

Activated carbon from agricultural residues: a review

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Received 17 March 2022; Accepted 12 October 2022

ABSTRACT

Because of its high adsorption capacity, activated carbon is frequently employed as an effective adsorbent. Activated carbon is a main element for treatment of wastewater, groundwater and water purification. The activating agents greatly affects the porosity and surface area of the produced activated carbon. In this study, the use of agricultural leftovers for the production of activated carbon is discussed in detail. The pyrolysis stage is investigated in relation to a number of process variables. The effects of physical and chemical activation circumstances on the properties of activated carbon are discussed. Under controlled process conditions, many active carbons with Brunauer–Emmett–Teller surface areas ranging from 250 to 2,410 m²/g and pore volumes ranging from 0.022 to 91.4 cm³/g were produced. A review of reaction kinetic modelling applied to pyrolysis of agricultural wastes is also carried out. In this study, effort has been given to show the preparation of activated carbon from various agricultural residues. Also the comparisons of different activated carbon prepared from various agricultural residues have been shown. In the present review, the preparation of activated carbon by treating with different chemicals has also been incorporated.

Keywords: Activated carbon; Chemical reactor; Carbonization; Physical activation; Chemical activation

1. Introduction

Many centuries ago, activated carbon (AC) was used as wood charcoal (carbonized). Activated carbon has various uses in medical field and it is also used as a purifying agent. In early times, in India charcoal was used as a filter media for the purification of water. The first use of activated carbon was done for sugar refining industry in 1900 [1]. Activated carbon is used for adsorption purpose due its large surface area, high porosity and its greater effectiveness of surface reaction. The usefulness of activated has found effective in various wastewater treatment, treatment of leachate and removal of heavy metal like cadmium(II), lead, chromium etc., from aqueous solutions.

Physical and chemical activation are the two ways used for activation. Physical activation involves carbonising the

raw material and then activating it in an inert atmosphere using carbonization or steam. While activating chemically, different type of chemical reactors are used such as potassium hydroxide, phosphoric acid, zinc chloride etc. The chemical reactor used for activated carbon plays an important role influencing its surface area and porosity. Upon comparison, it has been found that the chemical activation is more suitable than physical activation due to its lower temperature of carbonization and less activation time. Moreover, chemical activation is preferred because of its greater surface area of activated carbon [2]. Various researches have been carried out, where chemical activation of activated carbon is done by KOH [3].

In this review, various studies were carried out to know the efficiency of various chemical reactors for activation as

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well as the preparation of activated carbons. For the present study critical studies have been done on the preparation of activated carbon from easily and locally available residual materials.

1.1. Sources for activated carbon

Many researchers have carried out studies on various sources for preparing activated carbon and these are discussed below.

1.1.1. Rice husk

Rice husk (RH) was used to make activated carbon because it has a larger surface area. Temperatures of 293.15, 303.15, 313.5, and 323.15 K, as well as pressures of up to 3.5 MPa, are critical for rice husk activated carbon [4]. For its preparation RH was first rinsed and dried and dried rice husk was carbonized at temperature 1273 K in the presence of nitrogen. The RH was then crushed, and the potassium hydroxide was added to the crushed RH. The mixture was then heated to 1,073 K in a nitrogen environment for 2 h. The active product was rinsed with distilled water on a regular basis, and then vacuum dried at 393 K. As a result, AC was made.

1.1.2. Coconut husk

Activated carbon produced from coconut husk (CH) offers a greater benefit because it has been successfully tailored for basic colour adsorption. The basic materials for Optimized AC were sourced locally. To eliminate any dirt or debris from the surface, the raw material was first cleaned. Then it was dried in a 378 K oven. As mentioned in Eq. (1), the char was impregnated with potassium hydroxide (KOH) pellets at various impregnation ratios (IR).

$$IR = \frac{W_{\text{KOH}}}{W_{\text{Char}}} \quad (1)$$

The mixture was then dried to remove any remaining moisture. Under the influence of nitrogen, the AC was cooled to 298°F. Finally, the AC was cleansed in hot water.

