

# AN OVERVIEW ON THE DEVELOPMENT OF ACTIVATED CARBON FROM AGRICULTURAL WASTE MATERIALS

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## ABSTRACT

### Keywords:

*Activated carbon, Biomass, energy, Environment, Waste, Heavy metals*

*Agriculture waste-derived activated carbon has become a viable and renewable replacement for traditional activated carbon sources. This study examines the development, characteristics, and prospective uses of activated carbon derived from various agricultural waste products, such as crop residues, food scraps, and other biomass by-products. The use of these agricultural waste products shows a sizable potential for the synthesis of activated carbon and the impact of various activation procedures, including physical and chemical activation methods, on the structural and surface characteristics of the resulting activated carbons is discussed. Additionally, the composition, structure, and characteristics of activated carbon are evaluated with important variables, including activating agents, temperature, and impregnation ratio. Using agricultural waste helps to generate ecologically acceptable and sustainable materials while addressing important waste management issues*



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## 1. INTRODUCTION

The environment around us is becoming increasingly polluted, particularly the air and water resources. The necessity to clean up our environment and cleanse our water necessitates the creation of innovative processes for making highly effective filter media and useful adsorbents. In water treatment and purification, Activated Carbon (AC) is widely used because adsorption processes like physisorption and/or chemisorption allow impurities to move from a liquid to the solid surface (Dai et al., 2020; Lima et al., 2016). Because of its well-developed porous structures, wide active surface area, and good mechanical properties, AC has been regarded as one of the most effective adsorbents (Lua et al., 2006).

Activated carbon (AC) plays a crucial role in safeguarding the environment, enhancing the quality of food products, and aiding in medical applications. It finds applications in purifying wastewater and reducing

emissions from industrial facilities, as well as being utilized in the production of fruit syrups, alcohol, and various other beverages. Additionally, it is instrumental in the purification of drinking water, manufacturing pharmaceutical products, and providing protection against harmful chemicals for individuals (Sartova et al., 2018). This study examines the development, characteristics, and prospective uses of activated carbon derived from various agricultural waste products for application in wastewater treatment, heavy metals removal from water and other potential industrial waste treatment and waste to value addition products.

### Activated carbon as an adsorbent

AC can be produced by pyrolysis, a carbonaceous substance, from various affordable materials with high carbon and low inorganic content. According to these studies, the production of AC on a large scale involves the pyrolysis and activation of high-priced raw materials, including coal, oil, and wood, which makes it

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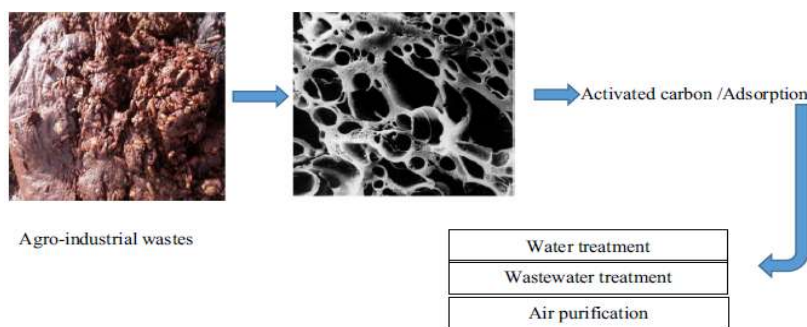
expensive and unnecessary as a method of pollution control (Luka, 2018). The surface of the AC also shows functional groups, which alters the pH of the solution and, as a result, the adsorption process (Alharbi et al., 2020; Mallek et al., 2018). Additionally, it is a black solid substance that resembles powdered or granular charcoal and is a tasteless, amorphous, microcrystalline non-graphite type of carbon (Olafadehan et al., 2012).

Solid sponges are another name for AC, also known as activated charcoal or coal. It is made from various carbonaceous precursors, including coal, peat, and nutshells. They are carbonised and then 'activated' by oxidation with CO<sub>2</sub> or steam or by treatment with acids, bases, or other chemicals. Its enormous adsorptive capacity is explained by the fact that the resultant carbon might have a surface area of 1500m<sup>2</sup> g or more (Naji & Tye, 2022).

Activated carbon cannot be characterised by any unique chemical formula. Powdered activated carbon (PAC), granulated activated carbon (GAC), extracted activated carbon (EAC), pellet activated carbon, fibrous activated carbon, activated carbon cloths, and other types of activated carbon can all be classified according to their physical characteristics (Tahvildari et al., 2009).

However, PACs and GACs are the two main forms in which AC is sold (Jjagwe et al., 2021). According to (Deng et al., 2015), the PACs often have high specific surface area and micro-porosity, which boosts their adsorption capability.

