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ORIGINAL RESEARCH ARTICLE

PRODUCTION OF ACTIVATED CARBON FROM PINEAPPLE CROWN WASTE FOR THE DEVELOPMENT OF A FUEL FILTER

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ABSTRACT

In this study, pineapple crown waste from pineapple farms is used to produce activated carbon, and the resulting product is applied in a fuel filtration system to overcome the problems of agricultural waste disposal and the lack of affordable means to purify fuels. Pyrolysis and chemical activation with potassium hydroxide (KOH) were used to produce activated carbon, and characterization of the material using BET surface area analysis (335.379 m²/g), SEM images, and adsorption tests was successfully conducted. It was found that when 400g of dried pineapple crown was used, 70g of activated carbon was synthesized and tested to improve fuel clarity and contaminant removal. The fuel filter developed has been found to have up to 75% efficiency in filtering up to 10 µm dirt. These fuel filters with activated carbon may be used for a variety of fuels, including diesel, kerosene, petrol and biofuels. The findings support the use of pineapple crown as a sustainable and economical source to produce activated carbon for use in fuel filtration systems, in line with the Waste to Wealth concept and promote environmental sustainability and resource recovery. Future studies should consider testing for the percentage removal of specific contaminants, such as a count of the particulates or dye concentration reading by spectrophotometric analysis.

1.0 Introduction

Waste management is a major global challenge, particularly in developing countries like Nigeria, where improper disposal of agricultural waste contributes to environmental degradation, pollution, and greenhouse gas emissions (Salve & Ray, 2020). The agricultural sector, which accounts for approximately 22.35% of Nigeria's Gross Domestic Product (GDP), generates large volumes of waste from crop residues, fruit processing, and other agro-industrial activities (Food and Agriculture Organization of the United Nations, 2021). One such waste material is pineapple crown, which is often discarded or burned in open fields, leading to harmful consequences such as air pollution and water contamination (Salve & Ray, 2025).

However, such waste material could be used for activated carbon production. Activated carbon is commonly used today in various materials research. Activated carbon is a porous material widely used in water purification, air filtration, gas adsorption, and fuel treatment due to its excellent adsorption properties (Mistar *et al*., 2020). A study by Shah *et al.* (2023) reviewed the impact of waste-based activated carbon and discovered that using waste precursors significantly decreases energy and resource use compared to traditional sources.

It is noteworthy that activated carbon plays a critical role in fuel treatment by removing nitrogen- and sulphur-based impurities, colour bodies and other contaminants that could reduce the efficiency of the fuel (Danyuo *et al*. 2023). Conventionally, activated carbon is produced from non-renewable res such as coal, wood, and peat through energy-intensive processes that further contribute to environmental issues of concern. Reliance on these precursors not only depletes natural resources but also raises production costs (Danyuo *et al*., 2023).

To address these challenges, researchers have explored agricultural-waste-derived activated carbon as an alternative to conventional sources. Saleem *et al*., (2024) and Jiawen (2025) explored the potential of coconut shells, rice husks, palm-kernel shells, and fruit peels to serve as effective precursors for producing high-performance activated carbon. The potential of using agricultural wastes in activated carbon production is demonstrated by the conversion of rice straw to activated carbon by pyrolysis and the KOH activation process (Wu *et al*., 2020).

However, pineapple crowns, which are the green leafy tops of the pineapple fruit, are usually discarded as waste after harvesting, which remains an underutilized feedstock to produce activated carbon despite their abundance, high lignocellulose content and porous potential (Abdulrahim *et al*., 2023). Tsai *et al*. (2022) found that pineapple production in the world was about 28 million tons in 2020, with a good amount of the waste products being discarded, highlighting the issues for the environment. Converting this waste into activated carbon aligns with the waste-to-wealth concept, a sustainability-driven approach that transforms waste materials into valuable products, promoting both economic and environmental benefits (Tsai *et al*., 2022). Mahmuda *et al*. (2021) prepared activated carbon from the peel of pineapple crown is used for methylene blue adsorption. This directly supports the use of pineapple waste for activated carbon production used in pollution removal as reported by d'Oliveira *et al*. (2024).

