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Review paper

An economic analysis of biomass gasification and power generation in China

C.Z. Wu *, H. Huang, S.P. Zheng, X.L. Yin

Guangzhou Institute of Energy Conversion, Chinese Academy of Sciences, 81 Xianlie Zhong Road, Guangzhou 510070, China

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Abstract

With vast territory and abundant biomass resources China appears to have suitable conditions to develop biomass utilization technologies. As an important decentralized power technology, biomass gasification and power generation (BGPG) has a potential market in making use of biomass wastes. In spite of the relatively high cost for controlling secondary pollution by wastewater, BGPG is economically feasible and can give a financial return owing to the low price of biomass wastes and insufficient power supply at present in some regions of China. In this work, experimental data from 1 MW-scale circulating fluidized bed (CFB) BGPG plants constructed recently in China were analyzed; and it was found that the unit capital cost of BGPG is only 60–70% of coal power station and its operation cost is much lower than that of conventional power plants. However, due to the relatively low efficiency of small-scale plant, the current BGPG technology will lose its economic attraction when its capacity is smaller than 160 kW or the price of biomass is higher than 200 Yuan RMB/ton. The development of medium-scale BGPG plants, with capacity ranging from 1000 to 5000 kW, is recommended; as is the demonstration of BGPG technology in suitable enterprises (e.g. rice mill and timber mill) in developing countries where large amounts of biomass wastes are available so that biomass collection and transportation can be avoided and the operation cost can be lowered.

Keywords: Biomass waste; Gasifier; Circulating fluidized bed; System design; Scale-up; Electric power generation; Demonstration project; Economics; Commercialization

1. Introduction

Biomass is an important renewable energy resource. It not only has a wide distribution, but also abounds in quantity. However, biomass is one kind of resource scattered randomly with low energy density; it is difficult to deal with centrally on a large scale. This is likely to be one of the reasons why the biomass utilization level is not high in most of the developing countries. Biomass gasification and power generation (BGPG) technology can reach reasonable efficiency at a certain scale, and provide high-quality power supply to the users, so it may be suitable for rural areas in developing countries (Wu et al., 1997a, 1999; Bureau of State Statistics, 1997; Novem, 1997; Dai, 1998). In China, there is on one hand an enormous amount of biomass resources, mainly from the agricultural and forest sectors, and on the other hand there has been, for some time, insufficient electricity supply in rural areas. So there are in existence good conditions and development space for BGPG technology and its technical and economic advantages may be embodied to a large extent in China.

2. Status of biomass gasification and power generation technology in China

2.1. General situation of the development

The R&D activity of biomass gasification-power generation technology started as early as the 1960s, characterized by a 60 kW rice hull gasification and power generation system. Now, the 160 and 200 kW systems are mainly adopted and there are dozens of these small rice husk gasifier-power generator sets in use. In recent years, a study on MW-scale BGPG system was carried out, aiming at the mid-scale application of biomass technology. In 1998, the 1 MW BGPG system with a circulating fluidized bed (CFB) gasifier was developed by the Guangzhou Institute of Energy Conversion

* Corresponding author. Tel.: +86-20-8778-7136; fax: +86-20-8760-8586.

E-mail address: wucz@ms.giec.ac.cn (C.Z. Wu).

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(GIEC), and constructed at a rice mill in the Fujian Province of China. Waste rice husk from the rice mill is fed to the CBF gasifier; the gas produced is cleaned in cyclones followed by Venturi-tube and water scrubbing; then the clean gas is stored in a gas tank and used to drive gas engine/power generator sets. Based on the experiences from this first MW-scale biomass gasification-power generation system, in 2000 a new demonstration plant with a capacity of 1.2 MW was constructed at Sanya, Hainan Province of China. Summary data of BGPG systems currently used in China are presented in Table 1.

2.2. Technology review

2.2.1. Gasifier

China has studied all kinds of gasifying fashions, and finished the development effort of many kinds of gasifiers, including up-draft, down-draft, stratified down-draft and circulating fluidized bed gasifiers (Wu et al., 1997b, 1992; Xu et al., 1994). From the fundamental aspect, all kinds of gasifiers may be used for gasification and power generation, but only three kinds have been studied well and put into practical running; i.e., stratified down-draft, down-draft and CFB gasifiers, as listed in Table 2. Their generation capacity is in the range from several kW to MW. Performance data of circulating fluidized bed biomass gasifiers used for BGPG are given in Table 3.

