

# A COMPREHENSIVE ANALYSIS OF THE USE OF CHEMICAL ACTIVATION TECHNOLOGY TO PRODUCE ACTIVATED CARBON FROM AGRICULTURAL RESIDUES

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Environmental and industrial sectors widely use activated carbon with a porous structure, a product of chemical or physical activation. In this work, we looked at both processes for making activated carbon from agricultural residue. The review focuses on the chemical agents used during chemical activation, namely phosphoric acid, potassium or sodium hydroxide, and zinc chloride. Despite phosphoric acid's extensive use in lignocellulosic materials, it produces a smaller specific surface area than zinc chloride. However, the use of the latter remains limited due to environmental problems. Potassium and sodium hydroxide generally produce activated carbons with remarkable porosity, which is beneficial for adsorbing large pollutants, such as dyes. Physical activation yields activated carbons with greater porosity, compared to chemical activation. Although chemical activation can introduce mineral impurities trapped in the pores of the coal, it remains profitable and offers the advantage of resulting in a diversified and controlled pore size distribution. This review talks about how different activating agents can change chemicals to make activated carbon from biomass. The effectiveness of activated carbons and their applications, such as wastewater pollutant absorption, are also discussed.

**Keywords:** activated carbon, agricultural waste, chemical activation, physical activation, adsorption, removal

## INTRODUCTION

In today's global scenario, environmental concerns regarding emissions have escalated significantly. Industrial effluents often contain a myriad of heavy metals and organic pollutants, which, when constantly released into the environment, pose serious risks to both aquatic ecosystems and human health.<sup>1-7</sup> Thus, wastewater containing persistent pollutants not properly controlled with the increase in global population causes water pollution worldwide.<sup>5-7</sup>

The problem becomes even more serious when it comes to non-biodegradable and toxic substances. Originally, heavy metals were considered to be the most harmful elements. Furthermore, the environment still contains heavy metals, as well as dyes. At very low levels, they are essential for living beings.<sup>3,8-12</sup> Conversely, at elevated quantities, they are very harmful because of their impacts on organisms, their chemical, physicochemical, and biological characteristics,

and their toxic effects and impacts on the environment. In this regard, upstream treatment of industrial effluents is essential in order to protect natural reserves. In this environmental context, reducing pollutant concentrations remains a major concern. Thus, investigations in this area are required, and therefore, various wastewater treatment techniques have been developed and improved to overcome this problem. Among them are electrochemical degradation,<sup>13–15</sup> adsorption,<sup>2,16–18</sup> photocatalytic degradation,<sup>19–21</sup> advanced oxidation processes,<sup>15,22</sup> and ion exchange.<sup>23</sup> The treatment most commonly used for the elimination of these pollutants is notably adsorption, due to its technically and economically very interesting performances.<sup>2,16</sup> A variety of materials are employed in this process, including aluminas, clays, silicas, activated carbon, ion exchange resins *etc.* The use of these materials is effective due to their feasibility of design and operation, processing efficiency, and regeneration of adsorbents.<sup>2,18,24</sup>

A great deal of study has been done on the production of inexpensive, eco-friendly adsorbent materials from abundant, renewable biomass sources.<sup>25–27</sup> The manufacturing of a broad range of adsorbents made from biomass has increased recently. The methods utilized to create activated carbon as an adsorbent are the main subject of this research. Active carbon's high specific surface area and high porosity make it an especially effective adsorbent.<sup>2,18,24,27</sup> This allows it to effectively hang on to a variety of contaminants, even when there are only trace levels of certain pollutants present. Activated carbon often inhibits the removal of contaminants from the effluent when living organisms cannot break them down or when harmful compounds reduce the effectiveness of biological treatments. Many studies suggest that plant biomass can be used to produce high-quality activated carbon. This includes the utilization of bamboo plants, wood, olive pits, apricot pits, coconut shells, waste oranges, date pits, coffee grounds, almond hulls, corn cob waste, sawdust from *Acacia glauca*, potato residue, rice husks, sunflower pits, tomato stems, banana peels, and other materials.<sup>2,27,29–33</sup> Cellulose, which accounts for 35–83 percent of plant biomass; hemicelluloses, which account for 0–30 percent; and lignin, which accounts for 1–43 percent, are the three components that separate plant biomasses from animals.<sup>34–36</sup> Typically, the creation of activated carbon begins with carbonization, followed by an activation process

that enhances the morphological features of the carbonized material.<sup>2,29</sup> Activation can be of two different types: chemical and physical. Activated carbons are commonly used in treating wastewater, purifying gas, and facilitating catalytic processes. Furthermore, activated carbons find applications in the fields of biomedical engineering and metal recovery, in addition to their usage in the electronics sector.

