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Enhancement of Muffler System with Adsorptive Capacity of Water Hyacinth (*Eichornia crassipes*) Biochar for Vehicle Exhaust Emission Reduction

Transportation is one of the main contributors to air pollution. As time passes, the number of vehicles has been gradually increasing, which ensures that more emissions along with the pollutants are released into the air. On the other hand, water pollution is one of the known significant problems faced by different countries. One of its contributors is the infestation of water hyacinth that causes cloggings and other noxious effects. Therefore, the researchers created a filter for the diesel-powered vehicles' emissions using activated carbon derived from water hyacinth. Water hyacinth leaves were carbonized in a furnace at 300°C for an hour and were activated with 2 M Potassium Hydroxide (KOH) overnight. Afterwards, it was heated in an oven for half an hour. Samples were characterized using FTIR and SEM and underwent an adsorption test using an Opacity Smokemeter. The FTIR analysis showed that the peaks of water hyacinth-based activated carbon (WHAC) and commercial activated carbon (CAC) are comparable and identical. SEM results showed the activated and non-activated carbon's micrographs, which indicate that the activated carbon successfully achieved a porous state that makes it capable of adsorption. The findings of the Opacity Smokemeter showed that WHAC is capable of filtering the emissions at $p = 0.05$. In conclusion, the modified muffler with water hyacinth-activated carbon filter reduced the emissions of a vehicular diesel-engine and is comparable to the commercial mufflers at $p = 0.01$.

Introduction

At our time of the Fourth Industrial Revolution, the Philippines faced problems associated with air and water. Air and water pollution are two of our country's major concerns that bring adverse effects to people and the environment. Recent studies indicate that air pollution stemming from transportation is an important contributor to human health risks and other noxious effects. Studies claim that emissions can harm human health because these emissions contain dangerous pollutants that make the air quality poor.[6,12,15] According to the World Bank in 2002, transport contributes 58% to air pollution. The majority of its contributors are over 65% of diesel-powered vehicles in the Philippines, which account for the majority of urban exposure and health impacts.[18] Water pollution is becoming a problem in most countries.[5,10] Disposable wastes, plastics, and rubbers are one on the list but there is also one thing that caught many countries' attention. Water hyacinth (*Eichornia crassipes*) is a free-floating, invasive plant species that has attracted many countries due to its rapid growth and has become one of the contributors to water pollution.[7,10,13] Some articles state that Water hyacinths cause clogging in some areas such as Laguna de Bay, which is the largest lake in the Philippines which extends over in Metro Manila, especially in Navotas City. Since Navotas City is the Fishing Capital of the Philippines, the fishermen's livelihood is affected by this invasive plant.[9] It is also known for removing the nutrient concentrations, oxygen concentrations to water bodies and other unpleasant effects that sometimes lead to ecological damage.[2,7,16,17] Hence, researchers came up with this study to provide an effective solution to the problems.

Various studies reveal that water hyacinth can be treated to produce activated carbon for wastewater treatment. Since activated carbon is capable of adsorbing, the researchers decided to produce activated carbon prepared from water hyacinth to decrease the density of gases that standard diesel vehicles produce. Researchers prefer to filter emissions from vehicular diesel engines, given that diesel is the most usual fuel and that its emissions contain the most dangerous gases[11].

With these facts in mind, the researchers decided to develop a muffler by placing an activated carbon derived from water hyacinth that would serve as an adsorbent within the muffler; or what the researchers call the Water Hyacinth Activated Carbon Muffler (WHACM). WHACM aims to decrease the density concentration of gas emitted by diesel-powered vehicles, specifically in this study, an L-300 van. Moreover, this study will significantly decrease the volume of water hyacinth floating in the rivers of Navotas and other nearby cities and transform it into something useful and economical.

This study, as per recent patent searches, does not exist yet. Commercial activated carbon is available on the market and filters have already been used for mufflers. However, the concept is unique as it is two-pronged – lessen the volume of water hyacinths in waterways and lessen the density of gases emitted by diesel-powered vehicles, which is related to decreasing the soot and particulate matter emitted by these emissions.

Methodology

Patent Search and Patent Information Utilization

Before further developing this study, the researchers did a thorough patent search through the database of Patentscope (https://patentscope.wipo.int/search/en/search.jsf), which is the IP portal of WIPO and where the IPOPHIL is connected. Another patent website, Google Patents (https://patents.google.com/), The researchers used various terms to check whether a similar study or similar innovation already existed. All patent search results and patent information gathered is logged in the innovator's logbook and is checked for similarities and completeness.

