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Effects of Multi-Factors on Biomass Gasification Based on Big Data

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Abstract. Bio gas is a kind of clean energy, which is often produced by biomass gasification. At the present work, the effects of multi-factors on the volume fraction of gas were analyzed numerically based on big data, and these factors included temperature, pressure, biomass species and various gasify agents. Moreover, the volume fractions and mass fluxes of gas was discussed. Pressure and temperature were set at the ranges from 1MPa to 6MPa and from 400°C to 1000°C, and the gasify agents selected H_2O, H_2O-O_2, O_2, CO_2 and H_2. The results show that the highest yields of gas were the pine sawdust with the highest content of C, H and H_2O since the yield of gas depend on the component contents of biomass. Pressure has a reverse effect on the variations of gas volume fractions compared to temperature. As pressure rose, the volume fractions of both H_2 and CO reduced, while the volume fractions of both CH_4 and CO_2 ascended. On the contrary, the volume fractions of both H_2 and CO increased, while the volume fractions of both CH_4 and CO_2 decreased with the increasing of temperature.

Keyword: Biomass gasification, gasify agent, temperature, pressure

1. Introduction

The emission generated by the combustion of fossil fuels have brought serious environmental pollution. As the exhaustion of fossil fuel and the calls on environmental protection, it is popularized for bio-gas as a kind of clean fuel due to its higher thermal value and lower emission. Valente et al. [1] checked the suitability of various gas production options based on the life-cycle. Gas production from biomass gasification performed significantly better than that from the steam methane reforming in environmental protection. Many scholars have studied the effects of operational parameters and gasify agents on biomass gasification at home and aboard. Fremaux et al. [2] run an experiment of the sawdust gasification with steam in a fluidized-bed. At 700°C and a residence time of 40min, as the addition of steam increased, the volume

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fraction of gas ascended, including H_2, CH_4 and CO_2. They reported that the increment in temperature surged slightly H_2 production, while reduced the tar content. Wang et al. [3] carried out an experiment of the sawdust gasification with steam in a fixed-bed, as residence time ascended from 8 min to 34 min and the temperature increased from 550 °C to 850 °C, the mass fraction of residual carbon reduced from 32% to 20%, the mass fraction of gas rocketed.

However, the present researches adopted the limited data to carry out their studies, the obtained results were only suit for given conditions. As the big data was applied widely, it is necessary to improve the application ranges of our findings under the help of the big data. Therefore, at the present work, on the basis of the big data, the numerical simulation was proceeded to analyze the effect of multi-factors on biomass gasification. The calculation work was done by Aspen Plus software, the conditions was selected based on the principle of big data.

2. Numerical Simulation

2.1. Principle of Biomass Gasification

Fig.1 shows the processing and principle of biomass gasification. Biomass first experiences drying and pyrolysis, forming gas products (CO, H_2, CH_4, CO_2, H_2O), liquid products (tar, liquid acid, macromolecule compound) and solid products (carbon and ash). Next, the pyrolysis products continue to be splitted, reformed, oxidated and reduced. Usually, the required heat during drying and pyrolysis will be satisfied by combustion reaction in biomass gasification, and main reactions was shown in Table 1.

Table 1. The main reactions in the Gasifier

Chemical reaction	ΔH ($kJ.mol^{-1}$)	Name
Biomass→H_2O+H_2+CO+CO_2+tar+hydrocarbon+coke	—	pyrolysis
C_mH_n+H_2O→CO+H_2	Endothermic reaction	Reforming between CmHn and steam
C_mH_n+CO_2→CO+H_2	Endothermic reaction	Reforming between H_2 carbon and CO_2
CO+H_2O=CO_2+H_2	-41	Water and gas reaction
3C+4H_2O=2CO+CO_2+4H_2	+353	coke and steam Gasification o
C+O_2→CO_2，C+CO_2=2CO	-394, +172	Coke gasification
CO+3H_2=CH_4+H_2O CO_2+4H_2=CH_4+2H_2O	-207, -166	Methanation reaction