The use of agricultural waste such as pineapple crowns to produce activated carbon for use in fuel filters presents a cost-effective solution for producing activated carbon compared to traditional methods was also reported by Danyuo *et al*., (2023). The environmental concerns of agricultural-waste disposal and the high cost of conventional activated carbon necessitate sustainable alternatives. This study investigates the application of pineapple crown waste as a renewable precursor to produce activated carbon to be used in a fuel filter. In the study, Niamu *al*., (2022) developed activated carbon from rice husk and potato peel using an H_3PO_4 activation process at varying impregnation ratios and carbonisation temperatures. The prepared carbons had high development of mesoporous structures and functional groups, with the carbon derived from rice husks having the best adsorption properties. The results show that the choice of biomass precursors and activation conditions is important to produce activated carbon with desirable functional properties. The efficacy of the activated carbon is, however, dependent on the precursor, and so other potentially abundant and underutilised agricultural residues must be investigated. The waste from pineapple crown is thus a potential alternative precursor for value-added production of activated carbon and activated carbon filters due to its lignocellulosic nature and carbonisation capacity, which is normally discarded. This study thus seeks to produce and characterize KOH-Activated Carbon from Pineapple Crown Waste and to assess its suitability as a sustainable fuel treatment medium.

2. Materials and Method

2.1 Raw Material Collection and Pre-treatment

The raw material used in this study (pineapple crown waste) was obtained from local fruit vendors who usually discard the crowns during the processing and sale of pineapples. The species of pineapple particularly used for this process was the cayenne variety, which is widely sold in the north-central part of Nigeria and recognized for its structural robustness. Crown wastes are typically disposed of as solid wastes and are a readily available, low-cost biomass material that can be used to produce activated carbon.

The pineapple crowns then underwent different pre-treatment processes before carbonizing and activation. The initial step was to thoroughly wash the crowns with clean tap water to remove any surface contaminants such as dust, soil particles or other debris from the plant shoots. The materials were washed and then dried in the air naturally for several days. The samples were then oven-dried at a controlled temperature of 105°C to remove the moisture from the samples after drying (Wang & Xu, 2024). After satisfactory drying, the pineapple crowns were manually chopped into small pieces to aid in handling and even heat distribution during thermal treatment. The finely chopped material was ground and processed into coarse material with a grinding machine to increase the surface area and to improve the efficiency of the subsequent carbonization and activation process.

This pre-treatment process was necessary to guarantee that the raw material was clean, dry and had a uniform particle size that helped to deliver the quality of the final activated carbon. The process of pre-treatment of pineapple crowns before carbonization can be seen in Plate 1. Plate 1a shows the collected pineapple crown waste, followed by the image of the washing a- Pineapple crowns, b- Washing process, c- Cut Pineapple Crown d- Dried Pineapple Crown e- Ground Pineapple Crown process of the pineapple crowns. The crowns

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were then cut into smaller pieces (Plate 1c) to achieve more effective air drying, followed by oven drying at a controlled temperature of about 105^{0}C to ensure removal of residual moisture. Plate 1d shows the fully dried pineapple crown and finally, Figure 3e shows the ground pineapple crown, which was in powdered form.

