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Research paper

Operational characteristics of a 1.2-MW biomass gasification and power generation plant

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ABSTRACT

In this study, we analyzed the operational characteristics of a 1.2-MW rice husk gasification and power generation plant located in Changxing, Zhejiang province, China. The influences of gasification temperature, equivalence ratio (ER), feeding rate and rice husk water content on the gasification characteristics in a fluidized bed gasifier were investigated. The axial temperature profile in the dense phase of the gasifier showed that inadequate fluidization occurred inside the bed, and that the temperature was closely related to changes in ER and feeding rate. The bed temperature increased linearly with increasing ER when the feeding rate was kept constant, while a higher feeding rate corresponded to a lower bed temperature at fixed ER. The gas heating value decreased with increasing temperature, while the feeding rate had little effect. When the gasification temperature was 700–800 °C, the gas heating value ranged from 5450–6400 kJ/Nm^3. The water content of the rice husk had an obvious influence on the operation of the gasifier: increases in water content up to 15% resulted in increasing ER and gas yield, while water contents above 15% caused aberrant temperature fluctuations. The problems in this plant are discussed in the light of operational experience of MW-scale biomass gasification and power generation plants.

1. Introduction

Biomass is highly dispersed over a wide area and its energy content is comparatively low, which makes collection and transportation costly (Leung et al., 2004). This suggests that decentralized utilization, using middle-scale biomass gasification and power generation (BGPG) technology, may be more feasible than large-scale combustion technology, and has the potential to be viable in developing countries (Wu et al., 2007).

Studies into BGPG technology started as early as the 1960s, characterized by the development of a 60-kW rice husk gasification and power generation system. Now, 160- and 200-kW systems are mainly adopted, and there are dozens of these small, rice husk gasifier-power generator sets in use (Wu et al., 2002; Wu et al., 1999). A 1-MW circulating fluidized bed BGPG plant established by Guangzhou Institute of Energy Conversion, Chinese Academy of Sciences in Putian, Fujian Province of China in 1998 (Yin et al., 2002) was the first demonstration project of a MW-scale BGPG plant in China. Since then, more than 20 BGPG plants with total installed capacities of 40 MW have been established in China and several Southeast Asian countries, based on the experiences obtained from the 1-MW power plant (Wu et al., 2003; Yin et al., 2007). To date, this has been the most extensively utilized BGPG technology in the world, and has resulted in obvious economic and environmental benefits. However, these systems are still hindered by low efficiency and poor reliability, and further research is required to improve their technical and economic feasibilities. After 10-years development, the MW-scale BGPG system has been shown to be an acceptable technology for self-generated power plants used by rice mills and timber mills with cheap biomass resources.

A 1.2-MW BGPG plant was established in a rice mill located in Changxing, Zhejiang Province, China. It started operation in October 2004 and closed in June 2008, due to management problems at the rice mill. However, its technical and economic feasibility was demonstrated during this 4-year period. This study analyzed the operational characteristics of the plant and presents several problems associated with the system.

2. Technical process of the plant

Fig. 1 shows a diagram of the 1.2-MW BGPG system. The system consisted of an air-blown fluidized bed gasifier, a combined gas cleaner (including an inertial separator, a cyclone separator, two Venturi tubes and two water scrubbers), and a power generation subsystem (containing four gas engines, each rated at 200 kW, and one gas engine rated at 400 kW), in addition to a wastewater treatment system. Rice husk was fed into the gasifier through a screw feeder, and then underwent strong oxidation, pyrolysis and gasification

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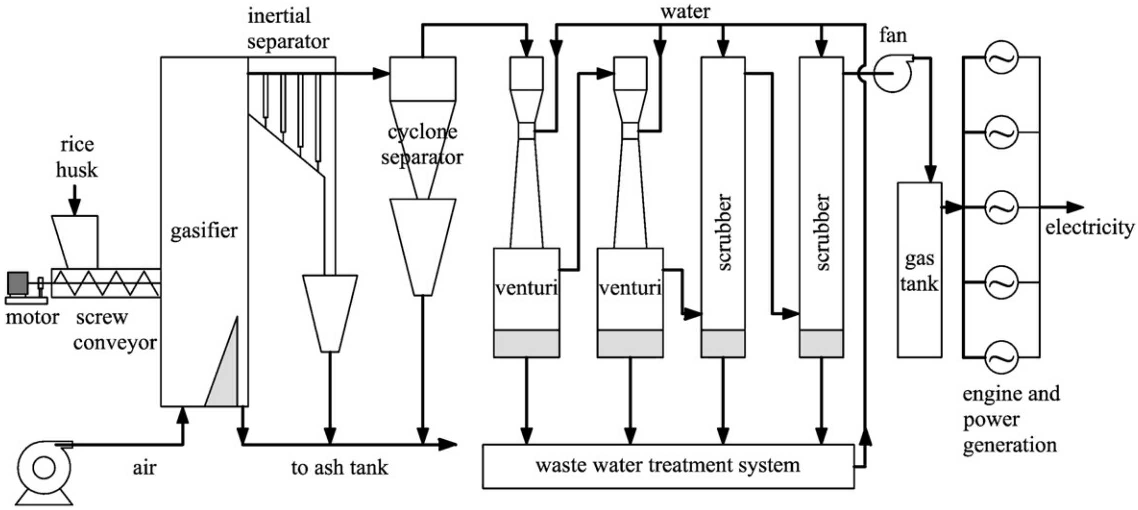