Studies on activated carbon preparation reported since 2012 will be discussed in this review. Likewise, the influence of the activating agents involved during chemical activation on the performance and characteristics of carbon materials will be discussed, focusing on the role that activated carbon plays in wastewater treatment.

## METHODOLOGY

In the course of our investigation, research publications that were published between 2012 and 2022 focusing on the generation of activated carbon from bio-waste have been reviewed. The purpose of these articles was to discuss various activation processes and the use of activated carbon for the purpose of removing various contaminants from aqueous media.

The first step was to conduct a thorough analysis of the resources that the researchers used. Specifically, this included doing an initial assessment of titles, abstracts, and techniques, where required. Additionally, the final articles selected required further investigation through full-text analysis, allowing for a more comprehensive evaluation of relevant publications. After that, the papers were carefully reviewed and selected as those that discussed the adsorption of various contaminants using activated carbon, which was produced by a variety of activating agents. More than 350 articles were found. After that, the study focus was narrowed to studies associated with obtaining activated carbon via chemical activation, specifically those focused on removing pollutants from aqueous media. As a result, 180 items were kept for additional study. The study concentrated on the primary agricultural waste, which undergoes chemical activation to prepare activated carbon. Additionally, the study examined the parameters that influence the preparation process. These parameters encompass the type of activating agent, the duration of activation, the activation temperature, and the impregnation rate. In addition, a comparison was

done between the performances and features of activated carbon that was manufactured utilizing various chemical agents throughout the process.

### PRODUCTION OF ACTIVATED CARBON

As a type of adsorbents, activated carbons are used in the process of purifying effluents that are either gaseous or liquid in nature. As a result, they have gained a great deal of notoriety and are used in a variety of industrial fields. Activation is a controlled oxidation method that is used to generate internal porosity in porous carbon materials. These materials are formed after the pyrolysis of biomass and are then taken through the activation process. It is possible to optimize

the porosity by taking into consideration the parameters of the pyrolysis, as well as the kind of activation. Activated carbons have the benefit of being excellent adsorbents, which are often used in a media that are either gaseous or aqueous, and are composed of either organic or inorganic chemicals.<sup>2,27,32,37,38</sup> A variety of treatment methods can produce activated carbon. Cost estimation and the latent extent of activated carbon primarily determine the method chosen. These activation methods are classified into two categories: one physical and the other chemical (Fig. 1).

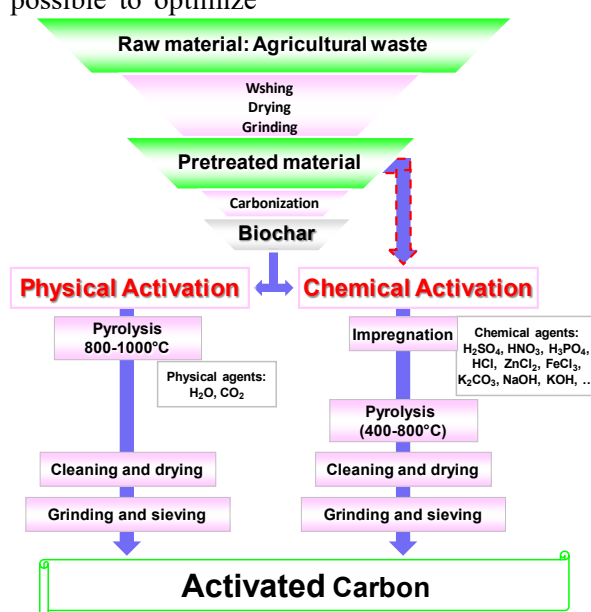


Figure 1: Schematic of the physical and chemical activation process

The raw material goes through a carbonization step before the activation step. This makes “biochar”, a solid carbonaceous framework that forms the basis for the porous properties of the activated carbon that follows. This carbonization process unfolds within an inert atmosphere, typically facilitated by a nitrogen purge. During this phase, the precursor material expels volatile components. Subsequently, the char produced during carbonization progresses to the activation stage.