In contrast to GAC, however, the microscopic PAC particles exhibit slower settling and removal tendencies (Jjagwe et al., 2021). The PAC cannot be regenerated despite having a higher adsorption capacity because it is difficult to separate from the aqueous solution (Deng et al., 2015) and because there may be high levels of dust pollution (Cai et al., 2019). These challenges lead to most PACs being used in batch modes, particularly in water treatment plants (Jaria et al., 2019). Several pollutants are currently successfully removed from water using the GAC as a water treatment material, including organic micro-pollutants (Brunner et al., 2019), pharmaceuticals (Lima et al., 2016), arsenic (Kalaruban et al., 2019), carcinogenic compounds (Myers et al., 2018), Heavy metals (Eeshwarasinghe et al., 2019), microplastics (Wang et al., 2020), colour and odour (Ziemba et al., 2020), and heavy metals (Wang et al., 2020). Figure 1 shows various utilization of AC.

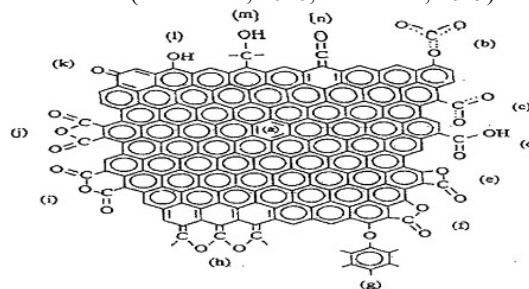


**Figure 1.** Application of activated carbon as an adsorbent for environmental remediation (Heidarinejad et al., 2020)

In functional groups or atoms that chemically connect to the structure, hetero atoms like oxygen, sulfur, hydrogen, nitrogen, halogen, and other elements are frequently found with activated carbon. According to (Gonzalez-Serrano et al., 2004), oxygen is observed to predominate and can be found in functional groups such as lactone, phenol, and carbonyl. In designs where continuous columns are more practical for treating water and carbon regeneration is necessary for environmental and financial reasons, GACs are the AC type that works best. According to (Jjagwe et al., 2021), this results from GAC's capacity to adapt to continuous contact without severing the carbon from the bulk fluid. GAC typically has lesser adsorption capabilities for pollutant removal from aqueous solutions when compared to the PAC (Cai et al., 2019).

However, there is increasing research interest in identifying inexpensive biomass waste sources and production procedures for AC because of the related environmental and financial problems (Gonçalves et al., 2019). More precisely, agricultural and industrial wastes have significant potential as antecedents for AC

generation in poor nations (Thakur et al., 2020). This is because they are widely available, inexpensive, and carbonaceous (Karri et al., 2020; Tran et al., 2019).



**Figure 2.** IR-active Functional Groups on Carbon Surface: (a) aromatic C<sup>1/4</sup>C stretching; (b) and (c) carboxyl-carbonates; (d) carboxylic acid; (e) lactone (4-membered ring); (f) lactone (5-membered ring); (g) ether bridge; (h) cyclic ether; (i) cyclic anhydride (5-membered ring); (j) cyclic anhydride (6-membered ring); (k) quinone; (l) phenol; (m) alcohol; and (n) ketene (Yahya et al., 2015a)

Open garbage burning pollutes the environment by releasing airborne particles and unpleasant fumes, and available waste deposits can clog drainage systems during rainy seasons. Pathogens can grow and reproduce in the deposited wastes (Chou et al., 2009).

## 2. WASTE PRODUCTS TO VALUE ADDED PRODUCTS (ACTIVATED CARBON)

Material selection is one of the most crucial aspects that must be properly considered in the production of AC since the nature of the raw material has a major impact on the attributes of the finished AC. The choice of material is made based on its accessibility, purity, and degree of activation (Jjagwe et al., 2021). According to a study conducted by (Y. W. Lee et al., 2002), activated carbon synthesis primarily relies on two primary sources: coal and agricultural by-products, which can also be referred to as lignocellulosic materials. Expense- and non-renewable-based precursors such as petroleum by-products, wood, coal, peat, and lignite produce commercial activated carbon (Singh et al., 2013). Therefore, in recent years, people have been concentrating on the preparation of AC based on agricultural waste and lignocelluloses materials that are efficient and very cheap such as coconut shell, wood,

hazelnut bagasse, kenaf fibre, sugarcane bagasse, jack fruit peel, bamboo, rice husk, ground nutshell, paper mill sludge, Prosopis (*Prosopis juliflora*), coconut husk (Yahya et al., 2015b). Activated carbon is produced from agricultural by-products, through controlled pyrolysis, the waste can be transformed into AC with or without chemical activators (Hasdemir et al., 2022). The proximal and final analysis of various agricultural leftovers is shown in Table 1. These by-products have lower carbon concentrations than anthracite, coal, or peat. As a result, it is anticipated that the yields of activated carbon from these precursors will be reduced. The cheaper cost has a larger impact than the poorer yield (Olafadehan et al., 2012). The high volatile matter concentration of the biomass made it possible to create an activated carbon structure that is highly porous (Lua et al., 2006).

