Study on the Preparation Method and Combustion Characteristics of Biomass Char Fuel Made from Chicken Manure Synergistic Plastic Waste

Jingfu Wang\textsuperscript{1},\textsuperscript{*}, Takamichi Matsushita\textsuperscript{2}, Jikyou Yuminaga\textsuperscript{3} and Hongxin Jia\textsuperscript{1}

\textsuperscript{1}MOE Key Laboratory of Enhanced Heat Transfer and Energy Conservation, Beijing University of Technology, Beijing, 100124, China
\textsuperscript{2}Eco Research Institute Ltd., Tokyo, 150-0036, Japan
\textsuperscript{3}Shinshu Trading Co., Ltd., Tokyo, 110-0005, Japan

\textsuperscript{*}Corresponding author email: jfwang@bjut.edu.cn

\textbf{Abstract.} In order to solve the problem of energy utilization of urban plastic garbage and livestock manure, this paper developed a method and technology to produce high-calorific value biomass char fuel through low-temperature pyrolysis in drying, thermal decomposition, extrusion and other processes, using urban plastic garbage and chicken manure as raw materials which are difficult to recycle. Established the verification experiment device in Chiba prefecture, with a 15\% plastic + 85\% chicken manure as raw material, the preparation of the calorific value of 5500-6000 kcal/kg of high calorific value of biomass char fuel. The ignition temperature, burning-out temperature, comprehensive combustion characteristic index $S$ and other combustion characteristics of fuel were analysed by thermogravimetric experiments. The kinetic analysis of fuel was carried out by means of Coats-Redfern method. The pre-exponential factor and activation energy of combustion temperature range were obtained. The results show that the volatilization of biomass char fuel exceeds 60\%, the ignition temperature and burnout temperature are low, and the ignition performance is good and the combustion speed is fast. The fuel calorific value is 24985kJ/kg (5976kcal/kg), the activation energy is 55.11kJ/mol, and the comprehensive combustion characteristic index $S$ is $4.57\times10^{8}$ min$^{-2}$ K$^{-3}$, which is similar to bituminous coal. In addition, biomass char fuel contains almost no sulphur and does not require desulfurization equipment. It is a kind of biomass fuel that can achieve clean and efficient combustion and replace coal.

\textbf{Keywords:} Biomass char fuel; Municipal plastic waste; Chicken manure; Combustion characteristic.

1. Introduction

Plastic has played a significant role in the development of human industry and people's livelihood in the 20th century, but now plastic waste is increasingly endangering human health and the global environment. With the development and progress of the society and the improvement of people's living standards, there are a large number of plastic garbage in the urban household garbage, such as plastic bags, disposable lunch boxes and other typical representative of the plastic garbage, the form of irregular, dirty mixed, unable to be classified. For this kind of plastic waste recycling technology, the international has not yet produced, can only be in landfill, incineration facilities for its terminal treatment. These plastic products, which bring convenience to our life, are not properly recycled after people have used them, but are thrown away at will, forming "white garbage". The non-degradable chemical characteristics of "white waste" have caused a new type of "white pollution", which has...
become one of the important problems harmful to the environment [1]. Developed countries have generally banned the landfill of plastic waste, plastic waste incineration caused by the non-landfill of plastic waste straight up. However, direct incineration of waste containing plastics is also a serious concern and limited by dioxins and other issues. The average calorific value of plastic waste is the highest among all garbage types, and it has the highest energy and economic value among all municipal solid waste. It is urgent to develop the technology of plastic waste energy utilization.

On the other hand, as an important part of the tertiary industry, aquaculture with the development of the economy, its production scale and production mode has gradually realized modernization. Among them, the development of chicken industry is not only increasing in number, but also expanding in scale, but the ensuing harmless treatment and resource utilization of chicken manure has become the focus and problem of chicken industry to be solved urgently at present. Relevant investigation shows that a chicken farm with about 100,000 chickens produces up to 10t of chicken manure every day, which is about 3600t of chicken manure every year. According to statistics, China alone produces about 15 million tons of chicken manure every year [2]. Such a large amount of chicken manure, if not treated in accordance with the scientific way, will not only lead to the loss of nutrients in chicken manure, but also produce ammonia, hydration, methane and other harmful gases, thereby polluting the environment and causing damage to life and health. At present, the harmless and resource treatment of chicken manure is mainly composting and biogas production. However, due to the high nitrogen content and stone powder content in chicken manure, pre-treatment and low gas production are required, which increase the operating cost. In addition, biogas slurry treatment is difficult, easy to produce secondary pollution. It is urgent to develop new energy utilization technology of chicken manure. It is an effective way to solve the problem of energy reuse of plastic waste and livestock waste to produce composite biomass fuel by mixing chicken waste and combustible high calorific value plastic waste in a certain proportion.