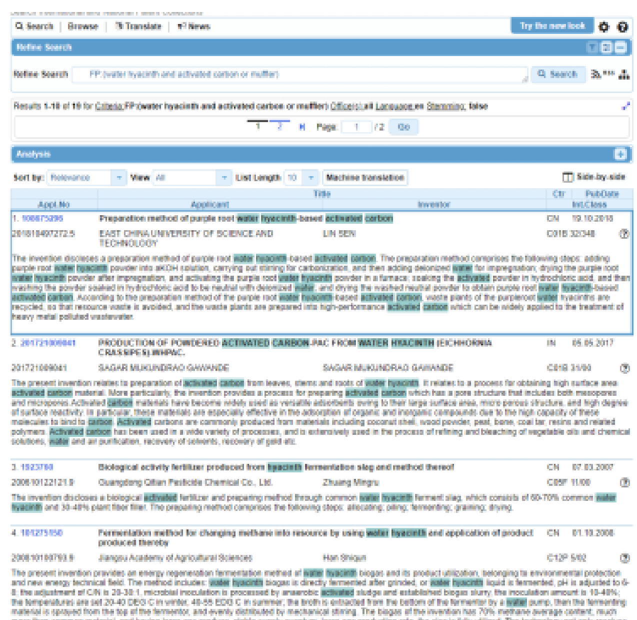


Photo 1: Patent searches done before the innovation process starts. The terms used for this patent search is "Water hyacinth and activated carbon or muffler." Screenshot taken by the researchers.

2D and 3D Modelling of the Muffler

After thoroughly doing a patent search, the researchers proceeded in designing the invention. It started with a rough sketch of the universal muffler. Afterwards, it is 2D modelled using Adobe Photoshop. After checking the

2D model and specifying the measurements, it is subjected to 3D modelling using SketchUp Make.

Collection and Preparation of Materials

The researchers collected water hyacinth on the river of Barangay NBBS, Navotas City and washed it thoroughly using tap water to remove unnecessary dirt. It was then authenticated in the Bureau of Plant Industry, Malate, Manila. The leaves were cut into small pieces and air-dried for five days. For the chemical activation, Potassium Hydroxide (KOH) pellets were purchased at

Alysons, Quezon City. The stainless tube and mesh were bought at a hardware store in

Navotas City. The muffler was bought at a muffler shop in Caloocan City

Photos 2 and 3: Collection of water hyacinth from Barangay NBBS, Navotas City. Photos taken by the researchers.

Photo 4: Potassium hydroxide pellets bought from Alysons. Due to its hygroscopic nature, it is quickly sealed again. Photo taken by the researchers.

Carbonization and Chemical Activation of Water Hyacinth Leaves

The process of carbonization and chemical activation is adapted and modified from Maulina, Kusumaningtyas, Rachmawati, Arkundato and Rohman in 2019. All processes here are done in the Agriculture and Soils Division of Philippine Nuclear Research Institute. The dried water hyacinth leaves were carbonized in a CARBOLITE Furnace at a steady rate of 300°C for 1 hour until weight is constant. Afterwards, it was transferred into a container for the chemical activation. 2M of KOH was prepared by mixing 11.22 g of KOH in 100 mL of deionized water. Measurements are carried out using a Mettler Toledo AB204-S analytical balance with 0.001 accuracy. The 2M KOH activator is poured into the carbonized leaves and it was rested for one day for the KOH to impregnate the carbon thoroughly. The ratio for the carbon and activator is 1:4 w/v. After one day, it was heated in an electric oven until excess water was removed.

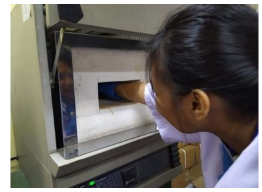


Photo 5 and 6: Dried water hyacinth leaves put into crucibles for carbonization and dried water hyacinths' carbonization in the CARBOLITE Furnace. Photo taken by the researchers.

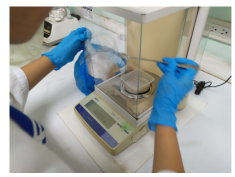
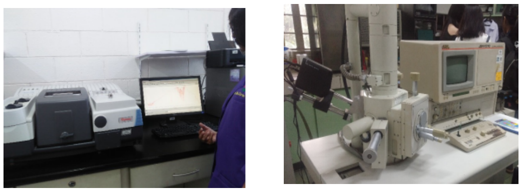


Photo 7: Measuring exact amounts of KOH for chemical activation using analytical balance. Photo taken by the researchers.

