__Original Research Article__

PREPARATION AND CHARACTERIZATION OF ACTIVATED CARBON FROM MELON SEED HUSK

ABSTRACT

Activated carbon, known for its remarkable adsorption properties, is widely used in various applications, including wastewater treatment, air purification, gas and vapour purification. This study explored the production and physicochemical characterization of activated carbon derived from melon seed husks, a readily available agricultural waste product in Nigeria. The process involved carbonization of the husks followed by impregnation with calcium chloride. Physicochemical analysis was performed on the resulting melon seed husk activated carbon (MHSAC) to assess its properties. The analysis revealed favourable characteristics with a pH level of 6.52, ash content of 5.13%, moisture content of 11.36%, density of 0.453g/ml, and an iodine number of 1759.18mg/g, meeting the criteria for an effective adsorbent. These findings demonstrate the potential of melon seed husk an agricultural byproduct, as a valuable source for generating high-quality activated carbon.

Key Words: Activated carbon, Melon seed husk, Carbonization, Physicochemical analysis, Calcium chloride, Characterization.

1. INTRODUCTION

Activated carbon also known asactivated charcoal is a highly porous and extensively processed form of carbon, characterized by its significantly large surface area, microcrystalline, non-graphitic, and amorphous structure, resulting in a network of interconnected pores [1, 2]. Carbons are either activated physically (pyrolysis) or chemically (use of reagent). Chemical activation process involves use of lower temperatures and shorter duration, it is therefore preferred over physical activation [3]. Generally, activated carbon exists mainly in two forms: powder and granules. Granular activated carbon (GAC) ranges from 0.2 to 5 mmand is applied in liquid and gas phase while powder activated carbon (PAC) comes in smaller sizes (less than 0.18 mm) and applied in the liquid phase and for flue gases treatment [4]. Powdered activated carbon and granular activated carbon are commonly used for wastewater treatment or water purification. However, GAC is mostly used in industrial adsorption applicationsdueto its larger particle sizes. PAC have greater exterior surface and faster adsorption capacity than GAC, but its lower particle size makesit difficult to regenerate and requires discarding after usage limiting its industrial application [5].

The characteristics of activated carbon include various physical and chemical properties. The physical attributes of activated carbon, such as its surface area and bulk density, along with chemical traits like pH, ash content, and conductivity, play crucial rolesin determining its applicability and suitability for specific purposes. These physicochemical characteristics determine the performance, suitability, and applications of activated carbon in various industries. Understanding these properties is crucial for selecting the appropriate activated carbon type for specific purification or adsorption requirements [6].Zulkania&Rezki (2018) [7] stated that parameters such as moisture content, ash content, and pH level have the potential to impact the adsorption characteristics of activated carbon.

Activated carbons (AC) are widely used in industries and homes, covering energy, healthcare, and environmental protection sectors [8].It isutilized for extracting, recovering, separating, and modification of diverse compounds in both liquid and gas forms [9].The use of carbon spans back in time. During the ancient Egyptian era around 1500 BC, charcoal was utilized by the

Egyptians as both a medicinal adsorbent and a purifying agent. In 1773,Scheele utilized charcoal to treat gases, and in 1786, it was employed to decolorize aqueous solutions marking the first quantification of coal's adsorptive power in the liquid phase [4].However, the concept of "activation" as we understand it today emerged in the 18th century. In 1822, Bussy introduced the first activated carbon produced through a combination of physical and chemical activation by heating blood with potash, which proved to be more efficient than char [10].Commercially viable activated carbon emerged with the contributions of Swedish scientist Von Ostreijko, who obtained patents in 1900 and 1901 [4].

