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Study on air gasification characteristics of straw in tube furnace

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Abstract. An experimental study on air gasification of straw was conducted in a tube furnace. The effect of the equivalence ratio (0.1-0.4) and temperature (600-900°C) on various gasification results, including gas composition and vaporized residue was investigated. The equivalence ratio(ER) appeared to have a significant effect on the result of gasification, and the experiment demonstrated the optimal gasification parameters (ER is approximately at 0.2, T is at 800°C). Under this operating condition, the residue after gasification of straw air accounts for about 7.39% of the original straw material, the combustible components in the gasification synthesis gas occupy 71.01% of the total volume, the H_2 content is 17.49%, the CO content is 38.02% and the CH_4 content is 15.49%. The intersection of the CO and CO_2 line charts has realistic implications for the selection of the optimal gas conditions (T, ER) and the increase of gasification efficiency.

1. Introduction

With the rapid development of economy and science, traditional fossil fuels have become increasingly depleted. In order to reduce dependence on fossil fuels and replace fossil energy with sustainable energy, countries all over the world are actively conducting research to find new energy sources [1]. Biomass energy is the fourth-largest energy source in the world, accounting for about 15% of global primary energy consumption, which accounts for about 38% for developing countries [2]. Biomass energy is one of the major renewable energy sources. Biomass energy can be directly or indirectly used by converting biomass into gaseous/liquid fuels. It is mainly converted into different forms of energy through thermochemistry and biochemistry [3,4]. Thermochemical methods include incineration, pyrolysis, gasification, and SCWG [5]; pyrolysis is heating in the absence of air to produce the corresponding fuel product; gasification is a process in which biomass is heated to high temperature to form combustible gas under the condition that the gasification medium participates. Many scholars are keen to use this method for academic research [4,6].

China's biomass resources are abundant. In 2016, out of a total of 945 million tons biomass resources only 900 million tons was not used effectively which was converted into 438 million tons of standard coal, resulting in huge waste of resources [7]. Therefore, it is an important issue in the process of energy utilization of solid waste in China, and to reduce the waste of biomass resources, develop suitable technologies for biomass gasification, and realize the recycling of biomass for energy use and recycling.

2. Experimental

2.1. Material

The material used was wheat stalk taken from Hu County, Shaanxi Province in this experiment. After being naturally dry, it was crushed by a crusher to within 3 mm in diameter. The ultimate and proximate analyzes of straw are reported in table 1.

Table 1. The Ultimate and Proximate analyzes of straw.

Ultimate analysis/%					**Proximate analysis/%**				**HHV(MJ/kg)**
C	H	N	S	O	M	A	V	FC	17.45
47.58	5.79	0.85	0.38	45.40	6.82	10.52	66.16	16.50	

2.2. Gasification experiment device

Gasification experiments were carried out in a high-temperature tube type electric furnace, which were produced by Shanghai Jiugong Electric Co. Ltd., model JGL1200, rated voltage 220 V, rated power 4 KW. The furnace size of the tube furnace is 106*6 cms, its space capacity is 3 L, the length of the heating section is 60cm, and three K-type thermocouples are arranged in the heating section, the usual temperature is 1100°C. The schematic diagram of the gasification experimental device is shown in figure 1.

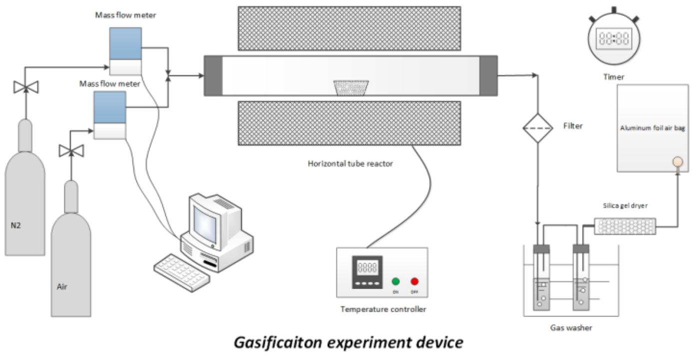

Figure 1. The schematic diagram of the gasification experimental device.

