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Activated Carbon: Eco-friendly Material for Wastewater Application

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Abstract
With the advancements of technologies, pollution is worsening day by day, especially water pollution. Water pollution was caused by the excess discharge of the toxic substances that enter the water bodies such as lakes, ponds, and streams. The toxic substances that accumulate in the water sources can be harmful for the living. This water is not safe for public use and requires treatments before it is disseminated for household use. As such, activated carbon is a powerful adsorbent in wastewater treatments. Production of activated carbon from agricultural sources has attracted the researcher's attention. Since agricultural sources are high in availability due to their abundance, low-cost operation, and eco-friendly materials. Activated carbon can remove various dyes including methylene blue, Rhodamine B, methyl orange, aniline yellow, and Remazol brilliant blue R in wastewater discharge from the industries. Activated carbon is also a powerful adsorbent for heavy metals such as Pb (II), Co (II), Ni (II), Zn (II), Cu (II), Cd (II), Mn (II), Hg (II) and As (V). Besides, activated carbon can act as an adsorbent for the removal of common pharmaceutical waste and phenolic compound of 2,4-dimethylphenol.

Keywords
Activated carbon; Adsorbent; Dyes; Heavy metals; Eco-friendly material; Wastewater treatment.

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1 Introduction

Technological modernisation has brought a huge impact on the environment, especially safety and cleanliness. Advancements of the world economies lead to pollution, specifically to the surface and groundwater contamination. Continuous water pollution can be intolerable in the future, so the remediation of the wastewater should be taken much earlier to help reduce water pollution. Due to that, the adsorption process is the best method used currently for the treatments of water pollutants because of the simplicity and effectiveness[1-6,8-10]. As such, activated carbon is one of the reliable materials that had been widely used in the remediation of wastewater due to the benefits it served and also its ease of operation[1-5,7,8-14,15]. This is due to the several advantages including large surface area and well-developed porosity of activated carbon[1,2,7-9,11-14]. Activated carbon owns attractive features including perfect porous structure as well as good surface chemistry functionality that boost the reaction with polar and non-polar compounds[16,17].

In the industrial field, activated carbon is usually used as purifier units, catalyst, solvent and hydrocarbon recovery, storage for natural gas, hydrogen, and energy[18,19]. Activated carbon is also widely used in deodorization, filtration, color removal, conversion of liquid, gas concentration, petroleum, pharmaceutical, and lastly food and beverage[19]. Activated carbon from agricultural sources is one of the adsorbent materials that are cheap and can be produced easily[20] which can reduce the cost of activated carbon production, agricultural sources and lessen the extent of poultry manures with high content of holocellulose and lignin[21]. Activated carbon produced from agricultural waste is eco-friendly and abundant. One of the most proposed sources of activated carbon is bamboo which can form a good quality of activated carbon at affordable operation cost[22].

2 Activated Carbon as an Adsorbent in Wastewater Treatment

With regards to environmental cleanliness and safety, the adsorbent is a frequent material used to help neutralize harmful substances in wastewater treatment. Water treatments are mainly conducted for the removal of water contaminants including solids, bacteria, toxins, and algae[23,24]. For instance, excess dyes and heavy metals can seriously lead to pollution in the environment. Industrial revolutions and the increase in population have worsened the pollution in water systems especially ponds and rivers which was caused by the discharge from the industries and households used that flows directly into the water body without any treatment and the toxic substances accumulate day by day. A clean and safe waters supply is required for the general usage of the household for daily use. The toxic substances may get into the human body through inhaling breath, eating exposed food, and skin absorption from surrounding environment[23,25]. Hence, such toxic waste should be treated or removed from water systems before the water is distributed for other household use.