Despite the wide application of activated carbon, the cost of commercially available activated carbon is high and may not be easily affordable.The extensive usage of activated carbon is hindered by the scarcity of inexpensive, high-quality materials meeting distinct consumer needs [Nedjai 2021].In addition, the use of imported activated carbon may have negative environmental impacts due to transportation emissions. Activated carbon is imported into developingcountries like Nigeria in large quantities and at a very high cost [12]. The use oflocally sourced activated carbon could be a possible solution to this problem. Local activated carbon may be more affordable and environmentally sustainable, and its properties may be tailored to local conditions.Intensive studies are being conducted globally to explore the utilization of biomass (agricultural or food waste), as its success will yield economic value [13].Lately, there has been increased attention on the production of activated carbons from agricultural residues such as rice husk [14], coconut fiber [15], castor seed hull [16], potato peels [17], sugarcane bagasse [18], cinnamon waste [8], guinea corn husk [19], Carica Papaya Trunk [20], date stone [21],Pistachio shells [22], Palm kernel shell and cake [23], etc, A significant amount of agricultural residue is produced each year in Nigeria, and this waste may be utilized to satisfy local needs or even be exported to promote economic development and prevent environmental deterioration.One of the agricultural wastes generated daily in Nigeria is the melon seed husk. Melon seed (Citrullus colocynthis L.) is a part of the cucurbitaceae family, which includes many varieties of melons. It is also known as "egusi" in West Africa. It is one of the 300 melon species found in tropical Africa. Waste (melon seed husk) is generated on daily basis in the country as a result of melon seed consumption. The economic value of melon seed husk has not been fully explored and is often overlooked. If well studied, the seed husk will not only improve the country's economy but will also reduce the amount of waste generated daily. Therefore, the aim of this study was to ascertain if activated carbon could be produced effectivelyfrom melon seed husk, an everyday agricultural waste product.

2. MATERIALS AND METHODS

2.1 Required Materials

Melon seed husk, calcium chloride, iodine solution,muffle furnace (electric furnace), oven, crucible, sieves,draining tray,aluminum dish, desiccator, beaker, graduated measuring cylinder,Whatman filter paper, pH meter, magnetic stirrer,electric blender, etc., were used for this research.The melon seed husk which was obtained from a local market served as the precursor material, undergoing carbonization and activation processes to produce activated carbon. Calcium chloride was employed as an activationagent during impregnation or activation of the melon seed husk (char). An iodine solution was used to determine the iodine number, to evaluate the adsorption capacity of the resulting activated carbon. The muffle furnace and oven facilitated heat treatment processes, including carbonization, and drying of the melon seed husk. A crucible potentially aided in specific sample processing or mixing. Sieves categorized particle sizes, while the draining tray handled materials during various stages. An aluminum dish was utilized for sample preparation and weighing. The desiccator was used to store samples under dry conditions, and the beaker forstorage of liquids. A graduated measuring cylinder was used to ensure accurate volume measurements. Whatman filter paper was used for facilitating filtration processes, while the pH meter measured solution or suspension acidity. The magnetic stirrer effectively mixed solutions or suspensions while the electric blender was used to crush the carbonized melon seed husk into powder form.

2.2 Collection and Pre-treatment of Raw Material

Melon seed husk (MSH) was sourced from a local market in Port Harcourt, Nigeria. To prepare the melon seed husk for carbonization, it was properly washed with warm water and rinsed with distilled water. This was done to ensure all residues were removed and there was no presence of substances that could affect the results. After washing, it was sun-dried for one week to reduce moisture content (Figure 1a).

2.3 Carbonization of Melon Seed Husk

The dried melon seed husk was placed in a muffle furnace for carbonization to produce charcoal (Figure 1b). The temperature regulator of the furnace was set at $500^{o}C$. The sample was heated for 1 hour, and after which it was allowed to cool to room temperature. Thereafter, the sample was crushed using a blender and sieved using sieve with a mesh size of 850µm to obtain powdered carbon as shown in Figure 1c. The crushed char was transferred into a container and properly sealed for experiment purposes.