The gas-phase product detection instrument is a North Fratelli 342A gas chromatograph, and all columns are Carboxen 1000 packed columns. It is detected by a TCD thermal conductivity cell detector using high purity argon as a carrier gas. The temperature was increased by the program, the initial temperature of the column was 50°C, the incubation time was 9.5 minutes, then the temperature was increased to 120°C at 50°C/min and held for 16 minutes, and then the temperature was raised to 220°C to complete the test. It takes 75 minutes to test a single sample. The experiment uses a single-point calibration method based on a standard sample, that is, the concentration of each component in the sample to be measured is calculated by comparing the corresponding peak areas in the chromatogram of the sample to be measured and the standard sample.

2.3. Experimental procedure

The porcelain boat filled with 2 g straw is placed on the outlet of the tube furnace, the sealing lid is locked tightly and the sealing performance of the tube furnace is checked. The mass flow meter controls the nitrogen flow rate to 0.15 L/min and pump nitrogen into the tube furnace remove the air from the tube furnace. A temperature control program is set on the temperature control panel of the tube furnace, and the temperature increase speed is 10°C/min. When the temperature of the tube furnace reaches the gasification temperature, the tail rubber plug is opened, and the porcelain boat is pushed into the tube furnace with a push rod, sealing the rubber plug. The mass flow meter controls the air flow and immediately collects the gasification syngas using air bags. The straw stays in the high temperature zone for 10 minutes, opens the sealing cover of the tube furnace tail, pulls the porcelain boat to the tail of the tube furnace with a push rod, waits for it to cool to room temperature, removes the porcelain boat, and weighs the residual solids; Finally, the porcelain boat was put into the tube again to allow enough air to burn the carbon residue in the porcelain boat residue. After cooling, the porcelain boat was taken out and weighed to obtain the weight of the ash.

The straw gasification reaction occurs in the high temperature zone. The reaction temperature and the air equivalence ratio are the main factors affecting the straw gasification effect. Because the straw material accumulation height and the straw particle size are fixed, their influence on the gasification reaction is ignored. The temperature range is 600 to 900°C, the air equivalent ratio is 0.1-0.4, and the straw material is about 2 g.

3. Result and discussion

3.1. Effect of temperature

In the process of gasification reaction of organic solid waste, gasification temperature is a key factor affecting the gasification. It not only affects the distribution of gas, liquid and solid three-phase products, but also the quality of gasification synthesis gas (components, calorific value, carbon conversion, etc.).

When the air-equivalent ratio is set to 0.2, it can be observed from figure 2 that combustible components in the syngas gradually increase with increasing temperature, and the carbon dioxide content of the non-burnable components tends to decrease. When the temperature is 700°C, the volume percentages of H_2 and CH_4 in the syngas are 9.02% and 16.33%, respectively, while the volume fraction of CO is as high as 35.29%, and the CO_2 content is as high as 39.35%. When the temperature was increased to 800°C, the H_2 and CO contents increased, the CH_4 decreased slightly and the CO_2 content decreased to 28.89%, which was a decrease of 45.69% compared to 600°C.

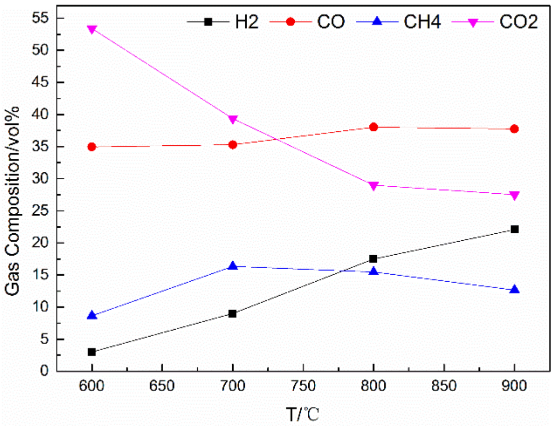

Figure 2. Effect of T on gas product.

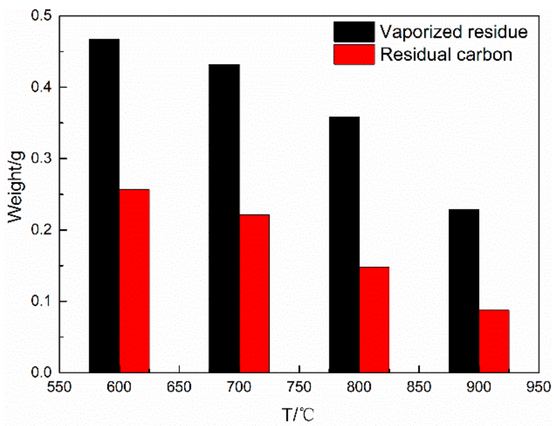

Figure 3. Effect of T on Gasification Residues.

