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Agricultural bio-waste materials as potential sustainable precursors used for activated carbon production: A review

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ABSTRACT

A review on the preparation of the activated carbon from agricultural waste material is presented. The physical properties such as proximate and ultimate analysis of agricultural waste material were reviewed. The chemical compositions such as cellulose, hemicelluloses and lignin contents were also discussed. The effects of various parameters on the preparation such as carbonization and activation temperature, time, types of activating agents and impregnation ratio were reviewed. Various physical and chemical processes for the activation of the agricultural residues and their effects on the textural properties such as surface area and pore volume were discussed. The low cost, renewable and relatively less expensive of the agricultural waste were found to be efficiently being converted into wealth. The uses of activated carbon derived from agricultural residues in many fields were evidently proven in the review. The reaction kinetic modeling on the pyrolysis and activation of agricultural wastes were also reviewed.

Contents

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1. Introduction

The term activated carbon is basically referred as carbonaceous materials [1], with high porosity [2–6], high physicochemical stability [7], high adsorptive capacity [8], high mechanical strength [9,10], high degree of surface reactivity [11,12], with immense surface area [13,14] which can be differentiated from elemental carbon by the oxidation of the carbon atoms that found at the outer and inner surfaces [15].

It is basically tasteless [16], amorphous [17–19], microcrystalline [20,21], non-graphite [22] form of carbon and a black solid substance which resembles powder or granular charcoal [23,24]. A non-graphite of activated carbon means that it cannot be converted into crystalline graphite even at a temperature of above 3000 °C [25].

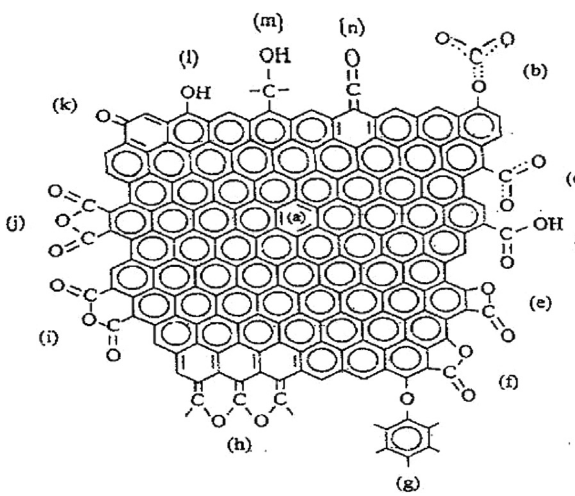

Fig. 1. IR-active functional groups on carbon surface: (a) aromatic C=C stretching; (b) and (c) carboxyl-carbonates; (d) carboxylic acid; (e) lactone (4-membered ring); (f) lactone (5-membered ring); (g) ether bridge; (h) cyclic ether; (i) cyclic anhydride (5-membered ring); (j) cyclic anhydride (6-membered-ring); (k) quinine; (l) phenol; (m) alcohol; and (n) ketene [36].

Activated carbon is also called as activated charcoal or activated coal [26] and sometimes called as solid sponge [27]. According to Cuhadaroglu and Uygun [1], activated carbon cannot be characterized by any distinctive chemical formula. Based on its physical characteristic, activated carbon can be classified into several classifications; powdered activated carbon (PAC), granulated activated carbon (GAC), extracted activated carbon (EAC) [21], pellet activated carbon [24], fibrous activated carbon [28], activated carbon cloths [11] and others.

Activated carbon has often been associated with the existence of the heteroatoms like oxygen, sulfur, hydrogen, nitrogen, halogen and other elements [29–31] in the forms of functional groups and/or atoms which bonded chemically to the structure. Oxygen is found to be predominant which exist in the form of functional groups such as carboxyl, carbonyl, phenols, lactone and others [32–34]. The nature and the amount of the oxygen surface groups that found the in the activated carbon also depend on the precursor and the activation treatment [11]. These carbon–oxygen groups of acidic (carboxylic, lactonic) and non-acidic (carbonyl, ether, quinone) evolve as CO_2 and CO, respectively, upon thermal decomposition. The phenol groups also evolve as CO, similar to those non-acidic, while anhydride gives rise to both CO and CO_2 [35]. Activated carbon have either protonated ($C–OH_2^+$), neutral (COH), or ionized (CO^-) on its surface. Those with protonated surfaces are called as H-type carbons, while ionized surfaces are called as L-type carbons [24]. Fig. 1 represents several IR-active functional groups that can be seen at the edges of and within grapheme layers of activated carbon after the oxidative treatment.