Fig. 1. Schematic of 1.2-MW rice husk gasification and power generation plant.

reactions with a gasification agent. The produced gas entered the inertial separator and the cyclone separator to remove ash, and then passed through two parallel Venturi tubes and two parallel water scrubbers, where the gas cleaning process took place. Rice husk ash (including residual char) was discharged from the bottom of the gasifier and the separators; tar was washed into the wastewater that then required additional treatment in a further step. The gas was cooled to room temperature after the gas cleaning process and was then sent to a gas storage tank using a Roots blower. The gas leaving the gas tank was burned in the combustion chambers of the gas engines, generating 1.2 MW of electricity.

The gasifier was the most significant component of the system, and its operating conditions affected the quality of the gas produced. Table 1 shows the main dimensions and technical parameters of the gasifier. During operation, the gasifier contained rice husk together with its char and ash, thus making it possible to achieve good fluidization conditions. However, the workload condition of the gasifier varied, and the fluidization velocity therefore also changed considerably. At low workload conditions, the fluidization velocity was too low to keep the fluidization stable and guarantee good distribution of the rice husk. The diameter of gasifiers should therefore be designed to change along the bed height (Yin et al., 2002). A smaller diameter bed results in a more efficient fluidization process when the gasifier is operated at low workload. To ensure good fluidization, the fluidizing velocity was chosen as 0.8–1.2 m s^{-1}. Five temperature measuring points were installed at different heights in the gasifier. Three were positioned in the dense phase: 1# (0.28 m), 2# (1.37 m), 3# (3.0 m), and the other two in the upper, dilute phase: 4# (5.8 m), 5# (7.2 m). The height of the bed of material was detected by the pressure difference between the bottom and top of the gasifier.

The temperature regulation of the gasifier was achieved mainly by regulating the speed of the screw feeder to control the feeding rate, and by adjusting the opening of the butterfly valve of the inlet pipe to alter the air input. In order to keep the gasifier operating normally, the Roots blower (variable frequency regulation) must be regulated simultaneously when feeding rate and air input are changed, so that the gasifier pressure can be controlled even at small positive pressure status. The correlation between the feeding rate and the speed of the screw feeder had been determined previously under cold conditions. The air input was measured using a vortex flowmeter (AVS250 type) installed at the inlet pipe, and the gas compositions were analyzed off-line using a gas chromatograph (GC-2010, Shimadzu, Japan). The proximate and ultimate analyses of the rice husk used in the plant are shown in Table 2.

3. Operating performance of the gasifier

3.1. Axial profile of gasifier temperature

The gasifier was auto-thermal, and its temperature was therefore altered by changes in feeding and air rates, thus ER was generally adopted as the main controlling parameter during the gasification process. Fig. 2 shows the axial profile of the gasifier temperature corresponding to different ERs at a fixed feeding rate. A dense phase and a dilute phase could obviously be detected in the gasifier, because the fluidizing velocity was very low. The temperature in the dense phase was relatively uniform, and was 50–100 °C higher than in the dilute phase. When ER was ≤ 0.24, the temperature at 1# was the highest, that at 2# was lower, while that at 3# was slightly higher than at 2#. This was mainly related to the feeding point: 2# was near the screw feeder. The rice husk entered the gasifier and underwent fast pyrolysis, which absorbed large amounts of heat, leading to a relatively low temperature; however, 1# was at the bottom of the gasifier (near the air distribution plate), where the hot char derived from pyrolysis directly oxidized with air provided by the air distribution room, so releasing large amounts of heat and making the temperature in this section the highest. 3# was located just at the

Table 1
Main parameters of the gasifier.