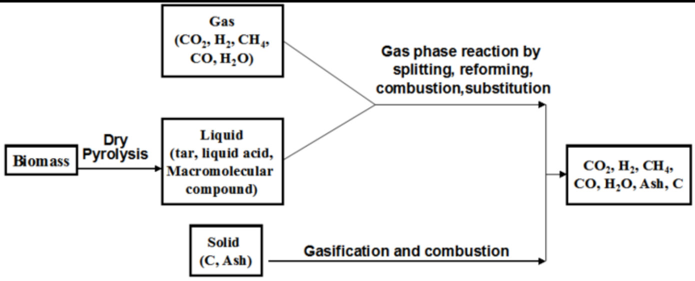

Fig. 1 Schematic diagram of the processing and principle of biomass gasification.

2.2 Calculated Method

Aspen Plus software has a successful application in coal chemical industry as a reliable method to simulate biomass gasification due to the similar components between biomass and coal. The assumption was done before the starting calculation[4].

(1) Gasifier is in a stable state without pressure and temperature gradients;
(2) O, H, S and N are transformed into gas, while C has a partial transformation;
(3) Ash is viewed as a kind of inertia substance without gasification;
(4) An instantaneous complete mixture occurs between gas and biomass;
(5) All gas phase reactions occur and reach an equilibrium state quickly;

A calculating processing was shown in Fig.2. Three modules were used, including RSTOIC (RS), RGIBBS (RG) and SSPLIT. Biomass was decomposed into the molecules in RS where realized a partial oxidation and gasification reactions, and then the produced heat was sent to RG for providing the oxidation reaction with uneven temperature. At the same time, various gasify agents were sent into RG, and both gas products and ash were separated with SSPLIT, and then entered to SEP for removing H_2O. Through the series of processing, the dried syngas was obtained.

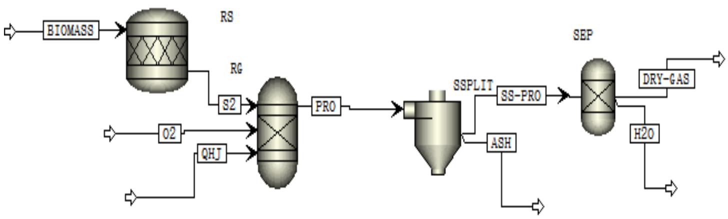

Fig. 2. Calculating processing of the biomass gasification model in Aspen Plus.

3. Comparison of Calculated Results to Experimental Data

In order to verify the reliability of Aspen plus simulation method, the experimental operational parameters in the reference [5] were simulated numerically. According to the experiment from the reference [6], the straw of 3g was used, and its components were shown in Table.1. The steam mass flux of 1.033g/min and the temperatures of 750℃, 800℃, 850℃, 900℃, 950℃ and 1000℃ were given. Fig. 3 shows a comparison of the calculated results to experimental data of H_2, CO, CO_2 and CH_4.

Table 2. Industry analysis and element analysis of sawdust.

Industry analysis (%)			Element analysis (%)					Q_{net}
FC_d	V_d	A_d	C_d	H_d	N_d	S_d	O_d	(MJ/kg)
15.33	84.1	0.54	46.73	6.54	1.71	0.95	43.47	18.85

It can be seen from Fig.3, as the temperature increased from 750℃ to 1000℃, the errors between the calculated results and experimental data ranged from -8% to 2% for the volume fraction of H_2, from -24% to 42% for the volume fraction of CO, from -52% to 27% for the volume fraction of CO_2 and from -28% to 95% for the volume fraction of CH_4.Their error ranged from -40% to 19% at 750℃, from -4% to 17% at 800℃, from -50% to 52% at 850℃, from -41% to 77% at 900℃, from -43%to 88% at 950℃ and from -42% to 95% at 1000℃. So, errors were neglected at from 700℃ to 800℃. It is mainly because the content of CH_4 reduced sharply and up to zero over

800°C, leading to an intensive increment in the error of CH_4. However, the calculated results at all temperatures are in agreement with the experimental data for the volume fraction of H_2.