A lot of research and exploration have been done on the preparation of composite fuel from high calorific value plastic waste. Li et al. studied the molding characteristics of straw and sawdust mixed with high-calorie-value garbage to produce composite molding biofuels in different proportions. It is concluded that sawdust has a good molding effect when the plastic content is lower than 50% and the moisture content is 10%~14%, indicating that it is feasible to prepare composite molding fuel from biomass and high calorific value waste, but the combustion characteristics of composite molding have not been studied [3]. Sun mixed corn stalks and high calorific value garbage in different proportions to make composite fuels, studied the combustion characteristics of fuels, and calculated the pre-exponential factor and activation energy of composite fuels by integral method [4]. Zhou et al. studied the pyrolysis characteristics of dried pine sawdust and plastics (HDPE, LDPE, PP) in N$_2$ atmosphere, and performed the kinetic analysis using Coats-Redfern method [5]. Guo et al. studied the combustion characteristics of garbage derived fuels and concluded that the combustion process of garbage derived fuels can be described by three first-order reactions [6]. The current research on the use of high-calorific value plastics to prepare composite fuels mainly focuses on the mixed combustion characteristics and dynamics of plastic waste and straw and other biomass, as well as plastics and coal [7-10]. There are few studies on the preparation of composite biomass char fuel and its combustion characteristics by low-temperature pyrolysis of high calorific value plastic waste and high water-containing organic solid waste such as chicken manure (livestock manure).

This paper adopts the low-temperature pyrolysis method to carry out the research and exploration of the technology and equipment for preparing composite bio-carbon fuel by mixing high-calorific value plastic waste with chicken manure (livestock manure) and other high-water organic solid wastes, and conducts experimental research on the performance and combustion characteristics of biomass char fuel. And use the Coats-Redfern method to analyse the fuel dynamics characteristics. This research helps to determine the practical application value of high-calorific value plastic waste and chicken manure (livestock manure) composite biomass fuel preparation technology and the development of efficient and clean combustion technology.
2. Biomass Char Fuel Preparation

2.1. Biomass Char Fuel Preparation Equipment and Method

There are many types of plastics in urban domestic garbage, and the proportions of various types are as follows: polypropylene (PP) 18%, polyethylene (PE) 48%, polyvinyl chloride (PVC) 7%, and the remaining 27% [11]. In this experiment, three materials, PE, PP, and PVC, which account for a large proportion of the plastic components, were selected to mold plastic waste. The ratio of PE, PP, and PVC used in the experiment is 65:25:10, the particle size is less than 3mm, and the composition is shown in table 1.

Table 1. Ultimate and proximate analysis of plastics.

| Ultimate analysis (%) | Proximate analysis (%) |
|-----------------------|------------------------|
| C                     | H                      | N   | O   | S   | M_{ad} | A_{ad} | V_{ad} |
| Plastics              | 80.77                  | 13.76| 0   | 0   | 0.02   | 0      | 100    |

The physical and schematic diagrams of the new biomass char fuel preparation device are shown in figure 1 and figure 2 respectively. The plastic waste and the chicken manure containing 55-60% water was mixed, dried, pyrolyzed, and extruded into a high-calorific value biomass char fuel in a ratio of 15:85 by mass percentage in the new biofuel preparation device (New energy creation system, NECRES). The core of the new type of biofuel preparation device is a twin-screw extrusion pyrolysis device, in which organic solid waste such as plastic waste and high-moisture chicken manure completes the pyrolysis and other biomass char fuel preparation processes.

2.2. Composition and Performance of Biomass Char Fuel

Table 2 and table 3 are the ultimate analysis and proximate analysis of the prepared biomass char fuel components, respectively. It can be seen from proximate analysis that the volatile content of biomass char fuel is very high compared to bituminous coal. Generally speaking, the higher the volatile content, the easier the fuel will catch fire. Therefore, compared with bituminous coal, biomass char fuel has the characteristics of better ignition performance and faster burning speed. The ratio and calorific value of volatile and fixed carbon in biochar are equivalent to that of bituminous coal, which can be used directly as a potential alternative fuel for coal.