#### Physical activation to produce activated carbon

Physical activation has the ability to produce activated carbon with a porous structure and good physical power. It is considered a green approach because it is chemical-free.<sup>39-41</sup> Notably, physical

activation diverges from chemical activation by not involving the impregnation of activating agents into the char. Instead, it relies on the development of the porous structure through exposure to gases possessing oxidizing properties, such as carbon dioxide, steam, or a combination thereof.<sup>32,38,40,41</sup> Operators place the biochar in an activation furnace and introduce high-temperature oxidizing gases. The choice of gas and the specific activation conditions, including temperature, duration, and gas flow rate, significantly impact the evolution of the porous structure. Carbon dioxide and steam react with the carbon, creating small pores both on the surface and within the char’s structure. Adjusting the duration of gas exposure and the flow rate allows precise control over the extent of pore formation, with longer exposure and higher gas flow rates

resulting in a more extensive porous network.<sup>32,38,40,41</sup> After reaching the desired level of activation, the activated carbon is collected and cooled for further processing and application. The end product boasts a highly porous structure, with well-defined pore sizes, rendering it suitable for a wide range of applications. When specific control over pore size and distribution is necessary, physical activation is preferred, despite its potential drawbacks of higher energy consumption and longer activation times, compared to chemical activation.<sup>30,37,40</sup>

### **Chemical activation to produce activated carbon**

Chemical activation, also known as wet oxidation, involves the use of a chemical product as an activator, which in turn encourages the process of dehydration. This is then followed by a pyrolysis stage, which guarantees a structural rearrangement of the material at temperatures ranging from 400 to 800 °C.<sup>32,37,42</sup> In the case of cellulose precursors, this particular method of activation is often used. To begin the chemical activation process, the biochar is first impregnated in an aqueous solution that contains the activating agent. This is then followed by thermal activation in an inert environment, typically with nitrogen aeration.<sup>2,32,42,43</sup> When it comes to chemical activation, the method of activation is often determined by the type of the activating agent. The activation agent has the potential to bring about alterations within the macromolecules that make up the lignocellulosic biomass, hydrolysis processes that take place and bring about the dissolution of numerous amorphous macromolecules, and the modification of the lignocellulosic matrix. All of these changes may take place during the impregnation process. In spite of the fact that chemical activation may result in the introduction of mineral impurities that get lodged in the pores of the coal, it continues to be economical and gives the benefit of producing a pore size distribution that is both diverse and regulated. The activators, in point of fact, undergo a reaction with the carbon matrices, which results in the release of gaseous compounds that produce a porous structure. At the conclusion of the activation process, it is necessary to do more than one washing phase in order to eliminate them, which is one of the issues that arises with this procedure. Additionally, chemical activation is more cost-effective than physical activation, which necessitates a greater activation

temperature during the activation process.<sup>2,32,42–44</sup> It has been discovered that the selection of chemical activation parameters serves as a significant factor in determining the effectiveness of the activation process, as well as the quality of the activated carbon that is produced. The influence of the activating agent, the impregnation ratio, the length of the pyrolysis process, and the temperature are the primary factors with which these parameters are concerned.<sup>32,42,45</sup> Within this framework, a number of studies that have been conducted on the process of preparing activated carbon using the chemical activation method have shown that the degree of impregnation is the primary factor that determines the pore size of the final materials: the greater the degree of impregnation, the bigger the pore diameter. These activated carbons, in addition, have a structure that is open and porous, making them an excellent choice for the adsorption of complex compounds. In many cases, the choice of activating agent is determined by the fundamental characteristics of the precursor materials. When activated for a longer period of time, the degree of activation, which is a measure of the porosity's quality, improves. Both the specific surface area and the average pore width of activated carbon are significantly impacted by the temperature and the length of time at which the pyrolysis process is carried out.

### **Activation with phosphoric acid**

Activation with phosphoric acid for preparing activated carbon is widely employed for various lignocellulosic materials.<sup>30,43,45</sup> Phosphoric acid is recognized for its effectiveness in this activation process; it reacts initially with cellulose and lignin due to cellulose's acid hydrolysis resistance. Table 1 illustrates selected studies on phosphoric acid activation and the corresponding details of the resultant activated carbon. The impregnation step is crucial to controlling the interactions with the substrate within the solution. The concentration of the solution plays a central role in the activation process using phosphoric acid, which has a high polarity.<sup>30,64</sup> In this context, research has revealed that the development of pores and cavities on the surface of activated carbon comes from the evaporation of phosphoric acid during carbonization at high temperatures.<sup>30,47,48,50,64–68</sup> Indeed, activation with phosphoric acid promotes the pyrolytic decomposition of the precursor and, consequently, the depolymerization and dehydration of the

constituent biopolymers. It also combines with the organic species of the precursor to form phosphate bridges crosslinked by a phosphate ester, thus connecting the biopolymer fragments.<sup>46,48,67,69</sup> Phosphor-carbon species, elemental phosphorus, after activation by phosphoric acid in phenolic resins and polymer fibers, can be formed according to the reactions listed in Figure 2.<sup>46,48</sup>