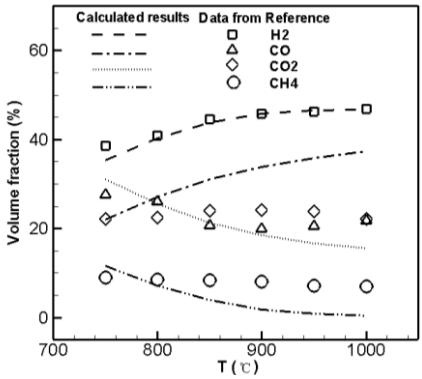

Fig. 3. Comparison of experimental data to calculated results.

4. Gasification Processing of Various Biomass

Biomass can be divided into herbaceous and woody plants with the macro-molecule polymer that consisted of C, H and O elements. Here, the herbaceous biomass selected the rice husk and corn straw, and the woody biomass considered the pine sawdust. Table.3 shows their industry analysis and element analysis. Aspen plus software was applied to simulate their gasification processing.

Table 3. Industry analysis and element analysis for three kinds of biomasses from reference [4].

Base	Component	Rice husk	Rice straw	Pine sawdust
Industry analysis (%)	M_{ad}	6.92	7.57	8
	A_{ad}	18.82	5.78	0.52
	V_{ad}	59.14	71.36	75.70
	FC_{ad}	15.12	15.29	15.78
Element analysis (%)	C_{ad}	36.68	42.93	46.49
	H_{ad}	5.39	5.07	6.51
	O_{ad}	31.84	37.17	37.82
	N_{ad}	0.31	1.41	0.14
	S_{ad}	0.04	0.13	0.52
Heating value	Q_{net} (kJ/kg)	13398	14400	18875

4.1 Effect of Temperature

Fig.4 shows the variation of volume fraction of gas products generated by three kinds of biomass with the increasing of temperature based on 3800 calculated data The volume fractions of both H_2 and CH_4 increased sharply at the temperature from 600°C to 900°C. The mass flux rose from 0 to 72kg/h for H_2 and from 0 to 1000kg/h for CO. It is indicated that an increment in temperature is helpful to produce more H_2 and CO via absorbing heat reaction of methanation. However, as the temperature rose, the volume fraction was reduced by 65%-70% for CO_2, and was almost equal to zero for CH_4 over 800°C. The mass flux ranged from 1380kg/h to 500kg/h for CO_2 and from

300kg/h to 10kg/h for CH_4. It was in agreement with the results from the reference [6-8], It is mainly because CO_2 generated by the water and gas reaction and coke gasification reactions were consumed. Moreover, the methanation reaction was an exothermic reaction, the increment in temperature caused the generated CH_4 to transform into H_2 and CO, and hence leading to the drop in the volume fraction of CH_4. However, the CH_4 yield has surpassed the yield of H_2 for the rice husk gasification at less than 600℃, and was less than the yield of H_2 at the temperature over 600℃. What is more, the turning point is larger than 600℃ for the corn straw and pine sawdust.

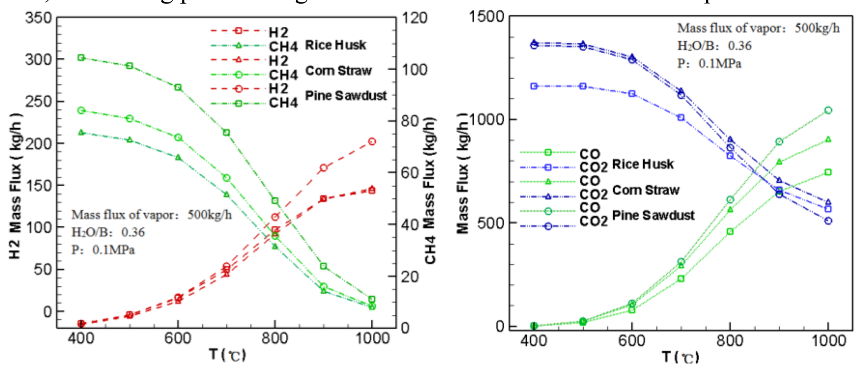

Fig. 4. Variations of volume fraction of gas products with the increasing of temperatures.