Plate 1: Pineapple Crown Pre-treatment before Carbonization

2.2 Carbonization Process

After the pre-treatment stage, the dried pineapple crown particles were carbonized to produce char (Wang & Xu, 2024). This was done using a muffle furnace, where the samples were placed in a covered ceramic crucible to reduce the amount of oxygen available and prevent burning. The furnace was set to a temperature of 400 °C, and the samples were heated for about 1 hour. This temperature and time were chosen to allow the material to break down thermally, reducing its moisture and volatile compounds, leaving behind mostly carbon. Once the time elapsed, the furnace was turned off and allowed to cool naturally before the samples were taken out. This method agrees with the work of Wang & Xu, (2024). Figure 2 shows the char obtained after carbonization which was black, lightweight, and more brittle than the original material. It was carefully stored in airtight containers to prevent moisture absorption or contamination before the activation process. This stage prepares the pineapple crown waste for activation, as it produces a high-carbon-content material, which will aid the development into activated carbon with good porosity and surface characteristics.

Plate 2: Carbonized Pineapple Crown Waste (Biochar)

2.3 Activation Process

The carbonized pineapple crown char was obtained by soaking about 100g of char in a 30% KOH solution at a 1:3 weight ratio. This mixture was left to soak for 24 hours at room temperature to ensure thorough impregnation of the activating agent into the char structure (Liu *et al.* 2024). After the soaking period, the impregnated sample was dried in an oven at 105 °C for 5 hours to remove moisture before activation. The dried material was then subjected to heat treatment in a muffle furnace at a temperature of 700 °C for 1.5 hours in limited air supply to avoid combustion (Oumabady *et al*., 2021). The reaction between the char and the KOH was promoted by this thermal treatment which made the char more porous and increased the internal surface area.

Upon completion of activation, the sample was cooled, and then a de-ashing process was performed. This included diluting the activated carbon in distilled water and repeating the filtration process until the carbon was free of any KOH and soluble inorganic by-products. The filtrate was washed until the pH was within a target range of 6 – 8 and the filtrate was clear. Finally, the activated carbon was dried once more at 105 °C, allowing all the moisture to be removed before storage. The final product was kept in an airtight container to prevent absorption of moisture and contamination before further characterization. (Zhengzhou, 2024). Tsai *et al.* (2019) noted that chemical activation using KOH produced a more potent activated carbon than that which was produced using physical activation.

2.4 Characterization Techniques

The last activated carbon product was characterized for its physicochemical characteristics:

BET Analysis: A BET analyzer (Brunauer-Emmett-Teller) was used to measure the specific surface area and pore size distribution by nitrogen gas adsorption at 77 K. The degassing temp/time is 300°C/3hl.

Surface morphology and microstructure of the activated carbon were observed by using scanning electron microscopy (Zeis Gemini SEM 300/360) (Kumar *et al*., 2025). 500× with a 10 μm scale bar and 1000× with a 2 μm scale bar. The pictures show the extent of porosity and the texture of the material.

Energy Dispersive Spectroscopy, (EDS Bruker X-Flash detector), spot analysis was performed in conjunction with SEM to determine the elemental composition of the activated carbon. This was used to confirm the high carbon content (Tomul *et al*., 2020) and identify any trace elements from the activating agent or raw biomass.

pH Measurement: The distilled water used for washing the activated carbon was tested for its final pH range (6-8) to confirm that all the activating agents were removed and the product is non-corrosive. Similarly, Cano *et al*. (2025) also conducted characterization tests on pineapple crown activated carbon using the methods mentioned above and revealed that the methods are standard to characterize different properties of activated carbon.

To manufacture and test fuel filter prototypes with support from the EPA. To produce and test fuel filter prototypes with EPA assistance. A prototype fuel filter was constructed to act as a filter for the activated carbon. The filter (Figure 6) was a simple filter housing with activated carbon produced in the filter. The test of the filter performance was done using methylene blue dye, small particles of dirt and water in a sample of fuel. A turbidity meter was used. This polluted fuel was then filtered, and the clarity of the filtered fuel was then compared to the original fuel sample. The efficiency of the filter (percentage of particle removal) was determined according to the relation of Cano *et al*., (2025):

$$efficiency\ \% = \frac{particles(in) - (particles\ (out)}{particles\ (in) \times 100} \quad 1$$

Flow rate measurement: The flow rate of the fuel passing through the filter was measured by timing the change in filter volume (10 cl or 0.1 L), and the pressure drop across the activated carbon bed was inferred from this flow rate. Figure 6. Fuel Filter Prototype Integrated with Activated Carbon.

