GROUP 10213

AEROPURE TIRES

Anas Mamdouh
Ibrahim Walid
Mohamed Ibrahim
Mohamed Hassan

STEM High School for Boys
6th of October
Grade 11
Semester 1 (2024-2025)

Keywords: Waste tires - Activated carbon - Air pollution - Nitrous oxides - Pyrolysis

ABSTRACT

Egypt's progress is delayed by several grand challenges. This project addresses recycling garbage and waste for economic and environmental purposes; addressing and reducing pollution fouling our air, water, and soil; reducing and adapting to the effect of climate change; working to eradicate public health issues and diseases; and dealing with population growth and its consequences. The purpose of the study is to utilize waste tires to produce activated carbon to remove air pollutants. The specific problem to be solved is reducing nitrogen dioxide emissions from the overuse of fertilizers in Al-Mena Safour. An air filter was constructed using recycled, cost-effective, and locally sourced materials. The prototype underwent specific tests to ensure it effectively fulfilled the design requirements, most importantly, decreasing the nitrogen dioxide in the air sample by 20% within at most 10 minutes. Some negative results were present but overcome through modifications. Major findings, after gathering the results, included the prototype's ability to reduce the concentration of NO_2 by 80.81%. Major conclusions confirm the prototype's effectiveness for overcoming the problem to be solved. In addition, scaling the prototype could significantly contribute to solving Egypt's Grand Challenges.

INTRODUCTION

Egypt faces grand challenges which impede its development. Egypt's population has reached 106,962,706 as of 2024, with an estimated growth rate of 1.647%. The resulting food demand has led to increased agricultural production. To increase crop yield, farmers turn to using fertilizers. With as much as 58% of nitrogen escaping into the atmosphere, 330.41 kilograms per hectare of nitrogen oxide is used, **as shown in Figure 1**, equating to 960,020 tons of excess nitrous oxide in Egypt. Nitrous oxide has been shown to be 273 times better than carbon dioxide (CO_2) at trapping heat over a 100-year period (IPCC, AR6), equating to ~262 million tons of CO_2. Additionally, inhaling nitrous oxides can lead to impaired memory and vitamin B12 inactivation. Long-term exposure can lead to low blood pressure and possibly heart attack.

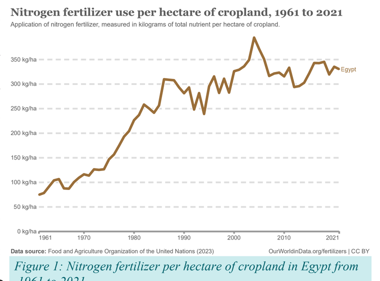


Figure 1: Nitrogen fertilizer per hectare of cropland in Egypt from 1961 to 2021.

Reducing the aforementioned negative effects defines the problem to be solved, mitigating nitrous oxide emissions from fertilizers in Al-Mena Safour. Currently, it contributes to the global problem of climate change and has severe effects on Al-Mena Safour's local population. If solved, it would lead to a positive feedback loop for soil quality and purer drinking water due to less contamination.

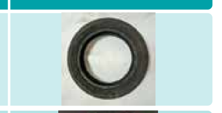
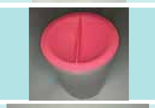
To broaden the perspective of the solution, prior solutions to similar problems were first reviewed. The most prominent of which, Electrostatic precipitator (EP) and Smog Free Tower (SFT), used renewable energy and allowed for pollutant selectivity respectively, both points of strength. In contrast, SFT had a limited coverage area, while the efficiency of EP decreased in the presence of high humidity.

After reviewing prior solutions, it was concluded that the chosen solution should meet a set of design requirements, where it must reduce the concentration of nitrous oxides by at least 20% in a period of 10 minutes whereas the volume of the air sample used should be at least 600 ml and up to 1500 ml.

The selected solution is to pyrolyze unneeded tires to make activated carbon, chosen for its simplicity, cost-effectiveness, replicability, and environmental sustainability. The materials **shown in Table 1** and the steps taken were chosen accordingly to meet the design requirements.