1.1.3. Grape stalk

To begin, grape stalks are impregnated with ZnCl_2 [5] in various ratios derived from raw material. The grape stalk is then impregnated with ZnCl_2 in a flask shaker (impregnation rate 150 rpm) for 24, 36, and 48 h. After that, it's removed, filtered, and dried at 378°F. At the end of the process, a cylindrical steel reactor with a height of 15 cm and a diameter of 6cm was activated at temperatures of 773, 873, and 973 K for periods of 30, 60, and 90 min, respectively, while a CO_2 stream ($0.1 \text{ dm}^3/\text{min}$) was allowed to go through the reactor and the muffle furnace was used to heat the system. The wet sample of AC was taken after the activation. The AC was cooled using CO_2 and then washed with a 3 M HCl solution to remove zinc compounds (a side product), before being chilled and dried. Following all of this, the prepared activated carbon yield was estimated by

dividing the mass of the created AC by the initial mass of grape stem residue.

1.1.4. Biomass

Activated carbons prepared from biomass sources are mostly popular due to their ease in preparation, easy availability of raw material, low cost, less mass density, high specific surface area and volume of micropore, fast and reversible kinetics, diversity of structure, and sustainable regeneration [6].

1.1.5. Jackfruit peel waste

Jackfruits were used as a raw precursor for AC synthesis [7]. The jackfruit peel (JFP) was then cleaned by separating it and removing the carpel fibres. To remove impure substances, the JFP was washed several times with distilled water. The dried sample of JFP was then oven-dried at 378 K to get a consistent weight dried sample. The dried material was next pulverised using a JANKLE and KUNKEL micro hammer mill to minimise the size of the sample particles. The dried JFP was then placed in a desiccator as a prelude for making the AC. The additional ingredients included in JFP were 4.22% moisture content, 10.19% ash, 50.17% volatile matter, and 35.42% fixed carbons, as determined by estimated analysis of the precursor material. The precursor materials, which weighed 20 g, were impregnated with phosphoric acid, which had an 85 wt.% concentration. The H_3PO_4 concentration ratio was set to 1:1, 2:1, 3:1, and 4:1, resulting in impregnation ratios of 1:1, 2:1, 3:1, and 4:1. (Weight of activating agent: Weight of JFP). The resulting slurry was placed in a desiccator. After a 24-h period, the slurry was ready to be processed through two processes. The slurry was deposited in a horizontal tube reactor in the first phase. Then it was placed in a muffle furnace for a half-hour of semi-carbonization at 473 K. The slurry then became black, generating a black sticky dry powder. After the semi-carbonization was completed, the powder was heated to the activation temperature. The carbonization procedure was then carried out for 45 min at a flow rate of $100 \text{ cm}^3/\text{min}$ of nitrogen gas at standard temperature and pressure. The powder was then activated, converting it to AC. The AC product was collected and then cooled in a desiccator before being washed many times with hot distilled water at 343 K to neutralize the pH of the washing solution. Finally, AC was vacuum oven-dried for 24 h at 383 K and kept in a desiccator for subsequent analysis.

2. Activated carbon basics

Activated carbon is largely present in amorphous form and is a highly porous, high-surface-area adsorptive material. It is mostly made up of aromatic carbon atom combinations linked together by random cross-linkages. Activated carbon is distinct from other types of carbon graphite in that it contains sheets or groups of atoms that are placed irregularly and in an unorganized manner. Depending on the starting raw material and thermal history, the degree of order varies. Steam-activated coal has fairly organised

graphitic platelets, whereas chemically activated wood has more amorphous aromatic structures.

Between the carbon layers, randomized bonding forms a porous structure with various fractures, fissures, and voids. Because of its large internal surface area and molecular size porosity, activated carbon is particularly effective at adsorbing a wide spectrum of pollutants from liquids and gases [8,9]. Fig. 1 shows two micrographs of the internal structure of steam-activated lignite.

2.1. Activating agent

Activated carbon has been prepared using a variety of activated agents/chemical reactors, including KOH, FeCl_3 , CaCl_2 , MgCl_2 , H_2SO_4 , H_3PO_4 , and others. The activated carbon generated by Lapsi seed stone and treated with the various chemical reactors listed above [2] were studied.

3. Activation

Activation of carbon can be done in two methods. Activated carbon can be formed by carbonization of the carbonaceous raw material below 800°C in the absence of oxygen or by physical or chemical activation of the carbonized material.