Because its calorific value is equivalent to that of coal, under the same conditions, burning unit fuel can produce less flue gas, and it is expected to obtain higher combustion temperature and heat utilization efficiency. In addition, biochar fuel has almost no sulphur element. Compared with coal, the cost of desulfurization is reduced and the service life of flue low-temperature heat exchanger such as boiler economizer and air preheater are increased.
Table 2. Proximate analysis of biomass char and coals.

| Fuels                              | V<sub>ad</sub> (%) | FC<sub>ad</sub> (%) | A<sub>ad</sub> (%) | M<sub>ad</sub> (%) |
|------------------------------------|--------------------|--------------------|-------------------|-------------------|
| biomass char                       | 62.6               | 11.7               | 23.4              | 2.4               |
| (85% chicken manure + 15% plastic) |                    |                    |                   |                   |
| Australian bituminous coal         | 34.9               | 48.0               | 15.3              | 1.8               |
| Chinese bituminous coal            | 34.9               | 48.0               | 15.3              | 1.8               |
| Indonesian sub-bituminous coal     | 40.0               | 38.0               | 8.0               | 14.0              |

Table 3. Ultimate analysis of biomass char and coals.

| Fuels                              | C (%) | H (%) | O (%) | N (%) | S (%) |
|------------------------------------|------|------|------|------|------|
| biomass char                       | 62.5 | 7.3  | 26.1 | 4.0  | 0.06 |
| (85% chicken manure + 15% plastic) |      |      |      |      |      |
| Australian bituminous coal         | 83.8 | 5.9  | 7.9  | 2.0  | 0.46 |
| Chinese bituminous coal            | 83.8 | 5.9  | 7.9  | 2.0  | 0.46 |
| Indonesian sub-bituminous coal     | 73.0 | 7.2  | 17.8 | 1.2  | 1.01 |

3. Experimental Research on the Combustion Characteristics of Biomass Char Fuel

3.1. Experimental Device and Method

In order to understand the combustion characteristics of high calorific value biomass char fuels such as ignition temperature, burning temperature, comprehensive combustion characteristic index S, thermogravimetric analysis experiments were carried out. The experimental instrument is Netzsch STA 449 F3 type thermogravimetric comprehensive analyser. The experiment can obtain the Thermo Gravimetric (TG) curve and Differential Scanning Calorimetry (DSC) curve of the fuel sample combustion, and the first-order derivation of the TG curve can obtain the Derivative Thermo Gravimetry (DTG) curve. In the experiment, about 10 mg of fuel sample was weighed each time and placed in an Al2O3 crucible. The experimental combustion atmosphere is dry synthetic air with a flow rate of 20mL/min. The temperature range is 100-800°C, and the heating rate is 10°C/min. In order to explore the influence of oxygen concentration on its combustion characteristics, experiments under oxygen-enriched conditions were carried out.

3.2. Fuel Thermogravimetric Analysis TG and DTG Curves

The TG and DTG curves of biofuel carbon under air and oxygen-rich atmosphere are shown in figure 3. From the TG and DTG curves, it can be seen that the combustion process of biocarbon fuel at 100-900°C in air and oxygen-rich atmosphere is similar, and it can be divided into the ignition phase, the volatile combustion phase and the fixed carbon combustion phase.

The TG curve represents the weight loss rate during fuel combustion. The higher the weight loss rate, the greater the proportion of fuel combustible. From figure 3 (a)-(d), it can be seen that the TG curve of the fuel is relatively flat before 270°C, and the weight loss is small, indicating that the combustion occurs after 270°C. The weight loss rate of the sample at about 500°C exceeds 60%. After 750°C, the TG stabilizes, indicating that the fuel burns and the remaining material is ash. At this time, the weight loss rate is about 75%, which is consistent with the fuel ash content of 23.4%.

The DTG curve represents the weight loss rate of the sample. The greater the weight loss rate, the faster the combustion. The maximum weight loss rate of fuel under different oxygen conditions occurs...
around 300°C, and the weight loss rate reaches -9%/min. The first weightlessness peak of the fuel indicates that the volatile matter starts to burn, and the temperature at which the peak occurs is slightly different at different oxygen concentrations. Under the experimental conditions, it appears between 265-275°C. There is another peak in the weight loss rate at about 500°C, indicating that the fixed carbon in the fuel accelerates combustion at this temperature.

