Life Cycle Assessment of Biochar Preparation of Chinese Traditional Medicine Residue by Low-temperature Pyrolysis

Qian Deng[1], *Aijun* Li[1,*], *Yangwei* Wu[1], and *Lushi* Sun[2]

[1] Huazhong University of Science and Technology, School of Energy and Power Engineering, 430074 Wuhan, China
[2] Huazhong University of Science and Technology, School of Energy and Power Engineering, State Key Laboratory of Coal Combustion, 430074 Wuhan, China

Abstract. This study aimed to evaluate the environmental impacts of the biochar production process through low-temperature pyrolysis of Chinese medicine residue via life cycle assessment (LCA). An LCA model consisting of biomass pretreatment, pyrolysis, separation and cooling was developed. The results indicated that the low-temperature pyrolysis process has the highest environmental impact on AP and GWP. The consumption and direct emission of pyrolysis process were the primary sources of environmental impact. In addition, by comparing to the traditional landfill process of Chinese medicine residue, it turns out that the low-temperature pyrolysis process has improved environmental protection performance.

1 Introduction

With the rapid development of Chinese medicine and the extension of the related resource based industrial chains, the yield of Chinese medicinal residue is increasing year by year. The annual discharge of Chinese medicinal residue in China is up to 30 million tons in 2015, among which the production of Chinese patent medicine takes up the largest part, accounting for about 70% of the total[1]. Chinese medicine residue contains a certain amount of active ingredients and a large amount of cellulose, hemicellulose, lignin, protein and other rich organic ingredients. Recently, it has been reported that traditional Chinese medicine residue is used for edible fungus, feed, pyrolysis and gasification[2-4], partly realizing its resource-oriented utilization. However, due to the long fermentation cycle, complex composition, difficult separation, and some residues may contain harmful substances, the utilization of the residue as feed and fertilizer is still under restriction[5]. Agricultural straw and garden waste have been widely used in the preparation of biochar, showing broad application prospects in soil improvement and environmental protection [6,7]. Chinese medicine residue is highly similar to agricultural and forestry wastes, which are characterized by high carbon content and easy to collect, and also can be used to prepare biochar. However, the existing literature has mostly focused on the performance and application of biochar, the environmental impact caused by its production process, and the quantitative assessment of its environmental performance are required to be identified systematically and comprehensively.

So far, several LCA studies have evaluated the production of activated carbon or bio-oil from biomass[8-13]. As a typical biomass, some researchers have attempted to investigate pyrolysis gasification from Chinese medicine residue[14,15], but there is still a lack of LCA investigation on biochar production from Chinese medicine residue through low-temperature pyrolysis.

The purpose of this study is to analyze the environmental impacts on low-temperature pyrolysis of Chinese medicinal residue to prepare biochar. This article indicates the influence of low-temperature pyrolysis on various environmental impact categories by comparing with the landfill process, so as to provide more intuitive and reliable scientific basis for its environmental protection performance.

2 Data source and methods

2.1 Data source

The Chinese medicine residue analyzed in this article is based on the research of Guo[16] from Henan Wanxi Pharmaceutical Co., Ltd. Table 1 represents the elemental and proximate analysis of Chinese medicine residue, respectively.

---

[*] Corresponding author: hust_laj@mail.hust.edu.cn

Table 1. Proximate and elemental analysis and LHV of Chinese medicine residue[16]

Chinese medicine residue	Proximate analysis (wt% wet basis)				Elemental analysis (wt% dry basis)					
Project	M	FC	V	A	C	H	O	N	S	LHV（MJ/kg）
Content	12.5	12.41	72.62	2.47	42.4	6.2	47.39	1.06	0.15	14.90

2.2 Process description

The pyrolysis system of Chinese medicine residue consists of four units: biomass pretreatment, pyrolysis, separation and cooling. The residue was first broken by crusher until the particle size is between 40-60 mu[17], and then dried until the moisture content is less than 10%. Once they meet the requirements of pyrolysis, low-temperature pyrolysis reaction can be carried out in the pyrolysis furnace to generate biochar and gas products. The temperature of pyrolysis is 550 ℃. Then biochar shall be rapidly cooled down to about 80 ℃ in a short time through an air-cooled and water-cooled two-stage heat exchanger. Gas products reacted with air in the combustion furnace to provide heat for drying and pyrolysis, resulting in exhaust gas such as CO2.

2.3 Life cycle assessment framework

2.3.1 Research methods and tools

This study intends to examine the gate-to-gate life cycle impacts of biochar derived from Chinese medicine residue with low-temperature pyrolysis techniques. LCA was carried out with eBalance software which is the first general LCA software with independent intellectual property rights developed by IKE Environmental Technology Co., LTD. (IKE). It provides high-quality database support in China and the world, which is suitable for LCA analysis of various products. Life cycle impact assessment (LCIA) with the eBalance software can provides comprehensive quantitative analysis results. The impact categories considered in this study include acidification (AP), Chinese resource depletion potential (CADP), primary energy demand (PED), eutrophication (EP), global warming potential (GWP) and respiratory inorganics (RI).