2.4 Activation of Carbon

Chemical activation was adopted in the activation of the carbonized product (char). This method was used as it improves the porosity and adsorption efficiency of the char. To activate the carbonized melon seed husks, it was impregnated with calcium chloride by adding the calcium chloride solution into the plastic container containing the char. The container was properly sealed and left for 24 hours. After which the treated carbon was transferred into a draining tray and allowed to drain for 1 hour in order to retrieve the carbon. For removal of trace chemicals from the char, the sample was washed and rinsed five times using distilled. Thorough washing is essential to get rid of the chemical solution, which otherwise will remain in the char. It is one of the most common problems in the preparation of activated carbon using chemical activation. After washing, the sample was returned to the draining tray to remove the water. Following this, it was transferred into an oven, the temperature was set at $110^{o}C$ and was allowed to bake for about 3 hours. After baking, the activated carbon was removed from the oven and crushed using a blender.

2.5 Characterization

To characterize the activated carbon produced from melon seed husk, standardized methods were used as proposed by the American Society of Testing and Methods (ASTM). The test included the determination of moisture content, ash content, pH, bulk density, and the iodine number of the activated carbon.

2.5.1 Determination of Moisture Content

The moisture content of the activated carbon was determined using the oven drying technique. A clean aluminum dish was washed thoroughly and dried in the oven, then cooled in the desiccator before being weighed. 2g of the sample was put in the dish and the weight of the dish containing the sample was taken. Thereafter, it was dried in the oven at $105^{o}C$ for an hour and then cooled in the desiccator. After which the dish containing the oven- dried sample was weighed. The percentage moisture content was calculated using Equation (1).

$$Moisture\ content\ = \frac{W2-W3}{W2-W1}\ X\ 100 \qquad (1)$$

where W_1 is the initial weight of empty crucible, W_2 is the weight of crucible plus sample before drying, and W_3 final weight of crucible plus sample after drying.

2.5.2 Determination of Ash Content

Exactly 1.0g of the sample was weighed in a platinum crucible and recorded as W_1. The sample was transferred to muffle furnace at the temperature of 550^oC for 8 hours to obtain a white ash. The platinum crucible was removed and placed in a desiccator to cool and then weighed. The value obtained was recorded as W_2. The ash content of the activated carbon was calculated in percentage using Equation (2).

$$\%\ ash\ = \frac{W1-W2}{Ws}\ X\ 100 \qquad (2)$$

where W_1, W_2 and W_3 are the initial weight of empty crucible, weight of crucible plus sample before drying and the weight of the sample used respectively.

2.5.3 Determination of pH

A pH meter with glass electrodes was used to ascertain the activated carbon's pH. After being turned on, the pH meter was given 15 minutes to warm up. To standardize the glass electrode, 2g of activated carbon was dissolved in 100ml of deionized water using a standard buffer with a pH of 7.0. To achieve appropriate dilution, the liquid was heated and agitated for 5 minutes using a magnetic stirrer. Then, it was filtered at room temperature using Whatman filter paper. The pH meter was then used to determine the pH of the filtered sample.

2.5.4 Bulk Density

A graduated measuring cylinder with a 10 mL capacity was weighed. The cylinder was topped out with the test sample (activated carbon). The test sample's weight inside the test tube or cylinder was calculated and expressed as a volume ratio. The bulk density (BD) was calculated using Equation (3).

$$BD = \frac{W}{V} \qquad (3)$$

where W is the weight of sample and V the volume occupied by the sample.

2.5.5 Determination of Iodine Number (IN)

The iodine number of the activated carbon was determined using the ASTM D4607-94 method. This method measures the amount of iodine adsorbed by 1.0 gram of carbon when the iodine concentration in the filtrate is 0.02N. The procedure involves treating a standard iodine solution with different weights of activated carbon. The activated carbon sample was first treated with 5% hydrochloric acid (HCl), boiled, and then cooled. Next, 0.1 N iodine solution was added and stirred. The resulting solution was filtered, and a portion of the filtrate was titrated with 0.1 N sodium thiosulfate using starch as an indicator. The iodine amount adsorbed per gram of carbon (X/M) was plotted against the iodine concentration in the filtrate (C) using logarithmic axes. The procedure was repeated with different carbon masses whenever the residual iodine concentration was outside the range of 0.008 to 0.04 N. A least square fitting regression was applied to analyze the three points, and the iodine number was determined when the residual concentration was 0.02 N. The X/M and C values were calculated by the Equations (4) and (5), respectively.