4.1. Effect of Pressure

Pressure is another key factor in the processing of biomass gasification based on 2600 calculated data. Fig.5 shows the variation of the gas products mass fluxes with the increasing of pressure at the mass flux of 500kg/h and the temperature of 800℃.

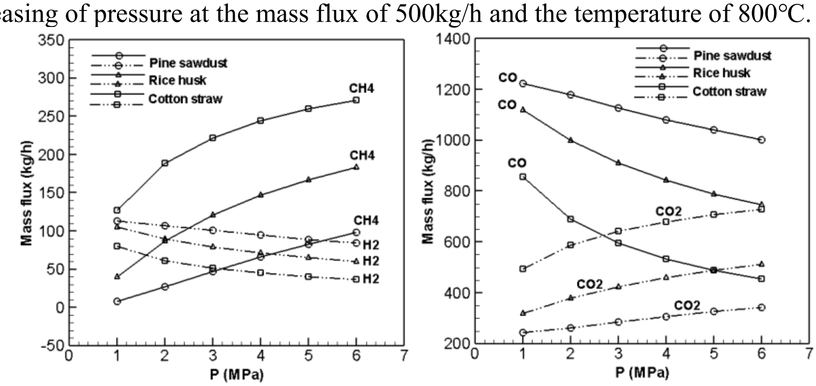

Fig. 5. Effect of pressure on mass fluxes of gas products.

As pressure rose from 1 MPa to 6 MPa, the mass flux of H_2 decreased from 113 kg/h to 84 kg/h for the pine sawdust, from 80 kg/h to 37 kg/h for the rice husk and from 105 kg/h to 60 kg/h for the corn straw. The mass fluxes of CO_2 rose from 243 kg/h to 343 kg/h for the pine sawdust, from 494 kg/h to 729 kg/h for the rice husk and from 319 kg/h to 513 kg/h for the corn straw. The mass flux of CO decreased from 1223 kg/h to 1002 kg/h for the pine sawdust, from 856 kg/h to 454 kg/h for the rice husk and from 1220 kg/h to 746 kg/h for the corn straw. The mass flux of CH_4 rose from 8 kg/h to 98 kg/h for the pine sawdust, from 127 kg/h to 271 kg/h for the rice husk and from

40 kg/h to 183 kg/h for the corn straw. It can be seen in Fig.5, as pressure rose, the mass flux of CH_4 rose, while the mass flux of both H_2 and CO reduced. It was in agreement with the results from the reference [9-10], in which the CO_2 production is encouraged at high temperature as a consequence of the occurrence of side-reactions. On the contrary, the CO_2 production was decreased as pressure ascended. Meanwhile, the pressure ascension drove the steam reforming reaction of the methane, causing the reduction in H_2 production. Similarly, the mass fluxes of gas products have the highest value for the pine sawdust, while the lowest value for the rice husk. It relied on the contents of C, H and H_2O in the biomass.

4.2. Effect of Various Gasify Agents

Here, H_2, CO_2, O_2, H_2O and H_2O-O_2 were used as the gasify agents, the rice husk was used as biomass that was sent into the gasifier at mass flux of 1400 kg/h at 700°C and 3Mpa. Fig.6 shows the volume fractions of gas at the ratio of the gasify agent to biomass masses (G/B) based on 7900 data.