Carbon adsorbents produce from agricultural sources are very popular these days to remove harmful substances that interrupt environmental cleanliness and safety. Considering the uncomplicated, easy procedure, recyclable, and high efficiency, the adsorption method had been widely employed in the remediation of wastewater treatments[15,24]. Activated carbon is not only beneficial for the adsorption of pollutants in wastewater and soil but also applicable for adsorption in the atmosphere[7,26]. Activated carbon is widely known to possess a highly porous structure and great surface area which is effective for removing pollutants, including heavy metals, dyes, gases, and pesticides[19,27]. As a result from the advantages including large internal surface area, mechanical integrity, and lastly reusable, activated carbon has become essential and the most frequently used adsorbent in wastewater treatments[28].

The adsorption process is described as the dissolving of contaminants in a form of liquids or gas disrupting onto the surface of the adsorbents[29]. The adsorption reactions were initiated via Van der Waal forces and induced dipole interactions in which the adsorbents induce neutral organic molecules into intra-molecular dipoles[29]. Hence, the induced dipoles lead the molecules to bind together and fill insides the adsorbents pore's[29]. The whole process is known as premature condensation and is assisted by the adsorption process by using activated carbon[29].

There are two types of activated carbon generally, in the liquid phase and gas phase[20]. The liquid phase activated carbon is in powder form while the gas phase is in granular or pellet form. However, among these two types of activated carbon, the liquid phase owns more pores in the transition area, which is mesopore, and the pore volume is around 0.2-10 mLg^{-1} whereas the gas phase is micropore and ranging around 0.15-0.5 mLg^{-1} [20]. The adsorption ability can be improved when the adsorbent owns a large surface area and there are several huge factors that might affect it, such as the porous structure of the activated carbon produced from bamboo charcoal[30]. The absence of pores or a vacant site on the surfaces of the activated carbons is influencing the main function for the adsorbent to capture the adsorbates.

3 Activated Carbon as an Adsorbent for the Removal of Dyes

The usage of activated carbon as an adsorbent for the removal of dyes is a most known fact. Different parameters are required to produce the activated carbon when different agricultural waste materials are used. These parameters have resulted in different efficiency in the removal of dyes. Agricultural sources are the most targeted raw materials to produce activated carbon since it is eco-friendly, easily available, and low-cost. Previous researchers have conducted studies to find the most effective activated carbon by using various types of materials from agricultural sources. The characteristics of the activated carbon produced brought huge effects to the efficiency of the activated carbon, where larger surface area and pore size can lead to greater adsorption efficiency of activated carbon[7,31]. Table 1 summarizes the material source used and the parameters of different activation process used in the production of activated carbon.

Table 1. The production of activated carbon using different activation process.

Material Source (Origin)	Parameters of Activation Process	Characteristics of Activated Carbon	References
Spent Coffee Grounds, CA	C = KOH, T = 900℃ Times = 1 hour	-	(34)
Pomegranate Fruit Peel, CA	C = KOH, T = 500℃ Times = 1 hour	APD = 4.04 nm SA = 845.96 m^2g^{-1} CC = 78.32%	(35)
Bamboo Chip CA	C = KOH, T = 700℃ Times = 1 hour	APD = 7.32 nm SA = 720.69 m^2g^{-1} CC = 52.90%	(36)
Bamboo CA	C = KOH, T = 900℃ Times = 1 hour	SA = 2133.2 m^2g^{-1} CC = 79.31%	(7)
Coconut Shell CA	C = KOH, T = 400-800℃ Times = 2 hours	SA = 1277.00 m^2g^{-1} CC = 88.31%	(37)
Black Cumin Seeds CA	C = H_3PO_4 (20%) T = 25 ℃, Times = 24 hours	APD = 7.13 nm SA = 21.54 m^2g^{-1}	(38)
Grass Waste CA	Chemicals = H_3PO_4 Temperature = 700℃ Times = 1 hours	APD = 3.12 nm SA = 707.90 m^2g^{-1} CC = 46.45%	(39)
Swietenia mahagoni Bark CA	C = NaOH, T = 200℃ Times = 15 minutes	-	(40)
Kendu Fruit Peel CA	C = Ammonium Carbonate, T = 400℃, Times = 2 hours	APD = 3.09 nm SA = 249.00 m^2g^{-1}	(41)