The straw is placed to a small porcelain boat of about 1cm height. When the air passes over the upper surface of the material in the high temperature zone of the tube furnace, and the lower surface is less exposed to the air, after the gasification reaction occurs, the solid remains on the bottom of the porcelain boat. The solid residue includes not only the ash of the straw itself but also the residual carbon black. As can be seen from figure 3, as the temperature rises, the less straw residue remains, the less residual carbon content. When the temperature is 700°C, the residual carbon content is 0.2216 g, accounting for about 11% of the original material; when the temperature is 900°C, the residual

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carbon content is 0.09623 g, accounting for 4.811% of the original material.

3.2. Effect of ER

When the gasification temperature is 800°C, it can be observed from figure 4(c) that the content of CO and CO_2 in the gasification synthesis gas is relatively large, which accounts for about 60% of the gasification synthesis gas. When the gasification temperature is 800°C, it can be observed from figure 4(c) that the content of CO and CO_2 in the gasification synthesis gas is relatively large, which accounts for about 60% of the gasification synthesis gas. When ER is between 0.1 and 0.2, the four gas do not change much; When ER is greater than 0.2, CO_2 increases sharply, and CO, H_2, and CH_4 decrease. H_2 decreases to 10.67%, CH_4 decreases to 10.28%, and CO decreases to 22.61%.

From figure 4, we can find a very interesting phenomenon: under different gasification temperatures, the CO and CO_2 content trends show a similar symmetry arrangement, and there is an intersection point between the two broken lines; The point of intersection occurs when the gas volume content changes, and if one gas content decreases, the other gas must show an increasing trend. As the gasification temperature increases, this point moves in the direction of increasing ER. It can be known from figure 5 that the range is (0.1, 0.25). When the ER is about 0.2, the straw air gasification is favorable. The combustible components in the gasification synthesis gas have a larger proportion and higher quality, so this point is for selecting the best gas chemical condition (T, ER), improving gasification efficiency has practical significance.

