EcoCharCleaner

El-Sadat STEM School - Grade 2 - Semester 1 - 2024 / 2025 - Team : 25211

Keywords: Biochar- Thermal decomposition- FTIR- VOCs- RSCS

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Abstract

Air pollution, particularly volatile organic compounds (**VOCs**), poses severe threats to human health and environmental sustainability. According to **Egyptian Ministry of Health and Population** there are in diseases as (**Asthma**, **COPD**, **Leukemia** and etc.…) that are the result of high concentration of **VOCs**.

Our capstone project proposes a **Biochar-based** air filtration system to reduce **VOCs** concentrations effectively, considering Biochar has high capacity for adsorption for **VOCs** due to its internal **pore structure** in addition to its **Eco-Friendly** Properties as it achieves sustainability through recycling of agricultural waste material. The prototype employs interconnecting chambers equipped with **Biochar sheets**, **Tubes**, and an **Arduino-monitored** setup for real-time data collection. Polluted air passes through biochar layers after introducing **VOCs** into beakers and pumping them through the system. **VOCs** sensors are implemented in both the before and after filtration stage to measure pollutant levels, initial tests demonstrated VOC concentration reductions of (**90–96%**).

Our project is aimed at showing not only one of the possible **low-budget** solutions to air pollution but also the potential of **Biochar** in other uses concerning sustainable environments as it uses accessible **low-cost materials** and hence is very applicable in areas under great **risk of pollution**.

Introduction

Egypt is facing big challenges: **polluted** air, **water**, and **soil**, along with mountains of waste and the effects of **climate change**. The Egypt Grand Challenge pushes us to find innovative ways to solve these problems, like recycling different waste materials and improving public health. For our **Capstone** project, we're taking on this challenge by turning agricultural waste into biochar to create a system that purifies the air. This project isn't just about meeting a goal—it's about making a real difference for the environment and the people who live in it.

Zeolites is considered as one of the most essential minerals in nature used for air purification which offer certain **advantages** as they are **non-toxic materials**, which makes them safe for **utilizing** without making any danger or additional pollutants. Their limits in handling complex pollutants like **VOCs** led us to look for more versatile solution. This search brought us to biochar, a material that aligns with the **Capstone** design requirements of sustainability, scalability, and pollutant reduction efficiency.

We came up with a simple, effective system using agricultural waste that undergoes process to form biochar. Its tiny pores **trap** and **collect** harmful pollutants like **VOCs**, followed by other harmful compounds like ammonia, sulfur dioxide, and more. Air flows through a **one-way valve** into layers of **biochar sheets**, and **cleaner air** comes out the other side after being filtered by the biochar's surface area.

Our system utilizes agricultural waste through thermal decomposition, producing biochar with a porous structure that captures pollutants like alcohol and toluene. This system not only filter **600 ml** polluted air in the **10 min** requirement — but far exceeding the **20%** target—also reuses the biochar as a soil enhancer, creating a circular, eco-friendly process.

Materials

Picture	Name	Price	Picture	Name	Price
	Agricultural Waste	10 L.E		Breadboard	40 L.E
	Jars	80 L.E		Plastic Tube	10 L.E
	Arduino Uno	400 L.E		Gauze	25 L.E
	Sensor MQ-135	230 L.E		Jumper Wire	10 L.E
	Air Tube and Elbows	30 L.E		LCD Display 16*2 and I2C	125 L.E
	Silicon and glue	80 L.E	Total Cost		1040 L.E

Table 1: table of materials

Methods & Test Plan

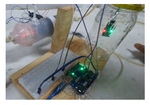
Methods

After conducting a significant amount of data collection, it was observed that safety tools are crucial. To ensure everything goes smoothly, certain **specialized** steps must be followed while building the **Prototype**. The team should adhere to the following steps:

- **Obtain** biochar which is a porous material which has high ability of adsorption of greenhouse gases and volatile organic compounds (VOCs).
- **Insert 67** gram of biochar in a tube in between sheet cloth to increase the efficiency of our system
- **Connect** one terminal of the tube containing biochar with a **600** ml jar using a **15** cm valve as shown in **fig(1)**
- **Insert** an MQ-135 sensor in the jar which to calculate the amount of VOCs in ppm initially before filtration as shown **fig(2)** and then another one after air purification
- **Connect** the jumper extended from each sensor to the test board.
- **Use** an Arduino Uno kit to connect the hardware (prototype) with the software (sensors' code) as shown in **fig(3)**
- **Finally** put a source of VOCs like ethyl alcohol and run the code. as shown in **fig(4)**

fig(1) prototype setup

fig(2) prototype setup



fig(3) arduino connection

fig(4) sensor's code lines

Test Plan

After constructing our prototype, we headed to conduct our test-plan in order to get results and determine how successfully our project purify **VOCs** from polluted air, while considering the safety precautions of wearing the overall, gloves and masks to avoid any injury.