Note: CA: Chemical activation; C: Chemical, T: Temperature, KOH: Potassium hydroxide; NaOH: Sodium hydroxide; H_3PO_4: Phosphoric acid; APD: Average pore diameter; SA: Surface area; Carbon content: CC

The activation process is the most crucial factor that can affect the effectiveness of the activated carbon produced. The most favored activation process is chemical activation due to the lower energy consumption since it is processed at lower temperatures and the high surface area of activated carbon produced. Potassium hydroxide (KOH) is the most used activating agent due to the high surface area of activated carbon obtained. The studies show the procedure of activated carbon produced from the spent coffee ground by using KOH as an activating agent at 900℃ for 1 hour[31] while from pomegranate fruit peel with KOH at 500℃ for 1 hour[32]. Pomegranate fruit peel activated carbon showed an average pore diameter, surface area, and carbon content of 4.04 nm, 845.96 m^2g^{-1}, and 78.32% respectively.

The production of bamboo chip with KOH at 700℃ for 1 hour produced activated carbon with an average pore diameter, surface area, and carbon contents of 7.32 nm, 720.69 m^2g^{-1}, and 52.90% respectively[33] (Table.2). Bamboo that has undergone at a higher activation temperature, at 900℃ for 1 hour using KOH produced a very high surface area value at 2133.2 m^2g^{-1} and carbon content of 79.31%[7] as well as used with KOH at 400℃ for the first 30 minutes and continued with 800℃ for 90 minutes for coconut shell and obtained high surface area and carbon content of 1277.00 m^2g^{-1} and 88.31% respectively[34]. Other than KOH, phosphoric acid (H_3PO_4) is also a popular activating agent for activated carbon production. Black cumin seeds were soaked in H_3PO_4 at 25℃ for 24 hours and produced an average pore diameter and surface area of 7.13 nm and 21.54 m^2g^{-1} [35]. The lower surface area obtained might be because of the lower activation temperature used.

Grass waste was used for activated carbon production with H_3PO_4 at 700℃ for 1 hour[34]. The product obtained has shown average pore diameter, surface area, and carbon content of 3.12 nm, 707.90 m^2g^{-1}, and 46.45% respectively. Apart from that, *Swietenia mahagoni* bark was activated with sodium hydroxide at 200℃ for 15 minutes[36]. Lastly, Kendu fruit peel and ammonium carbonate were activated at 400℃ for 2 hours and showed an average pore diameter and surface area of 3.09 nm and 249.00 m^2g^{-1} [37] (Table 2).

The adsorption process will be very fast in the earlier stage due to the higher number of sites on adsorbent surfaces. Besides, the extension of contact time can result in an increase in the efficiency of the adsorption process, nonetheless, the efficiency also will decline when the process reaches equilibrium due to the limited capacity of the adsorbent surface and pores[38,39]. Different parameters of the adsorption process are used to give different performance efficiency in the removal of dyes by activated carbon is shown in Table 2.

Methylene blue is a water-soluble cationic dye that is usually used in the cosmetic, textile, and paper industry[39,40]. However, uncontrolled disposal of this dye into the environment such as water body can lead to color changes to the water and are harmful to aquatic and human health[39]. Due to this, several alternatives to overcome this issue were made but the most effective one is the adsorption process which provides easy practice. The aromatic structure of the methylene blue naturally reacts with the functional group of the adsorbent and then forms π-π bonds[39]. A study was conducted for the removal of methylene blue by using bamboo chip activated carbon[33]. 0.10 gL^{-1} of adsorbent dosage at 40℃ for 12.5 minutes successfully recorded 96.70% removal of methylene blue. Grass waste is used as a raw material for activated carbon production for methylene blue removal[41]. 0.08 g of adsorbents at 45℃ for 75 minutes recorded removal of 79.60%.