MATERIALS & METHODS

Table 1: The materials used to construct the prototype.

Item	Quantity	Description & Usage	Picture
Waste tire	1 tire	A waste tire was utilized as the source of carbon black, which was subsequently processed to produce activated carbon.	
Plastic jar	2 jars	Two plastic jars were used as containers: one for polluted air and the other for the filter.	
3-way stopcock	2 stopcocks	Two stopcocks served as valves to regulate the airflow within the system.	
Silicon tube	2 tubes	Silicon tubes were utilized to link the two containers.	
KOH	240 g	Potassium hydroxide (KOH) was utilized in the pretreatment process of the waste tires.	
Micro air pump	2 pumps	Two micro air pumps were utilized to facilitate airflow through the two containers.	
MQ135 sensor	1 sensor	An MQ135 sensor was employed to measure the concentration of nitrous oxide pollutants.	
HC-05 BT module	1 module	A Bluetooth module connected the sensor to a mobile application to collect measurements.	
Arduino UNO	1 board	An Arduino UNO was utilized as the central control unit for the system of sensors and pumps.	
Breadboard	1 board	A breadboard was employed to assemble the electric circuit.	

Methods

Waste Tire Treatment

1. Prior to treatment, the tire was shredded into small particles approximately 0.5±0.05 cm in size, **as shown in Figure 2**, rinsed with water to remove any residual dust or clay, and subsequently dried.
2. In chemical pretreatment, a solution of KOH was prepared by dissolving 240±0.005 g of KOH in 800±5 ml of water. 120±0.005 g of shredded tires was then stirred in this KOH solution, **as depicted in Figure 3**, at a temperature range from 80°C to 100°C for 3 hours at an impregnation ratio of 2:1 KOH to tires. The tire-KOH slurry was then dried.
3. The pre-treated tire shreds were pyrolyzed in an underground hole to yield the carbon **shown in Figure 4**. The process involved heating the sample to a temperature range of 100°C to 280°C for 1 hour, followed by cooling the resulting residue.
4. After cooling, the products were stirred in 250±5 ml of 0.5 N HCl at 85°C for 30 minutes, **shown in Figure 5**, followed by filtration. The sample was then leached with 250±5 ml of distilled water at 85°C, with repeated filtration until the pH exceeded 6. Finally, the leached sample was dried to give the final carbon products.


Figure 2: Tire shreds of size range from 0.5 cm to 1 cm.


Figure 3: The carbon product from the pyrolysis of waste tires.


Figure 4: The carbon product from the pyrolysis of waste tires.


Figure 5: The tire shreds while stirring in the KOH solution.

Prototype Construction

1. Initially, a 3D model of the prototype, **depicted in Figure 6**, was created to aid in the construction process.
2. Holes of diameter 0.25±0.05 cm were drilled into the plastic containers at air entry and exit points, with two holes per container. An additional hole was made in the polluted gas container to insert a stopcock to introduce the gas.
3. The two pumps were connected to the containers using silicone tubes, **as shown in Figure 7**, to facilitate gas circulation between the containers.
4. A circular steel mesh of 15±0.05 cm was secured in the filter with wax to support the activated carbon layer and the sensor was installed in the gas container to measure the concentration of pollutants.
5. To filter particulate matter, two layers of the middle layer of a face mask, with pores measuring 0.5 micrometers in diameter, were utilized.

Air Quality Control System

1. The MQ-135 gas sensor, two micro air pumps, and an HC-05 Bluetooth module were integrated with an Arduino UNO board. The sensor was coded to measure the concentration of pollutants while the pumps were used to control the airflow and circulation through the filter.
2. An Android application, connected to the Arduino using the Bluetooth module, was developed using Android Studio and Kotlin to control the system and monitor the sensor readings.

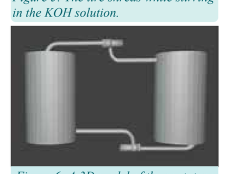


Figure 6: A 3D model of the prototype.


Figure 7: The two air pumps connected to the containers through silicon tubes.