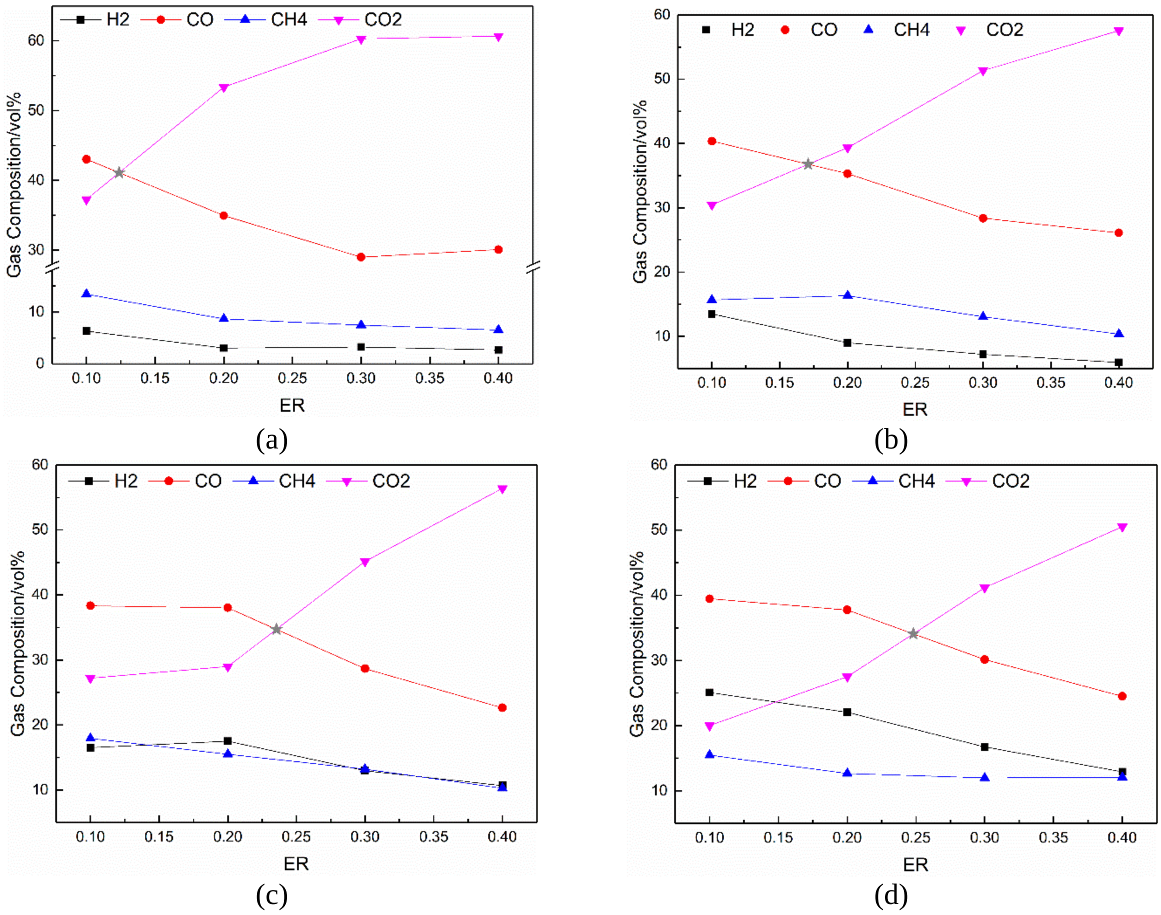

Figure 4. Effect of air equivalence ratio on gasification characteristics. (a) Gasification temperature is 600°C; (b) Gasification temperature is 700°C; (c) Gasification temperature is 800°C; (d) Gasification temperature is 900°C

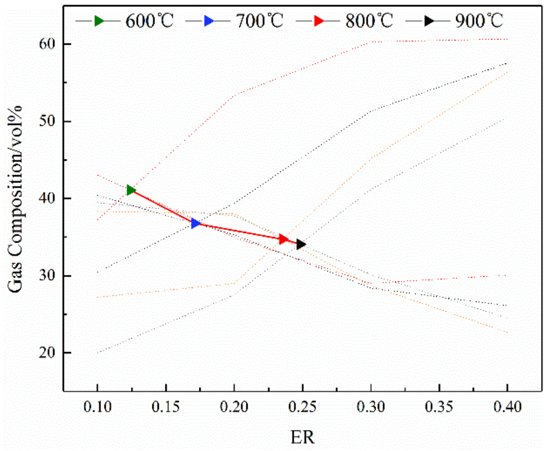

Figure 5. Migration of CO and CO_2 at different temperatures and air equivalence ratios.

4. Conclusions

In this paper, straw air gasification experiments were carried out on a tube furnace to study the effects of T and ER on straw gasification residue and gasification synthesis gas composition. The results show that when the gasification temperature is 700°C, the volume percentages of H_2 and CH_4 are 9.02% and 16.33% respectively, while the volume fraction of CO is as high as 35.29%, and CO_2 is as high as 39.35%. When the temperature was increased to 800°C, H_2 and CO increased, CH_4 decreased slightly, and CO_2 decreased to 28.89%, which was a decrease of 45.69% compared to 600°C. With the increase of temperature, the amount of residues of straw gasification is less, that is, the residual carbon content is less. At 900°C, the residual carbon content was 0.09623g, which accounted for 4.811% of the original material. When ER is between 0.1 and 0.2, the four gas contents do not change much; When ER is greater than 0.2, CO_2 increases sharply, CO, H_2, and CH_4 decrease, H_2 drops to 10.67%, CH_4 decreases to 10.28%, CO decreases to 22.61%, and the largest decline occurs.

Experiments show that the optimal operating conditions for straw gasification in the tube furnace are air equivalent ratio of about 0.2 and gasification temperature of 800°C. At this time, the residue after straw air gasification accounted for about 7.39% of the original straw material volume, and the combustible gas accounted for 71.01% of the total volume, H_2 was 17.49%, CO was 38.02%, and CH_4 was 15.49%. The intersection of the CO and CO_2 line charts has practical implications for selecting the best gas conditions (T, ER) and increasing gasification efficiency.

Acknowledgments

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