Researchers have noted that active carbons display acidity. The acidity of the activated carbon surfaces is enhanced by the presence of phosphoric acid, which leads to the formation of oxygen functional groups on the carbon. This increase in acidity is ascribed to the activation process.<sup>12,46,48,59,62,70,71</sup> Arampatzidou and Deliyanni<sup>62</sup> noticed that the activated carbons obtained from potato peelings by activation with

phosphoric acid were acidic, but the activated carbons obtained through activation with potassium hydroxide were basic. As a result of acid activation at a temperature of 400 °C, activated carbon has a microporous structure that has a specific surface area of 904 m<sup>2</sup>/g. Having a maximum adsorption amount of 445.92 mg/g, this structure with large pores proved to be advantageous for the retention of bisphenol-A. They all used acid activation to make activated carbon from fir sawdust, rape straw, and pomelo peel, and the results were similar. These were found by Popovici *et al.*,<sup>59</sup> Wang *et al.*,<sup>63</sup> and Sun *et al.*<sup>51</sup> Activated carbons were used to retain p-nitrophenol, carbendazim, and ciprofloxacin, with maximum adsorption capacities of 295.39 mg/g, 111.31 mg/g, and 400 mg/g, respectively.

Table 1  
Some textural characteristics and adsorption capacity of activated carbon prepared via phosphoric acid activation from agricultural wastes

Precursor	IR	T (°C)	t (min)	S <sub>BET</sub> (m <sup>2</sup> /g)	V <sub>T</sub> (cm <sup>3</sup> /g)	Pollutant	q <sub>max</sub> (mg/g)	Ref.
Persian mesquite grain	1	600	2	1243	0.651	Lead	273	46
Almond shell	1	400	75	1128	0.67	Toluene	601.7	47
	1	600	30	926	0.624	Toluene	598.4	
Potato peel waste	2	400	120	904	0.726	Co(II)	373	48
	2	600	120	1041	2.960	Co(II)	405	
Cotton cake	2	450	90	584	0.298	Methylene blue	250	49
	2.4	450	120	853	1.96	Cu(II)	8.3	
Kenaf	2.4	500	120	1567	2.8	Cu(II)	1.5	50
	2.4	550	120	2145	2.44	Cu(II)	1.3	
Fox nutshell	1.5	700	60	2636	1.53	Cr(VI)	74.95	43
<i>Arundo donax</i> Linn	2.5	450	60	675	0.312	Ciprofloxacin	244	51
Pomelo peel	2.5	450	60	1252	1.33	Ciprofloxacin	400	
Guava seeds	1	600	60	471	0.31	Lead	11	52
Water hyacinth biowaste	1.5	600	80	1421	0.741	Metformin	122.47	53
						Cr(III)	0.35	
Passion fruit shells	1	600	30	1.44	0.0039	Cu(II)	0.52	12
						Ni(II)	0.34	
Potato peel waste	1.66	500	30	676	0.26	Pb(II)	8.9	9
Watermelon rind	2	500	70	710	0.263	Pb(II)	40.98	54
						Zn(II)	11.31	
Walnut shell	2	500	70	789	0.304	Pb(II)	32.36	
						Zn(II)	6.079	
Lemon peel	2	500	60	1158		Lead	90.91	55
Hazelnut shell	0.6	500	60	717	0.1983	acetic acid	434.78	56
Spent tea leaves	1	600	60	1056		aspirin	178.57	57
Pinewood sawdust	1	500	3	1537	0.7272	Cu(II)	20.2	58
Fir sawdust	1	450	60	4.9	0.012	p-nitrophenol	295.39	59
<i>Vitis vinifera</i> leaf	0.4	600	60	295	0.18544	phenanthrene	89.13	60
Oak wood	1	450	60	790	0.545	phenol	250	61
Potato peel waste	2.5	400	120	904	0.726	bisphenol-A	445.92	62
Rape straw	1	400	120	1053	1.06	carbendazim	111.31	63