2.3.2 Goal and scope

The goal of this study was to evaluate the environmental performance of biochar preparation by low-temperature pyrolysis. The environmental footprints of all input processes of the entire life cycle from raw material (Chinese medicine residue) pretreatment to the final product (biochar) were included in this study. Besides, by comparing with landfill process, the degree of impact of low-temperature pyrolysis process of Chinese medicine residue on various environmental categories was determined. Additionally, further suggestions for optimizing production and reducing pollution were put forward. The functional unit was the dispose of 10 tons Chinese medicine residue. According to Fig. 1, the subsystems included biomass pretreatment unit (process 1), pyrolysis unit (process 2), separation unit (process 3), and cooling unit (process 4). All inputs and outputs involved within the system boundary were based on the processing of 10 tons of Chinese medicine residue. The use and abandonment of the product, and the manufacturing and maintenance of the equipment were not considered here to ensure the accuracy and operability of the model.

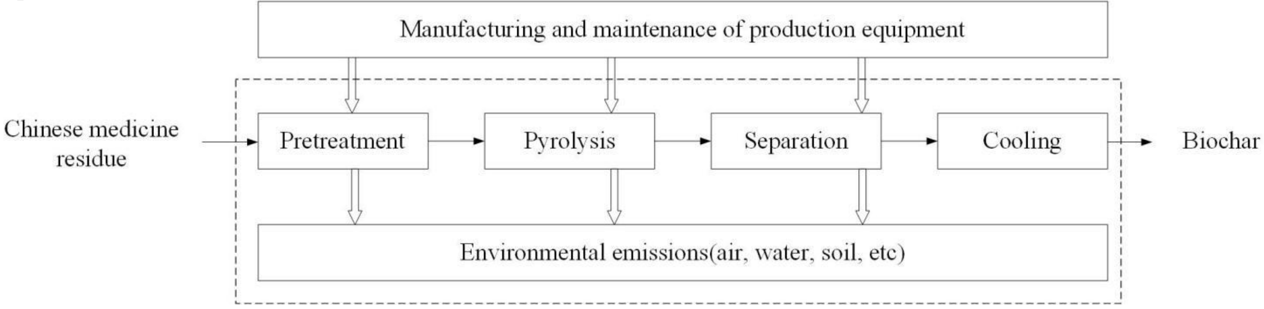

Fig. 1. System boundary of biochar production from Chinese medicine residue.

2.3.3 Life cycle inventory (LCI)

The Life Cycle Inventory (LCI) is the second phase of an LCA study, in which all inputs and outputs data to or from the system boundary are collected. The data for inventory analysis is based on the material input, output, resource and energy consumption and environmental emissions in all sectors within the defined system boundaries. Energy and water consumption for operation, biochar production, and the composition of the exhaust gas are given by previous simulation results. The CLCD Public, Ecoinvent Public and ELCD databases of the eBalance software were used for the background data (production of materials and energy sources). Tables 2 and 3 showed the details on input and output data.

Table 2. The input data used for four processes in biochar production.

Process	Substance	Unit	Input
Process 1	Chinese medicine residue	t	10
	Electricity	kWh	1480
	Air	kg	50000
	Heat	GJ	2.746
Process 2	Dry medicinal residue	t	9.722
	Heat	GJ	23
	Nitrogen	kg	96.3
Process 3	Air	kg	50000
	H2	kg	186.68
	CH4	kg	768.56
	CO	kg	312.46
	H2O	kg	2418.57
	N2	kg	92.75
	CO2	kg	3690.97
Process 4	Biochar	kg	1904.14
	Air	kg	15800
	Electricity	MJ	1494.77
	Water	kg	2495

Table 3. The output data used for four processes in biochar production.

Process	Substance	Unit	Output
Process 1	Dry medicinal residue	t	9.722
	Wastewater	t	0.278
Process 2	Biochar	kg	1904.14
	Ash	kg	245
	H2	kg	186.68
	CH4	kg	768.56
	CO	kg	312.46
	H2O	kg	2418.57
	N2	kg	92.75
	CO2	kg	3690.97
Process 3	H2O	kg	5820.37
	N2	kg	38332.70
	O2	kg	7014.30
	CO2	kg	6290.32
	SO2	kg	26.22
	NO2	kg	0.0263
Process 4	Biochar	kg	1904.14
	Wastewater	kg	2495

3 Results and discussion

3.1 Life cycle impact assessment (LCIA)

Fig. 2 showed the life cycle impact assessment results of low-temperature pyrolysis process of Chinese medicine residue. The order of impact categories was as following AP > GWP > RI > EP > CADP > PED. To dispose of 10 tons Chinese medicine residue, the highest amounts of impact categories were found to be for AP, GWP, and RI. The greatest indicator was related to acidification. This problem is due to the release of acid gases such as SO2, N O2, etc. resulting from biogas combustion. The second environmental problem was correlated to the global warming. Indeed, greenhouse gas emissions such as CO2 are directly involved with power consumption. The third main indicator of biochar production was RI.

