Biochar: its overview and potential tool for multiple applications

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Abstract : Access to clean drinking water is a key issue for about 40 percent population in developing country. An alarming figure has been anticipated to increase water insufficiency by 2030. Holistic approach for water treatment is required, especially in remote areas where centralized supply systems are not immediately feasible. Untreated domestic, industrial and agricultural wastes are major sources for water pollution. Specifically, the contaminants such as organic pollutants, heavy metals, pesticides, personal care product, fuel compounds and pharmaceuticals are emerging problem worldwide. Since these compounds bio-accumulate in human body and cause carcinogenic diseases. Biochar (low cost material) has reasonable capacity to remove such emerging contaminants from waste water. Biochar can be prepared using easily available biomaterials. Other low cost materials mainly remove pathogens and generate carcinogenic byproduct (e.g. chlorination). Biochar not only removes chemical, biological and physical contaminants but also uphold the organoleptic characteristics of water. This paper reviews the biochar production, uses and its application for the domestic waste water treatment.

Keywords: Biochar, pyrolysis, water contaminants, water treatment, water recycling.

Introduction

Contamination of drinking water and its sources by pathogenic organisms, toxic inorganics, radionuclides, and synthetic and emerging organic contaminants are public health concerns especially among poor communities [1]. Public health risks and disease outbreaks among poor and vulnerable communities are directly proportional to poor sanitation and unsafe drinking water sources[2]. Poor and vulnerable people lack investment for installation, operation and management of safe drinking water provision technologies. Water-borne diseases resulting from unsafe drinking water and poor sanitation are endemic in developing countries.[1][3]

Recent studies have also reported high concentrations of synthetic and emerging organic contaminants in aquatic systems [4]. Synthetic and emerging organic contaminants include persistent and toxic pesticides, pharmaceuticals, drugs, dyes, personal care products, endocrine disrupting compounds and carcinogens, which are rarely considered in routine drinking water testing. [5] Drinking of untreated contaminated water, which is prevalent in developing countries, constitutes the most significant transfer pathway of contaminants from the environment into humans[6]. Water-borne and water-related diseases or infection transmits either directly through water infected with pathogens or by vectors whose lifecycles are closely associated with water[7]. Yet efforts to provide safe drinking water in the developing world have overlooked water quality aspects, probably due to the high costs for analytical equipment and the requisite highly trained personnel[8]

In 1990, The Millennium Development Goal (MDG) aimed ensuring safe drinking water to those without adequate water and sanitation by 2015. But, up to 600 million people, mostly in developing countries, still lack access to safe water (WHO/UNICEF 2014). Ironically, developing countries, especially those in Africa and parts of Asia which have lagged behind in technological advances due to weak scientific research and poor funding,[9] will require a scientific knowledge along with a promising and inexpensive technology which can ensure safe drinking water supply. [10]. There are a few selected techniques which are in practice for water treatment at small level or domestic scale[11]. But, generally the high cost and maintenance of such household water treatment techniques is one of the major challenges[12]. Low-cost water treatment is one effective intervention for safeguarding public health and preventing water-borne disease epidemics among poor communities

Therefore, simplification and cost cutting of such techniques is an important area of research. In this direction, the purification of water by biochar is an interesting technique. Literature shows that it is an established method which is used in a variety of separation and purification processes[13][14]. Water treatment at domestic level is one of such process where the adsorption based techniques have significant implications. Due to its low-cost, presence of surface functional groups, porosity, and moderate surface area, biochar has been explored as a filter for waste water treatment [15]

Biochar: Biochar is preferably prepared by Pyrolysis of woody raw material to several hundred degree Centigrade temperature under anoxic condition. The properties and yield of biochar depends on the pyrolysis operating condition and raw material composition. Biochar can be modified further in order to make it suitable for wider applicability. Various physical and chemical activation methods has been used to alter its structural and physiochemical properties[16]. The pyrolysis process can be divided into three subcategories: conventional pyrolysis, fast pyrolysis, and flash pyrolysis.