$$X/M = \frac{NI \times 126.93 \times VI - \frac{VI + VHCl}{VF} \times NNa\,2S2O3 \times 126.93 \times VNa\,2S2O3}{Mc} \qquad (4)$$

$C = N_{Na2S2O3} \times V_{Na2S2O3}$ (5)

where N_I is the iodine solution normality, V_I is the added volume of iodine solution, V_{HCl} is the added volume of 5% HCl, V_F is the filtrate volume used in titration, $N_{Na2S2O3}$ is the sodium thiosulfate solution normality, $V_{Na2S2O3}$ is the consumed volume of sodium thiosulfate solution, and MC is the mass of activated carbon.

3. RESULTS AND DISCUSSION

Carbon (char) was successfully produced from melon seed husk by carbonization and chemically activated using calcium chloride as activating agent. The activated carbon was characterized to determine the pH, ash content, moisture content, apparent density and iodine number. These results are discussed in the subsequent subsections.

3.1 Characterization of the Activated Carbon

The physicochemical characteristics of the activated carbon produced from the melon seed husks and activated using Calcium Chloride ($CaCl_2$) are presented in Table 1. The characterization involved the determination of the activated carbon's pH, moisture content, bulk density, and iodine number. The pH of the activated carbon was 6.53. The ash content, moisture content, and the iodine number were 5.13%, 11.36%, and 1759.18%, respectively.

Table 1: Physicochemical characteristics of melon seed husk activated carbon

Parameters	**Values**
pH	6.52
Moisture content (%)	11.36

Ash content (%)	5.13
Bulk Density (g/cm^3)	0.453
Iodine Number (mg/g)	1759.18

3.1.1 pH

The pH of the carbon after activation as shown in Table 1 is 6.52, which is slightly acidic. Low pH activated carbon (AC) typically has a positive surface charge due to protonation of surface functional groups [24].At low pH conditions the adsorption capacity of activated carbon increases. In liquid phase, as pH decreases the rate of adsorption upsurges [25]. This pH of 6.52 is therefore an indication that the melon seed activated carbon could be a good adsorbent in the removal of impurities from solution.Evwierhoma et al. (2018) [26] obtained a similar pH (6.7) in their study in which they stated that this kind of activated carbon is preferable in the removal of polar organic compounds from water. Madu&Lajide (2013) [2] confirmed that activated carbon is more effective at low pH than high pH.

3.1.2 Ash Content

It is important to determine the ash content of activated carbon as this greatly impacts the overall quality and performance of the activated carbon. It is one of the major parameters that influences the adsorption properties of activated carbon. Activated carbon with high content of ash (>20%) reduces its specific surface area, potential reactivation and generates leakage of impurities.The amount of ash present in the activated carbon is relatively minimal at 5.13%. This is comparable to the ash content of 5.3% obtained by Obebe et al. (2021) [27] in their research on the preparation and characterization of activated carbon from bovine horns.For an activated carbon to serve as a good adsorbent, its ash content should be low. It should be less than 20%[28]. Activated carbon with low ash content suggests that the precursor material is well-suited for producing activated carbon [27].The low ash value obtained (as shown in Table 1) is an indication that melon seed husk is a good starting material for activated carbon production and may serve as a good adsorbent.