Photo 8 and 9: Impregnation of KOH to the non-activated carbon (NAC). The ratio of NAC to KOH is 1:4 and the drying process uses an ordinary electric oven. Photo taken by the researchers.

Characterization of Water Hyacinth Leaves-Activated Carbon

To characterize and confirm the water hyacinth activated carbon's chemical characteristics, Nicolet 6700 FT-IR Spectrometer was used to identify the present functional groups in the activated carbon. The KBr method was used for this specific IR spectrometry. The porosity and surface structure was examined and photographed using a JEOL JSM-5310 Scanning Electron Microscope for its morphological characteristics.All characterizations were made at De La Salle University Chemistry Laboratory and Solid State Laboratory, respectively, with their laboratory persons in-charge.



Photos 10 and 11: FT-IR analysis and SEM analysis at De La Salle university. Photos taken by the researchers.

Fabrication and Assembly of the Muffler System

The muffler was assembled based on the 3D model's design and modified from the study of Chafidz, et. al in 2017. The universal muffler has two openings, one for the exhaust manifold (inlet) and exhaust gas (outlet). Inside is a 10 cm stainless tubing with a diameter fit to the muffler's opening covered by 150 aluminum mesh or cloth with small pores at both ends so that granular water hyacinth activated carbon will not come out. 20 g of activated carbon samples is put inside the 5 cm tubing. The diagram of the assembly of the modified muffler is shown below.

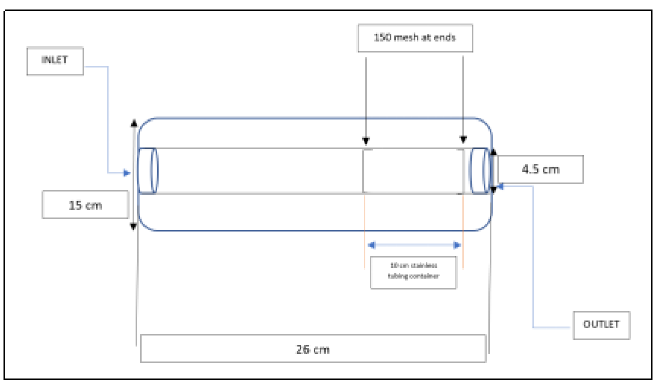


Figure 1: Simplified view of the muffler with corresponding measurements derived from Sketchup Make. Illustrations by the researchers

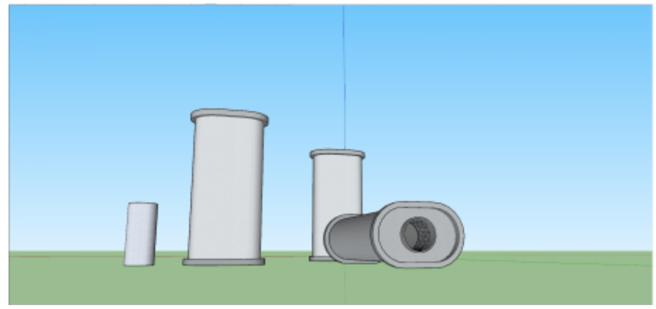


Figure 2: 3D models of WHACM

Photo 12: WHACM exterior look. Shown in the photo is the inlet part and Photo taken by researchers.

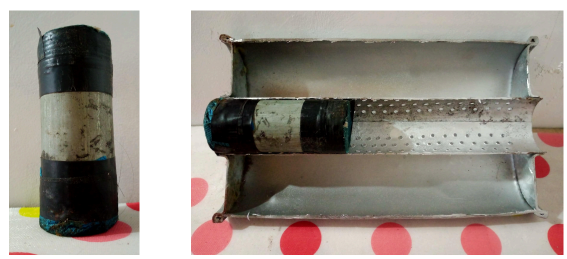


Photo 13 and 14: Prototype 10 cm tube containing activated carbon. Electric tapes are used to fasten the mesh around the end of the tubes and the actual look of the tube inside the WHACM. Photo taken by the researchers.

