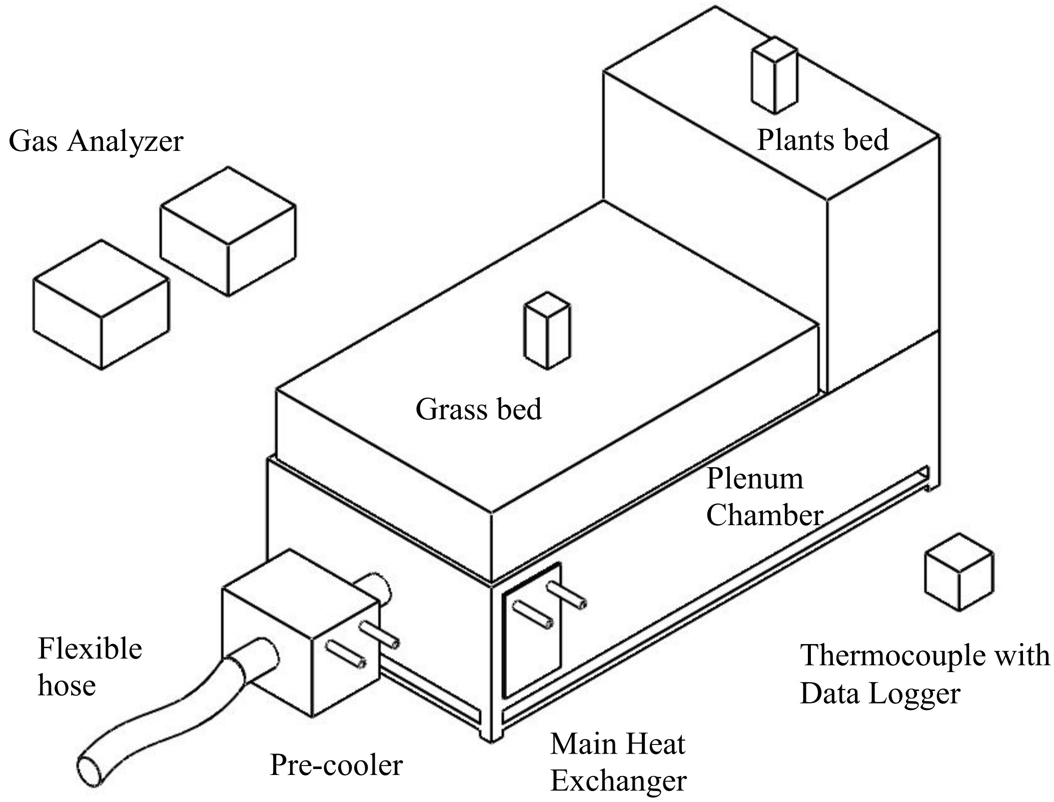

Fig. 2 Experimental Set-up of Biolftration System

Fig. 2 shows the experimental set-up of the study which is installed at the Takakura Briquetting Center at University of San Carlos.

Parameters such as gas velocity, temperature, and carbon dioxide concentration were measured were measured every 10 minutes for a period of 2 hours during testing using different equipment namely, hot wire anemometer, thermocouple and gas analyzer respectively. The diesel engine was maintained at 1/5 throttle with a speed of 530-540 rpm. During the replenishing period, the plants were watered, and the exhaust gas was purged out by removing all the botanical biofilters.

4. Results and Discussions

4.1 Carbon Dioxide Concentration

Fig. 3 shows the CO_2 drop from the Inlet to the botanical biofilter which are plants and grasses combination. The CO_2 concentrations measured per interval mostly decrease as the gas exits through the botanical biofilter. It can also be observed that there are times when the CO_2 concentration remains the same even if the gas passes through the biofilter. There are instances wherein the measured CO_2 in the Grass and Plants, the (CO_2) drop on the grass was higher than that of the Plants, sometimes Plants was higher than grass, and sometimes equal.