We have inserted the **MQ-135** sensor in a **600** ml jar and put **10** ml of ethyl alcohol as a source of VOCs (volatile organic compounds). In addition, we have used a pump to force air to flow though our purification unit which consists of biochar between sheet cloth then we connected the **sensor's code** with our project using Arduino Uno kit.
as shown in figure(5)

Failed test plan:

- Our test-plan initially failed, we found that results are inaccurate and didn't make sense and we have found that this issue occurred because the sensor should be calibrated before using it for measurement. so that we have exposed the sensor to pure air for about 24 hours. In addition, we have found that oven in our school's lab can only reach **250** Celsius and the biochar resulted from this relatively low temperature oven was not efficient as it removes only **5%** of the pollutants in 10 minutes. So, we take into consideration to deal with these issues in the second test-plan.

Successful test-plan:

- We have gone to a factory where we found an oven that it temperature can reach **800** Celsius and the resulted biochar successfully met our design requirements. Also, we have calibrated the sensor by exposing it to pure air for **24** hours and then the results became accurate, and we have found that the amount of VOCs have been reduced by **90%** through 3 **minutes**.

Results

The test plan was done successfully, our project meets the design requirements. As a result of our combined efforts we have succeeded to measure the amount of **Acetone**, **Alcohol** and **Toluene** before and after purification as well as the total amount of **VOCs** before and after purification. The sensors detected that the total amount of VOCs was **2338.99** (± 140)ppm before purification and **79.44** ppm after purification so that amount of air purified was **2259.02** (± 145.1)ppm. The amount of VOCs have been reduced by average **92%** through 3 minutes. the error of the sensor after calibrating is (2%-8%) we scaled by **6%** to be between (2%-8%) after following calibration steps. these result are shown precisely in Table (2) & Table (3)

	Before purification	After purification	Percentage of purification
First minute	2338.46 ppm (± 140.3)	79.44 ppm (± 4.8)	96.6% (± 1.2)
Second minute	820.58 ppm (± 49.2)	88.21 ppm (± 5.3)	89.25% (± 1.1)
Third minute	549.81 ppm (± 32.9)	51.43 ppm (± 3.1)	90.6% (± 1.09)

Table 2: Pollutant concentrations (ppm) and purification percentages over total time.

	Average Alcohol	Average Toluene	Average Acetone	Sum
Before Purification	1033.39 ppm (± 62.1)	758.08 ppm (± 45.5)	546.99 ppm (± 32.7)	2338.46 ppm (± 140.3)
After Purification	39.78 ppm (± 2.4)	22.29 ppm (± 1.52)	17.37 ppm (± 1.02)	79.44 ppm (± 4.8)
Purified	996.61 ppm (± 64.5)	735.79 ppm (± 46.8)	529.61 ppm (± 35.7)	2259.02 ppm (± 145.1)

Table 3: average alcohol, toluene, and acetone levels (ppm) before and after purification over first minute

Analysis

Connecting the Problem to Egypt's Grand Challenges

Air pollution is a major issue that faced Egypt, which reached it's peak after the industrial resolution, as it affects public health, agriculture, urban infrastructure and more. By targeting VOCs (volatile organic compounds), which are known to cause respiratory illnesses and environmental degradation. Our project aligns with several of Egypt's Grand Challenges to pose as its main requirement to solve in the first place:

- **Improving Public Health:** Cleaner air reduces the incidence of respiratory and cardiovascular diseases, lowering risks of getting infected by (Asthma, COPD, Leukemia and etc.…)

- **Promoting Recycling and Sustainability:** The use of agricultural waste from houses, restaurants and farms. And then categorized into similar groups as group for Rice Husk, Bambo, Sugarcane peel, etc... . Then to continue the process to transforming it to Biochar by thermal decomposition.

- **Reducing Air Pollution:** Biochar filtration system directly addresses air pollution by absorbing VOCs between its molecules as the major target pollutant and other like Sulfur Dioxide, Carbon Dioxide and other more

Scientific Basis for the Solution

Biochar is a carbon-rich material derived from biomass and modified through treatments (e.g., sulfur or potassium) to enhance its properties. Its functionality depends on its surface chemistry, which is revealed by FTIR spectroscopy. Let's explore the process:

How FTIR Works

FTIR is like a "molecular fingerprinting tool" that helps us understand the chemical structure of a material, such as biochar, by identifying the bonds and functional groups present. It uses infrared (IR) light to make the molecules in the sample vibrate and measures the energy absorbed by different bonds (Graph 1&2).