The activated carbon that derived from Kendu fruit peel was tested for methylene blue dye removal[37]. 2.40 gL^{-1} of adsorbent dosage used at 25 ± 2℃ for 100 minutes recorded removal of 144.90 mgg^{-1}. 0.10 g of black cumin seeds activated carbon used at 25℃ for 60 minutes and showed removal of 95.74% for methylene blue[35]. Besides, coconut shell activated carbon can also be used as an adsorbent[34]. In this context, 6.00 mg of adsorbent at 5 hours contact times has resulted in 96.00 % methylene blue dyes removal. Apart from the factors such as specific surface area, crystallinity, surface charge and functional group of adsorbents, the increases of solution temperature and presence of anionic surfactant were also found to improve the effectiveness in the removal of the dyes.

Table 2. The performance efficiency in the removal of dyes by activated carbon.

Material Source (Origin)	Parameters of Adsorption Process	Performance Efficiency	References
Bamboo Chip (Malaysia)	pH = 10.00, AD = 0.10 gL^{-1} T = 40℃, CT= 12.5 minutes	Methylene blue = 96.70%	(34)
Grass Waste (Malaysia)	pH = 10.0, AD = 0.08 g T = 45℃, CT = 75 minutes	Methylene blue = 79.60%	(37)
Kendu Fruit Peel (India)	pH = 6.0, AD = 2.40 gL^{-1} T = 25 ± 2℃, CT = 100 minutes	Methylene blue = 144.90 mgg^{-1}	(39)
Black Cumin Seeds (South Africa)	pH = 9.0, AD = 0.10 g T = 25℃, CT = 60 minutes	Methylene blue = 95.74%	(36)
Coconut shell (Indonesia)	AD = 6.00 mg CT = 5 hours	Methylene blue = 96.00%	(35)
Rice Husks (India)	pH = 3.0, T = 30℃ CT = 25 hours	Rhodamine B = 98.00%	(5)
Bamboo (China)	pH = 7.0, AD = 10.00 mg T = 60℃, CT= 12 hours	Rhodamine B = 1542.64 mgg^{-1}	(7)
Pomegranate Fruit Peel (Malaysia)	pH = 6.0 – 7.0, AD = 0.20 g T = 30℃, CT = 24 hours	Remazol Brilliant Blue R = 81.35%	(42)
Swietenia mahagoni Bark (Bangladesh)	pH = 3.0, AD = 10.00 gL^{-1} T = 25±2℃, CT = 2 hours	Methyl orange = 92.00%	(38)
Spent Coffee Grounds (Philippines)	pH = 7.0 - 9.0, AD = 0.60 g T = 25 ± 3℃, CT = 2.5 hours	Aniline yellow = 87.05%	(44)

Note: AD: Adsorbent dosage, T: temperature, CT: Contact time

Rhodamine B is a regular cationic dye that is discharged from the factories of textile, cosmetics, leather, plastic, and paper[7]. The release of this dye into the water body from the factories can cause harmful effects on human health. In addition, it causes a lower light penetration for the photosynthetic process of aquatic plants due to the visibility of its presence on the surface of the water that blocks the sunlight from reaching the aquatic plants[7]. The activated carbon produced using rice husk was also used for the removal process[5]. A temperature of 30℃ for 25 hours recorded 98.00% removals efficiency. A 10.00 mg of bamboo activated carbon was used for the removals and recorded an amount of 1542.64 mgg^{-1} at 60 ℃ for 12 hours[7]. Activated carbon from pomegranate fruit peel was used to remove Remazol brilliant blue R dyes[32]. Using 0.20 g of activated carbon at 30℃ contact time of 24 hours and recorded 81.35% of the removal. Methyl orange was removed using *Swietenia mahagoni* bark activated carbon[36]. Based on 10.00 gL^{-1} of adsorbent for 2 hours contact time at 25 ± 2℃, the results showed 92.00% of dyes were removed. Lastly, coffee grounds activated carbon for the removal of aniline yellow dyes proceeds with 0.60 g of adsorbent at 25 ± 3℃ for 2.5 hours and recorded 87.05% removals[42].