3.1. Physical activation

The process of physical activation is two-fold. As shown in Table 1, it entails carbonizing a carbonaceous material and then by activation of the produced char at high temperatures in the presence of suitable oxidizing gases like air, carbon dioxide, steam or their mixes. CO_2 is commonly used as an activation gas because it is clean, easy to handle, and allows for better control of the activation process at temperatures about 800°C [10].

3.2. Chemical activation

In chemical activation there is a major advantage obtained by the combination of activation and carbonization,

which is done in a comparatively lower temperature leading to the development of porous structure. These two processes are done simultaneously by mixing the raw material with the chemical activating agents and oxidants. Though the concern can be developed for the use of chemical agents for the purpose of activation. A part of the chemicals supplied such as phosphoric acid, salts of zinc can also be easily recovered [9,17]. A two-step procedure (a method that combines physical and chemical processes) can be used instead [18]. Some studied chemical activation processes are illustrated using Table 2.

4. Properties and characteristics of agricultural leftovers used for the production of activated carbons

4.1. Surface area

In char, the surface area of Brunauer–Emmett–Teller (BET) plays an important role, because like any other characteristics of physico-chemical processes, BET surface area might influence the combustion behaviour and reactivity of the char. A greater surface area was formed by pyrolysis of char at a temperature above 400°C [20]. Study carried out by Tsai et al. [19,26] have shown that there was a decrease in surface area at high temperature of pyrolysis and time of soaking. The increased surface area is most likely owing to the opening of the previously closed pores. The proportion of micropores increased in lockstep with the increase in pyrolysis temperature, but not at the same pace as the rate of decline in surface areas. For both the KOH and K_2CO_3 series, the BET surface areas calculated by Tsai et al. [19,26] were seen to grow at higher activation temperatures, with the largest rate of increase occurring between 650°C and 700°C .

4.2. Volume and size of pores

The size and location of macropores, mesopores and micropores in ACs affect their adsorptive capacities. Large pores, that is, polar charged, molecules or non-polar

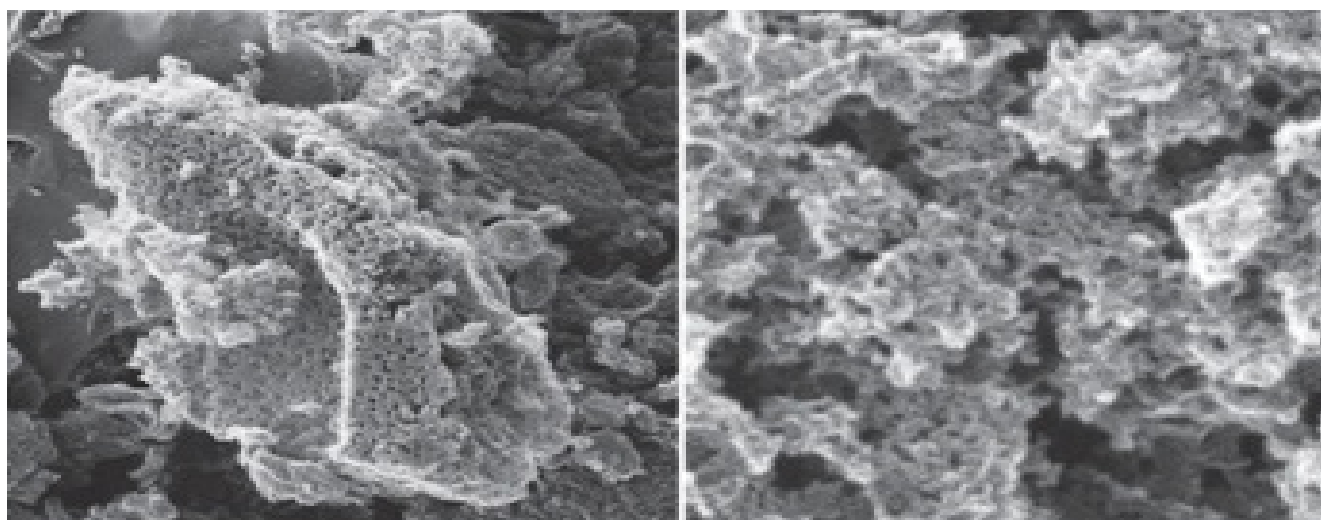


Fig. 1. Images from a helium-ion microscopes showing the pore structure of lignite-based activated carbon.