Because of its high carbon content, which leads to the development of alcohols, ketones, aldehydes, phenolic, carboxylic, and ether groups, the presence of polymeric organic compounds in agricultural waste is advantageous. These groups play a key role in adsorption because of their affinity for metal complexation (Pan et al., 2013). As a result, the thermal and chemical stability and reproducibility of agricultural waste-based activated carbon are improved.

**Table 1.** Performances of different types of agro waste-based AC for heavy metals removal from aqueous solutions (Yunus et al., 2022)

Agro waste AC	Metal uptake (mg/g) Removal (%)
Rock melon shell	Cadmium (3.38), Nickel (5.62), Cuprum (14.28)
Melon husk	Cadmium (7.81)
Lemma minor	Plumbum (174.5)
Watermelon shell	Plumbum (40.98), Zinc (11.31)
Walnut shell	Plumbum (32.36), Zinc (6.07)
Oakwood	Chromium (3.03)
Papaya peel	Plumbum (38.31)
Phragmites australis	Nickel (22.88), Cuprum (5.421), Cadmium (40.42)
Lignin	Chromium (77.85)
Avocado seed	Zinc (3.34)
Palm kernel	Plumbum (11.03)
Jaracanda mimosifola	Plumbum (4.46)
Pecan nut	Plumbum (79)
Jatropha seed	Chromium (1.25)
Coconut button	Plumbum (97.72), Cuprum (73.60)
Cashew nutshell	Zinc (455.7)
Coconut shell	Ferum (71%)
Orange peel	Ferum (75%)
Sawdust	Ferum (75%)
C. prorera leaves	Ferum (58%)
Cucumis melon peel	Chromium (98.10%)
Date palm stone	Chromium (120.48), Plumbum (139)

### 3. PROCEDURE FOR MAKING ACTIVATED CARBON

Chemical and physical treatment are the two methods used to prepare activated carbon (Buasri et al., 2012). Different forms and sizes result from both treatments (Ali, 2010). In order to characterise physical activation, there are two stages that must be taken. The first stage is activation, which involves treating the char by oxidising with the carbon-generating pores in the material using a carbon dioxide and steam gas stream (Bhatnagar et al., 2013).

On the other hand, the chemical solution is impregnated into the precursor of activated carbons that are ready to use chemical activation. The solutions  $H_3PO_4$ ,  $ZnCl_2$ ,  $HNO_3$ ,  $H_2SO_4$ , and  $KOH$  are employed as impregnation agents. After the impregnation process, carbonisation is carried out at various temperatures, typically between 400 and 600°C. The precursor is first carbonised at 600–1100°C in an inert environment, and then at a higher temperature, it is activated with steam or carbon dioxide (Kaomierczak et al., 2013). The material, predominantly carbon in the form of char, is left with an initial carbonaceous structure as a result of this process, which creates char burn-off char where the volatile substances may be detected.

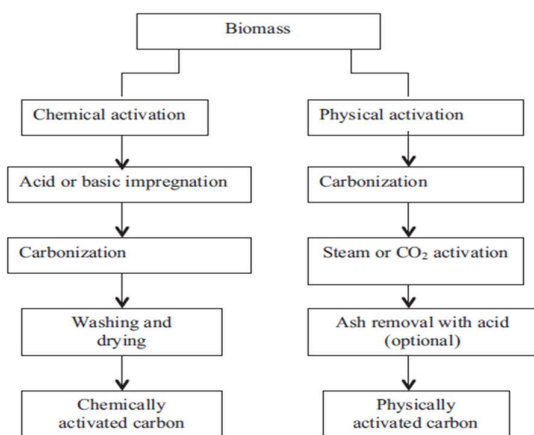


Figure 3. Method of activated carbon production.

The cellulosic components of the precursor might be dissolved, which would encourage the development of crosslinks. However, (Yahya et al., 2015a) found that chemical activation offers higher benefits than physical activation. Chemical activation does have certain drawbacks, such as the necessity for washing to remove impurities from the activating agents and the agents' corrosiveness (Lozano-Castelló et al., 2001). For materials with relatively higher carbon and lower inorganic contents, such as wood, peanut shells, rice husk, wheat straw, corn cob, and waste cellulosic materials, chemical activation is frequently used.