Adsorption Test

For the testing of WHACM, an L-300 diesel-powered van will be used as the test vehicle and Opacity Smokemeter OPA – 101 will be used to measure the gas density. As per the manual of the Smokemeter, place one foot on the accelerator pedal and burst accelerate the engine to its maximum revolution speed and then take gas samples. Each trial will have six runs of accelerations to be done thrice. The three setups to be used are as follows: Without WHACM, with WHACM, with Commercial Activated Carbon in the muffler. After each run, the averages will be computed and the difference between each set-ups will be determined using ANOVA and Tukey's post-hoc analysis.


Photos 14 and 15: The opacity smokemeter to measure gas density and a run of the smokemeter using WHACM. Photos taken by the researchers.

Results and Discussion

Patent Search and Patent Information Utilization Using the information from Patentscope, the researchers benchmarked on the different innovations and inventions by different people and further confirmed the project's novelty. The researchers used different keywords to search at Patentscope. The table below shows the results of the patent search.

Table 1: Results of Patent Search (Patent Scope)

Keywords	**Number of Results**
"Water hyacinth"	2,226
"Eichornia crassipes"	94
("Water hyacinth" or "Activated Carbon")	245,538
"Water hyacinth" AND "Activated Carbon"	146
("Water hyacinth" or "Activated Carbon" or Muffler)	297,683
"Water hyacinth" AND ("Activated Carbon" or Muffler)	180
("Water hyacinth" or "Activated Carbon") AND Muffler	57
"Water hyacinth" AND "Activated Carbon" AND Muffler	None
"Water hyacinth" AND "Activated Carbon" AND Silencer	None
"Water hyacinth" AND "Activated Carbon" AND "Mute Pedal"	None
(Muffler or "Mute Pedal" or Silencer or "Noise Queller" or Sordino or Sordine or Sourdine or Damper) AND ("Water Hyacinth" or "Eichornia crassipes" or "Eichhornia crassipes" or "Eichhornia Speciosa" or "Water Orchid") AND ("Activated Carbon" or "Activated Charcoal") or Biochar or "Activated Coal" or "Activated Carbon Filter" or "Active Coal" or "Active Charcoal")	7

Based on the patent search done by the researchers, the result showed a patent entitled *"Swiftlets Farming for Production of Edible Bird's Nest"* by Sia Yik Hei and Tan Jee Hong. This patent, however, is not similar to our research as it uses water . Therefore, no patent has been done utilizing water hyacinth activated carbon as a filter or an adsorbent or muffler system. The nearest patent available to our study or Prior Art is CN104314653 entitled *"Car muffler with the function of reducing smoke dust and carbon monoxide emission"* by Li Huaming and Li Tiancai. It does not use activated carbon in its model thus it is safe to assume that no one has utilized activated carbon as an adsorbent for smoke emitted through a muffler in the database of WIPO.

FTIR Spectroscopy Analysis

As seen in Fig. 3, the water hyacinth-based activated carbon spectra showed the peak at 3331.02cm^{-1} indicating the presence of an O-H functional group. The peak at 2171.59cm^{-1} showed that there is a present -C≡C- groups of alkyne compounds. While the presence of C=C of an alkene compound was indicated by uptake of 1657.97cm^{-1}. The peak at 1634.24cm^{-1} showed that there is also a C=C group of alkene compounds. The presence of C=C groups of aromatic compounds was indicated at peak 1595cm^{-1} . In Fig. 4, the commercial activated carbon spectra showed the peak at 3378.26 cm^{-1} indicating an O-H functional group's presence. The peak at 2925.71cm^{-1} showed that there is a present C-H group of alcohol. The peaks at 1581.03 cm^{-1} and 1408.57 cm^{-1} showed the presence of C=C groups of alkene compounds. While the peak at 1370.97 cm^{-1} showed -C-H groups of alkane compounds, C-F groups of Alkyl Halide compounds and N-O groups of Nitro compounds. Both spectra showed presence of the same compounds but in different peaks and the same range. This indicates the presence of the same functional groups in the compound and a big possibility of having the same characteristics.

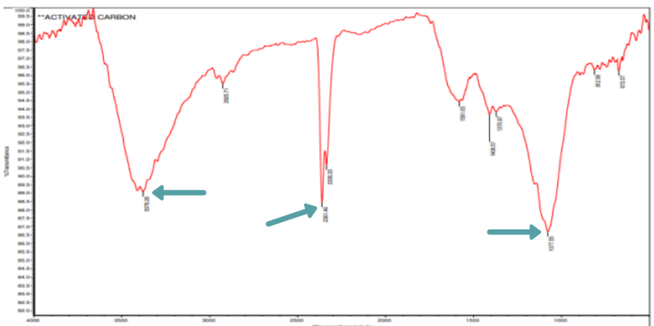


Figure 3: FT-IR spectrum of water hyacinth activated carbon (WHAC).