Table 1
Physical activation of agricultural residues, reported in the literature

Activating agent	Material	References
Steam	Rice husk, olive waste cakes, shells of sunflower, residues from olives, corncob	[11–14]
CO ₂	Hulls of corn, shells of pistachio nuts, shells of pecan, hulls of peanut, almond shells	[10,15–17]

Table 2
Activation of agricultural residues (chemical)

Activating agent	Material	References
K ₂ CO ₃	Hulls of peanut, shells of almond, shells of pecan, corncob	[21]
H ₃ PO ₄	Rice straw, peel of cassava	[22,23]
KOH	Corncob, <i>Macadamia</i> nutshells, hulls of peanut, olive seed	[21,24,25]
ZnCl ₂	Corncob, <i>Macadamia</i> nutshells, hulls of peanut, shells of almond, shells of hazelnut, apricot stone, rice husk	[21,24]

uncharged, chemicals, might not be able to maintain small adsorbates. ACs with a microporous structure are made from lignin-rich raw materials such as seeds of grape, cherry stones etc., whereas ACs with a microporous structure are made from cellulose-rich raw materials (apricot stones, almond shells) [27].

The determination of pore size was done using the Barrett–Joyner–Halenda (BJH) method in the work of Tsai et al. [19,26], which was done by activating chemically with ZnCl₂. Tsai et al. [24,28], on the other hand, found that as the activation temperature rises, the total pore volume increases rapidly. At 800°C, the maximum values of total pore volume, that is, 0.87 and 0.74 cm³/g for 15 wt.% KOH and 37.5 wt.% K₂CO₃ ACs, respectively are higher than those of commercial ACs, that is, 0.60 and 0.52 cm³/g for BPL and PCB, respectively (Calgon Carbon Co., Pittsburgh, USA). Table 3 shows the various characteristics of ACs from agricultural residues.

5. Review on the use of agricultural waste for the production of activated carbon

The synthesis of AC from agricultural wastes comprises of the two following steps: pyrolysis in presence of inert gases or nitrogen in order to break the bond between carbon atoms and activation process in presence of chemicals used for activation like carbon dioxide or vapor to enhance the formation of pores (physical activation). In order to optimize a process, it is necessary to do a kinetic study of the process.

5.1. Applications and uses of agriculturally based active carbons

Due to their outstanding adsorptive characteristics, which are connected to their extensive internal pore structure, ACs are employed in a wide range of industries like food processing industry, mining, pharmaceutical industries, chemical, nuclear, petroleum, automotive, and vacuum production. High porosity is influenced by the precursor as well as the activation process [25,39].

The chemical characteristics of activated carbon have a significant impact on properties such as electrochemical and catalytic properties. Activated carbons having acidic surface chemical properties are suitable for adsorption of basic gas such as ammonia, whereas having basic surface chemical properties are suitable for acidic gas adsorption such as sulphur dioxide [19]. Table 4 summarises the uses of the AC produced by agricultural leftovers.

6. Kinetic models for pyrolysis

Biomass pyrolysis known as a complicated process as it makes difficulties in order to explain the thermal degradation mechanism by using kinetic models. For many kinetic formulations of reactions of solid state, the applicability of isothermal homogeneous gas or liquid phase kinetic equations are found to be effective. That is why, at any time for a particular reaction, for the demonstration of thermal decomposition, the kinetic equation can be given as [69]:

$$\frac{dw}{dt} = k_0 \exp\left(-\frac{E}{RT}\right) f(W) \quad (2)$$

where w is the solid mass fraction and $f(w)$ is obtained by thermal decomposition. In most cases, Eq. (2) is stated in terms of the parameter α , which is defined as:

$$\alpha = \frac{W_0 - W}{W_0 - W_\infty} \quad (3)$$

where w = mass fraction at any time; w_0 = initial mass fraction; w_∞ = mass fraction at infinity time.

Thus, for a single reaction, the kinetic equation can be given as:

$$-\frac{d\alpha}{dt} = k_0 \exp\left(-\frac{E}{RT}\right) f(W) \quad (4)$$

Zabaniotou et al. [68] considered kinetics of first-order and a single reaction. Eq. (5) is used to describe their model.