2. Agricultural waste material as activated carbon precursors

According to Girgis et al. [37], activated carbon can be produced by both naturally occurring and synthetic of carbonaceous solid precursor. It has been classed based on its starting material. The type of starting material or precursor plays a primary role in influencing the quality, characteristics and properties of the resulting activated carbon [18,38–43]. Cagnon et al. [44] has added that structure of the starting material also could influence the properties of the activated carbon.

Table 1
Proximate and ultimate analysis for agricultural residues.

Agricultural waste	Proximate analysis (% w/w)			Ultimate analysis (% w/w)					References
	Moisture	Ash	Volatiles	C	H	N	S	O	
Palm shell	7.96	1.10	72.47	50.01	6.9	1.9	0.0	41	Adinata et al. [64]
Palm stem	6.06	4.02	72.39	45.56	5.91	0.82	–	47.71	Alothman et al. [65]
Grape stalk	15.69	10.16	51.08	46.14	5.74	0.37	0.0	36.60	Amaya et al. [47]
Bamboo	–	3.90	80.6	43.8	6.6	0.4	0.0	–	Choy et al. [66]
Coconut shell	8.21	0.1	73.09	48.63	6.51	0.14	0.08	44.64	Daud and Ali [67]
Olive mill	< 5.0	< 1.0	–	45.64	6.31	1.42	–	–	Gokce et al. [56]
Almond shell	10.00	0.60	80.30	50.50	6.60	0.20	0.01	42.69	Gonzalez et al. [68]
Wallnut shell	11.00	1.30	71.80	45.10	6.0	0.3	0.0	48.60	Gonzalez et al. [68]
Almond tree pruning	10.60	1.20	72.20	51.30	6.50	0.80	0.04	41.36	Gonzalez et al. [68]
Olive stone	10.40	1.40	74.40	44.80	6.0	0.1	0.01	49.09	Gonzalez et al. [68]
Bamboo	2.44	6.51	69.63	45.53	4.61	0.22	–	–	Hirunpraditkoon et al. [45]
Durian shell	11.27	4.84	–	39.30	5.90	1.00	0.06	53.74	Jun et al. [69]
Chinese fir sawdust	4.88	0.32	79.92	48.95	6.54	0.11	0.00	39.20	Ke-qiang et al. [70]
Banana empty fruit bunch	5.21	15.73	78.83	41.75	5.10	1.23	0.18	51.73	Sugumaran et al. [16]
Delonix regia fruit pods	0.22	2.80	92.03	34.22	4.50	1.94	0.42	58.91	Sugumaran et al. [16]
Corn cob	4.3	0.90	78.7	46.8	6.0	0.9	–	46.3	Tsai et al. [87]
Pomegranate seed	5.38	1.83	78.71	49.65	7.54	4.03	0.65	38.13	Ucar et al. [63]
Birch	4.4	0.18	–	48.4	5.6	0.2	–	45.8	Zanzi et al. [27]
Salix	7.3	0.75	–	48.8	6.2	1.0	–	43.4	Zanzi et al. [27]
Sugarcane bagasse	6.2	0.90	–	47.3	6.2	0.3	–	46.2	Zanzi et al. [27]
Wheat straw	3.3	3.23	–	46.5	6.3	0.9	–	46.3	Zanzi et al. [27]
Bagasse	–	6.2	83.3	41.55	5.55	0.03	–	52.86	Boonpoke et al. [71]
Rice husk	–	16.7	67.5	36.52	4.82	0.86	–	41.10	Boonpoke et al. [71]
Cassava peel	11.4	0.3	59.4	59.31	9.78	2.06	0.11	28.74	Sudaryanto et al. [72]
Rice stalk	14.17	14.93	66.33	40.79	7.66	1.17	0.49	49.89	Ai et al. [73]
Woody birch	6.6	0.2	81.2	48.4	5.6	0.2	–	45.8	Budinova et al. [74]