2.5 Activated Carbon Yield Calculation

The common method of calculating activated carbon yield according to Oumabady *et al.* (2021) is by calculating the mass yield % using the relation yield %.

$$\text{yield } \% = \frac{mass\ of\ activated\ carbon}{mass\ of\ dry\ raw\ material} \times 100 \quad 2$$

3. Results and Discussion

3.1 Production Yields

The production process yielded 70 g of activated carbon from an initial 400 g of dried pineapple crowns, for an overall yield of 17.5%. The carbonization step yielded 217 g of char, corresponding to a char yield of 54.25%. These yields were compared with the yields obtained with other agricultural waste precursors and confirmed the efficiency of the production parameters selected. Mahmuda *et al*., (2021), Danyuo *et al*., (2014), and Saleem et al. (2019) reported similar yield results.

3.2 Activated Carbon Characterization

The activated carbon specific surface area measured was 335.379 m^2/g, which is like that obtained in another study done on peanut shells (Liu, Y. *et al.*, 2022). The surface area of 335.379 m2/g is within the range of 300-700 m2/g that is typical for activated carbon made for non-industrial uses. This outcome successfully revealed that the present study carbonization and activation process has successfully resulted in the production of carbon with high porous structure and surface area to absorb the material. The BET plot (Figure 1) is found to be highly correlated (0.997019), which shows that this measurement is reliable. The correlation coefficient shows the goodness of fit of the experimental adsorption data to the linear BET model. The strength of the correlation coefficient indicates that activation parameters have a significant influence on the development of pineapple crown activated carbon porosity. The adsorption isotherm (Figure 2) also characterizes the adsorption behaviour, while the Pore Size Distribution (DFT Method) plot (Figure 2) shows the size of the pores, and there are micropores and mesopores.