2.2.2. Gas engine

According to the kind of gas fuel, gas engines mainly include natural gas, methane and low-heating-value biogas engines. In China, little attention has been paid to the low-heating-value gas engines. The devices below 100 kW are usually modified from diesels, and there is no approved product. Some work has been done on devices over 500 kW, but there are no approved prod-

Table 1
Summary data of biomass gasification and power generation systems in China

Electrical capacity (kW)	200	1000
Gasifier	Down-draft	Circulating fluidized bed
Gas cleaner	Water scrubber	Water scrubber
Application	Gas engine for power generation	Gas engine for power generation
Water consumption (ton/h)	20	20
Overall efficiency (%)	12.5	17
Capital cost (Yuan RMB/kW)[a]	2750	3060
Electricity cost (Yuan RMB/kW)	0.35	0.27
Number of sets in use	ca. 30	2

[a] 1 Yuan RMB = 0.12 USD.

Table 2
Biomass gasifiers used for BGPG in China

Gasifier type	Stratified down-draft[a]	Down-draft	Circulating fluidized bed
Fuel type	Wood chip, bark	Rice hull	Rice hull, wood waste
Electrical capacity (kW)	2–3	60–200	1000–1200
Heating value of gas (kJ/Nm^3)	4100–5300	3800–4600	4600–6300
Temperature (°C)	1100	700–800	650–850
Cold gas efficiency (%)	70	50	67–75

[a] Only one laboratory experimental set has been tested.

Table 3
Performance data of circulating fluidized bed biomass gasifiers

Feed rate of wood (kg/h)	1500	885	885
Feed rate of air (Nm^3/h)	1650	1350	1610
Gasifier temperature (°C)	775	800	940
Gas composition (vol%)			
H_2	7.59	6.33	7.04
CO	24.83	18.66	18.29
CO_2	13	11.57	13.76
CH_4	5.91	5.58	3.63
C_2H_6	0.3	0.11	0.6
C_2H_2	0.27	0.27	0.55
N_2	48	51.8	56
Lower heating value of gas (kJ/Nm^3)	6360	5300	5010

ucts yet. As far as the approved products are concerned, there are only two kinds of gas engines: 160 and 200 kW. Due to the small capacity of a single engine, mid-scale gasification and power generation systems have to employ several gas engines (each 200 kW) together, which prevents the capacity of gasification and generation system from further increasing above a certain level.

2.2.3. Gas cleaning

Raw gases from biomass gasifiers usually contain a considerable amount of ash and tar which must be removed to avoid operating problems in the gas engines. At the present technology level, tar cracking and wastewater treatment for re-circulation are two essential points of gas cleaning. However, the current way of water scrubbing not only decreases system efficiency, but also produces tar-containing wastewater. Gas cleaning is the weakest section for BGPG systems; it should become a major studying topic with more research work.

2.3. Economic characteristics of biomass gasification and power generation in China

2.3.1. Investment

The investment of BGPG systems mainly includes three parts: gasification and gas cleaning, power generation device and civil work. Table 4 gives the investment components for the case of a 1 MW rice hull gasification and generation system. From Table 4 it can be learned that the unit investment of this 1 MW system is about 3060 Yuan RMB/kW (note: 1 Yuan RMB = 0.12 USD), which is much lower than that of small-scale coal-fired power stations (about 6000 Yuan RMB/kW). The reason is that BGPG for rice mills does not need special collection and transportation devices, or storage facilities. However, the unit investment of BGPG will increase with the diminution of the system capacity. The capital investments for BGPG of different capacities have been calculated in a way similar to Table 4, and are compared in Fig. 1. It can be seen that when the capacity is below 60 kW, the unit investment of BGPG is higher than that of coal-fired power stations.

