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Gasification Characteristics of Biomass Wastes in Fluidized Bed Gasifier

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With high efficiency and compactness, the circulating fluidized bed (CFB) gasifer has become more important and promising. Several kinds of biomass waste have been experimented with on the bench-scale CFB gasifier. Study focused on the gasification characteristics of biomass wastes in CFB. It has been found that temperature of the gasifer is determined by the equivalence ratio (ER) and that the composition of fuel gas varies with the ER. The product gas is influenced by a second reaction and residence time. The experimental results also indicate that the CFB gasifier is suitable for different kinds of biomass and can operate over a broad range of operating conditions.

I. Introduction

Background

WITH the rapid depletion of fossil fuels, people will confront an energy crisis in the future. It will have a direct influence on the existence and development of people. As a renewable energy source, biomass, which exists in huge quantity, may become a prospective and decisive alternative energy source as a substitute for conventional energy. However, biomass is just waste before treatment and recycling, which will become an environmental pollutant due to landfill and pileup or to malignant sources that result in accidental fire. Biomass utilization has two potential major advantages: saving energy and protecting the environment. Under these conditions, it is very important to develop an effective technology for biomass treatment that can be economically accepted and extensively commercialized.

Biomass gasification with a fluidized bed, which can treat biomass in a huge quantity with high efficiency and low cost, is one of the most important and effective technologies in biomass treatment. Therefore, investigation of gasification characteristics has a special significance. In this paper, the gasification characteristics of biomass wastes are analyzed and compared. The influence of temperature, equivalence ratio, residence time, feedstock property, etc., are discussed.

Basic Chemical Process of Fluidized Bed Gasifier

During the gasification procedure (see Fig. 1), in the combustion zone, partial char and gas generated by biomass pyrolysis meet air and combust. This simultaneously provides thermal energy and maintains a certain temperature required by the pyrolytic reaction. As most other feedstock are fed into gasifier from hopper, along with the fluidized bed these feedstock will immediately pyrolyze in the pyrolysis zone. Pyrolysis, in which the volatile in a biomass will be emitted as a combustible gas, is the key process of biomass gasification. When the gas product enters the upper area of the bed, reduction zone, a reduction reaction occurs, which promotes more combustible gas by the further reaction of carbon conversion and tar cracking into a permanent combustible gas.

Because most of a biomass is very light and gasification processes form many char particles, a lot of char particle will blow off from the fluidized bed when the feedstock is too small or fluidization velocity is somewhat high. To overcome these disadvantages and to increase the productivity of gasification, our fluidized bed gasifier employs a circulating fluidized bed (CFB). In the CFB gasifier, small char particles can be reclaimed and higher fluidization velocity can be used; consequently, more compact and higher efficiency will be achieved.

II. Experiments

A bench-scale gasifier has been designed specifically to meet various workloads, especially a low workload. In its designated workload, the gasifer will operate in the CFB model, whereas in a low workload, the gasifier will operate in bubbling fluidized bed (BFB) model. Its diameter (in meter) changes along with the bed height,

$$D_1 = \left(\frac{4}{3.14} \times \frac{\mathrm{ER} \cdot V \cdot G}{3600 \times U} \times \frac{T_1}{273} \times \eta_1\right)^{\frac{1}{2}}$$

$$D_2 = \left(\frac{4}{3.14} \times \frac{\mathrm{ER} \cdot V \cdot G}{3600 \times U} \times \frac{T_2}{273} \times \eta_2\right)^{\frac{1}{2}}$$

where

V = stoichiometric air of unit biomass, $\mathrm{Nm^3/kg}$
T_1 = temperature of combustion zone of gasifier, K
T_2 = temperature of the top of gasifier, K
U = fluidization velocity, m/s
η_1 = 40% (experimental result): workload ratio of BFB gasifier to CFB gasifier
η_2 = 79/50 (experimental result): ratio of N_2% for air to produced gas

and where equivalence ratio (ER) is 0.2 ~ 0.25 (see Fig. 1). The dimension of the gasifier is decided by empirical equations as follows.[1] The height (meter) of the biomass CFB gasifier is determined by the gas residence time and can be expressed as

$$H = H_0 + U \times t$$

where H_0 is the height of the feeding point (m) and t is the gas residence time (s). Here, $D_1 \approx 120$ mm, $D_2 \approx 150$ mm, and $H \approx 2000$ mm.

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Table 1 Properties of sawdust and rice hulls

Biomass	Sawdust	Rice hulls
Moisture, %	6.0	5.0
Elemental analysis		
C%	45.60	36.74
H%	7.11	5.51
O%	47.34	42.55
Ash, %	1.0	>15.0
Ash melting, °C	>1400	986
Heating value, kJ/kg	17,138	14,630
Size (average), mm	0.32	1.2
Density, kg/m^3	430	450

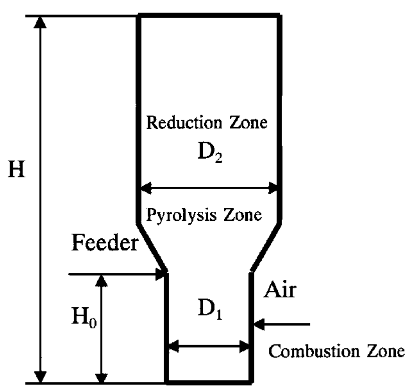

Fig. 1 Key parameters of a CFB gasifier.