Table 3
 Characteristics of activated carbons from agricultural residues

Raw material	S_{BET} (m ² /g)	V_o (cm ³ /g)	Yield (%)	References
<i>Macadamia</i> nutshell	1,718	0.723		[24]
Cherry stones	875	0.28	11.2	[27,29]
Shells of pistachio nut	778	0.466		[30]
Shells of nut	743	0.21	17.9	[27,31]
Rice straw	2,410	1.4		[20,32]
Apricot stones	1,190	0.50	18.2	[27]
Seeds of grape	497	0.12	26.2	[27]
	1,169	0.529		
Hulls of peanut	80.8–97.1	0.022–0.043	30	[18]
	253	0.079	29	
	420	0.173	30	
	228–268	0.033–0.076	27–32	
	240–1,177	0.036–0.57	22–36	
Shells of almond	998	0.40	17.8	[27]
Shells of almond	1,005.7–1,217.7, 1,157.4–1,315.4		15.84–6.34	[30]
Hulls of oat	349	91.4		[33]
	431	88.4		
	522	86.8		
	625	84.2		
Corn cob	960	0.486	28.8	[26]
	774	0.349	30.4	
	747	0.368	27.8	
	682	0.335	29.2	
	706	0.345	27.8	
	721	0.342	28.2	
Corn cob	0.1–1.806		12.8–31.3	[21,34]
	0.2–1.541		17.4–33.5	
Corn cob	607	0.296	8.7	[13]
	960	0.629	18.3	
	618–786	0.321–0.430	20.1–20.8	
Straw				[35]
Cotton stalk	37.28		30.30	[36]
	3.33		29.17	
	3.32		27.93	
	3.14		25.56	
Oak	642	0.2704		[30]
	644	0.2450		
	845	0.3212		
	985	0.3792		
Corn hulls	977	0.3352		[30]
	902	0.3284		
	1,010	0.4348		
	975	0.3792		
Corn stover	660	0.2817		[30]
	432	0.1818		
	712	0.2849		
	616	0.2343		
Corn stover	424	88.7		[33]
	442	86.2		
	374	85.0		
	311	84.2		
Cakes of olive-waste	514–1,271	0.217–0.557		[15,37]
Seed of olive	1,339		76	[38]
	1,334		72	
	1,550		65	
	1,462		59	
Peel of cassava	1,378	0.583		[25]

Table 4
Utilisation of agricultural leftover produced activated carbons

Uses	Raw materials	References
Industrial gas treatment, indoor air (air pollution control)	Rice husk, orange peel	[17]
Methylene blue adsorption (liquid purification)	Peanut hulls, rice straw	[24,38,40]
Trace metals	Rice husk	[12]
Acid dye adsorption	Orange peel	[14,41,42]
Ions removal	Palm kernel fiber	[43,44]
Arsenic removal		[45]
Atrazine adsorption	Pitch-based carbons	[46,47]
Cleaning of vegetables and fruits	Activated carbon membranes	[48]
Nitrate and pesticides removal	Wheat straw	[49,50,51,52]
Treatment of wastewater	Jute, rice husks	[53,58]
Treatment of groundwater	Jordanian olive stones	[59]
Drinking water purification	Olive stones	[60,61]
Heavy metal removal	Rice husk	[62,63]
Mercury-vapor removal	Vegetable and fruit extracts	[64]
Volatile organic compounds removal	Olive residue	[65,66]
NO _x and SO _x removal	Almond shells	[67]
Phenols and phenolic compound removal	Vegetable peel	[46,47,68]

$$-\frac{dV_i}{dt} = K_i (V^\infty - V_i)^n \quad (5)$$

$$K_i = K_{0i} e^{E_i/RT} \quad (6)$$

where V_i = volatile percentage in time t , V^∞ = the ultimate attainable yield, K_i = Arrhenius kinetic constant, k_{0i} = the pre-exponential factor, E_i = activation energy.

However, because agricultural leftovers are mostly made up of cellulose, hemicellulose, and lignin, their degradation entails a significant number of simultaneous and sequential events. As a result, the number of events that occur simultaneously in even the simplest pyrolysis process is so large that developing a kinetic model that accounts for all of them is almost difficult. Pyrolysis is frequently explored as pseudo-mechanistic models [69] to circumvent this difficulty.