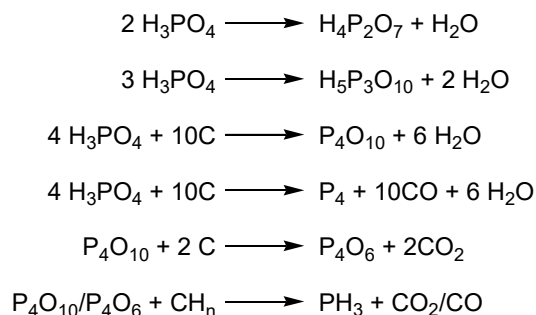


Figure 2: Activation mechanisms using phosphoric acid

Based on the findings of many studies,<sup>50,53,58,60,67,68,71,72</sup> it has been shown that increasing the quantity of phosphoric acid results in the activator and precursor coming into greater contact with one another. This facilitates the opening of pores in the final substance, which in turn causes the holes to get larger. Nevertheless, the creation of an insulating layer on the activated carbon is ensured by the presence of an excessive amount of acid. During the process of preparing activated carbon from pinewood sawdust, Gao *et al.*<sup>58</sup> found that an increase in the concentration of phosphoric acid resulted in a larger porosity, which was accompanied by the creation of tiny pores. An impregnation ratio of one results in the production of a material that has a structure that is comparable to that of the predecessor and is characterized by pores that are honeycomb-shaped. Moving to an impregnation ratio of four and increasing the temperature of the pyrolysis to 800 °C caused the particles to get smaller, which ultimately led to the amazing destruction of the tunnels. The specific surface area expanded from 1537.5 m<sup>2</sup>/g to 1750.7 m<sup>2</sup>/g, while the total pore volume increased from 0.7272 cm<sup>3</sup>/g to 1.7716 cm<sup>3</sup>/g. Both of these expansions occurred simultaneously. According to the findings of these scientists, the honeycomb structure has a capacity of 20.2 mg/g for the adsorption of copper(II), making it an ideal candidate for the process.<sup>58</sup> At the same time, other researchers reported that a pyrolysis temperature that ranged from 400 to 600 °C and an impregnation ratio that was less than three were suitable for the production of activated carbon from a variety of biomass resources that possessed suitable characteristics for the retention of a wide range of pollutants.<sup>9,12,47,50,54,56,61,62</sup> According to the findings of these investigations, phosphoric acid is an effective activator because it creates holes on the surface of activated carbon that are in the form of tunnels and have a honeycomb structure. When it comes to the

retention of organic contaminants and metals in aqueous solutions, this structure is an excellent choice.

#### **Activation with zinc chloride**

Activators frequently use zinc chloride, a Lewis acid, to create activated carbon from biomass. Table 2 presents the main properties of activated carbons resulting from the activation with zinc chloride. Despite the potential environmental issues, the widespread preference for zinc chloride stems from its effective production of activated carbon with a larger surface area.<sup>90,95-97</sup> Activated carbons with a high mesoporous volume are suitable for the adsorption of large molecules and find their applications in many applications (catalysis, batteries, electrochemistry, *etc.*), while those with a high microporous volume are suitable for small molecules.<sup>79,90,95,97</sup> Zhang *et al.*<sup>73</sup> prepared activated carbon from waste potato residue. They obtained a mesoporous material with a specific surface area and a mesopore volume of 1357 m<sup>2</sup>/g and 1.065 cm<sup>3</sup>/g, respectively, prepared with an impregnation rate of 1.5, a temperature of 600 °C, and a holding time of 60 min. This carbon was successfully used to retain Methylene blue with an adsorption capacity of 540 mg/g. Other studies,<sup>76-78,80,82,86,87,89,92,95</sup> have produced activated carbon, with a large specific surface area and a porous structure, from various agricultural wastes. These studies suggest that these carbons were favorable for the elimination of large pollutants, such as ciprofloxacin, acid orange 7, methylene blue, phenol, norfloxacin, congo red.

A comparative study between activation by potassium hydroxide and zinc chloride during the synthesis of activated carbon from *Pisum sativum* pea pod<sup>82</sup> showed that activation with ZnCl<sub>2</sub> is preferred to obtain an activated carbon with a high specific surface area of 1299 m<sup>2</sup>/g, a total pore volume of 0.618 cm<sup>3</sup>/g, and a maximum

adsorption capacity of Acid Orange 7 of 473.93 mg/g.<sup>82</sup> Indeed, ZnCl<sub>2</sub> acts as a strong desiccant, allowing dehydration and dehydrogenation of the hydroaromatic structure by reaction with the hydroxyl groups present in the biomass. Thus, hydrated zinc oxide chloride is formed, which releases ZnCl<sub>2</sub> gas under the effect of raising the temperature, which prevents the formation of tar inside the pores formed.<sup>75,82,90,95</sup> Thus, during pyrolysis, dehydration of the raw material occurs, which results in carbonization and aromatization