Graph 1: FTIR spectra of RSC samples (RSCS and RSCK).

Graph 2: FTIR spectra of WSC samples (WSCS and WSCK).

Wavenumber (X-axis):

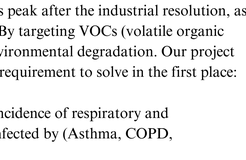
- **What It Represents:** The energy of absorbed light, with higher wavenumbers indicating stronger vibrations.
- **Why It Matters:** Specific bonds absorb IR light at unique wavenumbers, identifying biochar's functional groups.

Intensity (Y-axis):

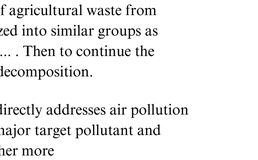
- **What It Represents:** The IR light absorbed by a bond, indicating its abundance.
- **Why It Matters:** Higher intensity shows more of a functional group in the biochar.

Selection of RSCS

Made from rice **husks** using **thermal** processes to optimize **carbon** and **functional** groups. as shown in Graph (3) **RSCS** biochar was selected for its superior adsorption capacity as Rice husks contain cellulose, hemicellulose and lignin, so they are potentially processed as liquids volatile matter', higher functional group activity (e.g., **-OH**, **-COOH**), and optimal surface area, as shown by wave number analysis. It achieved the best **VOCs** reduction (**20-30%** better than **RSC** and **RSCK as shown in Graph (4)**) and proved more durable and sustainable, aligning perfectly with project goals.



Graph 3: Biochar production techniques



Graph 4: Biochar absorption capacity

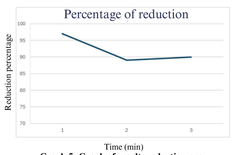
Analyzing Result

We used two **MQ-135** sensors to measure the results for **3 minutes** and employed (**Equation 1)** to compute the overall purification efficiency, expressed as the total percentage achieved.

By calculating the average VOC reduction achieved across the tests (96.6% + 89.2% + 90.6%) ÷ 3 = 92.15 (±3.39)% we can confirm that the design requirements are not only met but significantly exceeded, far passing the target of 20% reduction(Graph 5)

$$\frac{Before\ Purification - After\ Purification}{Before\ Purification} \times 100$$

Equation 1 : Equation of calculation percentage of reduction



Graph 5: Graph of results reduction over the 3 minutes

Learning Transfer

Cs.1.02	We have studied the algorithms and logical thinking which benefits us writing the Arduino code
En.2.01	we have studied the sources of air pollution and ways of air purification
Ch.1.09	we have studied the types of chemical reaction in our project as we used thermal decomposition in order to get the biochar
Ch.2.01	We studied concentrations that we used to determine the amount of VOCs by the sensor after calibration
Ph.2.03	We applied Ohm's Law to interpret the sensor's resistance and convert it to ppm concentration, using the sensor's R_0 for calibration.

Table 3: table of learning outcome

Conclusion

Biochar made from rapeseed cake (RSC) treated with steam or KOH is more efficient than non-activated biochar to absorb VOCs. Additionally, the biochar activated with H2SO4 has higher adsorption capacity than the biochar activated with KOH due to their larger pore volume and surface area. Our prototype achieved 92.15% VOC purification in 3 minutes, confirming activated biochar's superior efficiency. These results meet with our research findings and highlight the significance of activated biochar of removal VOCs. Additionally, it is more effective compared to other VOC reduction like activated carbon or materials like metal-organic frameworks (MOFs).

The activated biochar has the potential to be an efficient material for air purification filters that can capture and remove VOCs with low production cost, good stability and performance. By that, our capstone project has contributed to the Egypt grand challenges especially the air pollution.

Recommendation

After building, constricting the prototype and searching to solve Egypt's grand challenge we recommend to anyone who will do the prototype in real life to do the following:

- **Train** a machine learning model to predict the amount pollution in future
- **Use** a ccs811 sensor that can detect all the (TVOCs). Additionally CCS811 sensor is a digital sensor unlike MQ135, so it is more accurate.
- **Heat** the biochar at a specific temperature from **600** to **900 Celsius** to remove organic pollutants and restore its adsorption capacity.

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