Parameter	Data
Bottom diameter (m)	φ1.4
Bottom height (m)	1.2
Top diameter (m)	φ2.0
Total height (m)	8.5
Feed rate (kg h^{-1})	400–1500
Gas yield (m^3 h^{-1})	500–3000
Thermal power output (kW)	700–4000

Table 2
Proximate and ultimate analysis of rice husk.

Proximate analysis (dry basis)				
V (%)	FC (%)	Ash(%)	Q_{LHV} (MJ/kg)	
70.36	15.07	14.57	14144.47	
Ultimate analysis (dry basis,%)				
N	C	S	H	O
0.46	39.78	0.20	4.97	40.02

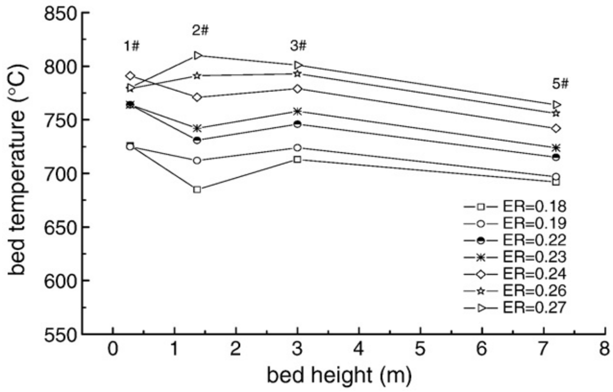

Fig. 2. Axial profile of gasifier temperature.

junction of the two phases, where the comprehensive effect of the oxidation and pyrolysis reactions led to a temperature midway between 1# and 2#. When ER was ≥0.26, the temperature distribution was 2#>3#>1#. The temperature at 1# decreased because of the entry of more cold air resulting from a higher ER. Moreover, the increase in fluidizing velocity elevated the position of the oxidation reaction zone, causing an increase in temperature at 2#. The temperature profile in the dense phase showed that the material was still not completely mixed, and partial oxidation and partial pyrolysis zones existed. Partial overheating and coking could thus easily occur.

3.2. Relationship between ER, feeding rate and bed temperature

Fig. 3 shows the relationship between gasification temperature (average temperature of 1#, 2# and 3#) and ER at different feeding rates. From Fig. 3, it can be seen that the gasification temperature increased linearly with the increase in ER at a fixed feeding rate. That is because more air input allowed more complete combustion, which in turn elevated the temperature of the gasifier. It can also be seen that a faster feeding rate resulted in a lower gasification temperature at the same ER. This is because a high feeding rate required more air input for the same ER, so increasing the fluidized velocity and finer fluidization, intensifying the transfer phenomenon, and promoting the whole gasification reaction. The feeding method may also be important: Fresh material was fed in at the bottom of the gasifier, while most ash was blown to the top because of its relatively low density, resulting in a higher ratio of cold material and leading to a lower temperature at the bottom.

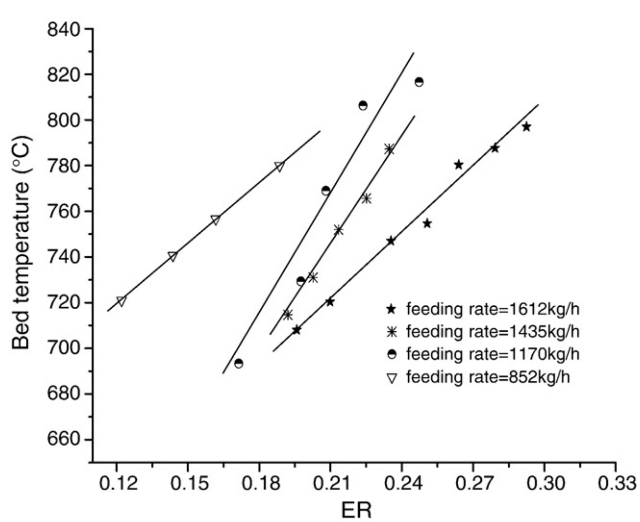

Fig. 3. Relationship of bed temperature and ER at different feeding rates.