A series of experiments have been performed on the bench-scale fluidized bed gasifier with several different biomass wastes: sawdust from a wood process factory, ground rice hulls from a cereal mill, lignin saccharide powder (a kind of waste from a paper mill), etc. The properties of two kinds typical biomasses are listed in Table 1. The produced gases were sampled in both the pyrolysis zone and the reduction zone, then injected to the automatic gas chromatograph for analyzing. Temperature and pressure were monitored and recorded through the whole experiment process to control stable operating conditions and investigate experimental results. The bed temperature was controlled so as not to reach 900°C while rice hull was performed as feedstock because the melting temperature of the rice hull surface is only about 986°C (1800°F) (Ref. 2).

III. Results and Discussions

Relationship of ER and Temperature

ER is a very important parameter in gasifier design and operation. It is an index

$$\mathrm{ER} = \frac{\text{weight air/weight dry wood}}{\text{stoichiometric air/wood ratio}}$$

implying the degree or proportion of gasification vs combustion, which is expressed by Wu et al.[3] It can also be expressed simply as

$$\mathrm{ER} = \frac{\text{air consumption in gasification}}{\text{air consumption in complete combustion}}$$

As ER increases, the bed temperature will go up almost in a direct ratio (see Fig. 2, which is for sawdust gasification). It can also be inferred easily because the more complete the combustion reaction, the more thermal energy it will yield and contribute to the temperature increment of the entire produced gas flow.

Relationship of ER and Gas Composition

The tendency of changing gas composition with ER is shown in Fig. 3 (also for sawdust gasification), and reflects the effect of the reaction temperature on the gas compositions indirectly. The decisive role that temperature plays on the composition of pyrolyzed

Table 2 Experimental results from ground rice hulls gasification

Composition	Percentage	Heating value, kJ/m^3
	Item 1	
H_2	3.5107	380.42
CH_4	1.6153	582.09
CO	17.3102	2195.63
C_nH_m	0.0696	44.43
CO_2	8.7803	——
O_2	3.5564	——
N_2	65.1578	——
		3202.57
	Item 2	
H_2	6.2265	674.70
CH_4	2.1776	784.72
CO	14.4825	1836.96
C_nH_m	0.3760	240.04
CO_2	13.9741	——
O_2	1.9532	——
N_2	60.8102	——
		3536.42

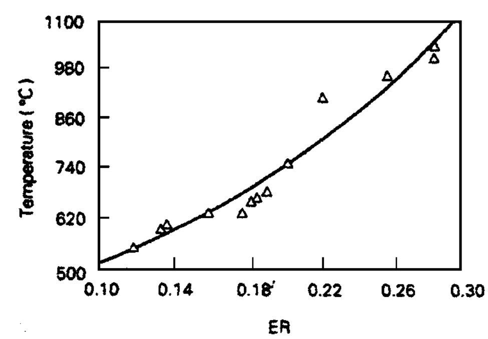

Fig. 2 Relationship of ER and temperature.

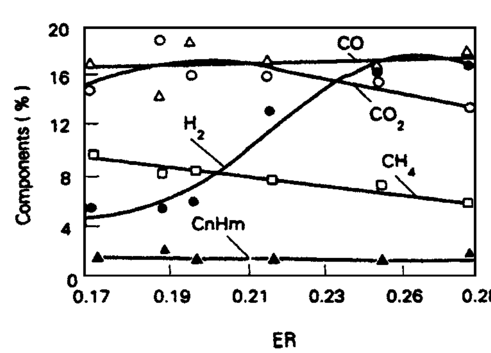

Fig. 3 Relationship of ER and gas composition.

gas has already been discussed in detail in previous research.[4] From Fig. 3, it can be seen that with an ER increase, H_2 content in the gas product goes up rapidly, CO_2 and CH_4 contents go down gradually, and CO and C_nH_m change only slightly. This result implies that the heating value of the gas will be mainly determined by the change of H_2 and CH_4. Usually a higher ER value corresponds to a higher general heating value of the produced gas. However, a higher ER also means higher temperature. Limited by the heat tolerable limitation of steel materials and the melting temperature of ash, ER may not be too high.

Gasification Characteristics of Biomass

A set of typical experimental results for ground rice hulls and sawdust are listed in Tables 2 and 3, respectively. Item 1 is the sampled gas from the pyrolysis zone, whereas item 2 is that from the reduction zone.