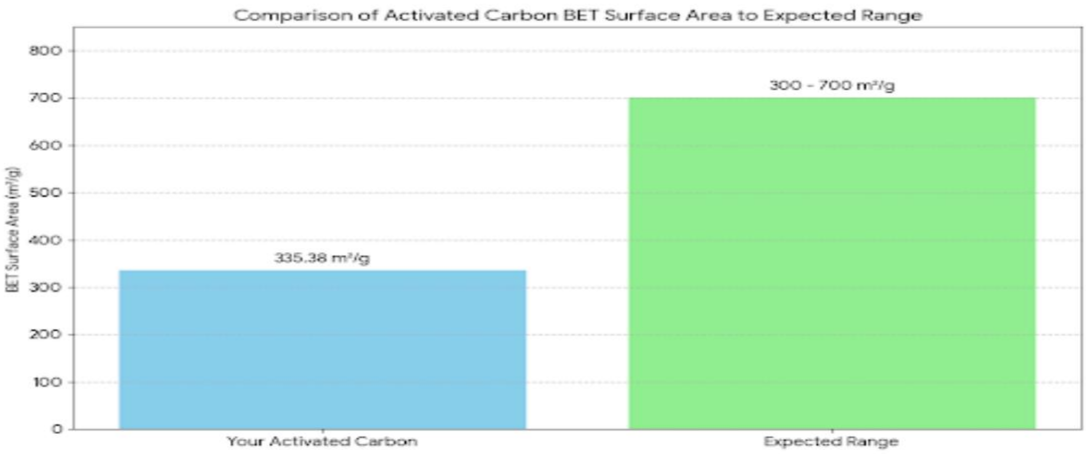


Figure 1: Comparison of Activated Carbon BET Surface Area to Expected Range

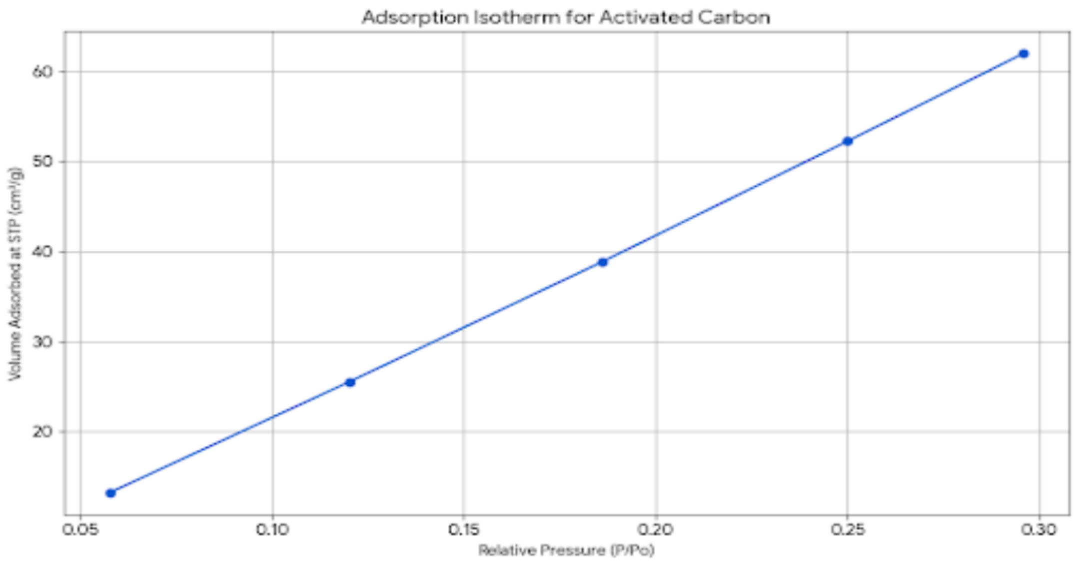


Figure 2: Adsorption Isotherm for Activated Carbon

3.3 Scanning Electron Microscope (SEM)

As can be seen, Figure 4 gives a visual understanding of the characteristics of the surface of our activated carbon. The SEM images of the activated carbon showed a very irregular surface morphology with pores. Moreover, it was confirmed visually that there are well-formed pores and a rough and complicated structure, which are characteristics of an effectively activated carbon material essential for use as an adsorption material.

