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Reutilization of discarded biomass for preparing functional polymer materials

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A B S T R A C T

Biomass is abundant and recyclable on the earth, which has been assigned numerous roles to human beings. However, over the past decades, accompanying with the rapid expansion of man-made materials, such as alloy, plastic, synthetic rubber and fiber, a great number of natural materials had been neglected and abandoned, such as straw, which cause a waste of resource and environmental pollution. In this review, based on introducing sources of discarded biomass, the main composition and polymer chains in discarded biomass materials, the traditional treatment and novel approach for reutilization of discarded biomass were summarized. The discarded biomass mainly come from plant wastes generated in the process of agriculture and forestry production and manufacturing processes, animal wastes generated in the process of animal husbandry and fishery production as well as the residual wastes produced in the process of food processing and rural living garbage. Compared with the traditional treatment including burning, landfill, feeding and fertilizer, the novel approach for reutilization of discarded biomass principally allotted to energy, ecology and polymer materials. The prepared functional materials covered in composite materials, biopolymer based adsorbent and flocculant, carrier materials, energy materials, smart polymer materials for medical and other intelligent polymer materials, which can effectively serve the environmental management and human life, such as wastewater treatment, catalyst, new energy, tissue engineering, drug controlled release, and coating. To sum up, the renewable and biodegradable discarded biomass resources play a vital role in the sustainable development of human society, as well as will be put more emphases in the future.

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Abbreviations: AA, acrylic acid; AM, acrylamide; BA, butyl acrylate; CF, chicken feather; CMC, carboxymethyl cellulose; CS, chitosan; DAAM, diacetone acrylamide; DMDAAC, dimethyl diallyl ammonium chloride; E-PHK, pig hair keratin; E-PHKPGel, (E-PHK)-based biopolymer hydrogel; FK, feather keratin; HA, humic acid; HTC, Hydrothermal carbonization; MAA, methacrylic acid; MMA, methyl methacrylate; MSW, Municipal solid waste; NOR, norfloxacin; ORR, oxygen reduction reaction; PAN, polyacrylonitrile; PC, polycarbonate; PdNPs, palladium nanoparticles; PE, polyethylene; PEG, polyethylene glycol; PEO, poly(ethylene oxide); PHA, polyhydroxyalkanoates; PLA, Polylactic acid; PLMA, polymalic acid; PNIPAAm, poly (N-isopropylacrylamide); PoSt-g-BMD, potato starch-based graft copolymer; PoSt-g-BMD-C, potato starch-based graft copolymer coatings; PP, polypropylene; PTE, polysulfide ester; PTT, Polytrimethylene terephthalate; PVA, poly-vinyl alcohol; SDZ, sulfadiazine; SHR, soybean hulls residue; TC, tetracycline; TTI, Time-Temperature Indicator; TYL, tylosin; WPCs, wood polymer composites; WSC, wheat straw carboxymethylcellulose; WSM, wheat straw matrix.

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1. Introduction

Biomass is abundant and recyclable on the earth, which has been assigned numerous roles to human beings from ancient times. However, accompanying with the rapid expansion of man-made materials, such as alloy, plastic, synthetic rubber and fiber, a great number of natural materials had been neglected and abandoned, such as straw, which cause a waste of resource and environmental pollution. In the beginning of 20th century, the rapid expansion of relatively low-priced petrochemical production inhibits the development of agricultural industry. In the midst of them, synthetic polymer materials have lots of advantages, such as easy-machined, beautiful and practical, which met the needs of different industry areas and gradually took the place of traditional materials (Wong et al., 2015). Every year, millions of tons of petrochemical polymer materials, such as polyethylene (PE), polypropylene (PP) and polycarbonate (PC), were produced and used in daily life, industrial and agricultural production. Most of non-renewable and non-biodegradable synthetic materials were used in a short period and promptly became wastes, which resulted in seriously environmental "white pollution" at present. On the other side, with the depletion of fossil resources and the soaring prices of crude oil, the production of petrochemicals from fossil as raw materials has been a severe challenge (Xiong et al., 2012a,b). Therefore, biomass resources have been paid increasing attention because of their renewability and biodegradability (Wang et al., 2016a,b; Komatsu et al., 2006). In particular, the composition and energy utilization of biomass energy are very similar to fossil energy. Thus, it has the largest potential to substitute for conventional energy (Zhou et al., 2016a,b).