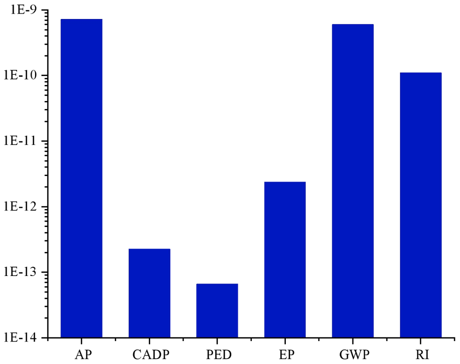

Fig. 2. Life cycle impact assessment results of low-temperature pyrolysis process of Chinese medicine residue

3.2 Analysis of process contribution

Analysis of process contribution was conducted for the above six environmental impact categories to identify the major pollution processes for effective improvement measures. Fig. 3 showed the analysis results of process contribution for key environmental impact categories. It's worth noting that pollution from upstream is also taken into account in eBalance software. Therefore, substances in process contribution assessment include pollution sources from upstream raw material production. Results presented that in the process of low-temperature pyrolysis of Chinese medicine residue, the separation unit has a relatively large impact on AP, GWP and RI, indicating that the consumption and direct emission in pyrolysis process were the main sources of environmental impact. For CADP and PED, the pyrolysis and cooling unit have great influence, accounting for more than 30 %. Moreover, the pretreatment unit also has a certain influence. For EP, the separation process has the largest environmental impact, reaching more than 40 %. Therefore, it can be concluded that the pyrolysis unit needs to be optimized urgently.

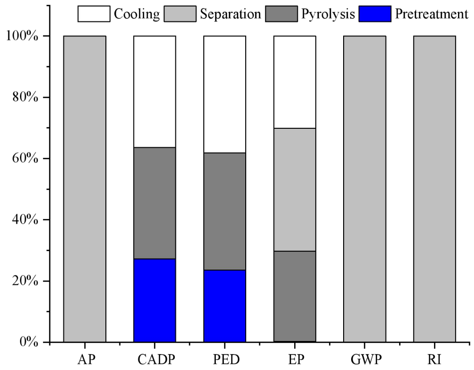

Fig. 3. Analysis of process contribution

3.3 Comparison with landfill process of traditional Chinese medicine residue

By comparing the low temperature pyrolysis with the landfill process of 10 tons Chinese medicine residue, we can further quantitatively analyze the environmental protection performance of the low-temperature pyrolysis process of Chinese medicine residue. The results of the comparison of environmental impact analysis between low-temperature pyrolysis and landfill process of Chinese medicine residue were shown in table 3.

Table 4. Comparison of environmental impact analysis results between low-temperature pyrolysis and landfill process

Impact category	Unit	Low-temperature pyrolysis	Landfill
AP	kg SO2 eq	26.2	52.5
CADP	kg Coal-R eq	3.46	4.72
PED	MJ	5.82	8.05
EP	kg PO43-eq	8.87×10-3	1.51×10-2
GWP	kg CO2eq	6290	12600
RI	kg PM2.5 eq	2.05	4.10
ECER-125-CN-2010	-	8.01×10-9	1.60×10-8

The results indicated that for the above six environmental impact categories, low-temperature pyrolysis had lower values in comparison to landfill process, respectively. Especially for GWP, AP and RI, low-temperature pyrolysis of Chinese medicine residue showed obvious advantages. The main reasons can be attributed into two aspects: On the one hand, the low-temperature pyrolysis process recycles the residue and reduces the discharge of solid waste and harmful substances; On the other hand, Chinese medicinal residue directly buried in the landfill, resulting in a large amount of land occupation, and will affect the mining of minerals. Additionally, Chinese medicinal residue decay in the natural environment, bringing about a large number of harmful substances which cannot be ignored.

In general, the low-temperature pyrolysis process of Chinese medicine residue showed better environmental performance than the traditional landfill process, which can better reflect the characteristics of environmental friendliness in all aspects.

4 Conclusions

This study assessed the environmental impacts of biochar production from Chinese medicine residue through low-temperature pyrolysis, and compared low-temperature pyrolysis with landfill process of Chinese medicine residue. The main conclusions are as following:

(1) Normalization results showed that low-temperature pyrolysis of Chinese medicine residue has the highest impact on acidification and global warming potential, followed by respiratory inorganics, eutrophication, Chinese resource depletion potential and primary energy demand.