#### 3.1 Physical Activation

Carbonization and activation are the two steps that make up physical or "thermal" therapy. According to (Al-Qodah & Shawabkah, 2009), dry oxidation is the reaction of samples with gaseous (such as  $CO_2$  and air), steam, or gaseous and steam at temperatures above 700°C. Due to its clean nature, ease of handling, and good controllability of the activation process at temperatures of about 800°C,  $CO_2$  has been frequently preferred.

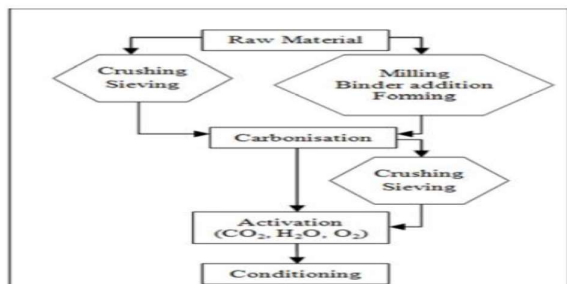
The raw materials used in this method's research were rice husk, corn cob, oak, corn hulls, corn stover, rice straw, rice hulls, pecan shells, peanut hulls, and almond shells. Temperatures for carbonization typically range from 400 to 850°C and occasionally exceed 1000°C, and activation temperature range between 600 and 900°C (Ioannidou & Zabaniotou, 2007). The more reactive carbon atoms will be removed during gasification, creating porosity. Activated carbon with a high porosity will eventually be produced by further gasification (Rodríguez-Reinoso & Molina-Sabio, 1992). The activation temperature is often between 600 and 900°C, while the carbonization temperature typically falls between 400 and 850°C (Al-Qodah & Shawabkah, 2009).

Further details were provided, describing physical activation as a two-step process that begins with the carbonisation of raw materials and ends with the activation of the char those results. Although the most widely used process for physical activation is two-step carbonization and activation using steam or carbon dioxide as the activation agent, the literature claimed that a single-step physical activation method using coconut shell could produce activated carbon with excellent properties and yield results that are comparable to the two-step method.

Charcoal is produced through the process of carbonization, which starts with the raw material. The resulting charcoal is inert and has a small surface area. The goal of the carbonization is to lower the volatile component of the starting material so that the char that results have higher fixed carbon content can be used for activation. The carbon atoms rearrange to resemble graphite during carbonization. The carbonized material must be activated physically or chemically after biomass carbonization. Inert gases ( $CO_2$ ,  $N_2$ , etc.) or steam are typically passed through the sample at high temperatures (700-900°C) to activate it physically (Selvaraju & Bakar, 2017).

Peroxidation, pyrolysis, and steam activation are the steps in physical activation by steam oxidation.  $N_2$  is initially used to dilute the air in peroxidation by half. In order to prevent the temperature from rising due to an exothermic reaction between oxygen and coal, the oxygen concentration must be reduced immediately. Peroxidation could thereby reduce the production of coal caking and coal agglomeration during pyrolysis. By switching off the  $N_2$  flow for a mixture of 50%  $H_2O$  and

50% N<sub>2</sub>, the sample will go through the pyrolysis stage and steam activation (Cal et al., 2000).



**Figure 4.** Basic Flow Sheet for Physical Activation for Development of Activated Carbons (T. Lee et al., 2014).



**Figure 5.** Gradual activation process of carbon during thermal treatment (Yahya et al., 2015b).

### 3.2 Chemical Activation

Chemical activation is a time-consuming technique for creating AC with various bio waste types. This method uses the precursor combined with KOH, NaOH, ZnCl<sub>2</sub>, H<sub>3</sub>PO<sub>4</sub>, and FeCl as preferred chemical activators (Yu et al., 2016). Moreover, to form activated carbon in wet oxidation (Al-Qodah & Shawabkah, 2009), the catalyst may need to be injected into the precursor and rinsed (Vargas et al., 2011). The hydroxide (KOH or NaOH) is first converted to free metals (Na or K) during activation. The carbon network then expands as a result of their intercalation. High temperatures remove these metals destructively, producing graphitic layers in the bio waste network and the necessary Microporosity (Agarwala & Kabra, 2017).

Chemical activation entails an impregnation step in which the material, whether in its raw or carbonized form, is mixed with a chemical before being activated. If the carbonized precursor is combined with the activating agent before being mixed with the raw precursor, the process can be accomplished in one stage or it can be accomplished in two steps.