The removal efficiency of the adsorption process is highly dependent on the adsorbent dosages and contact time. A higher adsorbent dosage will increase the number of active sites for the interactions of the dyes and the adsorbent surface. The higher the adsorbent dosage, the higher the removal efficiency, whereas a longer contact time provides time for the adsorption process to reach equilibrium states where there are no more active sites left for the adsorbate to react.

4 Activated Carbon as an Adsorbent for the Removal of Heavy Metals

Metals that have a higher density than water is considered as heavy metals and these metals can be toxic to living organisms in excess amounts[43]. Due to the high cost of heavy metals disposal, many factories choose to discard them simply into the water body such as rivers, lakes, and streams. As a result, pollution in water increases drastically, and thus, activated carbon has been used as an adsorbent for heavy metals removals. Hence, researchers have been hustling to investigate and to identify the most suitable material source and parameters to produce a better-quality activated carbon. Table 3 shows the material sources and parameters of the activation process for the activated carbon production. Activated carbon produced from *Citrus limetta* leaves by physical activation with nitrogen gas at a temperature of 700℃ for 3 hours and obtained activated carbon with an average pore diameter, surface area, and carbon content of 24.8 nm, 7.20 m^2g^{-1}, and 19.27 % respectively[1]. Banana empty fruit bunch activated with potassium hydroxide at 630 watts for 15 minutes and obtained activated carbon with 87.20% carbon contents[4]. The activation process of corn cob with potassium hydroxide at 400℃ for the first 30 minutes and followed by 800℃ for 1 hour and 30 minutes produce an average pore diameter and surface area of 2.41 nm and 1054.20 m^2g^{-1} [44].

Acai seeds were used as material source with potassium hydroxide at 850 ℃ for 60 minutes and obtained activated carbon with an average pore diameter, surface area, and carbon content of 1.90 nm, 705.00 m^2g^{-1}, and 59.69% respectively[45]. Mangosteen shells (*Garcinia mangostana L.*) were activated with phosphoric acid (H_3PO_4) at 150℃ for 24 hours and activated carbon showed a surface area value of 209.00 m^2g^{-3}. Black cumin seeds activated carbon with 20% phosphoric acid (H_3PO_4) at 25℃ for 24 hours showed an average pore diameter and surface area of 7.13 nm and 21.54 m^2g^{-1} respectively[33].

Magnetisation activated carbon was produced by using corn straw (*Zea mays L.*)[46] and rape straw powder[11] respectively. Activation process with phosphoric acid (H_3PO_4) by muffle furnace then followed by soaking the obtained activated carbon in Iron (III) chloride solution and oven-dried to get the final products. The surface area showed 115.43 m^2g^{-1} [46] and 553.30 m^2g^{-1} [11] respectively. The huge difference in the surface area of activated carbon obtained might be due to the starting material used and the activation temperature of both processes. Rice husk used to produce activated carbon by using ammonium chloride at 350℃ for 30 minutes[12] and lastly, activated carbon from *Moso* bamboo with sodium hydroxide at 25℃ for 24 hours[15].

Table 4 shows the parameters used and performance efficiency for the removals of heavy metals. A study was conducted by using *Citrus limetta* leaves activated carbon for the removal of Pb (II), Co (II), and Ni (II) in aqueous solutions[1]. By using 1.00 gL^{-1} adsorbent at 25℃ for 60 minutes, this parameter showed removals of Pb (II), Co (II), and Ni (II) for 99.53%, 98.63%, and 97.54% respectively. Olive branches activated carbon used for the removals of Pb (II), Zn (II), Cu (II), and Cd (II)[2]. The adsorbent dosage was fixed at 1.00 g in temperature of 30 to 50℃ for 24 hours and the removals showed an amount of 41.32 mgg^{-1}, 34.97 mgg^{-1}, 43.10 mgg^{-1}, and 38.17 mgg^{-1} for Pb (II), Zn (II), Cu (II), and Cd (II) respectively. Besides, mangosteen shells (*Garcinia manostana L.*) activated carbon used for the removals of Ni (II)[3]. Adsorbent dosage of 60.00 mg for 30 minutes of contact time successfully removed 99.00% of the metals from the aqueous solution.