Table 3 Experimental results from sawdust gasification

Composition	Percentage	Heating value, kJ/m^3
	Item 1	
H_2	4.1560	449.096
CH_4	3.1757	1138.945
CO	14.6630	1850.988
C_nH_m	0.9055	575.293
CO_2	17.1201	——
O_2	0.7763	——
N_2	59.2036	——
		4014.286
	Item 2	
H_2	5.8280	628.505
CH_4	3.2759	1174.881
CO	14.5349	1834.811
C_nH_m	0.9892	628.505
CO_2	13.1952	——
O_2	1.7866	——
N_2	60.3904	——
		4266.693

When comparing Table 2 with Table 3, it is obvious that the concentrations of CH_4 and C_nH_m of the produced gas from sawdust are higher than those from rice hulls; consequently, the quality of fuel gas from sawdust is better than that from rice hulls. These differences result from the various properties that sawdust has, such as more volatility and less ash than rice hulls, and from that sawdust heating value is also much higher than that of rice hulls (see Table 1). Nevertheless, both types of biomass are suitable to gasification in a CFB gasifier, it indicates that a CFB gasifier has better flexibility than other types of gasifier.

From Tables 2 and 3, it can be seen that, for both rice hulls and sawdust, the gas sampled from the reduction zone has a higher heating value than that from the pyrolysis zone. The reduction reactions and shift reductions are listed as follows.

$$C + H_2O \rightarrow CO + H_2$$

$$C + CO_2 \rightarrow 2CO$$

$$CH_4 + H_2O \rightarrow CO + 3H_2$$

$$CO + H_2O \rightarrow CO_2 + H_2$$

$$\mathrm{Tar} \rightarrow CH_4 + H_2O + C_nH_m + H_2$$

From Tables 2 and 3, it can be seen that due to reduction reaction and shift reaction, more H_2, CH_4, and C_nH_m are yielded in the produced gas and contribute to a higher heating value. On the other hand, CO reduces slightly with the increment of CO_2. Because of temperature loss (during experiments, bed temperature at the reduction zone was mostly around 300°C) reduction reactions, most of which are endothermal reactions, cannot play a decisive role in all of the processes. Only shift reaction can take place in the temperature around 400°C. It can be inferred that in our gasification experiment, the fourth reaction namely,

$$CO + H_2O \rightarrow CO_2 + H_2$$

is one of the most important reactions in biomass gasification and much easier to realize than the preceding three reactions in rather low temperature.

However, as a consequence of insufficient temperature, the H_2 concentration of the sampled gas from the reduction zone is only slightly higher than that from the pyrolysis zone, as we can see in Tables 2 and 3. In practical applications, the gasifier works in a continuous condition, the bed temperature can stay on a much higher level that benefits for the reduction reaction and brings out a higher quantity of H_2 and C_nH_m and less H_2O, C, and tar.

It is obvious that the bigger the reduction zone is, the higher the heating value or quality of gas would be. In other words, longer residence time can be advantageous to gas quality and contribute to higher heating value of gas. As a result, the carbon conversion rate and combustible components percentage in the gas product will be increased. However, the reduction zone cannot be too large because the dimension of device would be limited. A CFB can be a solution. However, its operation is much more difficult than the common fluidized bed. Sometimes a fluidized bed is a more preferable, practical means in treatment of biomass wastes. Under this situation, an economic analysis should be carried out to get optimum design for practical and commercial demand.

Some Problems

Rice hulls can produce good quality gas. However, different from wood wastes, which produce little ash (around 1%), rice hulls, when they combust, will produce much more ash (15.0%), similar to what has been described in the literature.[2,5] Once applied in practice, an extra ash treatment system must be designed specifically for the rice hull gasifier.

When lignin saccharide was used on the gasifier, the experiment was interrupted often due to unstable feeding and air supply. The root of the problem is in too low ash melting temperature of lignin saccharide, only about 800°C, just as in the results obtained by Frederick et al.[6] Once lignin saccharide combusts in the fluidized bed, the ash melts; consequently, it will block either the air supply entry or feedstock entrance or both so that the operating condition becomes very unstable and worsens until interrupted. Too much ash (about 35.2%) is another problem, just as with rice hulls, but even more serious. Under these conditions, to handle lignin saccharide effectively, other specific types of equipment, for example, fixed bed,[5] must be developed and designed for the special demands of handling lignin saccharide. The ash fusion can be avoided if combustion is substituted by other types of heating.

IV. Conclusion

1) ER is a very important parameter that has close relationship with bed temperature and gas components. Suitable ER will bring out better quality gas.

2) Reduction reactions benefit the increment of the gas heating value, but depend on long residence time and high enough temperature. Therefore, comprehensive and economical consideration of gasification system about cost of investment and return of profit should be emphasized at the same time.

3) Meticulous research for example, on melting point of ash, ash content, etc., for specific biomasses must be implemented to determine what kind of gasification and construction should be employed for the gasifier.

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