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Ultrasonic pretreatment effects on the co-pyrolysis of municipal solid waste and paper sludge through orthogonal test

Shiwen Fang[a,b], Wenlu Gu[a,b], Lin Chen[a,b], Zhaosheng Yu[a,b,*], Minquan Dai[a,b], Yan Lin[a,b], Yanfen Liao[a,b], Xiaoqian Ma[a,b]

[a] *School of Electric Power, South China University of Technology, 510640 Guangzhou, China*
[b] *Guangdong Province Key Laboratory of Efficient and Clean Energy Utilization, 510640 Guangzhou, China*

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ABSTRACT

In this study, the influences of ultrasonic pretreatment factors (frequency, power, treatment time) on blends of municipal solid waste (MSW) and paper sludge (PS) with additive (MgO) was explored, through orthogonal experiments design. The optimum operating condition wanted to be acquired. However, for the ultimate (H/C) and ash analysis after pretreatment, solid residue mass and oxygenates compounds contents in products, the influences of factors were in different results. With adding PS unceasingly, the contents of hydrocarbon compounds decreased. And the ultrasonic pretreatment had the obvious influence with high PS percentage. Longer treatment time resulted to the lower content of oxygenates compounds. After adding MgO, the residue mass reduced, which meant MgO had the catalytic action, and the oxygenates compounds content reduced only with 100 kHz, which had the sonochemical effect.

1. Introduction

Presently, energy consumption increase gradually as the living standard improved and social economy developed. However, the widely utilization of energy resources are still limited to fossil fuels, which are non-renewable resources and cause serious some environmental problems (Hu et al., 2013). Therefore, it is necessary to develop new energies to substitute for fossil fuels. Municipal solid waste (MSW) is a complex mixture containing many combustible substances, such as paper, fruit and kitchen waste, branches etc (Fang et al., 2018). Paper sludge (PS) from paper mill papermaking wastewater is a great issue risking the environment and human health (Fang et al., 2015). Nowadays, the most common methods for treatment or disposal of MSW and PS are dumping in landfills, agricultural application and incineration. Unfortunately, these methods involve many practical problems such as the production of a leachate that could contaminate ground waste. Hence, it is urgent to find some new methods to deal with the disposal problem.

Among all the available technologies, such as gasification, carbonization and liquefaction, pyrolysis, the thermal destruction lack of oxygen, has attracted the most interests (Fang et al., 2016; Imam and Capareda, 2012). Since one of the products of pyrolysis is bio-oil, which is a great carbon source, pyrolysis represents a potential source of energy. Moreover, co-pyrolysis could improve the quantity and quality of liquid products (Lin et al., 2016). Lin et al. (2017) explored the co-pyrolysis characteristics of bagasse and sludge through TG-FTIR and Py-GC/MS. The integral values calcium-based and iron-based compounds were benefit for the N-pollutant control in co-pyrolysis process. And the addition of sludge was beneficial for the production of group $C7_P$, which possessed over 7 carbon atom. Wu et al. (2014) indicated that the thermal stability increased through co-pyrolysis of PVC, PSand PE. In addition, the methyl ($-CH_3$) and methylene ($-CH_2-$) bonds were disappeared while PVC mixed with PE. To improve the efficiency of pyrolysis or ameliorate the effect of pyrolysis, additives were used.

Strictly speaking, small operational variations can lead to non-comparability during sequential extractions. Pretreatment is necessary for overcoming the recalcitrance of lignin and reducing the overall cost for bio-oil. There are a number of different pretreatments. Whatever the methods used for sample pretreatment of the solid materials can alter the results of the speciation. Depending on their general principal of operation, they could be classified as chemical, biological and physical pretreatments (Methrath Liyakathali et al., 2016). For our first knowledge, food and fruit waste, the mass content of which was 46.4% in MSW, were well thought-out as a complex organic substrate due to comprise of carbohydrates, proteins, and lipids, which limited the rate and efficiency of hydrocarbon production(Gadhe et al., 2014). According to some literatures, ultrasonic treatment has been used in a wide range from extractions to purifications and to enhance

* Corresponding author at: School of Electric Power, South China University of Technology, 510640 Guangzhou, China.
E-mail address: zsyu@scut.edu.cn (Z. Yu).

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solubilization of organic matter, because it provides a unique physicochemical environment for raw material progressing (Asfaram and Ghaedi, 2016; Wu et al., 2017). By definition, ultrasound is an acoustic and emerging green energy at a frequency higher than the upper normal human hearing limit (20 kHz) and is normally limited up to 1 MHz (Cherpozat et al., 2017). More recently, ultrasound technique have capacity to modify the surface structure of lignocellulosic biomass with beneficial effects on the saccharification process and has the potential to reduce the reaction time and the chemical loading (Bussemaker and Zhang, 2013). The application of ultrasound intensifies mass and heat transfer in reactions, and enhances the contact and disengagement of heterogeneous reactants, intermediates and products. It is an interesting potential alternative for enhancing industrial processes in applications such as waste pretreatment, extraction of products. Preeti B. Subhedar and Gogate (2015) studied the ultrasound-assisted bio-ethanol production from waste newspaper. The bio-ethanol productivity was increased by 1.8 times compared with the non-sonicated control fermentation. Overall, the work had demonstrated an intensified approach for the bio-ethanol production based on the use of ultrasound. Bussemaker et al. (2013) clarified some different ultrasonic effects on lignocelluloses. In some sense, the ultrasound had considerable potential to cleave the chemical bonds of the biomass components and thus could facilitate the extraction of compounds of interest, such as cellulose, hemicellulose or lignin. However, the work on ultrasonic pretreatment on the mixture of MSW and PS was hardly found.