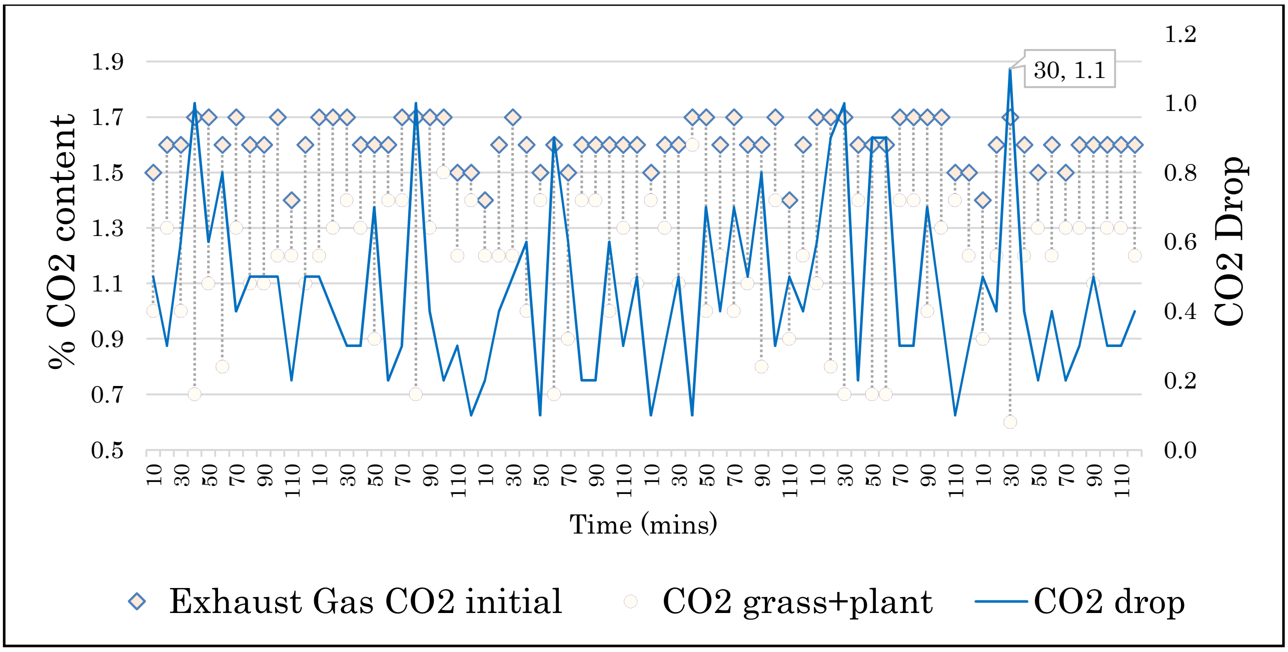

Fig. 3 Carbon dioxide Concentration Profile For Carabao grass – Lady Palm

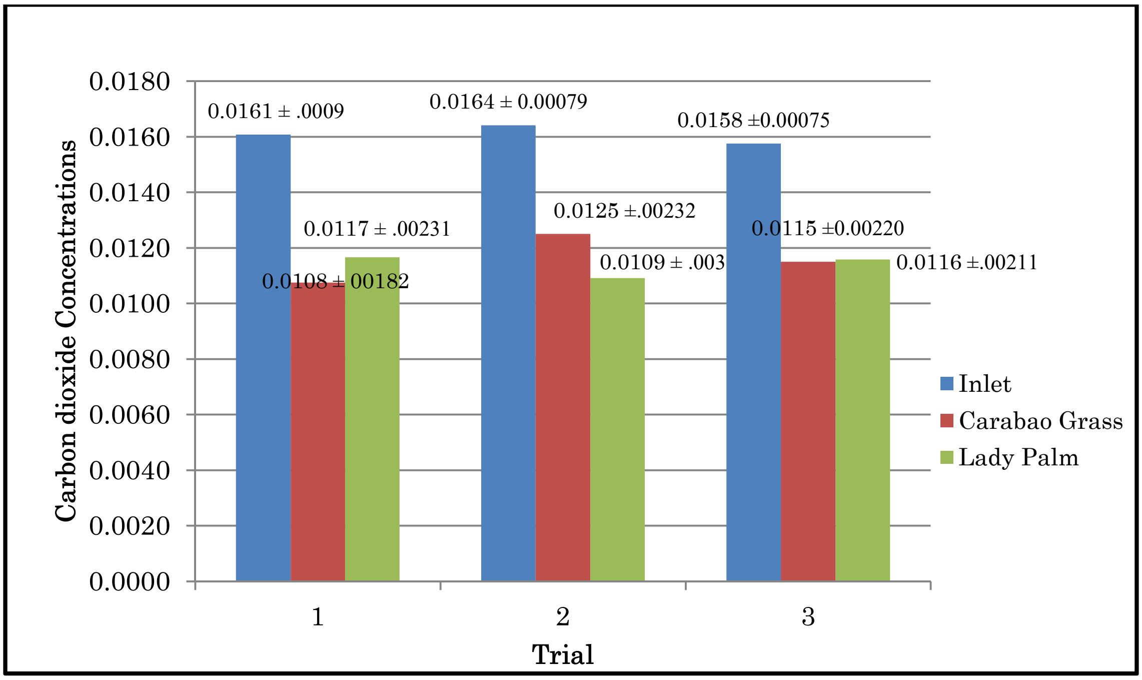

Fig. 4 Average CO2 Concentration for Carabao grass – Lady Palm

Fig. 4 shows the average carbon dioxide concentration for every trial for Carabao grass – Lady Palm combination. For the carbon dioxide concentrations at the inlet the standard deviation is 0.000818042 by this data the minimum and maximum carbon dioxide concentration ranges from 0.016083333 ± 0.001636084. At the grass outlet the standard deviation is 0.002119534, the minimum and maximum carbon dioxide concentration ranges from 0.011583333 ± 0.004239068. At the plant outlet the standard deviation is 0.002502, the minimum and maximum carbon dioxide concentration ranges from 0.011388889 ± 0.005004.