(2) Analysis of process contribution revealed that the separation unit had a relatively larger impact on AP, GWP and RI, indicating that the energy consumption and direct emission of pyrolysis process were the main sources of environmental impact. The pyrolysis unit is in urgent need of optimization.

(3) From the perspective of life cycle, the low-temperature pyrolysis process of Chinese medicine residue showed a better environmental protection performance in various environmental impact categories than traditional landfill process. It's not only because the residue is recovered in the low-temperature pyrolysis process, which reduces the discharge of solid waste and harmful substances, but also because the Chinese medicine residue is directly landfilled, resulting in a large number of land occupation and harmful substances.

In short, the low-temperature pyrolysis system showed evident advantages than landfill system, but still needs to be optimized. This study laid a foundation for the application and popularization of the low-temperature pyrolysis of Chinese traditional medicine residue.

Acknowledgments

This work was supported by "National Key R&D Program of China (2019UFC1906600)".

References

1. M. L. Na, J Chen, W. Z. Wei, et al. Research progress of biological processing of traditional chinese medicine residues. Lishizhen Medicine and Materia Medica Research. 01: 194-196. (2016)
2. J. Z Chen., Y. Z.Tan, X. H. Wang, et al. Effects of bushen yishou capsule residues on culture of pleurotus abalonus han,k.m.chen et.s.cheng and nutrition composition analysis. Southwest China Journal of Agricultural Sciences. 02: 740-742. (2012)
3. J. A. Duan, S. L. Su, G Sheng, et al. Research practices of conversion efficiency of resources utilization model of castoff from chinese material medica industrialization. China Journal of Chinese Materia Medica. 38: 3991-3996. (2013)
4. E. H. Wang, X. F. Cai and F. L. Zhang Effects of Degraded Astragalus Residue on Growth Performance and Flavor of Broilers. Southwest China Journal of Agricultural Sciences.(10): 69-72.(2020)
5. S. Guo, J. A. Duan, X. J. Lu, et al. Research and Practice on Utilization of Chinese Medicinal Materials Solid Waste by Pyrolysis and Carbonization. Modern Chinese Medicine. 19(12): 1665-1671. (2017)
6. W. F. Chen,, W. M. Zhang and J. Meng. Advances and prospects in research of biochar utilization in agriculture. entia Agricultura Sinica. 46(016): 3324-3333. (2013)
7. L. Qian, W. Zhang, J. Yan, et al. Effective removal of heavy metal by biochar colloids under different pyrolysis temperatures. Bioresource Technology. 206: 217-224. (2016)
8. K. Hjaila., R. Baccar, M. Sarra, et al. Environmental impact associated with activated carbon preparation from olive-waste cake via life cycle assessment. Journal of Environmental Management. 130: 242-247. (2013)

9. J. F. Peters, D Iribarren and J Dufour, Simulation and life cycle assessment of biofuel production via fast pyrolysis and hydroupgrading. Fuel. 139: 441-456. (2015)
10. L. Heng, H. Zhang, J. Xiao, et al. Life Cycle Assessment of Polyol Fuel from Corn Stover via Fast Pyrolysis and Upgrading. Acs Sustainable Chemistry & Engineering. 6(2): 2733-2740. (2018)
11. S. Suganya, P. S. Kumar, Evaluation of environmental aspects of brew waste-based carbon production and its disposal scenario. Journal of Cleaner Production. 202: 244-252. (2018)
12. X. Yang, D. Han, Y. Zhao, et al. Environmental evaluation of a distributed-centralized biomass pyrolysis system: A case study in Shandong, China. Science of the Total Environment. 716.(2020)
13. X. Zhang, L. L. Zhang, R. Li, et al. Life cycle assessment of straw fast pyrolysis based on energy integration. CIESC Journal. 72(5): 2792-2800. (2021)
14. P. Wang, H.B. Yu, X. F. Xue, et al. Study on characteristics and kinetics of pyrolysis of herb residue. Chinese Journal of Environmental Engineering. 04(9): 2115-2119. (2010)
15. P. F. Fan, J. D. Li, Y. T. Liu, et al. Experimental study of gasification of herb residues of Ganmaoqingre granules in pilot-scale dual-loop circulating fluidized bed. Chemical Industry and Engineering Progress.(8): 1979-1985,1991. (2014)
16. F. Q. Guo Study on pyrolysis gasification and tar oxidation reforming process of traditional Chinese medicine residue biomass. (Doctoral dissertation, Shandong University).(2013)
17. P. Badger, S. Badger, M. Puettmann, et al. Techno-economic analysis: Preliminary assessment of pyrolysis oil production costs and material energy balance associated with a transportable fast pyrolysis system. Bioresources. 6(1): 34-47. (2011)