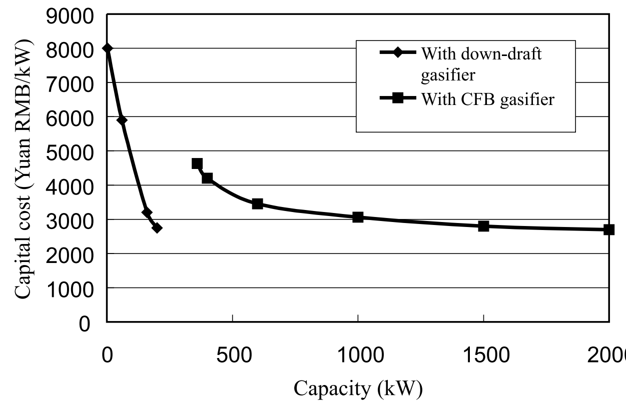

Fig. 1. Capital cost of BGPG varies with capacity.

2.3.2. Electricity cost

The operation cost of BGPG includes biomass cost, maintenance expense, depreciation expense and personnel cost. For a 1 MW rice hull gasification and generation system, it is about 0.27 Yuan RMB/kW h (see Table 5), which is about the same as the cost of a coal-fired power station, and much lower than that of diesel generation. But at a smaller scale, the rates of personnel cost and maintenance expense increase greatly; consequently, the electricity cost increases with diminution of the capacity. When the capacity is less than 100 kW, BGPG will lose competitive advantages, since the electricity cost is approaching that of diesel generation (see Fig. 2).

2.3.3. Cost for waste treatment

Because the problems caused by tar have not yet been well settled, it is necessary to invest on wastewater treatment facilities in order to avoid secondary pollution. According to different systems, the cost to treat wastewater will change (Fig. 3). In general, the smaller the capacity, the larger is the rate of wastewater treatment. This case has become a major obstacle to popularization of small-scale BGPG. Furthermore, the wastewater treating facilities will occupy a large area, so many users adopted no measures, to save investment

Table 4
Capital cost of 1 MW rice hull gasification and generation plant built in China (10^4 Yuan RMB)

(1) Gasifier	Rated 5 MWth capacity, with separator	50
(2) Water scrubber	For 2500 Nm^3 gas with Venturi-tube	10
(3) Gas engines	5 units, each with a 200 kW generator	150
(4) Power transmission	Power distribution panel and cable	6
(5) Waste treatment	For wastewater and ash	35
(6) Auxiliary devices	Transport, blowers, pumps and motors, etc.	15
(7) Construction	Installation of all equipments	10
(8) Civil work	200 m^2 workshop and all bases	20
(9) Monitor system	Instruments and control equipment	10
Total		306

Table 5
Electricity cost of 1 MW BGPG from rice husk

Electrical capacity	100 kW
Operation time	6500 h/yr
Electricity output	6 500 000 kW h/yr
Overall efficiency	17%
Biomass consumption	1.55 (dry) kg/kW h
Biomass price	80 Yuan RMB/ton
Biomass cost	806 000 Yuan RMB/yr
Personnel cost	150 000 Yuan RMB/yr
Maintenance cost	100 000 Yuan RMB/yr
Depreciation expense	700 000 Yuan RMB/yr
Electricity cost	0.27 Yuan RMB/kW h

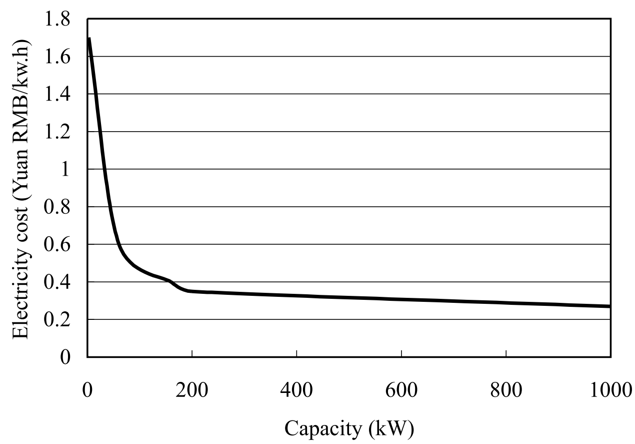

Fig. 2. Electricity cost of BGPG varies with capacity.