3.1.3 Iodine Number

One important metric that can be used to evaluate the adsorption capability of activated carbon is the iodine number. The iodine number, measured in mg/g of carbon, reflects the porosity of the activated carbon, and indicates the amount of iodine that can bind to a specific amount of activated carbon. The iodine number obtained from the test was 1759.18 mg/g (as shown in Table 1) According to the Indonesian National Standard (SNI 06-3730-1995), an effective activated carbon should have a minimum iodine number of 750 mg/g. Budianto et al. (2019) [29] conducted a study which found high iodine numbers (769–1019 mg/g) in their activated carbons. They noted that these high values indicate that the production conditions of the activated carbons met the requirements set by the Indonesian National Standard (SNI) in terms of iodine number. This also suggests that the activated carbon has high porosity and activity level, as a higher iodine number indicates a higher degree of activation.

3.1.4 Moisture Content

The amount of water that typically attaches to activated carbon is referred to as its moisture content.The ash content in carbons derived from by-products is highly influenced by the ash content present in the by-product[30]. According to Indonesian Industrial Standard (SII No. 0258-88), the maximum moisture level for activated carbon is 15%. It is a crucial parameter asit influences how well adsorption works. The capacity of activated carbon for adsorption could increasewith low moisture content[7]. Besidesthe adsorption efficiency, high moisture is undesirable as it may increase storage and transportation costs. The activated carbon's moisture content obtained from the experiment is 11.36% which is below the 15% limit of the Indonesian Industrial Standard. This is an indication that the activated carbon may serve as a good adsorbent.

3.1.5 Bulk Density

Bulk density refers to the weight of a given volume of the sample in the air, encompassing both the pore structure and the spaces between the particles [31]. The density of the activated carbon significantly influences the amount of adsorbate it can capture [32].The higher the density of an activated carbon the greater the filtration ability [33].For activated carbon to be used for practical purposes, the activated carbon should have a minimum bulk density value of 0.25g/cm^3 as specified by the American Water Work Association [34]. As shown in Table 1, the obtained bulk density is 0.453g/ cm^3. This implies that the activated carbon can be successfully used in practicalconduction.Powdered activated carbons needed for the removal of colour usually have bulk density that ranges from 0.25 to 0.75g/cm^3. This value of 0.453g/ cm^3 is within the range of the bulk density for powdered activated carbon required for removal of impurities.

4. CONCLUSION

This research was carried out to investigate the potential of melon seed husks, an agricultural waste, in the production of activated carbon. Activated carbon was produced from the melon seed husks by impregnating the husks with calcium chloride after carbonization. Physicochemical analysis was conducted on the melon seed husks activated carbon (MHSAC) to determine its characteristics. The result of this analysis revealed that the pH level, amount of ash, moisture content, density, and iodine number of the activated carbon prepared from melon seed husks were 6.52, 5.13%, 11.36%, 0.453g/ cm^3, and 1759.18mg/g respectively. These parameters were within their optimal ranges, affirming the suitability of the melon seed husk activated carbon as a high-quality activated carbon material for various applications.Further research is recommended to evaluate the practical application of melon seed husk activated carbon (MSHAC) in real-world scenarios, including adsorption experiments, regeneration studies, and scale-up processes.

Figure1a:Rawmelon seedhusk

Figure1b:Carbonatedmelo nseed husk

Figure1c:Crushed carbonatedmelonseed

Reference

1. Duruaku, J. N. (2012). Modification of surface, physical and chemical properties of activated carbons for water purification (Bachelor's thesis). Caritas University, Amorji-Nike, Enugu.

2. Madu, P. C. and Lajide, L. (2013). Physicochemical Characteristics of Activated Charcoal Derived from Melon Seed Husk. Journal of Chemical and Pharmaceutical Research, 5 (5) 94-98.

3. Egirani, D., Latif, M. T., Wessey, N., Poyi, N. R., and Shehata, N. (2021). Preparation and Characterization of Powdered and Granular Activated Carbon from Palmae Biomass for Mercury Removal. Applied Water Science, 1-11

4. Alves, A. T., Lasmar, D. J., Miranda, I. P. A., Chaar, J. S., and Reis, J. S. (2021). The Potential of Activated Carbon in the Treatment of Water for Human Consumption, a Study of the State of the Art and Its Techniques Used for Its Development. Advances in Bioscience and Biotechnology, 12(6).