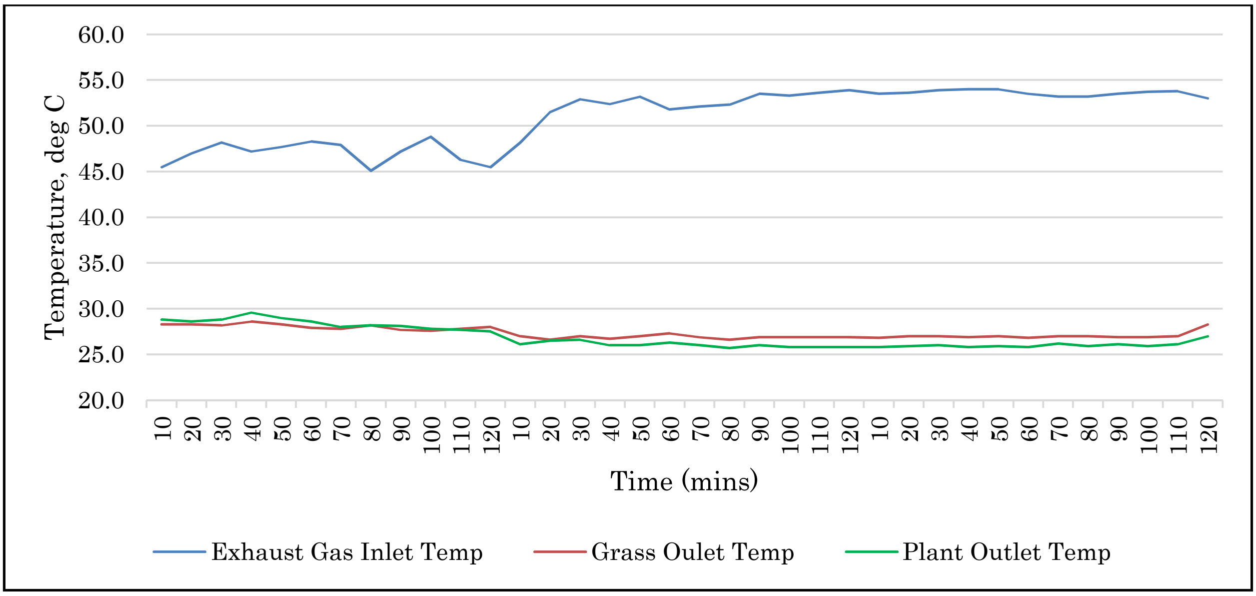

Fig. 5 The temperature profile for Carabao Grass and Lady Palm

Fig. 5 shows how the temperature of the exhaust at the inlet drops when in contact with the heat exchanger for Carabao grass – Lady Palm combination. The temperature profile of the exhaust gas at the inlet going to the botanical biofilter ranged from 45.5 ºC to 54.0 ºC was plotted for all the trials. The highest temperature recorded at the inlet from this combination was obtained during the Trial 3 after 50 mins of engine running which is 54.0 ºC then the lowest temperature was obtained in Trial 1 at the beginning of the testing which is 45.5 ºC. After undergone two stage of cooling, the temperatures at the inlet were dropped. The temperatures exited to the Lady Palm drop ranges from 26.6 ºC to 28.3ºC then for the Carabao grass ranges from 25.8 ºC to 28.3 ºC. The lowest