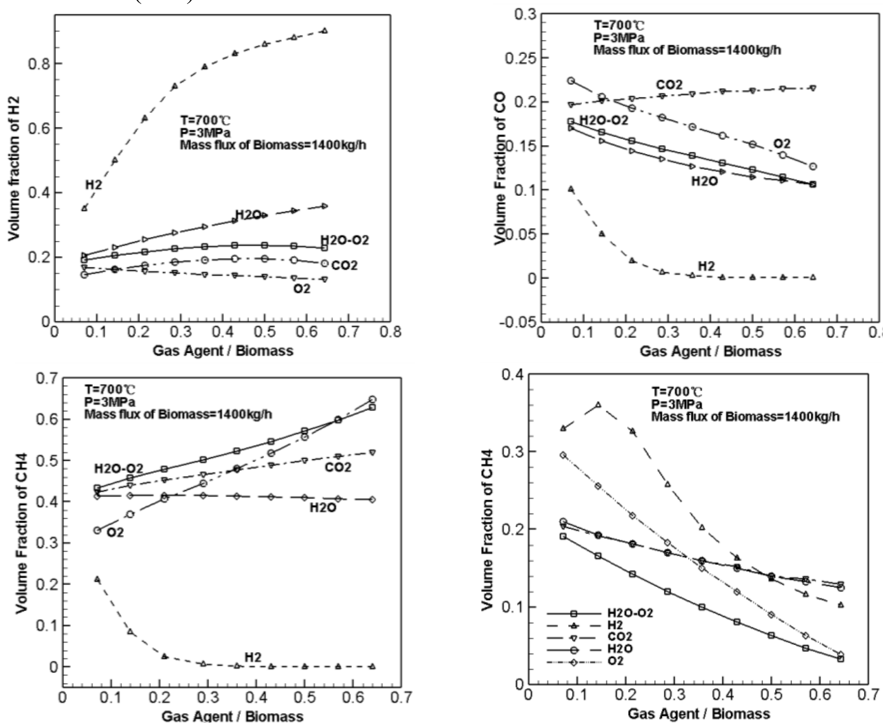

Fig. 6. Volume fractions of gas products at various G/B.

The volume fraction of H_2 was the highest in H_2 at various G/B. The volume fraction of H_2 reduced from 0.35 to 0.9 in H_2, ascended from 0.21 to 0.35 in H_2O, steadied in 0.19 to 0.2 in H_2O-O_2, dropped from 0.17 to 0.13 in O_2, and went up from 0.15 to 0.18 in CO_2. The volume fraction of CO was the highest in O_2 at G/B from 0.085 to 0.14 and in CO_2 over G/B of 0.14. The volume fraction of CO reduced from 0.225 to 0.125 in O_2, from 0.18 to 0.12 in H_2O-O_2, from 0.17 to 0.1 in H_2O and from 0.1 to 0 in H_2, while ascended from 0.19 to 0.21 in CO_2. The volume fraction of CO_2 was the highest in H_2O-O_2 at G/B from 0.22 to 0.56 and in O_2 over G/B of 0.56. The volume fraction of

CO_2 rose from 0.44 to 0.62 in H_2O-O_2, from 0.33 to 0.64 in O_2 and from 0.42 to 0.5 in CO_2, steadied in 0.42 in H_2O, while reduced from 0.22 to 0 in H_2. The volume fraction of CH_4 was the highest in CO_2 at less than G/B of 0.5 and in H_2O-O_2 over G/B of 0.5. The CH_4volume fraction rose from 0.205 to 0.1 in CO_2, went up from 0.33 to 0.36 and then dropped to 0.12 in H_2, and decreased from 0.19 to 0.04 in H_2O-O_2, from 0.3 to 0.03 in $O_2$and from 0.21 to 0.15 in H_2O.

5. Conclusions

Aspen Plus software was used to simulate the gasification processing of three kinds of biomasses at various gasification temperature and pressure when using various gasify agents. The gasification characteristics of herbaceous and woody plants were compared and the factors affecting gas were discussed. It comes to conclusions as follows.

1) The mass fluxes and volume fractions of gas products mainly depend on the contents of C, H and H_2O in the biomass. The highest mass flux and volume fractions of H_2, CH_4 and CO for pine sawdust gasification since it involves the highest mass fractions of C, H and H_2O.
2) Pressure has a reverse effect on the variations of volume fractions of gas products compared to temperature. The asension in pressure reduced the volume fractions of both H_2 and CO and increased the volume fractions of both CH_4 and CO_2. On the contrary, the increment in temperature surged the volume fractions of both H_2 and CO and decreased the volume fractions of both CH_4 and CO_2. The mass flux of gas reached the highest for pine sawdust.
3) It found that the gas consisted of CH_4 and H_2 if H_2/B is larger than 0.36.

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