Test Plan

A comprehensive set of criteria was established to ensure the feasibility of the prototype to meet the design requirement, reducing nitrous oxides concentration by at least 20%, facilitating enhancements in areas identified as potential weaknesses.

1. Nitrogen dioxide gas was produced through the redox reaction of nitric acid with copper **as shown in Figure 8**. This reaction yielded aqueous copper nitrate, nitrogen dioxide gas, and water, as represented by the chemical equation:

$$Cu_{(s)} + 4HNO_{3(aq)} \rightarrow Cu(NO_3)_{2(aq)} + 2NO_{2(g)} + 2H_2O_{(l)}$$

The resulting gas was captured and inserted into the contaminated-air container. The prototype was then operated for 8 minutes, **as shown in Figure 9**. The initial and final concentrations of nitrous oxide, denoted as C_i and C_f respectively, were recorded. The percentage reduction of the nitrogen dioxide was calculated using the formula:

$$\frac{C_i - C_f}{C_f} \times 100\%$$


Figure 8: The reaction of nitric acid with copper.

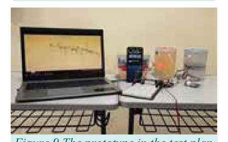


Figure 9: The prototype in the test plan.

RESULTS

Negative Results

The containers used in the prototype were initially not perfectly sealed, resulting in gas leakage. To address this issue, Teflon (polytetrafluoroethylene) was applied to seal the containers effectively, preventing any further leaks. In initial trials, the MQ-135 showed illogical concentration readings due to missing calibration.

Positive Results

Following an 8-minute operation of the prototype, the initial concentration C_i was determined to be 256.72 parts per billion (ppb), while the final concentration C_f was calculated to be 49.252 ppb. **Figure 10** illustrates the NO_2 concentration, measured at 5-second intervals, whereas **Table 2** shows the readings of the sensor every minute. According to the formula specified in the test plan, the percentage of pollutants removed was calculated to be 80.81%.

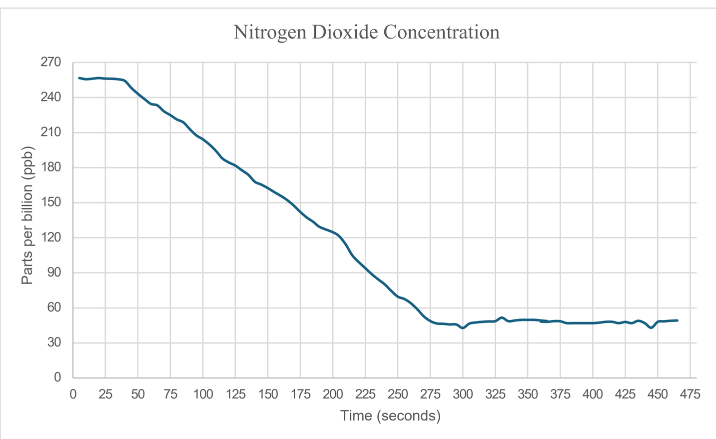


Figure 10: Nitrogen dioxide concentration VS time graph

Table 2: Sensor readings every minute in the test plan.

Time (min)	Parts per billion
0	256.716
1	234.613
2	184.514
3	137.367
4	80.124
5	47.569
6	49.260
7	47.009
8	49.252

ANALYSIS

Material Sciences & Environmental Impact

Table 3: Composition of tires according to type.

Material	Car/passenger	Truck
Rubber/elastomer	41-48	41-45
Carbon Black	22-28	20-28
Metal/steel	13-16	20-27
Textile	4-6	0-10
Additives	10-12	7-10

Tires represent a major source of pollution worldwide. Around 11% of old tires are thrown in landfills, making good homes for pests such as rodents. They are also commonly used by mosquitoes as breeding grounds due to their heat insulation, which can increase the spread of diseases like malaria. Additionally, sometimes, fires can result.