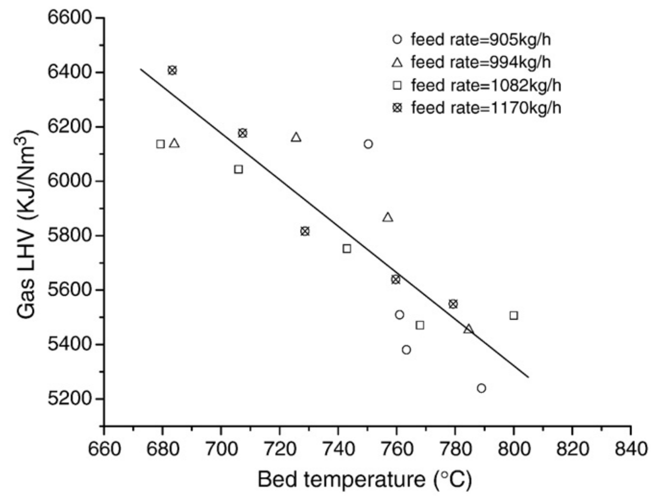

Fig. 4. Relationship between gas heating value and bed temperature at different feeding rates.

3.3. Effect of bed temperature and feeding rate on gas heating value and composition

Bed temperature was one of the most significant parameters influencing the operating performance of the gasifier, and had key effects on both the gas heating value and the gas composition. Fig. 4 shows the effects of bed temperature on the gas heating value at different feeding rates. The gas heating value decreased linearly with increasing temperature due to the dual functions of the biomass as both gasification material and heat provider. The heat for gasification was derived from the combustion enthalpy of the biomass, thus higher temperatures mean more biomass to combust and less material to gasify, resulting in more CO_2 and N_2 production and a lower gas heating value. When the operating temperature varied in the range from 700–800 °C, the heating value of the product gas fell to 5450–6400 kJ/Nm^3. The following formula could be produced, based on the experimental results: $Q_{LHV}(\text{kJ/Nm}^3) = 11{,}660\ (\text{kJ/Nm}^3) - 7.89T\ (°\text{C})$. Thus the change in feeding rate had little effect on the gas heating value.

Table 3 shows the typical gas composition and heating values at different temperatures and a fixed feeding rate. It can be seen that, when temperature fell to 700–800 °C, the content of H_2 in the fuel gas was 5–8%, CH_4, 46%, CO, 16–21%, CO_2, 15–16%, and C_2H_6, about 2%. The contents of H_2, N_2 and CO_2 increased, while the contents of CH_4 and C_2H_6 decreased slightly with increasing temperature. A high content of H_2, as an index of the intensity of secondary gasification, represented high gas quality. However, too high a H_2 content can jeopardize gas engines, as the H_2 combusts much faster than the other gases, and explosions can occur in gas engines when the content of H_2 is >14%.

Table 3
Typical compositions and heating values of gas at different temperatures.

T (°C)	Gas composition (%)									Gas heating value (kJ/Nm^3)
	H_2	O_2	N_2	CH_4	CO	CO_2	C_2H_4	C_2H_6	C_2H_2	
697	5.37	0.1	47.33	5.79	20.62	15.52	1.27	0.39	0.07	6407
726	6.22	0.1	47.80	5.54	19.50	15.64	1.19	0.34	0.07	6177
751	6.48	0.2	48.66	5.37	18.25	15.96	1.05	0.25	0.04	5817
780	7.26	0.15	49.55	4.96	17.26	16.21	1.08	0.20	0.07	5639
799	7.46	0.60	50.58	4.79	16.53	16.08	1.17	0.15	0.09	5549

Feeding rate: 1400 kg h^{-1}.

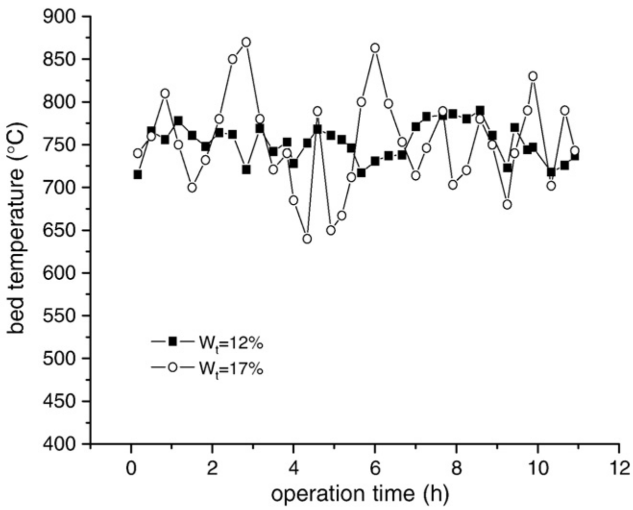

Fig. 5. Changes in bed temperature.