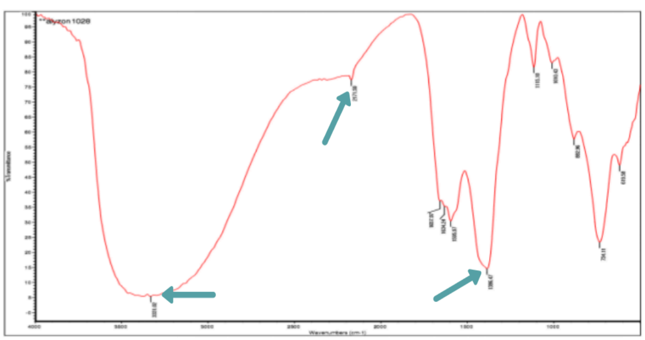


Figure 4: FT-IR Spectrum of Commercial Activated Carbon (CAC). The arrows in both spectra represent groups in the same range for both the WHAC and the CAC.

Morphological Analysis

The porosity and surface structure of the activated carbon were observed using Scanning Electron Microscope (SEM). The surface morphology of non-activated carbon and water hyacinth-based activated carbon was shown using SEM with a magnification of 1500x, 2500x, 5000x and 10000x. The obtained images were shown in Fig. 3 and Fig. 4. It showed that the non-activated carbon has a wide surface area but is less porous than the activated carbon derived from water hyacinth which achieved a more porous state after the activation. Related studies show that porosity is directly proportional to the capacity of a material to adsorb any substance.

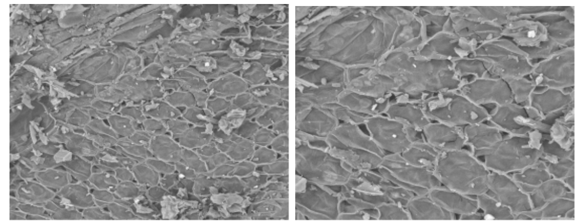


Figure 5: SEM micrographs of non-activated carbon.

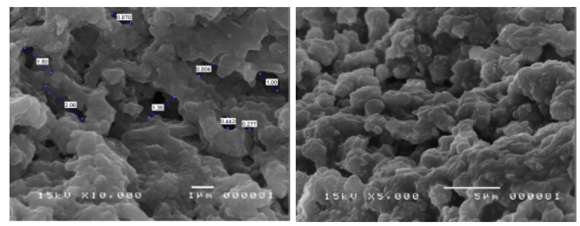


Figure 6: SEM micrograph of water hyacinth activated carbon.

Adsorption Analysis

Opacity Smokemeter OPA – 101 is used to measure the smoke level density in the emissions emitted by a diesel engine with and without filter (WHACM) and (CAC). The tables below show the data gathered from the device after three trials.

Table 2: Results of the Opacity Smokemeter in m^1 for smoke without WHACM

Trials	Average
TRIAL 1	0.57 ± 0.16
TRIAL 2	0.55 ± 0.06
TRIAL 3	0.58 ± 0.03

Table 3: Results of the Opacity Smokemeter in m^{-1} for smoke with WHACM.

Trials	Average
TRIAL 1	0.03 ± 0.02
TRIAL 2	0.05 ± 0.02

TRIAL 3	0.07 ± 0.01

Table 4: Results of the Opacity Smokemeter in m1 for smoke with Commercial Activated Carbon.

Trials	Average
TRIAL 1	0.07 ± 0.02
TRIAL 2	0.07 ± 0.01
TRIAL 3	0.09 ± 0.02

From the tables above with their corresponding averages and standard deviations, we can see a difference in the data given by the smokemeter using WHACM, not using WHACM and using commercial activated carbon. To further substantiate the case whether the difference is significant or not, the data is subjected to inferential statistics, namely Analysis – of – Variance and Tukey's Post Hoc Test.