Strong bases, acids, or salts can all be used as the activation agent. H<sub>2</sub>SO<sub>4</sub>, H<sub>3</sub>PO<sub>4</sub>, NaOH, KOH, HCl, ZnCl<sub>2</sub>, CaCl<sub>2</sub>, and HF are some of the often-used activating agents. Single-step activation often uses strong bases like KOH (Dai et al., 2020; Masoumi & Dalai, 2020). Because ZnCl<sub>2</sub> is a Lewis acid that only plays a dehydrating role in the production of AC and does not react with carbon, it is typically used to make AC with relatively high surface area and porosity (Ouyang et al., 2020). The two-step activation technique makes it possible for the activating agent to quickly permeate into the pores and react with the carbon, resulting in the formation of more pores (Chowdhury et al., 2013).

Because oxidizing gases are introduced into the char throughout the process and reaction products are removed through particles, pores and channels are created (Cuhadaroglu & Uygun, 2008). Three stages make up the pore development in the activation process: enlarging the existing pore, opening previously inaccessible pores, and new pores being developed by selective activation. During the heat treatment of the activated carbon, Figure 5 shows the gradual activation process.

The final morphology and therefore the adsorption properties of the generated carbons are influenced by the choice of the material state (raw vs. carbonized) and the activating agent (Jjagwe et al., 2021). In a two-step chemical activation process, carbonization temperatures are typically lower than activation temperatures (Fu et al., 2018). The impregnation ratio of the activator to the precursor has a significant impact on chemical activation. The developed surface area, carbon yield, adsorption capability, and activation energy are all impacted by the impregnation ratio. Due to a more intense chemical reaction that destroys pores, an excessive activator may diminish the specific surface area (Masoumi & Dalai, 2020).

The additional carbon burn caused by the excess activator increases the volume of the pores and reduces their adsorption capability. The extra activator increases the volume of the pores and increases carbon burn, both of which have an impact on the carbons' ability to absorb water (Foo & Hameed, 2012). The activation energy is also decreased by increasing the mass ratio of the activator to the precursor (Fu et al., 2018). The activator and the precursor may be impregnated either dryly or wetly (Rashidi & Yusup, 2017). However, the complex collection and recycling of the activating agent required by the chemical activation process results in liquid discharge that needs to be treated as effluent (Bachrun et al., 2016).

A physicochemical activation process can be created by combining both chemical and physical activation techniques. This entails either carbonizing a raw precursor that has been chemically impregnated and then physically activating it, or carbonizing char that has been chemically impregnated and then activating it with oxidizing gas or steam. The technique is used at a post-carbonization stage where, despite washing, the

chemical agents were not completely removed, which could prevent pore formation (Ao et al., 2018).

#### 4. THE COMPOSITION OF ACTIVATED CARBON

The adsorption capacity of activated carbon is significantly influenced by its structure.

##### 4.1 Activated carbon contains pores

In order for carbon to be an effective adsorbent, activation creates a porous structure. The porosity of AC, which includes elements like pore volume, pore size distribution, and surface area, is what essentially determines how successful it is at adsorbing substances. Around 15% of the ash in activated carbon is typically made up of mineral particles (Saleem et al., 2019) Activated carbon acquires its porous structure through carbonization and activation processes, as stated by (Dubinin, 1969). These pores exist in all activated carbon materials and can vary in size and shape, ranging from a few hundred to several thousand nanometers in diameter. The average pore width, which refers to the distance between the walls of a slit-shaped pore or the radius of a cylindrical pore, is commonly employed to classify these pores. The traditional categorization system, developed and officially accepted by the International Union of Pure and Applied Chemistry (IUPAC), is often utilized to classify pore diameters.

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##### 4.2 Crystalline composition

The activated carbon takes on a microcrystalline form as a result of the carbonization process. The crystalline structure is different from graphite's in terms of interlayer spacing. AC has an interlayer spacing of 0.34 and 0.35 nm, whereas graphite has one of 0.335 nm. Based on their capacity to graphitize, activated carbons can be divided into two groups: graphitizing and non-graphitizing. Carbons that graphitize are made up of many parallel layers of graphene. Due to weak crosslinking between adjacent microcrystalline, a less developed porosity structure results, making the final carbon material fragile.

On the other hand, non-graphitizing carbons display a more complicated structure as a result of strong crystallite crosslinking, which results in a well-developed micro-porous structure. By having linked oxygen or a hydrogen shortage in the initial raw

material, this non-graphitizing structure with strong crosslinks is encouraged to form. The types of graphitizing and non-graphitizing carbons are schematically depicted in Figure 6.