7. Experimental condition to produce carbon by using agricultural wastes

7.1. Pyrolysis

Table 5 shows the proximate and final analyses of agricultural residues, which are produced in large quantities around the world.

Investigation was carried out on corn stover with oat hulls for TGA activated carbon synthesis [70]. Before going for a fast pyrolysis in a nitrogen fluidized bed reactor at a typical biomass feed rate of 7 kg/h, there was no pre-treatment. Zhang et al. [16] investigated the carbonization of wastes of oak wood, hulls of corn, and corn stover in a fluidized bed reactor at 500°C. Haykiri-Acma et al. [33,71] employed TGA to pyrolyze and then gasify chars derived from pyrolysis of sunflower shell, rapeseed,

pinecone, cotton, and waste of olive. The obtained chars were heated in order to gasify in an equal volumetric ratio under a steam and nitrogen atmosphere. A thermogravimetric analyzer was used to assess atmospheric reactivity in *Pinus radiata*, *Eucalyptus maculata*, and sugar cane bagasse under isothermal circumstances [72–74]. The heat up was done at a notional rate of 40°C/min. Sugarcane bagasse, rice husk, rice straw and pecan shells were also examined in an inert environment furnace with retort at 750°C in a nitrogen gas atmosphere. The chars were turned on until they were about 30% burnt off.

The most important factor is the pyrolysis temperature, which is followed by the rate of heating in pyrolysis, the rate of nitrogen flow, and finally the residence time of pyrolysis. In general, increasing the pyrolysis temperature lowers char and AC yields increased temperature, as perfPutun et al. [36,75,76], results in a decrease in the production of solid and an increase in liquid and gas production. As the temperature rises, the amount of ash and fixed carbon in the atmosphere increases, while the amount of volatile stuff decreases. As a result, higher temperatures produce higher-quality charcoals. The decrease in production of char with an increasing temperature may attribute to either increased primary biomass breakdown or secondary char residue decomposition at higher temperatures. At higher temperatures, subsequent char decomposition may result in some non-condensable gaseous compounds, which contributes to the rise in gas production. The char yields drop when the temperature of primary degradation rises or the residence duration of primary vapors inside the cracked particle must be reduced [34,76,77]. Tsai et al. [22,26] investigated temperature for the manufacturing of activated carbon, activated chemically with ZnCl₂, and found that the production of char decreases with increasing temperature, but soaking duration has no influence on

Table 5
An ultimate and proximate analysis on the availability of agricultural residues

Agricultural wastes	Moisture (%ww)	Ash (%ww)	Volatiles (%ww)	C (%ww)	H (%ww)	O (%ww)	N (%ww)	S (%ww)	HHV (kcal/kg)
Pruning's of olive tree	7.1	4.75	–	49.9	6	43.4	0.7	–	4,500
Pruning's of almond tree	40	–	–	–	–	–	–	–	4,398
Straw of oats	15	4.9	–	46	5.91	43.5	1.13	0.015	4,321
Straw of durum wheat	40	–	–	–	–	–	–	–	4,278
Stalks of cotton	6	13.3	–	41.23	5.03	34	2.63	0	3,772
Stalks of corn	0	6.4	–	45.53	6.15	41.11	0.78	0.13	4,253
Leaves of sugar beet	75	4.8	–	44.5	5.9	42.8	1.84	0.13	4,230
Pruning's of vineyard	40	3.8	–	47.6	5.6	41.1	1.8	0.08	4,011
Corncoobs	7.1	5.34	–	46.3	5.6	42.19	0.57	0	4,300
Soft wheat straw	15	13.7	69.8	–	–	–	–	–	4,278
Rice straw	25	13.4	69.3	41.8	4.63	36.6	0.7	0.08	2,900
Pruning's of peach tree	40	1	79.1	53	5.9	39.1	0.32	0.05	4,500
Barley straw	15	4.9	–	46.8	5.53	41.9	0.41	0.06	4,489
Sunflower straw	40	3	–	52.9	6.58	35.9	1.38	0.15	4,971
Pruning's of cherry tree	40	1	84.2	–	–	–	–	–	5,198
Pruning's of apricot tree	40	0.2	80.4	51.4	6.29	41.2	0.8	0.1	4,971

char production. Some researcher have reported the efficient enhancement of shale inhibition of polyvinylpyrrolidone (PVP) by incorporating activated carbon modified dendrimer (ACD) represented as ACD/PVP with a low environmental footprint [78] Studies have also been carried out to describe the effect of diethylenetriamine modified activated carbon (DETA-AC) on the swelling inhibition of shale samples with high clay content and rheological features of water-based muds (WBM) [79].