temperature of the exhaust gas exited to the Lady Palm was obtained in Trial 2 which is 26.6 ºC then the lowest temperature exited to the Carabao grass was obtained in Trial 2 and Trial 3 which is 25.8 ºC.

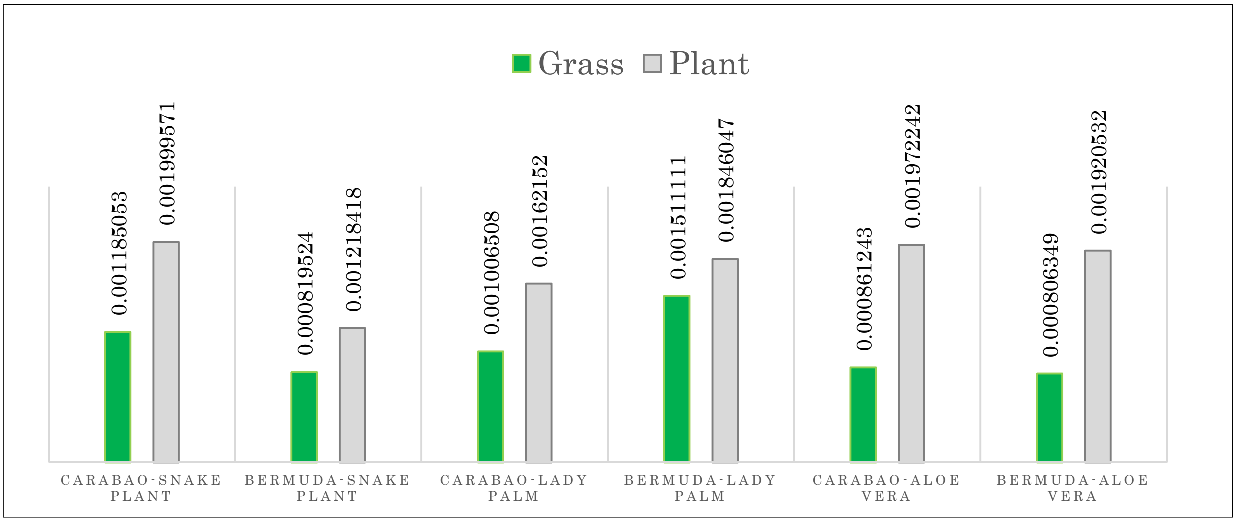

Fig. 6 The Data For The Maximum Loading Rate For Each Combination For All Trials.

Fig. 6 shows the average loading rate for every trials for all combinations. The highest loading rate calculated for plants were obtained during the experiment using Carabao grass – Snake Plant which is 0.001999571 CO_2/s and the lowest loading rate were obtained during the experiment using Bermuda Snake Plant which is 0.001218418 CO_2/s. The variation of the loading rate for every trial shows that the proponent was unable to achieve the stable condition used for the rest of the testing, due to inconsistent feed rate of the leaves to the shredder machine.