of the carbon skeleton, and consequently, pore enlargement occurs, and the micropores formed will be converted into mesopores.<sup>79,82,90,91,95,98</sup> A specific surface area of 2869 m<sup>2</sup>/g was found for fox shell activated at a ratio of 2 by ZnCl<sub>2</sub>, a temperature of 600 °C and a duration of 60 min.<sup>77</sup> It turns out that ZnCl<sub>2</sub> causes the molecular structure of cellulose to swell by breaking the lateral bonds of the cellulose chains, which results in an increase in voids for a higher specific surface area.<sup>77,86,95</sup>

Table 2

Comparison of textural characteristics and adsorption capacity of activated carbon prepared via ZnCl<sub>2</sub> activation from some agricultural wastes

Precursor	IR	T (°C)	t (min)	S <sub>BET</sub> (m <sup>2</sup> /g)	V <sub>T</sub> (cm <sup>3</sup> /g)	Pollutant	q <sub>max</sub> (mg/g)	Ref.
Waste potato residue	1.5	600	60	1357	1.065	Methylene blue	540	73
<i>Scenedesmus obliquus</i>	3	600	120	424	0.1643	Astrazon red	181.82	74
<i>Glycyrrhiza glabra</i> residues	2	850	60	959	0.5431	Phosphate	92.59	75
Vine shoots	0.75	700	120	1689	0.842	Rifampicine	476.2	76
Fox nutshell	2	600	60	2869	1.96	Phenol	75.37	77
Cashew nut shell	1.5	400	120	1100	0.565	Methylene blue	476	78
<i>Dipterocarpus alatus</i> fruit	2	500	60	843		Methylene blue	269.3	79
Ashitaba waste	4	800	90	1228		Congo red	345.17	80
Walnut shell	4	800	90	1627			281.45	
Buriti shells	3	700	90	843	0.490	Methylene blue	274.62	81
<i>Pisum sativum</i> pea pod	0.5	800	60	1299	0.618	Acid orange 7	473.93	82
Black wattle bark waste	1	700	120	414	0.064	Phenol	98.6	83
Potato peel waste	3	400	120	25	0.035	Bisphenol-A	197.01	62
Tomato waste	6	600	60	1093	1.569	Methylene blue	400	84
						Metanil yellow	385	
<i>Jatropha</i> husk	1	800	60	822		Acid blue 83	27.93	85
Red mombin seeds	1	600	120	1508	0.778		404	
Corn cob	1	600	120	1280	0.596		264	
Coffee husk	1	600	120	793	0.428		235	
Internal mango seeds	1	600	120	1279	0.661	Norfloracin	262	86
External mango seeds	1	600	120	1005	0.700		221	
Ice cream beans	1	600	120	306	0.186		84	
<i>Syagrus romanzoffiana</i>	1	450	45	1435	0.8762	Ciprofloxacin	335.8	87
Tea waste	1	600	120	865.4	0.5032	Sodium diclofenac	62	88
						Catechol	270.22	
<i>Helianthus annuus</i>	1.5	800	60	1374	2.0463	Resorcinol	247.45	89
Fir sawdust	1	450	60	31	0.069	p-nitrophenol	318.670	59
Grape waste	6	600	60	1455	2.318	Methylene blue	417	90
						Metanil yellow	386	
<i>Psidium guajava</i>	3	500	60	919	0.2726	2,4-dichlorophenol	20.9	91
Sugar cane bagasse	3	500	120	1145	1.3	Diclofenac sodium	315	92
Mangosteen peel waste	4	600	30	1622	1.805	Methylene blue	1193	93
<i>Caesalpinia ferrea</i> seed	1.5	600	60	1480	0.572	Captopril	535.5	94
<i>Elaeagnus angustifolia</i> L.	1.5	450	60	2021	1.293	Methylene blue	425	95

Optimizing the impregnation ratio and the temperature and duration of pyrolysis is necessary for the successful synthesis of activated carbon with the desired properties. There is evidence that

a lot of zinc chloride can break down and crack the structure of the activated carbon, which can change micropores into mesopores

**Activation with alkaline hydroxides**

Alkaline hydroxides (KOH, NaOH) are also widely used as activating agents (Table 3).<sup>2,95,99-104</sup> These basic agents are very effective in transforming carbonized carbons into activated carbons, which are characterized by narrow pores and a large specific surface area. Alkaline hydroxides promote the enlargement of the porosity of the obtained material. Reduction reactions and oxidative modifications link the development of microporosity to the degradation and separation of carbonic layers. Reactions thus occur between the intermediates formed (Fig. 3), causing the release of mono- and carbon dioxide and dihydrogen, allowing the enlargement of the pores.