Pyrolyzing tires, instead of natural decomposition which lasts many years, helps reduce the pollution effect while producing valuable products. Pyrolysis produces pyrolytic oil, used as a fuel or as a feedstock for making chemicals, synthetic gas, primarily hydrogen, and carbon monoxide, which can be used as an industrial fuel, and carbon black or char (Smith & Jones, 2022). Moreover, tires have on average a composition favoring carbon black, **as shown in Table 3**. Thus, they were chosen as the carbon precursor for activated carbon production. Activated carbon is an adsorbent material able to remove several types of air pollutants, facilitating in achieving the design requirements.

Adsorption

Adsorption refers to the attraction of molecules, atoms, or ions, called absorbates, to the surface of another substance, called absorbent (Aljamali et al., 2021). To achieve optimal results, the filtration material was chosen with adsorption properties rather than absorption. In the case of NOx, adsorption, compared to absorption, produces no liquid waste, has higher purification efficiency, and requires only simple equipment. While it does require large initial investment in comparison to absorption, this isn't a problem for the proposed solution (Zhu & Xu, 2022).

The prototype utilizes physisorption specifically to trap pollutants. Physisorption is caused by the one-sidedness of the Van der Waal forces acting between the outermost and second layer of absorbent materials, which results in an attraction force to the absorbent.

Activation of Carbon

The activated carbon was acquired from wasted tires using chemical methods. Alkaline hydroxides were chosen mainly due to their low ash content and high adsorption capacity (Linares-Solano et al., 2012, p.63). KOH was chosen as an activating agent as it can lead to activated carbon with high microporosity (Heidarinejad, Dehghani, Heidari, & et al., 2020, p.11), and thus surface areas up to $4000\frac{m^2}{g}$ (Gao et al., 2020, p.34). Additionally, it is less corrosive and environmentally threatening than alternatives, and thus safer for use in the prototype (Heidarinejad, Dehghani, Heidari, & et al., 2020, p.11).

Wet methods were used to mix the KOH with tires. The optimal ratio of KOH to water to form the activating solution was found to be 30 : 200 w/w respectively from older papers (Özbaş, Balçık, & Özcan, 2019, p.79). Previous papers have stated that the mixing of carbon precursors in activating agents increased surface area, total pore volume, and mesopore volume until the 5th hour (Gao et al., 2020, p.21). Due to lab regulations, the process was forced to stop in the 3rd hour.

Sensor Calibration

As studied in CH.2.01, the parts per million/billion property of a solute in a solution is used to describe the concentration of substances normally present in trace amounts. There are many different types of parts per billion, including volume-to-volume, mass-to-volume, and mass-to-mass. Volume-to-volume was chosen due to its ease of calculability.

To get accurate NO_2 ppb readings from the MQ-135 sensor, it first had to be calibrated. The calibration graph in the official datasheet of the sensor contains functions relating pollutant ppm to a resistance ratio to ease calibration for most gasses, excluding NOx. Thus, to calibrate the sensor, a function had to be first derived.

First, the sensor resistance is measured using the following equation (Kinnera, Subbareddy, & Luhach, 2019):

$$R_S = \frac{5 * R_l}{V_{rl}} - R_l = \frac{5 * 20}{V_{rl}} - 20$$

Where is the resistance load, which ived from the datasheet). To calibrate, in n o r m a l R_l atmospheric air, known as , was measured 100 times and averaged, equating to 581.76471. R_s

Secondly, 3 samples of known R_0 NO_2 ppb were prepared and diluted to different ppbs using the redox reaction of copper with nitric acid, shown in the following equation:

Then, for each of the $Cu_{(s)} + 4HNO_{3(aq)} \rightarrow Cu(NO_3)_{2(aq)} + 2NO_{2(gas)} + 2H_2O_{(l)}$ raged to obtain 3 values, which turned out to be = 618.2325, = 599.0540449, and = 592.1692452. Each sample resistance was R_s t h e n paired with its ppb in R_{s1} the form : R_{s2} R_{s3}

$(ppb, \frac{R_S}{R_0})$

The functions used to mo $(47085.89, 1.063)$, $(15317.27, 1.029)$, $(4984.87, 1.018)$ ithmic functions. Thus:

The slope of the conversion function o $\log(y) = m * log(x) + b$ using the following equation:

Where y₂, x₂, y₁, and x₁ $m = \frac{\log(y_2) - \log(y_1)}{\log(x_2) - \log(x_1)} = \frac{\log(1.029) - \log(1.063)}{\log(15317.27) - \log(47085.89)} = 0.0289$

Now, substituting in the function with the third pair to obtain b, or the y intercept:

$$\log(y) = 0.0289 * \log(x) + b,$$
$$b = \log(1.018) - 0.0289 * \log(4984.87) = -0.0992$$

Thus, the function is:

Where y is the ratio and x is the $\log(y) = 0.0289 * \log(x) - 0.0992$

HEPA Filter $\frac{R_s}{R_0}$

As studied in ES2.04, Sieves are used as semi-permeable membranes to clear large flowing particles. Thus, in the same way, High-Efficiency Particle Arresting filters, known as HEPA filters, were used to capture relatively large airborne particles. HEPA filters can capture at least 99.97% of airborne particles as small as 0.3 microns (μm). Incorporating HEPA filters in air filtration systems can reduce respiratory-related diseases by up to 20% in urban environments, particularly where PM2.5 levels are high (Zhao et al. 2015).

In this project, surgical face masks were used to include the activated carbon inside. The typical face mask can capture in the range of 300 nm to 5 μm in size (Walawalkar et al., 2021) Particularly, the third layer of the mask was used as it contains pores of 0.5 μm. On one hand, this ensures the carbon particles are held without penetrating the mask. On the other hand, it increases the lifetime of the carbon as it prevents large particles, like dust, from mixing with the carbon, which can decrease the area susceptible to physisorption. Estimates vary, but the use of a HEPA filter can approximately double the effective lifespan of an activated carbon filter, depending on the specific environmental conditions and pollutant load.

L.O.	Description & Usage	L.O.	Description & Usage
CH 1.01	CH 1.01 explains parts per million (PPM), which was crucial in understanding the pollutant concentration. It also helped in measuring the efficiency of the prototype.	ES 2.04	ES 2.04 explains how water is treated. The process is similar to that of air, thus it inspired the idea of making a HEPA filter using recycled materials to capture large particles.
ENW.2.1.2	ENW.2.1.2 explains how to write process analysis essays. This type of essay was used extensively throughout the analysis.	CH 2.05	CH 2.05 explains activation energy and catalysts. It helped in deciding between focusing on physisorption and chemisorption, and also in the choosing of activated carbon due to it acting like a reactive surface.
CH 1.03	CH 1.03 explains the PH scale, acids, bases, and salts. Acids and bases like HCL and KOH were used throughout the prototype, thus it was essential as it gives the necessary preliminary information.		

CONCLUSIONS

The selected problem to be solved through this project was the reduction of nitrous oxide (NOx) emissions caused by the overuse of fertilizers in agriculture. Activated carbon, known for its high efficiency in adsorbing air pollutants, was chosen to be the solution. Waste tires were used as the raw material to produce the activated carbon, undergoing pretreatment using potassium hydroxide (KOH), followed by pyrolysis, thermal decomposition under high temperature, and finally activation process, also using KOH. Despite some negative results, the prototype, successfully, has proven to meet all the design requirements, achieving a reduction of 80.81% in NO_2 concentration within 8 minutes. Compared to previous solutions, like Smog Free Tower, this project uses easily accessible recycled materials and is eco-friendly and more cost-effective. By combining the strengths of earlier methods while addressing their limitations, this project delivers a practical and sustainable alternative for reducing NOx emissions, offering significant potential for environmental improvement.

RECOMMENDATION

Real-life Application

The recommended location for implementing the project is Al-Mena Safour, **shown in Figure 11**. Al-Mena Safour, situated in Sharqia, is a rural area where agriculture predominates and serves as the primary source of livelihood for the residents. The extensive use of nitrogenous fertilizers to achieve high crop yields has significantly contributed to nitrous oxide emissions in the region, necessitating immediate attention. The real-life project will replicate the prototype's filter, designed for household use to reduce pollutant concentrations. The activated carbon layer should be integrated into a porous material, allowing for easy replacement when necessary.