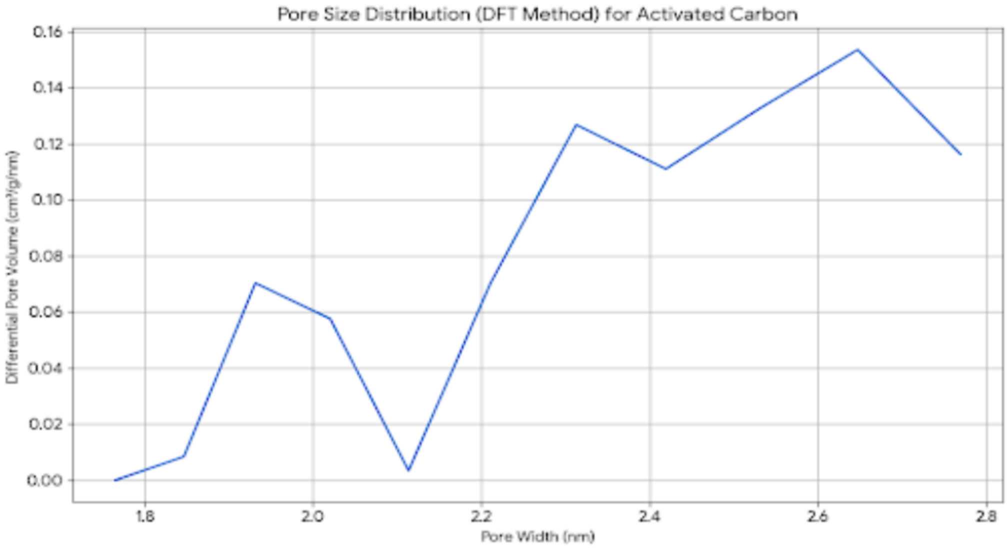
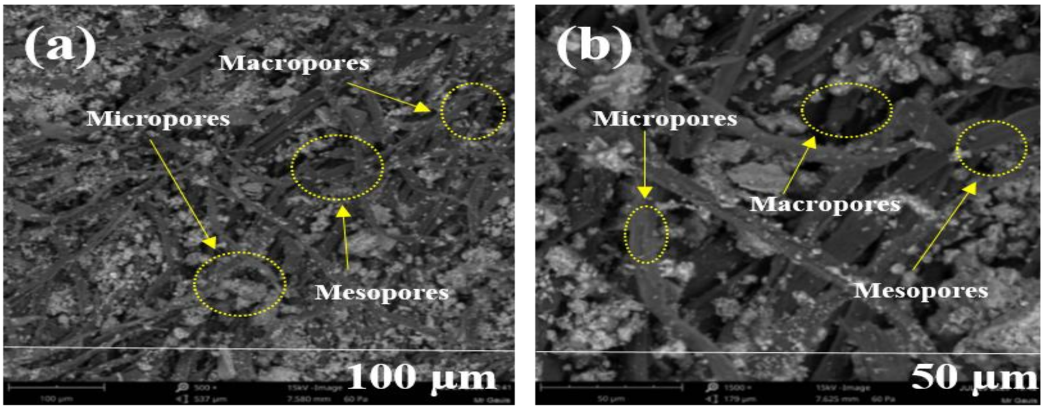
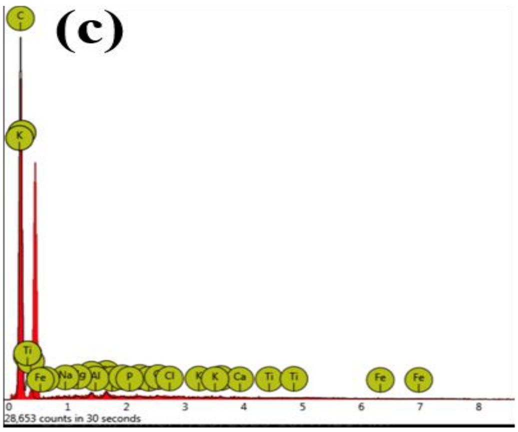


Figure 3: Pore Size Distribution (DFT Method) for Activated Carbon

In addition, elemental analysis using Energy Dispersive Spectroscopy (EDS) was carried out in conjunction with the SEM, which gave very important information about the chemical composition of the activated carbon produced. Analysis results revealed the presence of Carbon (C) as the major element (87.26 Weight%), which confirmed the successful carbonization and transformation of biomass to a carbon-rich material. Significant is Potassium (K) which was found at 9.29 Weight%. While extensive washing steps were taken to remove the KOH activating agent, the presence of residual K suggests that complete removal is challenging or that some K compounds are strongly embedded within the carbon matrix. Other minor elements, originating from the biomass itself, were detected in trace amounts, confirming the successful conversion of the pineapple crown.





(d)

Element	Concentration (wt%)
C	87.26
K	9.29
Si	0.77
Al	0.73
Cl	0.34
Mg	0.33
Ca	0.31
S	0.31
Na	0.30
P	0.26
N	0.10

Figure 4: Combined SEM Micrograph and EDS Analysis of Activated Carbon

3.4 Fuel Filter Performance

Plate 3 shows the produced fuel filter, which contains the activated carbon in a mesh housing.