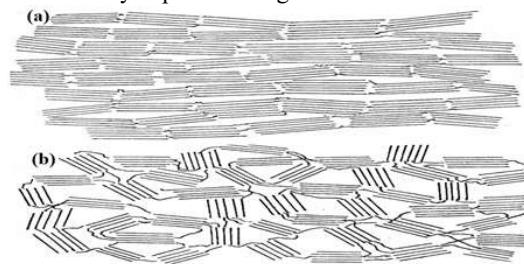


Figure 6. (a) Graphitized carbon (b) Non-graphitized carbon

##### 4.3 Chemical composition

Activated carbon has a chemical structure in addition to being porous and crystalline. While the porous nature of activated carbon plays a major role in determining its adsorption capacity, a very small number of chemically bound heteroatoms, particularly oxygen and hydrogen, also have a substantial impact. The configuration of electron clouds in the carbon framework results in unpaired electrons and partially saturated valences, which affects the adsorption capabilities of activated carbon, especially for polar chemicals.

#### 5. FACTORS INFLUENCE ACTIVATED CARBON CHARACTERISTICS

##### 5.1 Effect of Activating Agent

Physical activation that uses steam and air as activating agents has produced quick reactions. According to research by (Chowdhury et al., 2013), air responds 10 times faster than CO<sub>2</sub> whereas steam reacts with carbon eight times faster. However, a hostile attitude toward carbon can result in burnout both inside the pore structures and on the carbon's exterior surface. The yield is reduced as a result. Due to its slower reaction rate and simpler handling and cleaning procedures, CO<sub>2</sub> is therefore favored (Ioannidou & Zabaniotou, 2007; Tseng & Tseng, 2005).

ZnCl<sub>2</sub>, H<sub>3</sub>PO<sub>4</sub>, NaOH, and KOH are examples of regularly used activating agents in chemical activation (Yahya et al., 2018).

Each of these agents affects the raw materials differently. For instance, KOH was shown to produce the maximum percentage of micropores in activated carbon made from the acorn of the Holk oak (Tezcan Un et al., 2015). By contrasting H<sub>3</sub>PO<sub>4</sub> and ZnCl<sub>2</sub> for the synthesis of activated carbon, the scientists also looked into the effects of activating agents. They discovered that although ZnCl<sub>2</sub> activation produced a pore distribution that included both micropores and mesopores, H<sub>3</sub>PO<sub>4</sub> activation produced a mesoporous

structure. The same goes for (Boualem et al., 2014). Comparable results using  $H_3PO_4$  activation to create activated carbon from sewage sludge. It is therefore hypothesized that utilizing  $H_3PO_4$  as an activating agent aid in the formation of primarily mesoporous carbon with some microporous properties.

According to an earlier work (Prahas et al., 2008), utilizing  $H_3PO_4$  as an activating agent produced more activated carbon than the raw materials fixed carbon content. When activated or carbonized, biomass waste, which is made up of organic polymers like cellulose, lignin, and hemicellulose, goes through a process of decomposition and releases non-carbon components like hydrogen, oxygen, and nitrogen.  $H_3PO_4$  facilitates depolymerization, dehydration, and redistribution of the constituent biopolymers after activation. Additionally, it makes it easier for aliphatic chemicals to transform into aromatic compounds, increasing the amount of activated carbon produced.

According to (Nsi et al., 2016),  $H_3PO_4$  generates a greater yield of activated carbon when compared to  $ZnCl_2$ . However, employing  $ZnCl_2$  results in a higher fixed carbon content. According to research on the activation of Hura Crepitans Linn seed shells with  $H_3PO_4$  and  $ZnCl_2$ , the production of  $H_3PO_4$ -activated carbon was 44.90%, whereas the yield of  $ZnCl_2$ -activated carbon was 31.94%.  $ZnCl_2$ -impregnated activated carbon was more effective at adsorbing methylene blue than  $H_3PO_4$ -impregnated activated carbon. As a result, it can be concluded that  $ZnCl_2$ -impregnated activated carbon possesses well-developed mesoporosity that is advantageous for adsorbing methylene blue molecules of a greater size. (Chowdhury et al., 2013) claim that chemical activation with KOH and NaOH yields activated carbon with large surface areas more than 1000  $m^2/g$ . A prior study found that rice husk activated carbon activated with KOH had a surface area of 2551  $m^2/g$  and activated with NaOH had a surface area of 2952  $m^2/g$  (Chen et al., 2011). These related findings imply that metallic sodium intercalates more slowly than metallic potassium inside the raw material structure, most likely as a result of metallic sodium's higher boiling point (Yang & Qiu, 2011).