Table 1 Different Pyrolysis process

Methods	Temp (°C)	Residence time (min)	Heating rate	Major products

Conventional/Slow Pyrolysis	Medium-high 400-500	Long 5-30 mint	Low 10	Gases Char Bio-oil (tar)
Fast Pyrolysis	Medium-high 400-500	Short .5-2 Sec	High 100	Bio-oil(thinner) Gases Char
Ultrafast/Flash Pyrolysis	High 700-1000	Very short <0.5 sec	Very high >500	Gases Bio-oil

Source information: (Boyt, R., (November 2003), **Wood Pyrolysis*.*** ***Retrieved from Bioenergylists.org***

Temperature has the most significant effect after retention time and heating rate. Normally, when the reaction temperature increased, it causes reduction in biochar production, while at the same time, increasing the pyrolysis temperature leads to a drop off of solid yield and an increase in both gases and liquid percentages yield. On the other hand, raising the temperature leads to raised ash and Biochar percentage, whereas the volatile matter gets reduced. Therefore, biochar with greater quality is obtained at a higher temperature. [17]. Increasing the temperature that eventually decreases biochar yield could also be because of major decomposition of biomass at elevated temperatures or in the course of secondary decomposition of char residues.

Uses of Biochar:

There are many beneficial uses of biochar other than just working in the soil- whether as storage for volatile nutrients, as an adsorbent, as energy storage in batteries, as a filter in a sewage plant and as a feed supplement.[18]

Uses of biochar in diverse field				References
A	Animal Farming	1	Silage Agent	[18]
		2	Feed Additive/supplement	[19]
		3	Litter Additive	[20]
		4	Slurry Treatment	[21]
		5	Manure Composting	[22][23]
		6	Waste water in fish farming	[24] [25]
B	Soil conditioner	1	Carbon Fertilizer	[26]
		2	Compost	[19]
		3	substitute for peat in potting soil	[27]
		4	Plant Protection	[28]
		5	Compensatory fertilizer for trace element	[29][30][31]
C	Decontamination	1	Additive	[32][33]
		2	Soil Remediation	[34][35][34]
		3	Soil Substrate[36]	
		4	A Barrier preventing pesticide getting into the surface water[37]	
		5	Treating Pond and Lake water	[38][39]
D	Bio gas Production	1	Biogas Additive	[40][33]
		2	Biogas Slurry Treatment	[38]
E	waste water	1	Active Carbon Filter	[41]
		2	Pre-rinsing additive	[42]
F	Building sector	1	insulation	[18]
		2	Air decontamination	
		3	Humidity Regulation	
G	Textile			
H	other uses	1	Controlling Emission	[18]
		2	Room Air Filter	
		3	Carbon Fibres	[43]
		4	Plastics	
		5	Batteries	[44]

6	Cosmetics (Soaps. Skin-creams)

Biochar application for water purification

The low-cost water treatment methods such as sand and ceramic filters, solar water disinfection, chlorination and boiling have several drawbacks[45]. While sand and ceramic filters are effective in removing suspended solids, turbidity and colour, they have limited capacity to remove dissolved chemical contaminants and to some extent pathogenic organisms,[46][47] Conventional wastewater treatment processes are ineffective for eliminating the emerging contaminants at trace concentrations[48]. other techniques are energy intensive and needs power to maintain water pressure and other functions, like in reverse osmosis, membrane separation, photo oxidation, oznolysis [49][50].Significant reductions in water-borne disease after using simple water treatment systems such as filtration has been reported As an effective, efficient, and economic approach for water purification. Removal by adsorption has several advantages, including use of locally available materials, high efficiency (>90%) and selectivity, cost effectiveness, while maintaining the taste and colour[51]. A largely unexploited opportunity is the conversion of agricultural wastes (e.g., crop residues) from food production systems into biochar through pyrolysis, and its subsequent use for water treatment [52]. Purification by biochar needs no external power requirement. Biochar, a carbon-rich solid formed by pyrolysis of biomass, is an emerging low-cost technology which has attracted international research attention [53] However, it is believed that the use of this technique can be further encouraged by modification and reducing its running as well as maintenance cost.[38]