Table 5: Results of ANOVA for the three samples

source	sum of squares SS	degrees of freedom νν	mean square MS	F sta-tis -tic	p-value
treatment	0.5096	2	0.2548	714.3480	**7.3143e-08**
error	0.0021	6	0.0004		
total	0.5117	8			

The results of ANOVA show a p-value lower than 0.05, therefore, the difference between the groups is significant. This shows that WHACM is an effective muffler in decreasing the smoke density from a diesel-fueled engine.

Table 6: Tukey's HSD Data. Without WHAC is A, with WHAC is B and with CAC is C.

treatments pair	Tukey HSD Q statistic	Tukey HSD p-value	Tukey HSD inference
A vs B	47.3543	0.0010053	** p<0.01
A vs C	45.1532	0.0010053	** p<0.01
B vs C	2.2011	0.3325744	insignificant

For Tukey's HSD Data, there is a very significant difference between the results of emissions in smoke without using WHAC and with using WHAC and with using CAC at p = 0.01. However, there is an insignificant difference between WHAC and CAC, proving that WHAC can substitute expensive commercial activated carbon as filters for mufflers. The values displayed by the smokemeter, with unit of m^{-1} is also known as Absorption coefficient. This follows the principle of Beer-Lambert's law. Therefore, the higher the value of K, the more opaque the smoke is. The more opaque the smoke is, the higher concentrations of soot and particulate matter is in the smoke. Thus, from the data shown above, it can be safely concluded that WHACM decreased the soot and particulate matter present in the engines' smoke emitted. For further study, it is recommended that the experimentation be extended to include the kinetic studies for the activated carbon, like the reusability of WHACM and how many kilometers an average driver can drive before he/she must replace his/her muffler.

Moreover, studies can be conducted to extend the project since that activated carbon is carbon itself. The spent activated carbon for WHACM can be used as alternative fertilizers in plants or in water treatment facilities. It can also be suggested that WHACM be used in gasoline – powered engines and in different vehicles. On a bigger scale, it is recommended to use WHACM or even WHAC in emissions of factories to see if there is a significant difference in the compositions of their emissions before and after.

Table 7: Costing for Production of WHACM

Universal Muffler	Php 800
Production of water hyacinth activated carbon	Php 100
10 cm aluminum steel cylinder	Php 50
TOTAL COST	Php 950

Table 8: Costing for Production of CAC + M

Universal Muffler	Php 800
Commercial activated carbon	Php 250
10 cm aluminum steel cylinder	Php 50
TOTAL COST	Php 1100

Table 7 and 8 compares the costs of producing WHACM and procurement of CAC + Muffler. Notice the difference in the costing. It is more economical to produce WHACM rather than buy commercially activated carbon. Moreover, if one looks at the Internet prices, one can notice that a muffler with filter costs around Php 6,000 to Php 10,000. Thus, the use of WHACM will be economical and environment friendly.

Conclusion and Recommendation

Water Hyacinth Activated Carbon Muffler (WHACM) is a study that solves at least two problems that are also pressing according to Sustainable Development Goal (SDG) is – Climate Action and Life on Water. It can be used in different vehicles to lessen its smoke density and potentially lower the particulate matter, soot and other harmful gases that petroleum powered engines emit like carbon monoxide. The concept can be used not only in vehicles but also in house emissions and industrial gas emissions. Users of this will benefit jeepney operators since they will have less expenses in installing commercially available mufflers.
Moreover, the jeepneys and other public utility vehicles will pass the gas emission tests because it is proven that the modified muffler significantly decreases the smoke opacity emitted by these engines. WHACM will impact SDG on climate action since the rise of temperatures is inevitable. Lessening particulate matter, harmful gases and other soot in the atmosphere will contribute to the government's efforts towards green and renewable energy.

Moreover, it will impact SDG on Life on Water since water hyacinth usually competes with oxygen demand in the seas and rivers. Harvesting them will mean more oxygen supply for fishes and other beneficial aquatic animals. In addition to that, clogging of waterways will be lessened because water hyacinths will be immediately eliminated from the waterways. It will also benefit the people living near the rivers since they can have extra income by harvesting water hyacinths in the waterways to be sold by people to make this research study.

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Appendices

Patent searches using Google Patents. The terms used for this patent search is "Water Hyacinth and Activated Carbon and Muffler". Screen shot taken by the innovator.