Figure 3. TG, DTG curves of the biomass char in different oxygen concentration, (a) TG and DTG curves at 21% oxygen concentration, (b) TG and DTG curves at 23% oxygen concentration, (c) TG and DTG curves at 25% oxygen concentration, (d) TG and DTG curves at 30% oxygen concentration.

3.3. Fuel Ignition Characteristics and Burning-out Characteristics

The ignition characteristics of the fuel are mainly reflected by the ignition temperature. The ignition temperature is usually determined by the tangent method. On the DTG curve, the peak point is taken as a vertical line to intersect the TG curve at a point, and the tangent line to the TG curve is crossed over this point. The point where the tangent line parallels the initial weight loss of the TG curve is the ignition point, and the corresponding temperature is the ignition temperature. The lower the ignition temperature, the easier the fuel is to ignite. The ignition temperature of the biomass char fuel at different oxygen concentrations was calculated according to the above method, and the results are shown in Table 4. The ignition temperature of the biomass char fuel under the condition of air atmosphere is 272.6°C, and the ignition temperature is 271.2°C, 270.1°C and 267.8°C respectively when the oxygen enrichment is 23%, 25% and 30%. As the oxygen concentration of the combustion aid increases, the ignition temperature of this biomass char fuel is reduced, just like solid fuels such as coal. But it needs to be specially pointed out that the oxygen-enriched combustion has little effect on the ignition temperature. When the oxygen concentration is 25%, the ignition temperature is only reduced by 2.5°C compared with air. Even when the oxygen concentration is as high as 30%, the ignition temperature is reduced by less than 5°C. It can be considered that because the fuel has a volatile content of more than 60%, it has good ignition and combustion characteristics, and there is no need to consider the oxygen-enriched combustion method to enhance combustion.

The burning-out characteristics of fuel are closely related to the burning rate. The burning-out characteristics are reflected by the burning-out temperature of the fuel. The burning-out temperature
can be determined by the DTG curve, which is defined as the burning-out temperature when the weight loss rate is -1%/min. The burning-out temperature of the biomass char fuel at different oxygen concentrations is shown in Table 4.

The burning-out temperature of the biomass char fuel under the air atmosphere condition is 761.7°C, and the burning-out temperature is 758.0°C, 758.0°C and 751.9°C respectively when the oxygen enrichment degree is 23%, 25% and 30%. Similar to the ignition temperature, because the fuel has high volatile content and is easy to burn, the oxygen concentration has little effect on the burning-out temperature of the biomass char fuel. When the oxygen concentration is as high as 30%, the burning-out temperature is lowered by less than 10°C.

### Table 4. Ignition and burning-out temperature of biomass char.

| Oxygen concentration (%) | Ignition temperature (°C) | Burning-out temperature (°C) |
|--------------------------|---------------------------|-----------------------------|
| 21                       | 263.6                     | 761.7                       |
| 23                       | 253.4                     | 758.0                       |
| 25                       | 253.8                     | 758.0                       |
| 30                       | 252.3                     | 751.9                       |

3.4. **Comprehensive Combustion Characteristic**

The combustion performance of solid fuels can be evaluated through the comprehensive combustion characteristic index $S$ [12]. The higher the value of the index $S$, the better the combustion performance of the fuel. The index $S$ adopts the calculation method shown in formula (1) [12]:

$$S = \left( \frac{dX/\text{dt}}{max} \right) \times \left( \frac{dX/\text{dt}}{mean} \right) \times \left( Tn^2 \right) \times \left( Tm \right)$$

Where $S$ represents the comprehensive combustion characteristic index, $(dX/\text{dt})_{max}$ denotes the maximum burning rate of the process, $(dX/\text{dt})_{mean}$ is the average burning rate of the process, $T_n$ is the ignition temperature, and $T_m$ is the burning-out temperature.

This experiment evaluates the combustion performance of biomass char fuel prepared from plastic waste and chicken manure through the index $S$. According to equation (1), the index $S$ under different oxygen concentrations is calculated as shown in Table 5. It can be seen from Table 5 that the oxygen-rich atmosphere helps to improve the index $S$ of the biomass char fuel. The index $S$ of the biomass char fuel is slightly lower than the index $S$ of plastic waste and sawdust composite fuel in literature [10] and bituminous coal in literature [11], but it is generally at a similar level.