Banana empty fruit bunches activated carbon used for the removal of Pb (II) and Cu (II)[4]. The result obtained showed 87.41% and 62.35% of Pb (II) and Cu (II) removed respectively. Rice husks activated carbon produced to remove Pb (II) and Cd (II) from wastewater[12]. 0.50 g of activated carbon was used at 25℃ for 90 minutes and showed removal of 80.44% and 78.93% of Pb (II) and Cd (II). On the other hand, rice husk activated carbon is used to remove Mn (II)[5]. The percentage of removals showed 93.00% at 30℃ for a contact time of 25 hours. *Moso* bamboo is used as the material to produce activated carbon for the removals of Pb (II) from the aqueous solution[15]. 1.00 gL^{-1} of the adsorbent dosage used at 25℃ for 6 hours showed 166.70 mgg^{-1} of

Pb (II) removed from the solution. Another study was conducted to remove Hg (II) by using corn cob activated carbon[44]. 20.00 mgL^{-1} of adsorbent dosage at 25℃ for 120 minutes successfully removed 97.20% of Hg (II).

Table 3. The production of activated carbon as an adsorbent for heavy metals.

Material Source (origin)	Parameters of Activation Process	Characteristics of Activated Carbon	References
Citrus limetta Leaves, PA	Chemical = Nitrogen gas T = 700℃, Times = 3 hours	APD = 24.8 nm SA = 7.20 m^2g^{-1} CC = 19.27%	(1)
Banana Empty Fruit Bunches, CA	C. = KOH, T = 630 watts Times = 15 minutes	CC = 87.20%	(4)
Corn Cob CA	C. = KOH, T = 400- 800℃, Times = 90 minutes	APD = 2.41 nm SA = 1054.20 m^2g^{-1}	(46)
Acai Seed CA	C. = KOH T = 850℃, Times = 60 minutes	APD = 1.90 nm SA= 705.00 m^2g^{-1} CC = 59.60%	(47)
Mangosteen Shell (*Garcinia mangostana L.*), CA	C. = H_3PO_4 T = 150℃, Times = 24 hours	SA= 209.00 m^2g^{-1}	(3)
Black Cumin Seeds CA	C. = H_3PO_4 (20%) T = 25℃, Times = 24 hours	APD = 7.13 nm SA = 21.54 m^2g^{-1}	(36)
Corn Straw (*Zea mays* L.) CA	C. (activation) = H_3PO_4 T = 600℃ (90 minutes) C. (magnetization) = $FeCl_3$ (soaked), T = 150℃ (oven dried) (12 hours)	SA = 115.43 m^2g^{-1}	(48)
Rape Straw Powder CA	C. (activation) = H_3PO_4 T = 300 ℃ (2 hours) C. (magnetization) = $FeCl_3$ (soaked), T = 180℃ (oven dried) (10 hours)	SA = 553.30 m^2g^{-1}	(11)
Rice Husk CA	C. = Ammonium Chloride T = 350℃, Times = 30 minutes	-	(12)
Moso bamboo CA	C. = NaOH, T = 25℃ Times = 24 hours	-	(17)

Acai seed activated carbon is used to remove Pb (II), Fe (II), and Mg (II)[45]. 1.00 gL^{-1} adsorbent used at 25℃ for 1 hour and showed removals of 86.00%, 69.00%, and 8.00% for Pb (II), Fe (II), and Mg (II) respectively. Corn straw (*Zea mays L.*) activated carbon applied for the removal of As (V)[40]. 0.05 g of activated carbon used at 25 ± 1℃ for 24 hours showed 6.77 mgg^{-1} removal of As (V). Additionally, black cumin seeds activated carbon implemented to remove Pb (II)[35]. 2.4 gL^{-1} of activated carbon was used at 25 ± 2℃ for 100 minutes and successfully removed 78.43% of Pb (II). Lastly, rape straw powder activated carbon produced to remove Pb (II) and Cd (II) from aqueous solutions[11]. Adsorbent dosage of 0.25 gL^{-1} at 25℃ for 12 hours recorded the removals of 253.20 mgg^{-1} and 73.30 mgg^{-1} for Pb (II) and Cd (II).