Mechanism of water purification

When a solution containing adsorbable solute comes into contact with a solid with a highly porous surface structure, there is higher concentration of materials at the surface or interface between the two phases, it is called interphase accumulation. The substance which is being adsorbed on the surface of another substance is called adsorbate. Whereas, the solid present in bulk, on which it is retained is called as an adsorbent. This surface accumulation of adsorbate on adsorbent is called adsorption. The interface may be liquid–liquid, liquid–solid, gas–liquid or gas–solid, only liquid–solid adsorption is used in wastewater treatment. Following four steps are considered, in which solute (adsorbate) is moved toward the interface layer and attached into adsorbent. (1) Advective transport: solute particles are moved from bulk solutions onto immobile film layer by means of Advective flow or axial dispersion or diffusion, (2) film transfer: solute particle is penetrated and attached in immobile water film layer, (3) mass transfer: attachment of solute particle onto the surface of the adsorbent and finally (4) intraparticle diffusion: Movement of solute into the pores of adsorbent

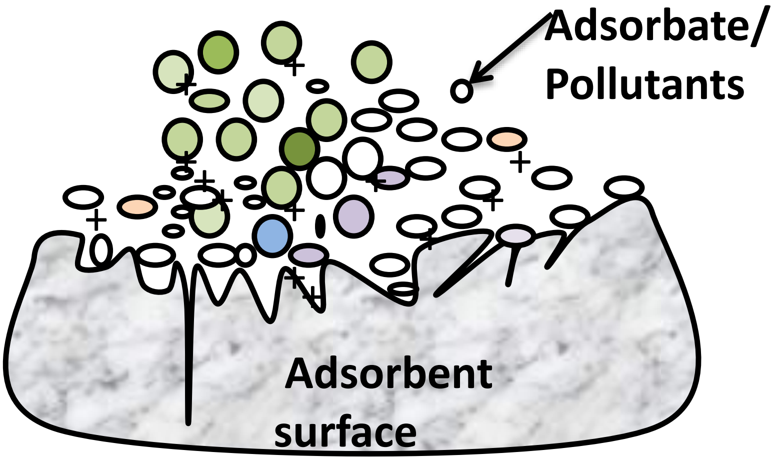

Figure 1 mechanism of adsorption on the biochar surface

So, the pores and high surface area of the biochar effectively uptake and bind the contaminants. All the bonding requirements (be they ionic, covalent, or metallic) of the constituent atoms of the material are filled by other atoms in the material. However, atoms on the surface of the adsorbent are not wholly surrounded by other adsorbent atoms and therefore can attract adsorbates. The exact nature of the bonding depends on the details of the species involved, but the adsorption process is generally classified as physisorption (weak Van Der Waals forces, reversible and low enthalpy) and chemisorption (covalent bonding, Ionic bonding, irreversible and high enthalpy value). It may also occur due to electrostatic attraction including dipole-dipole interaction. As the adsorption progress, equilibrium of adsorption between the solute and adsorbent is attained. The adsorption amount (qe, mmol g^{-1}) of the molecules at the equilibrium step is determined according to the following equation:

$$qe = \frac{(c0-ce)}{m}\,\mathrm{V}$$

Where V is the solution volume (L); M is the mass of adsorbents (g); and Co and Ce are the initial and equilibrium adsorbate concentrations, respectively. The adsorbents are broadly divided into three classes: (1) Synthetic adsorbent: Various porous materials are synthesized in laboratory using different processes, which have high adsorption capacities. Disadvantage is that this process of manufacturing is comparatively costly. (2) Natural adsorbent: Natural materials like plant root, leaf and agricultural waste are dried, crushed, sieved, again washed with distilled water and used as adsorbent for treatment of real as well as synthetic wastewater. This process is cheap, but adsorption capacity is comparatively low. (3) Semi-synthetic adsorbent: Natural materials undergo chemical as well as physical activation to develop highly porous surface. The major advantages of this adsorbent include: low cost, high efficiency, minimization of chemical or biological sludge, no additional nutrient requirement and regeneration of absorbent and possibility of metal recovery. A very brief review of the literature about use of feedstock in adsorbent (biochar) development is described below in this perspective.