### 5.2 Effect of Impregnation Ratio

The weight ratio of the activating agent to the raw material being impregnated, known as the impregnation ratio, is crucial in the chemical process of creating activated carbon (Yahya et al., 2015b). The impregnation ratio has a significant impact on pore growth in addition to carbonization.  $ZnCl_2$  was utilized as the activating agent in a study on the industrial processing of grapes (Yang & Qiu, 2011), which demonstrates this. The raw materials were carbonized at 500°C for 60 minutes using a variety of impregnation ratios of  $ZnCl_2$  (1:1, 2:1, 4:1, 6:1, and 8:1).

According to the findings, mesopores formed when the impregnation ratio was higher, whereas micropores formed when the ratio was lower. This is due to the increased swelling and volatile matter release that happens at higher impregnation ratios, which causes pore widening. On the other hand, lower impregnation ratios encouraged the development of micropores by encouraging the elimination of volatile materials and preventing tar accumulation (Yahya et al., 2018).

The yield of activated carbon is also impacted by the impregnation ratio. This was seen in a study utilizing jackfruit peel that had been impregnated with  $H_3PO_4$  in a variety of ratios (1:1, 2:1, 3:1, and 4:1), then carbonized at a variety of temperatures (350°C, 450°C, and 650°C) (Prahas et al., 2008). The study found that for all carbonization temperatures examined, the yield of activated carbon decreased as the impregnation ratio increased. This can be explained by the extra  $H_3PO_4$  encouraging activated carbon to gasify, which results in a reduction in body weight. Another study also found a similar pattern.

### 5.3 Effect of Temperature

The properties of activated carbon are significantly influenced by the temperature during the carbonisation process. Its pore volume, surface area, and pore shapes are all included in this (Yahya et al., 2015b). The yield of activated carbon typically decreases as carbonisation temperatures rise. Activated carbon composition is also influenced by the temperature at which it is carbonized; at higher temperatures, ash and fixed carbon contents are higher while moisture and volatile matter contents are lower (Ioannidou & Zabaniotou, 2007).

In a study, (Yorgun & Yildiz, 2015) created activated carbon from Paulownia wood at 30, 400, 500, and 600°C carbonisation temperatures. The activating agent,  $H_3PO_4$ , was impregnated in a 4:1 ratio. They noticed that when the carbonisation temperature rose, the output of activated carbon dropped. Additionally, the BET surface area and pore volume rose with the temperature increase from 300 to 400°C. However, as the temperature rose from 400 to 600°C, the surface area and total pore volume shrank. These alterations could be the result of shrinkage in the activated carbon's structure brought on by these temperature variations. The microporous and mesoporous features of the activated carbon produced at carbonisation temperatures between 300 and 600°C were visible.

While different carbonisation temperatures (ranging from 600 to 800°C) were employed, similar patterns were seen in a previous study that used Fox nutshell as the lignocellulosic material for creating activated carbon (Prahas et al., 2008). The activation agent was  $H_3PO_4$ , and the impregnation ratio was 3:2. As the carbonisation temperature rose, the output of activated carbon dropped. As the carbonization temperatures rose, the activated carbon's Microporosity likewise decreased but its

mesoporosity grew. When the carbonisation temperature was increased from 700 to 800°C, BET surface area and total pore volume decreased. The shrinking of the activated carbon structure and the oxidation of the compositions of the raw materials may be responsible for these changes in characteristics.

## 6. APPLICATION OF ACTIVATED CARBON

Since it was initially created in the 1970s, activated carbon has been used in a variety of applications. These utilize activated carbon electrodes in electric double-layer capacitors, wastewater treatment, industrial water treatment, water purification, CO<sub>2</sub> particle capture (Shafeeyan et al., 2010),

pharmaceutical use (Subha & Namasivayam, 2009), gold purification, and other uses.

Organic dyes can be removed from water more effectively with activated carbon thanks to its improved physicochemical properties. According to considerable research that has been documented in this area by numerous studies, activated carbon has mostly been utilized to extract dyes like methylene blue, levafix red, and remazol brilliant blue (Tran et al., 2017). through As reported in a prior study (Spagnoli et al., 2017), activated carbon generated from cashew nuts exhibits superior methylene blue adsorption after chemical treatment with ZnCl<sub>2</sub> because of its improved composition of functional groups and porosity. According to a different study, activated carbon that had been exposed to HCl exhibited poor surface growth and mesopores, which are crucial elements affecting methylene blue's adsorption (Tran et al., 2017).