Table 4. The removal of heavy metals by activated carbon.

Material Sources (Origin)	Parameters of Adsorption Process	Performance Efficiency	References
Citrus limetta Leaves (Iran)	pH = 6.0, AD = 1.00 gL^{-1} T= 25℃, CT = 60 minutes	Pb (II) = 99.53%, Co (II) = 98.63%, Ni (II) = 97.54%	(1)
Olive Branches (Libya)	pH = 5.0 (Pb, Cu, Cd ions) pH = 3.0 (Zn ions) AD = 1.00 g, T = 30 – 50℃ CT = 24 hours	Pb (II) = 41.32 mgg^{-1} Zn (II) = 34.97 mgg^{-1} Cu (II) = 43.10 mgg^{-1} Cd (II) = 38.17 mgg^{-1}	(2)
Mangosteen Shell (*Garcinia mangostana L.*) (India)	pH = 5.0, AD = 60.00 mg CT = 30 minutes	Ni (II) = 99.00%	(3)
Banana Empty Fruit Bunches (Indonesia)	pH = 7.0	Pb (II) = 87.41% Cu (II) = 62.35%	(4)
Rice Husks (Nigeria)	pH = 3.0, AD = 0.50 g T = 25℃, CT = 90 minutes	Pb (II) = 80.44% Cd (II) = 78.93%	(12)
Rice Rusks (India)	pH = 5.0, T = 30℃ CT = 25 hours	Mn (II) = 93.00%	(5)
Moso bamboo (China)	pH = 5.0, AD = 1.00 gL^{-1} T = 25℃, CT = 6 hours	Pb (II) = 166.70 mgg^{-1}	(17)
Corn Cob (China)	pH = 7.0, AD = 20.00 mgL^{-1} T = 25℃, CT = 120 minutes	Hg (II) = 97.20%	(46)
Acai Seed (Brazil)	AD = 1.00 gL^{-1}, T = 25℃ CT = 1 hour	Pb (II) = 86.00% Fe (II) = 69.00% Mg (II) = 8.00 %	(47)
Corn Straw (*Zea mays* L.) (China)	pH = 6.0 ± 0.1, AD = 0.05 g T = 25 ± 1 ℃, CT = 24 hours	As (V) = 6.77 mgg^{-1}	(48)
Black Cumin Seeds (South Africa)	pH = 9.0, AD = 0.10 g T = 25 ℃, CC = 60 minutes	Pb (II) = 78.43%	(36)
Rape Straw Powder (China)	pH = 5.0 ± 0.1, AD = 0.25 gL^{-1} T = 25 ℃, CT = 12 hours	Pb (II) = 253.20 mgg^{-1} Cd (II) = 73.30 mgg^{-1}	(11)

Note: AD: Adsorbent dosage, T: temperature; CT: Contact time

5 Activated Carbon as an Adsorbent for the Removal of Pharmaceutical Waste

Water discharge from pharmaceutical industries is usually behaving as organic substance in nature and causes polar organic pollutants to the water body[47]. Due to the continuous operation of the pharmaceutical factories, the situation is worsening by the addition of pollutants discharged into the water body[47,48]. The discharge from pharmaceutical activity into the water body leads to damaging effects, mainly when used for domestic function especially household use[47]. Table 5 showed the parameters for the removal process of pharmaceutical waste.

The pollutants are referred to as pharmaceutically active compounds including common substances such as Paracetamol, Salbutamol, Amoxicillin, Ibuprofen, Chloramphenicol, and more[47,49]. A study was conducted on the adsorption of the activated carbon produced from *Bambusa vulgaris* for the treatment of pharmaceutical wastewater[47]. The activated carbon was modified using phosphoric acid (H_3PO_4) as a chemical agent at 350℃ in the muffle furnace. 2.0 g amount of the adsorbent dosage was used for a contact time of 30 minutes at room temperature. The result of the adsorption process on pharmaceutical wastewater was recorded as 63.90%, 66.70%, and 82.20% for Paracetamol, Salbutamol, and Chlorpheniramine respectively. Hence, activated carbon is a promising material for the remediation of pharmaceutical wastewater.