Biomass materials had been used as structural materials or common materials from ancient times because their major components were natural polymers, such as lignin, cellulose, starch, chitin and protein, which guaranteed enough strength and stability. However, a lot of natural polymers were discarded as forms of biomass on account of the ignorant of their real value. In the past decades, increasing emphases were turned to natural polymers in the development of environmentally-friendly products and fuels (Moon et al., 2011; Wang et al., 2012). Overall, the depletion of non-renewable resources and the environmental pollutions motivate the increasing demands of renewable resources and there is still a long way towards dealing with all of problems. In this review, from the perspective of polymer chemistry and functional materials, the development and research progress on reutilization of discarded biomass and the preparation of functional materials has been summarized.

2. Sources of discarded biomass and traditional treatment

Almost all discarded biomass are come from plants, animals and microbial wastes. The plant wastes are generated in the process of agriculture and forestry production and manufacturing processes. The animal wastes are generated in the process of animal husbandry and fishery production, and the residual wastes are produced in the process of food processing and rural living garbage. In addition, microbial wastes are mainly produced in the plant and animal wastes and they are contained among them. In the global scope, there is 140 billion metric tons of biomass generated from agriculture annually (Oladeji and Oyetunji, 2013). These volumes of biomass are converted into a substantial amount of raw materials. Meanwhile, they produced different forms of discarded biomass residue (Vaisanen et al., 2016). Extraordinarily in China, as a large agricultural country with a high-ranking in global crop production (Huang et al., 2012), it has abundant agricultural waste resources, such as the crops straw. The annual production of waste crop straw is as high as approximately 0.7 billion tons, of which 70% is composed of rice straw, wheat straw and corn stalk. So China has the most discarded biomass resources in the world (Liu et al., 2013). In the process of forestry production, generally, wastes come from the process of forest harvesting, raw wood manufacturing and wood processing, such as wood chips, sawdust, shavings (Tan et al., 2015), which are up to about 110 million tons each year. Urban greening and wood wastes also occupy a large proportion of city solid wastes. It is also known as "another kind of forest", which is the forest that lying on the ground. Besides, there are many kinds of natural polymer in the living garbage, such as walnut shell, coconut shell, fruity nucleus, chestnut shells, cotton seed shell and pineapple peel. Additionally, a large number of residues, such as bean curd, lees, bagasse, and food industrial scraps, have been discharged from food processing industry (Marcet et al., 2016; Moreno et al., 2016; Raak et al., in press; Steur et al., 2016). For instance, in the fish or shrimp processing, the amount of wastes can be reached as high as 60% of the marine animals' weight. After obtaining the fish fillets, the remaining 50–60% of the whole fish is discarded as by-products or wastes (Torres et al., 2007). It is understandable that why the problem of industrial by-products and wastes in food processing has attracted the interest of researchers, regulatory departments, industry and consumers and has urged the European Union towards "a zero-waste economy" by 2025 (Naziri et al., 2014).

During development in thousands years, human have gradually accumulated valuable experience in processing and recycling of discarded biomass resources. Except for landfill, the typical methods are burning, feeding and fertilizer. In the agrarian age, some of agricultural wastes were directly used as animal feed. Part of discarded biomass materials can be disposed by microbial transformation, which provides microbial protein products, then becoming animal feed (Sun et al., 2005). Meanwhile, in some undeveloped, rural and agricultural districts, as well as several peri-urban areas, people cooked or heated by burning agricultural residues in their daily lives. Direct incineration of discarded biomass is deemed to a common way of disposal in developing countries including China (Huang et al., 2012). The direct combustion of discarded biomass in cropland is a kind of lower-priced way for disposal of discarded biomass. However, the excessive combustion of discarded biomass releases large quantities of greenhouse gases and dust, which not only lead to formidable air pollution such as fog and haze, smog and acid rain (Ding et al., 2013; Li et al., 2016a,b), but also a seriously waste of valuable natural resources including energy, materials, nutrients and minerals substances. It was reported that the concentration of particulate matter may increase dramatically in downwind suburbs and rural