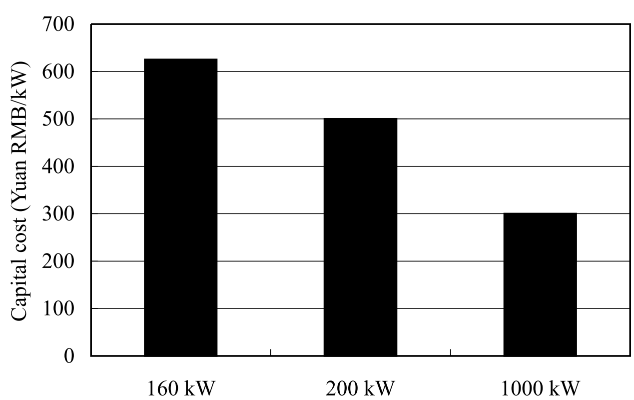

Fig. 3. Capital cost of wastewater treatment for different capacities.

and cut down the operation costs. Consequently, many environmental problems have been caused.

3. Key points influencing the application of biomass gasification and power generation technology

3.1. Biomass collection and pretreatment

Because of low energy density and scattered dispersion, the cost of collection and transportation is a main part of the biomass price. Besides, the pretreatment process needs additional facilities and investment. The two parts will both raise the operation cost of BGPG. Fig. 4 shows the relationship between the biomass cost and the electricity cost. It can be seen from Fig. 4 that if the biomass price is higher than 200 Yuan RMB/ton, the electricity cost of BGPG will reach about 0.5 Yuan RMB/KW h, and BGPG will lose its economic attraction. Fig. 5 shows the current market price of different waste materials; it reflects the effect of different collection and transportation conditions on the biomass cost. From Figs. 4 and 5, we can learn that under the current conditions, when the range radius of biomass collection exceeds 50 km, the electricity cost will be more than the electric network price (about 0.55 Yuan RMB/kW h), so the competitive advantage of BGPG will be lost. In other words, it appears that current 1 MW-scale BGPG technology will be economically competitive only for such conditions that the biomass waste is available in large quantity (e.g. in a rice mill) and there is no need for biomass collection, transportation and pretreatment.

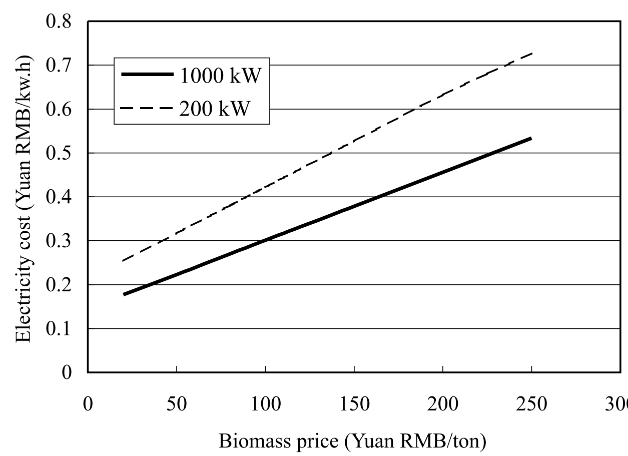

Fig. 4. Electricity cost of BGPG varies with biomass prices.

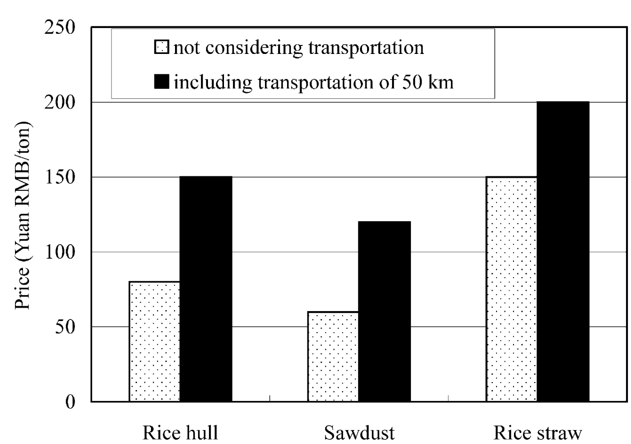

Fig. 5. Price of biomass.

3.2. Secondary pollution

As mentioned above, the wastewater problem has now become a main barrier to application of BGPG. Because the treatment facilities need rather large investment and area, many users of small-scale BGPG devices have not done anything before discharging wastewater. Therefore, only when the secondary pollution problem is settled can BGPG technology compete with others on an equal basis.