Table 5. The removal of pharmaceutical waste by activated carbon.

Material Sources	Adsorption Process	Removal	References
Bambusa vulgaris Agent: Phosphoric acid Temperature: 350℃	Dosage: 2.0 g Temperature: 25 ± 1℃ Contact time: 30 minutes	Paracetamol = 63.90% Salbutamol = 66.70% Chlorpheniramine = 82.20%	(49)
Bamboo waste Agent: phosphoric acid Temperature: 800℃	Dosage: 0.1 g Temperature: 25℃ Contact time: 24 hours	Ciprofloxacin = 172.50 mgg^{-1} Norfloxacin = 293.20 mgg^{-1}	(51)

Bacterial infections are very harmful to health for both humans and animals. Usually, it was treated by using quinolone antibiotics[50,51]. Common types of antibiotics used for the treatments of bacterial infections are Ciprofloxacin and Norfloxacin. Both antibiotics are commonly used and are troublesome to be degraded naturally[50,52]. The removal of Ciprofloxacin and Norfloxacin using bamboo activated carbon was studied[50]. Activated carbon was produced by phosphoric acid (H_3PO_4) activation at 800 ℃ in a muffle furnace. 0.1 g of adsorbent dosage used at 25℃ for 24 hours showed 172.50 mgg^{-1} and 293.20 mgg^{-1} for Ciprofloxacin and Norfloxacin respectively.

6 Activated Carbon as an Adsorbent for the Removal of Pharmaceutical Waste

2,4-dimethylphenol is a common type of phenolic substance that mainly results in a discharge of oil refinery waste[53]. This substance is also known as 2,4-xylenol and it is one of the regular toxic wastes of petrochemical discharge[53]. Due to the benefits of the substances, 2,4-dimethylphenol is required in the production of various types of commercial goods for factories and agricultural essentials[53,54]. The existence of the substance in the petroleum fraction and coal tars, simultaneously with its application for a chemical feedstock or else used in manufacturing various goods is leading to the possible root of water pollution[51]. Hence, immediate action should be taken to remove the substance from the water systems before it causes harmful effects to humans and aquatics.

A study on activated carbon based on bamboo canes was conducted[53]. The bamboo was activated by using sodium hydroxide (NaOH) at 400 ℃ for 2 hours. The adsorption process was conducted by using 0.05 g of activated carbon at room temperature for 60 minutes. The result showed rapid adsorption for the early 15 minutes followed by a slower reaction and finally, this parameter reached equilibrium state after the past 60 minutes of the reaction. 68% of the 2,4-dimethylphenol were removed in the adsorption process and this efficiency is owing to the vacant adsorption sites present on the surface of the activated carbon at the early phase[53].

7 Conclusion

Activated carbon is a smart material that gained popularity recently due to its benefits as an adsorbent for wastewater pollutants. Activated carbon can remove the pollutants in wastewater conveniently without additional systems or technology. The heavy metals including Pb (II), Co (II), Ni (II), Zn (II), Cu (II), Cd (II), Mn (II), Hg (II), and As (V) as well as dyes including methylene blue, Rhodium B, Remazol brilliant blue R, methyl orange and aniline yellow can be removed from wastewater by the adsorption process using activated carbon. Besides, activated carbon can be used to remove common pharmaceutical waste and phenolic compounds of 2,4-dimethylphenol from wastewater. Moreover, activated carbon produced from agricultural sources has been used because of its availability, low cost, and easy production. To conclude, the activated carbon as an eco-friendly and effective adsorbent for the broad application of wastewater remediation. Further usage of activated carbon for removing other dangerous substance in existing water bodies is promising due to its relatively inexpensive preparation and highly versatile adsorption mechanism.

Conflict of Interest

The authors declare that there is no conflict of interest.

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