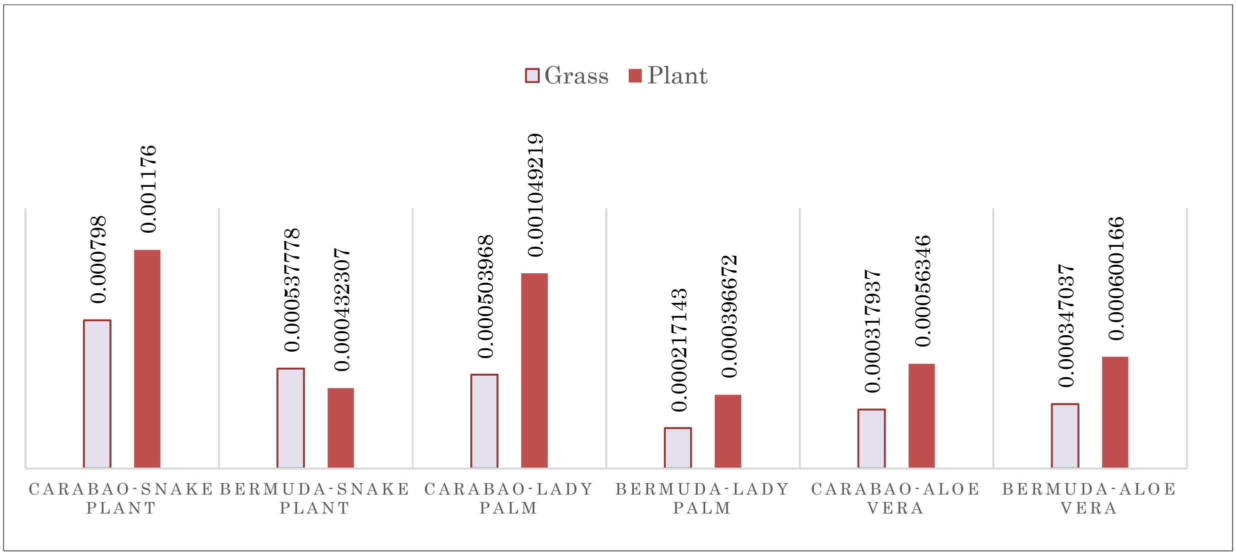

Fig. 7 The Maximum Elimination Capacity For Each Combination For All Trials.

Fig. 7 shows the average elimination capacitry for all combinations. The elimination capacity for all combination ranged from 0.000217143 CO_2/s to 0.001176 CO_2/s. The highest elimination capacity calculated for plants was obtained using the Carabao grass – Snake Plant which is 0.001176 CO_2/s and the lowest was obtained using Bermuda – Lady Palm which is 0.000396672 CO_2/s .

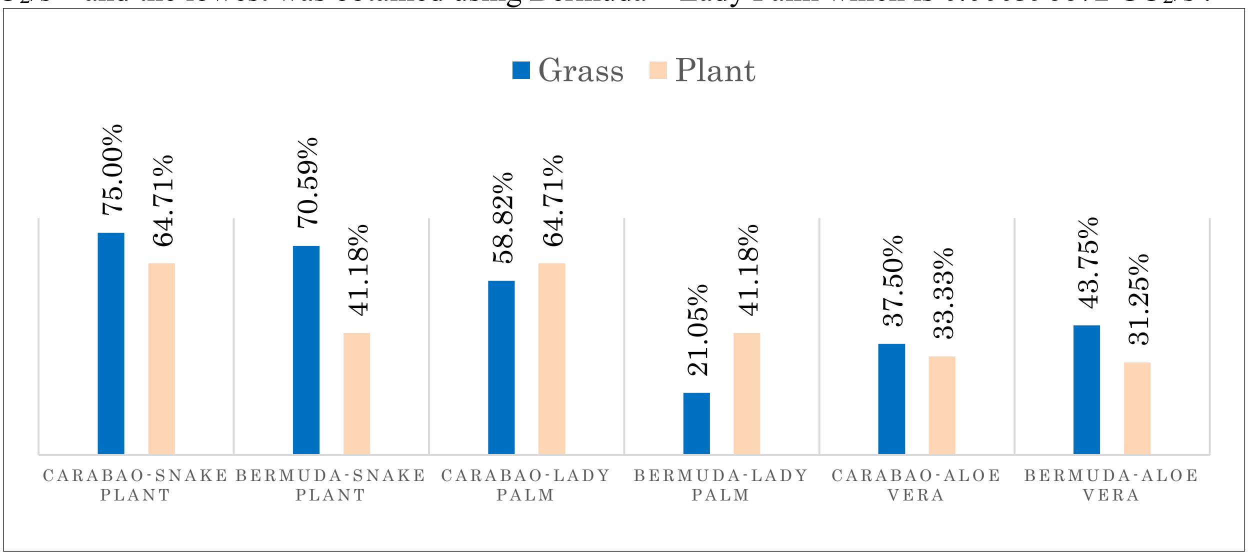

Fig. 8 The data for the maximum capacity for each combination for all trials.