This study evaluated, for the first time to our knowledge, the ultrasonic system through orthogonal test operated at various frequency, power, mixing ratios, treatment time for pretreatment of MSW and PS. The differences of samples before and after ultrasonic pretreatment were elaborated. Afterwards, the comparing of solid residue mass through tube furnace and the chemical compositions through Py-GC/MS in each mixing ratio and pro or post pretreatment, as well as the differences in addition of additive (MgO) would be researched. This work had demonstrated the value of ultrasonic techniques used as pretreatment for MSW and PS co-pyrolysis.

2. Materials and methods

2.1. Materials

The municipal solid waste (MSW) was a complex mixture of components (food and fruit waste, wood, paper and PVC). And according to Zhou et al. (2015), the composition of MSW on as received basis was showed in Fig. 1. Paper sludge (PS) was provided by a paper mill in Guangdong Province, China. MSW and PS were extremely heterogeneous materials independent of geometry and particle size. Hence, the MSW and PS were mechanically milled in a grinder and sieved to obtain fractions of original samples with particle size < 178 μm after air-dried at 105 °C for 24 h. The MSW and PS were uniform mixed in a micro rotary mixer for 2 h. The percentages of PS were 10%, 30% and 50%, which were named as 90M10P, 70M30P and 50M50P, respectively. Afterwards, the mixture were air-dried at 105 °C for 24 h in an oven. The ultimate analyses and proximate analyses of MSW and PS on dry basis were displayed in Table 1. MgO purchased from a shop, is a nontoxic, economical and environment-friendly material and it was already widely used for solid waste treatment (Chen et al., 2015). According to our former studies (Fang et al., 2017a,b), MgO with 5% was suitable to played as additive, compared to ZnO, Al_2O_3, $ZnCl_2$, $AlCl_3$, $MgCl_2$ and activated carbon. Hence, 5% mass ratio of MgO was added into the mixture. Finally, the samples were placed in the dry dish for the following experiments.

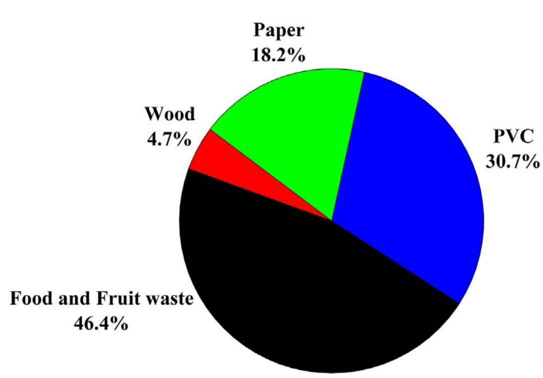

Fig. 1. The composition of MSW on as received basis (wt%).

Table 1
The ultimate analyses and proximate analyses of MSW and PS on dry basis.

Samples	Ultimate analyses (wt%)					Proximate analyses (wt%)		
	C	H	O	N	S	Volatile	Fixed carbon	Ash
MSW	40.66	5.45	43.80	0.54	0.18	76.51	14.12	9.37
PS	18.92	1.79	16.71	1.89	0.68	39.15	0.84	60.01

2.2. Experimental facility and methods

2.2.1. Orthogonal experiments design

The influence factors of the ultrasound pretreatment mainly include the ultrasonic frequency, ultrasonic power, treatment time and so on Subhedar and Gogate (2015). The challenge is how to scan all the parameters systematically in an efficient way with a minimum of the computational load. For the purpose, the orthogonal test method is introduced. It has several advantages of the evenly distributed points for data collection, of the minimized trials for a complete analysis, and of convenient range and variance analysis. The four influencing factors were denoted by the characters from A to D, respectively. Each factor had three levels indexed from 1 to 3, which denoted the chosen values of the operations parameters (Zhang et al., 2015). A $L_9(3^4)$ orthogonal test on the ultrasonic frequency (45, 80 and 100 kHz) named as A, the ultrasonic power (200, 300 and 400 W) named as B, the mixing ratios of MSW:PS (9:1, 7:3 and 5:5) named as C and the treatment time (1, 2 and 3 h) named as D was designed and displayed in Table 2. The range method was used for the results of orthogonal experiment analysis. K_{Jm} was named as sum of the corresponding experiments of the m level of column J factor. The number could determine the quality of the level of J factor. In addition, k_{Jm} was the average of the K_{Jm} ($k_{Jm} = K_{Jm}/3$). R_J was the range of column J factor, which responded the fluctuation of each level. That was to say, $R_J = k_{Jmax} - k_{Jmin}$. The larger R, the greater influence of the level on the text index. In this sense, according to the number of R, the influence order of factors could be judged.

Table 2
The $L_9(3^4)$ orthogonal test used for study.

Treatment Numbers	Factors			
	A/kHz	B/W	C	D/h
1	45	200	9:1	1
2	45	300	7:3	2
3	45	400	5:5	3
4	80	200	7:3	3
5	80	300	5:5	1
6	80	400	9:1	2
7	100	200	5:5	2
8	100	300	9:1	3
9	100	400	7:3	1