### Table 5. Comprehensive combustion characteristic index.

| Fuels                        | Oxygen concentration (%) | $dX/\text{dt}_{max}$ (%·min$^{-1}$) | $dX/\text{dt}_{mean}$ (%·min$^{-1}$) | $S$ $(10^{-8} \text{min}^{-2} \cdot \text{K}^{-3})$ |
|------------------------------|--------------------------|------------------------------------|-------------------------------------|-----------------------------------------------|
| Biomass char fuel            | 21                       | 9.35                               | 1.50                                | 4.57                                          |
| Biomass char fuel            | 23                       | 9.42                               | 1.52                                | 4.75                                          |
| Biomass char fuel            | 25                       | 10.15                              | 1.54                                | 5.07                                          |
| Biomass char fuel            | 30                       | 10.44                              | 1.59                                | 5.50                                          |
| Plastic waste + Sawdust      | 21                       | 7.05                               | 2.28                                | 5.82                                          |
| Bituminous coal              | 21                       | 7.26                               | 2.66                                | 5.14                                          |
4. Dynamic Analysis of Fuel Combustion

The purpose of dynamic analysis is to quantitatively characterize the reaction process and provide a quantitative description of the fuel combustion process. Dynamic parameters such as fuel activation energy \( E \) and pre-exponential factor \( A \) can be obtained through combustion dynamic analysis. The reaction rate is described quantitatively and the mechanism is deduced, and the reaction rate and the degree of difficulty are predicted, which provides an important basis for the utilization of fuel and the optimal design of combustion furnace. The kinetic parameters are calculated according to the law of conservation of mass and the Arrhenius equation [2].

According to the literature [1,13], the kinetic characteristic parameters were obtained by Coats-Redfern method.

It can be seen from figure 3 that the biomass char fuel starts to react at around 270°C, and basically ends when it reaches 500°C. In this paper, the temperature range was 270~500°C, the step length was 5°C, and the heating rate \( \beta = 10 \) K/min. The first-order reaction was used for calculation. The dynamic parameters such as \( A \) and \( E \) of the biochar fuel in the temperature range of 270~500°C under different oxygen concentrations are shown in table 6. It can be seen from table 6 that the kinetic parameters of the biomass char fuel obtained by using the first-order reaction equation in the temperature range of 270~500°C, the correlation coefficients are all above 0.98, and the fitting results are good. As the oxygen concentration increases, the fuel activation energy increases.

| Oxygen concentration (%) | Temperature range (°C) | E (kJ/mol) | A (1/min) | Correlation coefficient |
|--------------------------|------------------------|------------|-----------|------------------------|
| 21                       | 270-500                | 55.11      | 7.17×10^0 | 0.9919                 |
| 23                       | 270-500                | 58.43      | 1.55×10^1 | 0.9932                 |
| 25                       | 270-500                | 62.43      | 4.12×10^1 | 0.9951                 |
| 30                       | 270-500                | 65.00      | 7.84×10^1 | 0.9943                 |

5. Conclusion

To address the energy utilization situation of urban plastic waste and animal manure, this paper uses urban plastic waste and chicken manure that are difficult to recycle as raw materials, and develops a method of low-temperature pyrolysis through drying, thermal decomposition, extrusion molding and other processes to prepare high calorific value. The characteristic parameters of the fuel were analysed by thermogravimetric experiments. Kinetic analysis of fuel was carried out by using Coats-Redfern method, and dynamic parameters of temperature range were obtained.

The calorific value of the biomass char fuel prepared with 15% plastic waste and 85% chicken manure as raw materials is 24985kJ/kg (5976kcal/kg), reaching the level of high-quality bituminous coal. The volatile content of biomass char fuel exceeds 60%, and the ignition temperature is 263.6°C, which has the characteristics of good ignition performance and fast combustion speed. The activation energy is 55.11 kJ/mol, and the index S is \( 4.57 \times 10^8 \cdot \text{min}^{-2} \cdot \text{K}^{-3} \). Its characteristics are comparable to bituminous coal. Biomass char fuel contains almost no sulphur and is a fuel that can be burned cleanly and efficiently.

The low temperature pyrolysis technology to produce high calorific value biomass carbon fuel has practical significance and prospect for the energy utilization of high water-containing organic wastes such as municipal plastic waste, livestock manure, municipal sewage sludge and coffee grounds.

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