Fig. 8 shows the average removal efficiency for all combinations. The removal efficiency for all combination ranged from 21.05 % to 75.00% . Those combination contains one of this botanical biofilters namely Lady Palm and Snake Plant have higher removal efficiency compare to other combinations. The removal efficiency calculated for plants was obtained using Carabao grass – Snake Plant and Carabao grass – Lady Palm which is 64.71% and the lowest removal efficiency was obtained using Bermuda Grass – Aloe Vera which is 31.25%. The highest removal efficiency calculated for grass was obtained using Carabao grass – Snake plant which is 75.00% and the lowest was obtained using Bermuda grass – Lady Palm which is 21.00%.

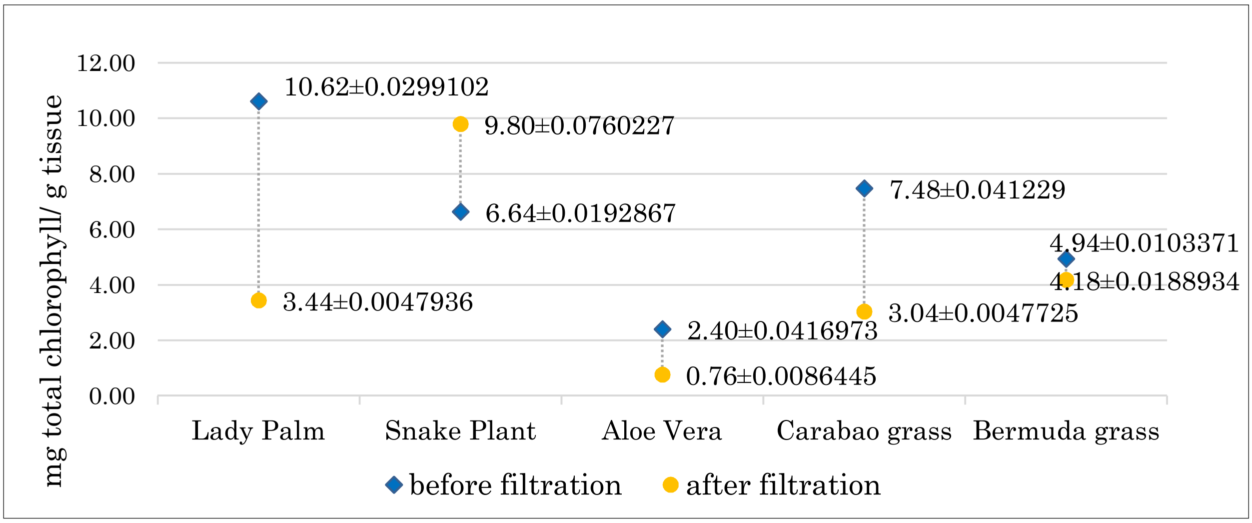

Fig. 9 The chlorophyll content for each sample before and after biofiltration

Fig. 9 shows how the chlorophyll change when the leaves are directly exposed to diesel exhaust. It was found out that after three (3) trials of testing the botanical biofilters all chlorophyll content for each sample leaves decreases but except for the Snake Plant. The data for Snake plant increases from 6.64 ±0.076022 to 9.80 ± 0.0760227 mg chlorophyll/gtissue unlike the other botanical biofilter.

5. Conclusion

The data gathered shows that all botanical biofilters are capable in reducing the carbon dioxide concentration of the diesel engine exhaust. However, the direct exposure of the exhaust to the biofilters has an effect to its properties. Before undergoing biofiltration process, the chlorophyll was extracted from each sample leaves, and after biofiltration it was observed that the amount of the extracted chlorophyll are all decreasing except the Snake Plant. It increases from 6.64 ±0.076022 to 9.80 ± 0.0760227 mg chlorophyll/gtissue. According to the study of Fleischer (1934), that the chlorophyll content is directly proportional to the rate of photosynthesis [9]. In addition, the chlorophyll is the one that traps the sunlight and absorbed carbon dioxide then converted into sugar which serve as food [10].

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