Various studies have shown that, when an alkaline hydroxide is used to chemically activate carbon, numerous micropores and mesopores are formed on the surface of the resulting material.<sup>2,17,102,105,108,112,114,118,124,125</sup> A study conducted by Mistar *et al.*<sup>102</sup> to examine the physicochemical characteristics of activated carbon synthesized from *Bambusa vulgaris striata*

by chemical activation using KOH showed that an impregnation rate of 3 and a temperature of 800 °C for 60 min were the optimal conditions. The synthesized activated carbon has a specific surface area of 980 m<sup>2</sup>/g and a mesoporous structure. Increasing the activation temperature and the impregnation ratio increases the microporosity of the synthesized activated carbon. Conversely, mesoporosity decreased. The activated carbons produced in this study were mostly microporous, but they also had mesopores. These results are consistent with other research using alkali hydroxides as an activating chemical agent.<sup>17,105,108,116,114,117</sup> An excess of activating agent could lead to catalytic oxidation and decomposition of the carbon skeleton of the biochar or the precursor of charcoal, resulting in a reduction in porosity and specific surface area. Baysal *et al.*<sup>117</sup> reported that NaOH-activated active carbon from sunflower pith had a specific surface area of 2690 m<sup>2</sup>/g, which was higher than that of KOH-activated carbon (2090 m<sup>2</sup>/g) (Table 3).

Table 3  
Some textural characteristics and adsorption capacity of activated carbon prepared via Potassium or sodium hydroxide activation from agricultural wastes.

Precursor	IR	T (°C)	t (min)	KOH		Pollutant	q <sub>max</sub> (mg/g)	Ref.
				S <sub>BET</sub> (m <sup>2</sup> /g)	V <sub>t</sub> (cm <sup>3</sup> /g)			
Coconut fibers	2	900	150	1556	0.72	Methylene blue	21.3	103
						Congo red	22.1	
						Neutral red	20.7	
Corn cob	2	800	60	1054		Hg(II)	2.39	101
Date fruit residues	3	700	90	2760	1.3085	Cefixime	571.5	105
Rice husk	3	750	60	2138		Phenol	201	106
Date stones	1.25	500	60	817	0.638	Levofloxacin	100.38	107
						Cu(II)	84.7	
<i>Ulva lactuca</i>	3	800	180	345	0.320	Cd(II)	84.6	108
						Cr(III)	82	
						Pb(II)	83.3	
						Pb(II)	492	
Rice husk	3	800	90	2786	1.671	Pb(II)	492	104
Banyan root	2.5	500	60	988		Phenol	26.95	109
<i>Euryale ferox</i> shell	4	800	120	2028	0.98	Methylene blue	617	110
Potato peel waste	1.4	600	120	271	0.306	Bisphenol-A	195.52	62
Cocoa pod husk	0.75	800	30	1800	1	Methylene blue	109.9	111
<i>Schima wallichii</i>	2	600	120	1005	0.491	Fluoride	2.524	112
Tea waste	1	600	120	416	0.2155	Sodium diclofenac	74.6	88
Olive pomace	4	840	120	2451		Sulfadiazine	66.22	113
Coconut fiber	3	800	180	1755	1	chloramphenicol	523	114
Fir sawdust	1	450	60	12	0.033	p-nitrophenol	305.81	59
Pomegranate peel	1	700	30	941	0.470	Remazol brilliant	370.86	115
						Blue reactive		
Pomelo peel	2	800	150	1892	1.095	Methyl orange	680.2	116