8. Scanning electron microscope (SEM) micrographs

The microstructure of activated carbon has been extensively studied using scanning electron microscopy (SEM). The morphological study by SEM micrographs of activated carbons is shown in Fig. 2.

SEM micrographs of activated carbon particles (Fig. 2A–F) revealed holes, pores, and rough surfaces on the produced carbon samples. It reveals that the topographical properties of the carbon surface were modified by the activation chemical. Fig. 2A shows a micrograph of pyrolyzed char, which demonstrates that the surface has very few pores. The surface of the activated carbon generated by CaCl_2 and KOH procedures indicates the presence of pores in all of the micrographs. In comparison to pyrolyzed char, KOH impregnated activated carbon (Fig. 2B) clearly revealed partially created honey comb like highly defined pores and cavities. The pores, on the other hand, are not all the same size. Similarly, the surface of CaCl_2 impregnated carbon (Fig. 2C) has a lot of tiny pores. Activated carbon impregnated with MgCl_2 , FeCl_3 , and H_2SO_4 (Fig. 2D–F), on the other hand, does not have a porous structure. The occurrence of diverse reaction pathways is indicated by the pore architectures of activated carbon produced with various activating chemicals.

The method by which potassium hydroxide does the activation of an existing carbon is more difficult which causes disintegration of structure after inter catalation as well as some gasification by oxygen molecules of hydroxide, whereas activation done with metal chloride accelerates the removal of water molecules from lignocellulosic materials leading to formation of porosity. The SEM images show that the surface of KOH-soaked activated carbon has well-developed pores, implying that absorption into the pores surface is more likely [80–82]. It is also to report that, SEM images for adsorption of different dyes using non activated carbon adsorbents confirms the adsorption of dye [83–89].

9. Conclusion

- The differentiations between the final and initial analysis of activated carbon, under the same condition shows that the structure and composition of the raw material have significant influence on their reactivity in the pyrolysis/activation reactions.
- Pyrolysis done on agricultural residues, such as olive husks, wheat, residues from grapes, rice husks etc. creates char with a double yield that of wood char.
- While the ash content of activated carbons from apricot, almond and stones of cherry stones is low, the content of ash of carbon from seeds of grapes are relatively high. All of the sample have a low Sulphur content. In order of suitability for activated carbon synthesis, the raw materials shells of hazelnut, stone of apricot, and shells of almond were ranked.
- Olive wastes, birch, and bagasse gives more production of activated carbons having BET, making them suitable for activated carbon preparation, although straw and miscanthus samples appear to be more suited for transformation into gaseous and liquid products.