Plate 3: Produced filter from activated carbon

The prototype filter's purification performance was very successful. The filtration efficiency achieved was 75% with the 10µm dirt. The visual purification test was conducted using Methylene Blue dye, and the outcome was a clear fuel product, which was like the results obtained in the tests of sorghum and coconut shell (Sorghum Study, 2019; Coconut Shell Study, 2024). The adsorption performance shows that pineapple crown activated carbon can be used for purification of liquid fuels such as petrol, diesel and kerosene to reduce the presence of impurities in the fuel that often leads to poor performance of the fuel engine. The flow rate was measured to be 0.286 L/min. Although this is not the optimum goal of 1 L/min, it does indicate that there is a significant pressure drop that can be made more optimal in future designs by either the filter housing or the size of the carbon granules.

The influence of the variable, Activation Time (min), on the variable, Surface Area (m 2/g) was examined using a linear regression analysis as shown in Figure 5.

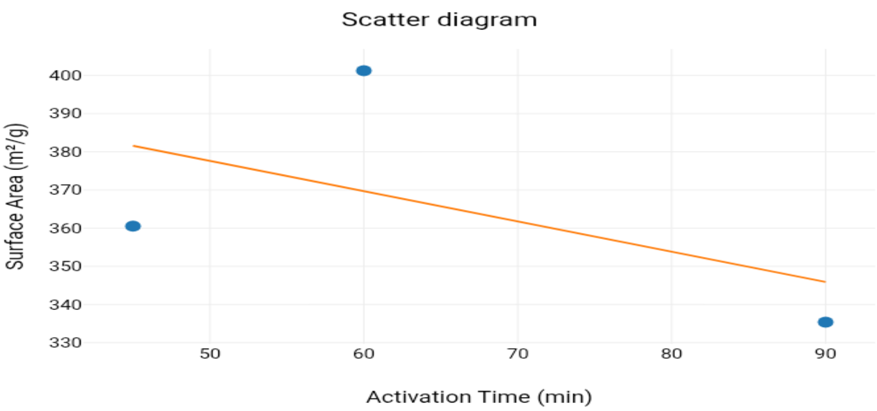


Figure 5: Regression Analysis Graph

The regression model showed that the variable Activation Time (min) explained 29.89% of the variance in the variable Surface Area (m^2/g). An ANOVA was used to test whether this value was significantly different from zero. Using the present sample, it was found that the effect was not significantly different from zero, p = 0.56.

The following regression model is obtained:

Surface Area (m^2/g) = 417.26 -0.79

When all independent variables are zero, the value of the variable Surface Area (m^2/g) is 417.26.

4. Conclusion

This study showed the possibility of pineapple crown waste as activated carbon to be used in fuel filtration using KOH activation. The overall yield of the production process was 70 g of activated carbon from the 400

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g of dried pineapple crown, which gave a BET surface area of 335.379 m2/g and a porous surface morphology of micropores and mesopores. The prototype filter, which was manufactured containing the activated carbon, showed up to 75 % filtration efficiency for 10 μm dirt and is found to be potentially a low-cost filter medium for contaminated fuel.

Overall, the results highlight the potential of pineapple crown waste as a valuable raw material for activated-carbon production, offering a sustainable solution to reduce waste and recover resources in the agricultural sector. The relatively low flow rate measured (≈ 0.286 L/min), however, suggests that the filter characteristics and pressure drop of the present prototype need to be optimized for practical deployment. Furthermore, the present investigation did not quantify the removal of individual fuel contaminants, so an additional set of experiments quantifying the removal of individual contaminants and conducting the appropriate chemical analyses would be required to determine fuel contaminant-specific removal efficiencies.

Results in general validate pineapple-crown-derived activated carbon as a viable option for sustainable fuel filtration that can be optimized for future conditions of activation and filter design to enhance the surface properties, filtration efficiency and flow performance. The prototype fuel-filtration system has been demonstrated in the present study, but more testing needs to be conducted under controlled conditions to test its suitability for diesel, kerosene, petrol or biofuel applications with other fuel types and quantitatively characterised contaminants.

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