5. Allen, S. J. andKoumanova, B. (2005) Decolorization of Water/Wastewater Using Adsorption. Journal of the University of Chemical Technology and Metallurgy, 40, 175-192.

6. Ahmed, M. J., andTheydan, S. K. (2012). Physical and Chemical Characteristics of Activated Carbon Prepared by Pyrolysis of Chemically Treated Date Stones and Its Ability to Adsorb Organics. Powder Technology, 229, 237-245.

7. Zulkania, A., Hanum, G. F., and Sri Rezki, A. (2018). The Potential of Activated Carbon Derived from Bio-char Waste of Bio-oil Pyrolysis as Adsorbent. MATEC Web of Conferences, 154.

8. Nasr Ettish, M., El-Sayyad, G. S., Elsayed, M. A., andAbuzalat, O. (2021). Preparation and Characterization of New Adsorbent fromCinnamon Waste by Physical Activation for Removal of Chlorpyrifos. Environmental Challenges, 5, 100208.

9. Heidarinejad, Z., Dehghani, M.H., Heidari, M., Javedan, G., Ali, I., and Sillanpää, M. (2020). Methods for Preparation and Activation of Activated Carbon: A Review. Environmental Chemistry Letters18, 393–415.

10. Bubanale, S., and Shivashankar, M. (2017). History, Method of Production, Structure and Applications of Activated Carbon. International Journal of Engineering Research & Technology (IJERT), 6(6).

11. Nedjai, R., Kabbashi, N. A., Alam, M. Z., and Al-Khatib, M. F. R. (2021). Production and Characterization of Activated Carbon from Baobab Fruit Shells by Chemical Activation Using $ZnCl_2$, H_3PO_4 and KOH. Journal of Physics: Conference Series, 2129, 012001.

12. Olafadehan, O.A., Jinadu, O.W., Salami, L. and Popoola, O. T. (2012). Treatment of Brewery Wastewater Effluent using Activated Carbon Prepared from Coconut Shell. International Journal of Applied Science and Technology, 2 (1), 165-178.

13. Serafin, J., andDziejarski, B. (2023). Activated Carbons—Preparation, Characterization and their Application in CO2 Capture: A Review. Environmental Science and Pollution Research.https://doi.org/10.1007/s11356-023-28023-9

14. Oluwatoyin, A. O. and Olalekan, A. A. (2021). Adsorption of Crude Oil Spill from Aqueous Solution using Agro-Wastes as Adsorbents. Journal of Scientificc Research and Reports, 27(4), 27-52.

15. Ohimor, E. O., Temisa, D. O., andOnoniwu, P. I. (2021). Production of Activated Carbon from Carbonaceous Agricultural Waste Material: Coconut Fibres. Nigerian Journal of Technology, 40(1), 19–24.

16. Neme, I., Gonfa, G., andMasi, C. (2022). Preparation and Characterization of Activated Carbon from Castor Seed Hull by Chemical Activation with H3PO4. Results in Materials, 15, 100304

17. Njewa, J. B., Vunain, E., andBiswick, T. (2022). Synthesis and Characterization of Activated Carbons Prepared from Agro-Wastes by Chemical Activation. Journal of Chemistry, 2022, 1-13

18. Zuo, H., Xia, Y., Liu, H., Liu, Z., and Huang, Y. (2023). Preparation of Activated Carbon with High Nitrogen Content from Agro-Industrial Waste for Efficient Treatment of Chromium (VI) in Water. Industrial Crops and Products, 194.

19. Shaba, E. Y., Mathew, J. T., Musah, M., Mohammed, M., Muhammad, A. I., andObetta, H. C. (2021). Adsorption of Heavy Metals from Electroplating Wastewater Using Guinea Corn Husk Activated Carbon. Lapai Journal of Science and Technology, 7(1), 122-132.