4. Possible solutions for development of biomass gasification and power generation in China

4.1. Technology research and improvement

According to the current technology problems, in order to develop BGPG it is necessary to carry out study on the following aspects.

4.1.1. Tar cracking technology and wastewater treatment

Tar cracking is one way to get rid of the secondary pollution; only after the maximal decrease in tar, can the wastewater production be avoided. However, since no technology can guarantee that the tar can be removed absolutely, and a certain amount of water is needed for cooling and washing, study on wastewater treatment and re-circulation is indispensable.

4.1.2. Improvement of the generation cycle and system efficiency

Limited by the gasification and gas-engine efficiency, it is very difficult for BGPG with gas engine to attain an overall efficiency higher than 20%. Therefore, the biomass consumption is usually greater than 1.1 kg (dry)/kW h. From the analysis of electricity cost as above, the biomass cost is the main part of the electricity cost, so if we cannot lower the biomass consumption, we can hardly utilize those biomass resources for which long-distance collection and pretreatment are needed. So in the long term, improving the total system efficiency by adopting advanced systems like IGCC cycle is a prerequisite to develop BGPG technology widely.

4.2. The application and demonstration of biomass gasification and power generation

Comparing with other countries, China has good market conditions for BGPG. However, from the above analysis of electricity cost, even if the secondary pollution problem is well settled, large-scale biomass collection and transportation will still raise the total cost, resulting in the loss of economic advantages. So under current conditions, those enterprises and areas having a large amount of biomass waste without the problem of long-distance collection and transportation should become the principal users of BGPG systems. It is desirable to set up BGPG demonstration plants in suitable enterprises to show the technical and economic advantages of BGPG technology, then to make it popular and acceptable. On the above basis, we can further improve the technical performance of BGPG, and discuss the possibility of applying BGPG for large-scale treatment of agriculture straw or forest wastes.

Considering the characteristics of current Chinese enterprises, the most suitable users of BGPG will be rice mills and timber factories. In China, now about 200 million tons of rice and more than 10 million cubic meters of artificial board are produced every year; and there are several hundred plants in operation. Even if they are the only users, the market for BGPG is still very large.

5. Concluding remarks

Gasification and power generation is an effective way to utilize biomass resources, and can match the current economic level of developing countries. China has already had a good grounding in biomass technology; as long as the problem of wastewater pollution is resolved, biomass technology will have advantages for competing with traditional power generation technologies. In order to develop and further spread the BGPG technology, now three aspects of work should be emphasized:

1. Study the tar treating technology, and remove the secondary pollution.
2. Modify the current gasification and generation technology and system, and improve the total efficiency, to further reduce the electricity cost.
3. Set up demonstration plants in some enterprises which have large amounts of biomass wastes, avoiding the problem of collection and transportation.

References

Dai, L., 1998. The development and prospective of bioenergy technology in China. Biomass and Bioenergy 5, 181–186.

Novem, 1997. Technical and economic feasibility of an indirectly fired gas turbine for rural electricity production from biomass (Phase 1), The Netherlands.

The Bureau of State Statistics, 1997. Statistical Yearbook of China. Beijing, China.

Wu, C., Xu, B., Luo, Z., Zhou, X., 1992. Performance analysis of a biomass circulating fluidized bed gasifier. Biomass and Bioenergy 3 (2), 105–110.

Wu, C., Xu., B., Yin, X., Luo, Z., 1997a. The current state of rice hulls gasification and power generation in China. In: China–EU Renewable Energy Technology Conference, September 1997, Beijing, China.

Wu, C., Liu, P., Luo, Z., Xu, B., Chen, Y., 1997b. The scale-up of biomass circulating fluidized bed gasifier. In: 6th China–Japan

Symposium on Fluidization, October 9–11, 1997, Beijing, China, pp. 196–200.

Wu, C., Zheng, S., Luo, Z., Yin, X., 1999. The status and future of biomass gasification and power generation system. In: China–EU Renewable Energy Technology Conference, March 1999, Brussels.

Xu, B., Wu, C., Luo, Z., Huang, H., Zhou, X., 1994. Design and operation of a circulating fluidized-bed gasifier for wood powders. In: A.V. Bridgwater (Ed.), Advances in Thermochemical Biomass Conversion. Blackie, Glasgow, UK, pp. 365–376.