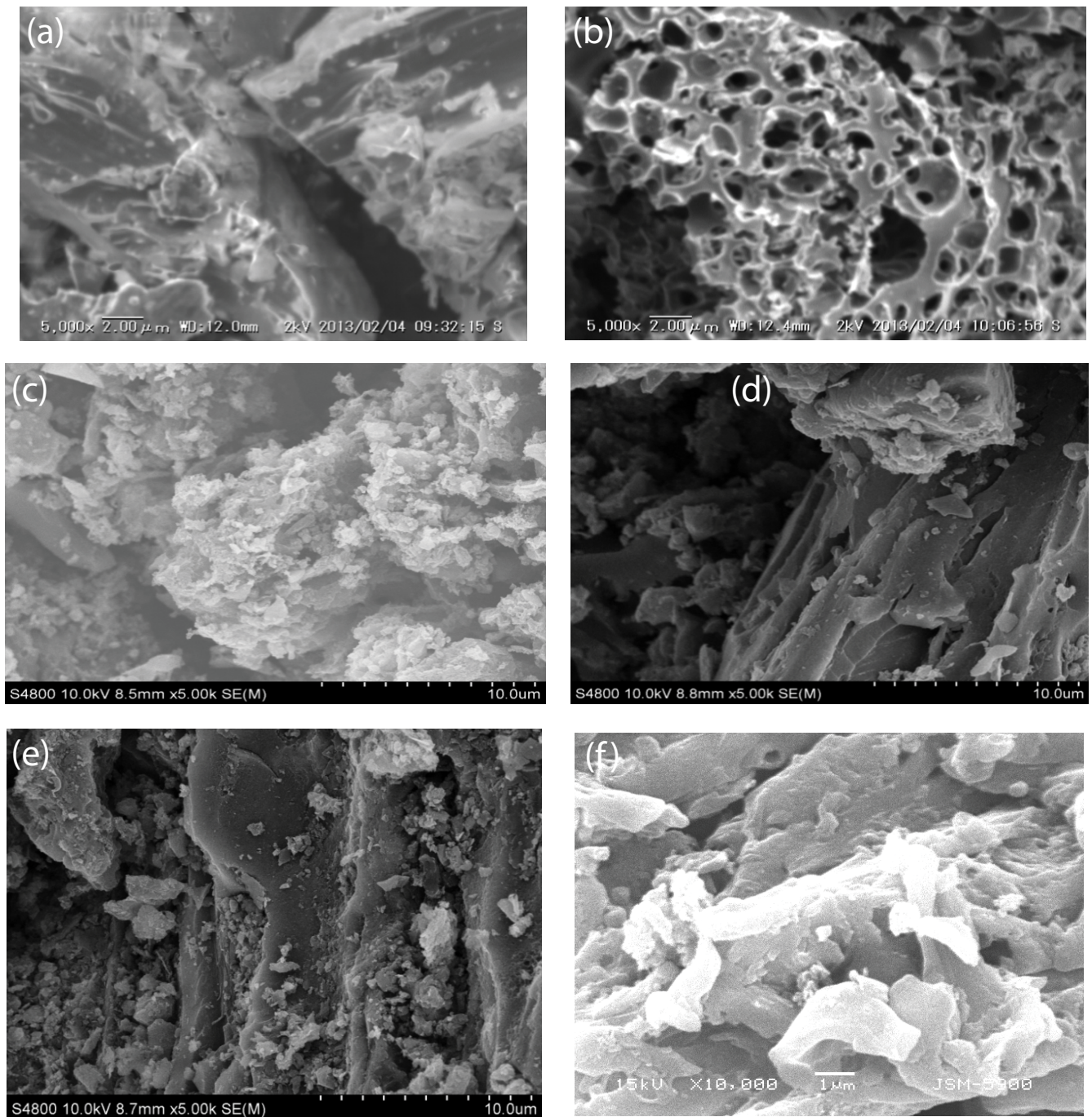


Fig. 2. AC prepared by (A) direct pyrolysis, (B) activation with KOH, (C) activation with CaCl_2 , (D) charred with FeCl_3 , (E) activation with MgCl_2 , and (F) charred with H_2SO_4 .

- According to the experimental results of *Macadamia* nutshells, the samples were found to have a large surface area and micropore volume, when activated chemically with ZnCl_2 than those produced by KOH. Chemical activation of peanut hulls with H_3PO_4 at 500°C can easily produce high-quality carbon.

On activated carbon surfaces, pore size shows adsorption capacity, chemical structure regulates the bond between

polar and non-polar adsorbates, and active sites control the type of chemical interactions with other molecules. Converting abundant by-products into activated carbons for the treatment of water, trash, dye removal and heavy metal removal from water would add value to agricultural commodities, solve environmental concerns, and assist minimize waste disposal costs. The cost of producing carbons is expected to be low, as the materials used as precursors obtained from agricultural residues are low cost and

available in plenty, and present a possible low-cost alternative to currently available commercial adsorbents generated from non-renewable sources. The present study was carried out basically to know the effectiveness of activated carbon in various fields. In this study, the preparation of activated carbon out of various natural residues and their chemical treatment were investigated.

Author contributions

This is to state that R.G. (PhD Scholar) did the literature review and wrote the manuscript and A.K.D. (Assistant professor) revised the manuscript.

Conflict of interest statement

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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