20. Udeh, N. U., and Amah, V. (2022). Modelling the Adsorption of Lead (II) Ion from Aqueous Phase with CaricaPapaya Trunk Activated Carbon. Journal of Engineering Research and Reports, 22(8), 44-54.

21. Abderrahim, N., Boumnijel, I., Amor, H. B. and Djellabi, R. (2022). Heat and $ZnCl_2$ Chemical Carbonization of Date Stone as an Adsorbent: Optimization of Material Fabrication Parameters and Adsorption Parameters and Adsorption Studies. Environmental Science Pollution Research. 29, 46038-46048.

22. Barjasteh-Askari, F., Davoudi, M., Dolatabadi, M. andAhmadzadeh, S. (2021). Iron-Modified Activated Carbon Derived from Agro-Waste for Enhanced Dye Removal from Aqueous Solutions. Heliyon, 7, e07191.

23. Igbemi, I.A, Nwaogazie, I.L, Akaranta, O. and Abu, G. O. (2021). Adsorption Dynamics of Agricultural Waste Activated Carbon in Water Quality Improvement. European Journal of Engineering and Technology Research. 6 (7), 11-19.

24. Lafi, R., Montasser, I. and Hafiane, A. (2019). Adsorption of Congo Red Dyefrom Aqueous Solutions by Prepared Activated Carbon with Oxygen-Containing Functional Groups and its Regeneration. Adsorption Science & Technology, 37(1-2), 160-181.

25. Aznar, S. J. (2011). Characterization of Activated Carbon Produced from Coffee Residues by Chemical and Physical Activation (Master's thesis). KTH Chemical Science and Engineering, Stockholm, Sweden

26. Evwierhoma, E. T., Madubiko, O. D. and Jaiyeola, A. (2018). Preparation and Characterization of Activated Carbon from Bean Husk. Nigerian Journal of Technology, 37, 674 – 678.

27. Obebe, E. O., Yashim. Z. I. and Agbaji, E. B. (2021). Preparation and Characterization of Activated Carbon from Bovine Horns. Nigerian Research Journal of Chemical Sciences, 9 (1), 196-206

28. Ayvral, C. (2009). Elimination of Aromatic Pollutants by Catalytic Oxidation on Activated Carbon (Doctoral thesis) University of Toulouse.

29. Budianto, A., Kusdarini, E., Effendi, S. S. W. and Aziz, M. (2019). The Production of Activated Carbon from Indonesian Mangrove Charcoal. IOP Conference Series: Materials Science and Engineering, 462.

30. Ibrahim, A., Ismail, A., Juahir, H., Ihsan, Y. N., Sudianto, S., Ovinis, M., Kassim, A. M., Hanapi, N. H. M., and Hafizi, A. D. (2023). Preparation and Characterization of Activated Carbon Obtained from Melaleuca Cajuputi Leaves. Carbon Trends, 13, 100301.

31. Zhonghua, H., Srinivasan, M. P., and Yaming, N. (2001). Novel Activation Process for Preparing HighlyMicroporous and Mesoporous Activated Carbons.Carbon, 39, 877-886

32. Ravichandran, P., Sugumaran, P., Seshadri, S., andBasta, A. H. (2018). Optimizing the Route for Production of Activated Carbon from Casuarina Equisetifolia Fruit Waste. Royal Society Open Science, 5(7)

33. Verla, A. W., Horsfall, M., Verla, E. N., Spiff, A. I., and Ekpete, O. A. (2012). Preparation and characterization of activated carbon from fluted pumpkin (TelfairiaoccidentalisHook.f) seed shell. Asian Journal of Natural & Applied Sciences, 1 (3), 36-50.

34. Tchuifon, T. D. R., Anagho, S. G., Nche, G. N., andKetcha, J. M. (2015). Adsorption of Salicylic and Sulfosalicylic Acid onto Powdered Activated Carbon Prepared from Rice and Coffee Husks. International Journal of Current Engineering and Technology, 5, 1641-1652.