3.4. Effects of moisture in the material

The moisture content of the material is one of the most significant parameters influencing the operating performance of the gasifier. Because rice husk ash melts when the temperature exceeds 850 °C, the bed temperature must be maintained below 850 °C. Water evaporation and steam gasification reactions are both endothermic, and an increase in moisture in the material therefore leads to a decrease in bed temperature. In this case, ER should be increased. For a fixed bed temperature, having the appropriate amount of steam in the gasification reaction can contribute to increases in gas heating value, gas yield and gasification efficiency.

Fig. 5 shows the curves of bed temperature for two kinds of materials with different moisture contents. It can be seen that the operating temperature was quite stable at moisture contents <15%, but higher moisture levels led to intensive fluctuations, deteriorating fluidization, uncontrolled temperature, and finally massive coking. It is therefore important that rice husk be dried before it enters the gasifier, in order to keep the moisture levels within an acceptable range.

4. Problems with the system

4.1. Control of gasification process

This system was very sensitive to changes in moisture content in the material. For the bubbling fluidized gasification of rice husk, the system became out of control with aberrant temperature fluctuations when the moisture content was above 15%. For woody sawdust gasification, unstable temperatures could be overcome by using a relatively high operating velocity. It is therefore possible that the moisture sensitivity of rice husk gasification could also be counteracted by increasing the gas velocity, which causes turbulence or a fast fluidized state and avoids unwanted fluidization. Alternatively, the carrier air could be preheated by high temperature fuel gas before blasting it into the gasifier, which would not only increase the heating value of the product gas, but would also reduce the sensitivity of the system to changes in moisture content.

4.2. Problems of gas cleaning and wastewater treatment

The issue of how to deal with the wastewater formed in the gas cleaning system is a perennial problem for BGPG plants, especially for relatively large scale plants. Although microbial degradation is effective, resulting in the discharge of virtually no wastewater, it must be remembered that microbes are more difficult to maintain in some cold northern areas. In addition, the whole water treatment system is very costly. The development of more efficient wastewater treatment technologies is therefore essential.

The traditional water-scrubbing technology carries the tar, as well as the ash, into the wastewater treatment system, which increases the difficulty of subsequent cleaning. The separation of ash from tar at high temperatures still leaves the tar to be dealt with. With the traditional methods of water scrubbing, although no ash remains, the tar is inclined to form an aerosol with water mist which is hard to remove and jeopardizes subsequent reactions. It is therefore necessary to introduce some devices, e.g., an electrostatic tar-catcher, into the gas cleaning system.

4.3. Problems of gas generator systems

The 200-kW and 400-kW gas engines employed in the system are too small, thus several units are required, making the management of the plant inconvenient. A larger gas engine, e.g., 800–1000 kW, would be more cost-effective, but no tar-tolerant engine of that size is currently available. Gas engines of 450 kW were used in a 5.5-MW BGPG demonstration project, and a power generation efficiency of 30% was achieved, which was higher than the 25% produced by the 200-kW system. However, for some, even larger-scale plants this power output is still much lower than required, and other problems exist, such as loud noise, low automation, and intensive maintenance.

4.4. Controlling system

At present, the automation of BGPG plants is still at a low level, and this high dependence on empirical operation requires relatively more staff. Improvements in automation and the security of the whole system are therefore urgently required.

5. Conclusions

Although there were some problems with the 1.2-MW BGPG plant, we showed that the system was able to run safely and continuously for 4 years, with obvious economical and environmental benefits. The plant was closed recently, due to market and management problems of the rice mills, but the successful operation of the BGPG system has confirmed it as a reliable technology, supporting the extension of this technology on a large scale. As the core equipment of the system, the gasifier was shown to be feasible and stable over a long operating period. It can be concluded that:

(1) The temperature of the gasifier had a close relationship with ER and feeding rate, so the gasification process must be controlled based on the changes in these parameters. With an increase in gasifier cross-sectional area, the materials in the dense phase mixed incompletely, and local over-heating and coking was likely. For a rice husk fluidized bed gasifier, the fluidizing velocity should be increased carefully in order to improve fluidization quality.
(2) When the gasifier temperature ranged from 700–800 °C, gas heating value fluctuated in the range of 5450–6400 kJ/Nm3. The gas heating value decreased with increasing gasifier temperature, but was seldom affected by feeding rate. The H_2 content of the fuel gas was 5–8%, CH_4, 4–6%, CO, 16–21%, CO_2, 15–16%, and C_2H_6 etc., 2%.
(3) The moisture content of the material had a significant influence on the operation of the gasification system. When the moisture exceeded 15%, the running of the gasifier became unstable. Biomass should therefore be pretreated by drying when the moisture content is relatively high.

Acknowledgements

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