Date press cake	3	750	90	2632	1.239	Methylene blue	546.8	39
Sunflower pith	3	700	60	2090	1.24	Methylene blue	580.6	117
<i>Elaeagnus angustifolia</i> L.	1.5	800	60	1816	0.978	Methylene blue	727.4	95
NaOH								
Precursor	IR (g/g)	T (°C)	t (min)	SBET (m <sup>2</sup> /g)	Vt (cm <sup>3</sup> /g)	Pollutant	q <sub>max</sub> (mg/g)	Ref.
Date palm petiole	2	600	120	655		Indigo carmine	35.08	118
Coconut shells	3	600	60	876	0.441	Methylene blue	200	119
Date fruit residues	3	700	90	2623	1.3394	Cefixime	557.9	105
Guava seeds	3	750	90	2573	1.260	Amoxicillin	570.48	99
Olive stones	1	700	60	1299	0.432	Cu(II)	50.29	8
						Zn(II)	43.72	
<i>L. leucocephala</i> seed shell	0.1	550	120	89	0.0232	Cr(VI)	27.53	120
Macadamia nut shells	3	700	90	1524	0.826	Tetracycline	455.33	121
Rattan	3	600	60	1135	0.61	Methylene blue	359	122
Date press cake	2	650	90	2025	0.932	Cr(VI)	282.8	123
<i>Opuntia ficus indica</i>	2	600	120	332	0.017	p-nitrophenol	16.835	17
Sunflower pith	3	700	60	2690	1.75	Methylene blue	965	117

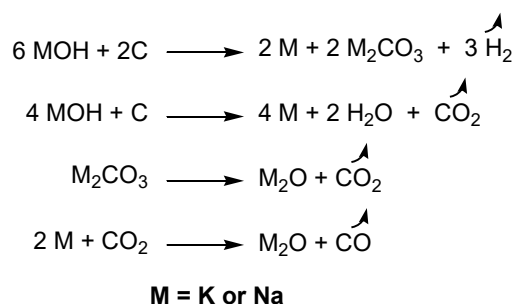


Figure 3: Activation mechanisms using alkaline hydroxide

The maximum adsorption capacity of Methylene blue was calculated at 965 mg/g and 580 mg/g respectively. Sodium hydroxide (NaOH) appeared to be more reactive, causing the micropores in the structure to coalesce and collapse to form mesopores, while activation with potassium hydroxide mainly caused the development of micropores with a very narrow pore distribution. Furthermore, Hasanzadeh *et al.*<sup>105</sup> reported that the activation with potassium hydroxide was more favorable for producing activated carbon with a microporous structure from date fruit residues, with a specific surface area of 2760 m<sup>2</sup>/g, which has a retention capacity of Cefixime of the order of 571.5 mg/g.<sup>105</sup> Indeed, the penetration of alkaline hydroxides into the structure of the precursor and the combustion of certain carbon bonds cause the development of pores in the carbon structure. Thus, an expansion of the pores occurs, which then reduces the specific surface area of the porous material.<sup>105</sup> As a result, sodium hydroxide has greater resistance to breaking carbon bonds in date fruit residue. The same observation was made by Pezoti *et al.*,<sup>99</sup> who reported the effectiveness of sodium

hydroxide as an activating agent for disordered carbonaceous materials by promoting pore enlargement. These authors were able to obtain activated carbon from guava seeds with a specific surface area of 2573 m<sup>2</sup>/g and a microporous structure with cavities on the surface in the form of channels, suitable for the retention of Amoxicillin molecules in the carbon structure, with an adsorption capacity of 570.48 mg/g.<sup>98</sup> Furthermore, Ibrahim *et al.*<sup>108</sup> synthesized activated carbon from *Ulva lactuca* by activation with potassium hydroxide with an impregnation ratio equal to 3, an activation temperature of 800 °C and duration of 180 min. The material obtained has a microporous structure and a specific surface area of 345 m<sup>2</sup>/g to be used effectively for the retention of Cu(II), Cd(II), Cr(III), and Pb(II) with maximum adsorption capacities of 84.7 mg/g, 84.6 mg/g, 82 mg/g, and 83.3 mg/g.<sup>108</sup>

## CONCLUSION

This review article presented a diverse range of activated carbons derived from agricultural wastes. The paper strongly emphasized the need

to select the optimal activation method. Thus, a comparative analysis of the three main activating agents most commonly used for the preparation of activated carbon has been meticulously presented in tabular form. Micro- and meso-porous volumes, surface area, and the judicious selection of activating agents and raw materials play a crucial role. Neutral activation is a safer approach, but it leads to relatively lower and less economically favorable returns. Therefore, acid activation emerges as the most effective treatment, capable of improving surface area and microporosity, when performed under tightly controlled conditions. Furthermore, the complex mechanism underlying the adsorption of contaminants on the activated carbon surface was discussed. In this context, activated carbons are highly recognized and extensively utilized across various industrial sectors. These porous carbon materials are produced following the pyrolysis of biomass and subjected to a controlled oxidation process called activation to develop internal porosity. Taking into account the pyrolysis conditions (nature of the precursor, pyrolysis temperature, and heating rate) and the type of activation (either physical or chemical) leads to the optimization of the porosity (specific surface area, size, and pore volume).

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