Figure 11: Location of Al-Mena Safour..

Chemical-Thermal Reactivation of Spent Activated Carbon (SAC)

Reactivation, or regeneration, involves removing impurities adsorbed on the surface of spent activated carbon (SAC) while preserving its porous structure. This process allows AC to be reused across multiple cycles, reducing the need for new AC production and minimizing waste generation. Among the various reactivation methods, past studies have concluded that combining acid-washing (chemical) with thermal reactivation of SAC is essential for achieving a higher reactivation degree (Toledo et al., 2020). While acid-washing removes impurities through dissolving, thermal reactivation eliminates organic waste by thermal decomposition. According to the study, the optimal experimental conditions for reactivating SAC were achieved through acid washing with HNO_3 at 20% v/v at 50°C for 30 minutes, followed by thermal reactivation at 850°C for 1 hour.

Microwave Pyrolysis

Microwave pyrolysis, first introduced by Tech-En Ltd., involves mixing scrap tire crumbs with a microwave-absorbent material and heating it in a microwave bed, **as shown in Figure 12**. The material captures thermal energy, heating the waste tires to produce volatile material and char. The volatile material condenses into pyrolytic oil, while the char remains, ideal for activated carbon production. A key advantage is its efficiency in producing solid char, though scaling up remains a challenge. Experiments show the yield of pyrolysis oil and char ranges between 30-44% and 40-65% by weight, respectively. This process produces the highest percentage of solid char, optimal for activated carbon production (Liang et al., 2023).

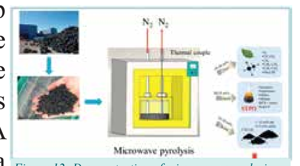


Figure 12: Demonstration of microwave pyrolysis of waste tires.

LITERATURE CITED

1. Abd, A. A., Naji, S. Z., Hashim, A. S., & Othman, M. R. (2020). Carbon dioxide removal through physical adsorption using carbonaceous and non-carbonaceous adsorbents: A review. Journal of Environmental Chemical Engineering, 8(5), 104142. https://doi.org/10.1016/j.jece.2020.104142
2. Aljamali, N., Khdur, R., & Alfatlawi, I. (2021). Physical and chemical adsorption and its applications. International Journal of Theoretical and Computa-tional Chemistry, 7(12), 1–8. https://doi.org/10.37628/IJTCK
3. Linares-Solano, Angel & Lillo-Ródenas, Maria & Marco-Lozar, Juan & Kunowsky, Mirko & Romero-Anaya, Aroldo. (2012). NaOH and KOH for preparing activated carbons used in energy and environmental applica-tions. International Journal of Energy, Environment and Econom-ics. 20. 59-91.
4. Senin, M. S., Shahidan, S., Leman, A. S., & Hannan, N. I. R. R. (2016). Analysis of physical properties and mineralogical of pyrolysis tires rubber ash com-pared natural sand in concrete material. IOP Conference Series: Materials Science and Engineering, 160(1), 012053. https://doi.org/10.1088/1757-899X/160/1/012053
5. Y. Gao, Q. Yue, B. Gao, et al., Insight into activated carbon from different kinds of chemical activating agents: A review, Science of the Total Environment (2020), https://doi.org/10.1016/j.scitotenv.2020.141094
6. Zhu, Z., & Xu, B. (2022). Purification Technologies for NOx Removal from Flue Gas: A Review. Separations, 9(10), 307. https://doi.org/10.3390/separations9100307

ACKNOWLEDGEMENTS

We want to start by expressing our gratitude to Allah for enabling us to complete this productive project. Secondly, we would like to express our gratitude to everyone who helped us along the way, particularly the capstone general Mr. Mohamed Bakheet, our capstone leader Miss. Ninette Refaat, our capstone teacher Miss. Mona Abdo, as well as everyone else who contributed to making this project successful. We could not have achieved these successes without all the help we received.