Feed Stock used in development of biochar

S.NO	Feed Stock	Removed compounds	Reference
1	Bamboo	Bisphenol, 4-nonylphenol	[54]
2	Reed stalk	Florefenicol	[55]
3	Municipal sludge	Tetracycline	[56]
4	Wood	Acid orange	[57]
5	Camphor leaves	Ciprofloxacin	[58]
6	Chicken bone, Chicken feather	Tetracycline & fluorescent dye, Cd, Pb	[59][60]
7	Bagasse	Caffeine , Diclofenac	[61]
8	Sewage sludge	Cu(II)	[62]
9	Marine macroalgae	Phosphate	[63]
10	Douglass fir	Aniline & nitrobenzene, benzoic acid	[64]
12	Herbal medicine waste	Tetracycline	[65]
13	Corn stalk	Cr(VI)	[66]
14	Coconut, Pine nut & walnut shells	Carbazepine, tetracycline	[67]
15	Switch grass	Metribuzin	[68]
16	Pine sawdust	Sulfamethoxazole	[69]
17	Waste hydro char	Tetracycline	[70]
18	Wood chip, Garden wood, Pristine,	Phosphate	[68]
19	Rice husk	Cd	[68]
20	Rice straw	Nitrate, Phosphate and ammonium	[71]
21	Peanut hull, Kitchen waste, Corn straw	Pb, Cd	[72]
22	Phoenix tree leaves	Cr(vi)	[73]
23	Palm fiber	Sulphur di oxide	[74]
24	Coffee ground	As(v)	[75]
25	oak wood	Cd	[76]
26	Agriculture waste	Tetracycline, Pb(II)	[77][78]
27	Apple pomace	Ag(I)	[79]
28	Fruit peel	Ammonia	[80]
29	Glucose	Pharmaceutical	[81]
30	Cocoa pod husk, Corn cob, Rice husk, Palm kernel shell	Orthophosphate	[82]
31	Water hyacinth	Cr(II)	[83]
32	Pomelo peel	Sulphate Ion	[84]
33	Sewage sludge and walnut cell	Ammonium and sulfate	[85]
34	Pine tree	Cd (II)	[86]
35	Rice straw, Phragmites communis, Sawdust and Egg shell	Ammonium NH_4^+	[52]
36	Cow dung	Tetracycline	[87]
37	Maize straw	2,2′,4,4′-Tetrabromodiphenyl Ether (BDE-47)	[88]
38	Macauba endocarp	U (VI)	[89]
39	Wheat straw	Pb(II)	[90]
40	Taro straw, Corn straw, Cassava straw, Chinese fir straw, Banana straw, and Camellia oleifera shell	Nitrogen, Phosphorus	[91]
41	Gingko (Spiraea blumei) leaf, peanut shell, and Metasequoia leaf	Pb, Cu	[92]

In literature, large number of material has been claimed for biochar as adsorbent from plant material. Several parts of the plant have been successfully employed as preliminary materials in the production of charcoal. These include empty fruit bunches, fibers and shell. These materials are renewable low-value agricultural wastes. Nutshells are preferred precursors In addition to it; most of the biochar have been prepared for specific removal of compounds. Therefore, this poses limitation in overall treatment of waste water. So, the modification of biochar needs to be discussed and also requires deep analysis emphatically like complexation, ion exchange, electrostatic attraction, reduction, chemical precipitation and hydrogen bonding etc.

Apart from that, waste materials or by products of industrial process can be used. For instance food waste, sewage sludge, biomass tires etc. The key benefits of using waste-based precursors would significantly reduce the cost of technology along with the valorization of these wastes.

Conclusion

More efforts should be carried out to study the removal of contaminants by biochar. Based on the above discussions and investigations, the future research on the preparation and application of biochar in water treatment can be carried out from following aspects. 1) the modification of biochar and its physiochemical properties of should be further studied in future; 2) the removal of organic matters and emerging contaminants as well as the adsorption and removal mechanism of organic matters need to be deeply explored; 3) research on dealing with the toxic and harmful substances produced during the production should be attached with high importance; 4) development of biochar with catalytic degradation activity for organic contaminants in water is another interesting research direction. 5) In developing country where forest and agricultural residue traditionally burnt or not used in elsewhere should be assessed as an alternative for biochar production. 6) The magnetic biochar may become a research focus and gain greater development in the near future. Further, the technology should require lesser skills to make appropriate for poor communities.

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