**Table 2.** Adsorption Studies of Activated Carbon

Objectives	Characterization	Adsorption analysis	Findings	Drawback	Sources
Watermelon seeds to remove reactive yellow 145 dye from an aqueous solution	FTIR, DRX, SEM, specific surface and elementary analysis	Langmuir, Freundlich, Temkin, Elovich and Dubinin-Radushkevich isotherms models. Pseudo-first and pseudo-second-order models.	Watermelon seeds is a good and low-cost adsorbent that can be used for the removal of dyes from aqueous solutions	2m <sup>2</sup> /g is very low surface area for adsorption process, no regeneration	(Benkaddour et al., 2018)
Watermelon seed investigation in the removal of Pb (II) ions from aqueous solutions.		Langmuir, Freundlich. Isotherm Models. Pseudo-first and pseudo-second-order models.	Watermelon seed has viable characteristics for preparing biosorbents	No characterization performed No regeneration	(Adeoye et al., 2020)
Pyrolysis of watermelon seeds for Pb (II) adsorption from wastewater	XRD, FTIR, EDS, Zeta potential analysis, SEM, TEM	Langmuir, Freundlich, Dubinin-Radushkevich isotherms models. Pseudo-first and pseudo-second-order models.	Watermelon seeds biochar can be considered as a promising and cost effective in Pb (II) removal from water/wastewater	No surface area characterization of the adsorbent	(Ahmed et al., 2021)
Pyrolysis of peanut shells and agricultural wastes to adsorb Pb <sup>2+</sup>	SEM, FTIR, partial and elemental analysis, and BET tests.	Langmuir, Freundlich, and Temkin isotherm	The adsorbent was chemically stable enough to adsorb the Pb ions onto the surface.	No kinetic and regeneration studies reported	(Natrayan et al., 2022)
Melon shell to remove Fe (II) and Mn (II) from fish pond Aqua culture	FT-IR, BET EDX and SEM analysis	Freundlich Isotherm and Longmuir it fit Pseudo-first and pseudo-second order kinetics	Melon shell has the potentials for treatment of waste water From fish pond.	No regeneration, and no surface area for the adsorption process	(Ibrahim A, Oluwarade Al, Adekola F, 2022)



Objectives	Characterization	Adsorption analysis	Findings	Drawback	Sources
Rock melon shell for the removal of Cd (II), Ni (II) and Cu (II) from waste water	FEM SEM, BET, AAS	Freundlich Isotherm and Langmuir it fit Pseudo-first and second-order and second order kinetics	RMAC act as a potential low-cost adsorbent for removal of heavy metals from aqueous solution waste water model	No Regeneration	(Nuridin et al., 2015)
Melon husk used in industrial water treatment	-	Langmuir and isotherms Second-order sorption kinetics	Melon husk is very suitable in the removal of electroplating industrial waste water	No characterization and regeneration	(A. Ajala, 2022)
Melon peels for removal Cu (II), Cd (II), and Pb (II) ions from aqueous solution	BET, SEM and FTIR	Langmuir and isotherms models Pseudo-first and second-order kinetic models	The hazardous heavy metals were successfully removed with high efficiency and regeneration of metals was carried out using mineral acid HCl.	-	(Ahmadi et al., 2022)
Melon Seed Husk for removing Cr (IV) from electroplating waste water	SEM, BET	SE and isotherms models Pseudo-second-order kinetic models	Effective adsorbent for removal of Cr(iv) ion from electroplating waste water	No regeneration	(Bernard, 2021)

It has been used to produce alcohol and other alcoholic beverages, fruit syrups, fresh water, medical supplies, and to shield humans from harmful chemical substances. It has also been used to clean industrial sewage and gas emissions. Additionally, numerous studies have emphasized the potential of agriculturally sourced activated carbon in the pharmaceutical business. For substances such acetaminophen, tetracycline, ofloxacin, caffeine, and penicillin, it works well as an adsorbent (Yahya et al., 2018). Pharmaceutical contaminants have been observed to be removed more effectively by activated carbon adsorption than by biological treatment, chemical oxidation, and membrane filtration (Tan et al., 2017).

## 7. CONCLUSION

This study revealed that activated carbon may be successfully produced with desirable characteristics as a large surface area, high micro porosity, and selectivity. Agricultural residues can be found locally, are useful, and are more affordable than commercially manufactured activated carbon in a number of applications such as precursors for activated carbon. Substantial additional research is required on AC especially in the manufacturing procedures, enhancing the qualities and applications of activated carbon in a variety of industries, including the mineral industry, food industry, gas cleaning, and wastewater treatment.

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