Results of Patent Search (Google Patent)

KEYWORDS	NUMBER OF RESULTS
Water Hyacinth	77,336
Eichornia Crassipes	1,573
Water Hyacinth or *Eichornia crassipes*	1,245
Water Hyacinth or *Eichornia crassipes* or Activated Carbon	400
Water Hyacinth and Activated Carbon	17,070
Water Hyacinth or Activated Carbon or Muffler	789
Water Hyacinth or Activated Carbon and Muffler	789
Water Hyacinth and Activated Carbon or Muffler	789
Water Hyacinth or Activated Carbon or Silencer	652
Water Hyacinth or Activated Carbon or Mute Pedal	5
Water Hyacinth and Activated Carbon And Muffler	795

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Water Hyacinth and Activated Carbon and Mute Pedal	5
Water Hyacinth and Activated Charcoal and Muffler	23
Water Hyacinth and Biochar and Muffler	2

Results of the Opacity Smokemeter in m^1 for smoke without WHACM

TRIALS	RUNS					
	1	2	3	4	5	6
TRIAL 1	0.59	0.5	0.61	0.42	0.86	0.42
TRIAL 2	0.57	0.57	0.61	0.55	0.57	0.43
TRIAL 3	0.58	0.56	0.6	0.54	0.58	0.62

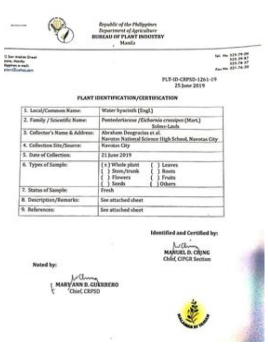
Results of the Opacity Smokemeter in m^{-1} for smoke with WHACM

TRIALS	RUNS					
	1	2	3	4	5	6
TRIAL 1	0.59	0.5	0.61	0.42	0.86	0.42
TRIAL 2	0.57	0.57	0.61	0.55	0.57	0.43
TRIAL 3	0.58	0.56	0.6	0.54	0.58	0.62

Results of the Opacity Smokemeter in m^{-1} for smoke with Commercial Activated Carbon

TRIALS	RUNS					
	1	2	3	4	5	6
TRIAL 1	0.1	0.07	0.05	0.03	0.07	0.08
TRIAL 2	0.07	0.06	0.06	0.05	0.07	0.09
TRIAL 3	0.1	0.12	0.11	0.07	0.08	0.08

Certificate of Authentication of Water Hyacinth


Republic of the Philippines
Department of Agriculture
BUREAU OF PLANT INDUSTRY
Manila

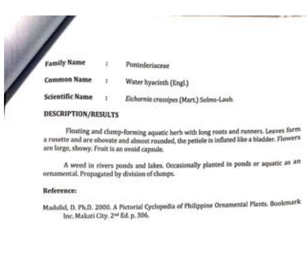
PLT-ID-CRPSD-1261-19
25 June 2019

PLANT IDENTIFICATION/CERTIFICATION

1. Local/Common Name:	Water hyacinth (Engl.)
2. Family / Scientific Name:	Pontederiaceae /*Eichornia crassipes* (Mart.) Solms-Laub
3. Collector's Name & Address:	Abraham Deogracias et al. Navotas National Science High School, Navotas City
4. Collection Site/Source:	Navotas City
5. Date of Collection:	21 June 2019
6. Types of Sample:	(x) Whole plant ( ) Leaves ( ) Stem/trunk ( ) Roots ( ) Flowers ( ) Fruits ( ) Seeds ( ) Others
7. Status of Sample:	Fresh
8. Description/Remarks:	See attached sheet
9. References:	See attached sheet

Identified and Certified by:
MANUEL D. CHING
Chief, CIPGR Section

Noted by:
MARY ANN B. GUERRERO
Chief, CRPSD


Family Name : Pontederiaceae
Common Name : Water hyacinth (Engl.)
Scientific Name : *Eichornia crassipes* (Mart.) Solms-Laub.

DESCRIPTION/RESULTS

Floating and clump-forming aquatic herb with long roots and runners. Leaves form a rosette and are obovate and almost rounded, the petiole is inflated like a bladder. Flowers are large, showy. Fruit is an ovoid capsule.

A weed in rivers ponds and lakes. Occasionally planted in ponds or aquatic as an ornamental. Propagated by division of clumps.

Reference:

Madulid, D. Ph.D. 2000. A Pictorial Cyclopedia of Philippine Ornamental Plants. Bookmark Inc. Makati City. 2nd Ed. p. 306.

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ATTESTED:
MICHELLE A. FLOR
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