Design and Analysis of Circulating Fluidized Bed Biomass Gasifier
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Abstract— A circulating fluidized bed (CFB) biomass gasification & power generation system for rice husk was designed to provide power for a rice mill with a capacity of 150 t d⁻¹. The system consists of a CFB gasifier, a gas cleaner, and power generation subsystem (containing five parallel gas engines rated 200 kW each), in addition to a wastewater treatment system. It is found that the system can be operated stably within the temperature from 7000C to 8500C, and its optimal condition was reached when the workload is increased above 750 kW. The main performance indices are: capacity: 1500 kg h⁻¹, gasification efficiency: 70%, rice husk consumption: 1.75–1.95 kg kW⁻¹ h⁻¹, total efficiency: about 19%.

Key words: Biomass, Rice Husk, CFB, Gasification, Power Generation

I. INTRODUCTION

Biomass is widely available as a resource in India, and its modern use offers a sustainable resource for the future. Today as the economy improves, less and less biomass is used in traditional ways, and there source is becoming underutilized. Nevertheless, the demand for electric power is rising rapidly with growth in India’s economy. The application of biomass gasification and power generation (BGPG) technology would be both cost effective and improve the environmental performance of biomass systems in general. From the 1960s, there has been extensive development and deployment of fixed bed gasifier generator sets which have grown in size from 50 to 250 kWe output[1]. Increasing concentration of scale of the rice milling industry calls for even larger capacities to meet the electricity demand of the mills, which can no longer be satisfied by the earlier fixed bed gasifiers. Middle or large-scale systems for the purpose of electricity self-supplying and waste rice husk handling are needed.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>200 kW</th>
<th>1000 kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter of gasifier (m)</td>
<td>0.2</td>
<td>1.8</td>
</tr>
<tr>
<td>Capacity (kg h⁻¹)</td>
<td>400</td>
<td>1500</td>
</tr>
<tr>
<td>Productivity (kg m⁻² h⁻¹)</td>
<td>127</td>
<td>960</td>
</tr>
<tr>
<td>Heating value (kJ N⁻¹ m⁻³)</td>
<td>3800–4600</td>
<td>4600–6300</td>
</tr>
<tr>
<td>Gasifier efficiency (%)</td>
<td>47</td>
<td>65</td>
</tr>
<tr>
<td>Total efficiency (%)</td>
<td>12</td>
<td>17</td>
</tr>
<tr>
<td>Rice husk consumption (kg/kW h⁻¹)</td>
<td>2.2</td>
<td>1.7–1.9</td>
</tr>
</tbody>
</table>

Table 1: The performance comparison of a 250 kW downdraft gasifier BGPG system and 1 MW CFB BGPG system for rice husk.

II. DESIGN

A. Characteristics of Rice Husk

Rice husk is a kind of biomass with 16–23% [2,3] ash contents and its ash contains more than 95% silica [3]. Table 2 shows the composition of the rice husk used. Fig. 1 [5] is a scanning electron micrograph (SEM) of rice husk ash that shows a rigid skeleton-like structure composed primarily of silica and potassium, which remains intact during pyrolysis [5]. When the temperature is more than 8500C, the silica and potassium oxide in the ash form a liquid phase that fuse onto the surface of the rice husk char particles, forming a glass-like barrier, which prevents further reaction of the remaining char and jams in exit of the ash [3–5]. When the temperature is 7000C, part of carbon in the fuel remains unburnt and accumulates in the reactor, resulting in lower efficiencies [3]. Due to such characteristics of the ash, the CFB gasifier is supposed to be a promising choice for rice husk, since the bed temperature can be kept below the ash slagging temperature by controlling its operating parameters properly. Though it is difficult to fluidize rice husk because of its cylindrical shape, non-granular and flaky nature [3], the fluidization behavior of rice husk can be improved by mixing it with other small solid particles and forming a multi-solid system [3–5].

<table>
<thead>
<tr>
<th>Ultimate analysis (%)</th>
<th>Proximate analysis (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>H</td>
</tr>
<tr>
<td>36.9</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Table 2: Ultimate and proximate analysis of the tested rice husk (air dry basis).

B. Composition of Mid-Scale BGPG System

The mid-scale BGPG system consists of a CFB gasifier, a combined gas cleaner (including an inertial separator, a cyclone separator, a venturi and two water scrubbers), and a power generation subsystem (containing five parallel gas engines rated 200 kW each), in addition to a wastewater treatment system. Fig. 2 shows the schematic representation of the system. The matching characteristic of the gasifier, gas cleaner and power generator is the key point of the whole system. The relationships of these parts are shown in Fig. 3. The main system technical specifications are: (1) capacity: 1000 kW, (2) total efficiency: 19%, (3) available fuel: sawdust, rice husk or straw, etc.

C. Gasifier

In India, the first CFB gasifier for biomass has been operating since 1992. Thereafter, more than 10 sets of CFB
gasifiers have been operating in wood processing factories and rice mills, and several kinds of biomass wastes have been utilized successfully. It has been proven that the CFB gasifiers have obvious advantages in the aspects of scalability, feeding flexibility and controllability.

During actual running of the 1 MW BGPG system, the CFB gasifier contains rice husk together with its char and ash, thus making it possible to achieve a good fluidization condition. However, the workload condition of the gasifier keeps on varying, so the fluidization velocity was changed considerably. Consequently, at low work load condition, the fluidization velocity is too low to keep the fluidization stable and guarantee rice husk being well distributed. Therefore, the diameter of the CFB gasifier should be designed as changing along the bed height (See Fig. 3). The smaller diameter bed makes the fluidization process under good conditions when the CFB gasifier was operated at low workload. The diameter can be estimated from the empirical relationships:

\[ D_1 = \left(\frac{4 \times ER \times V \times T_1 \times n_1}{\pi \times 3600 \times 273 \times U_f}\right)^{\frac{1}{2}} \]
\[ D_2 = \left(\frac{4 \times ER \times V \times T_2 \times n_2}{\pi \times 3600 \times 273 \times U_f}\right)^{\frac{1}{2}} \]

The height of the gasifier is determined by the gas residence time, which is mainly associated with the tar cracking process. In biomass CFB gasifier, in order to reduce the tar product, it is necessary to ensure the gas residence time to be about 3–4 s [6]:

\[ H = H_0 + U_f \times t(m) \]

The following parameters are required to support the determination of the bed diameter and height:
- Load: 800–1000 kW,
- G feed rate (1500 kg h\(^{-1}\)),
- ER equivalence ratio (0.2–0.25),
- V stoichiometric air of unit biomass (1.2Nm\(^3\) kg\(^{-1}\)),
- T\(_1\) temperature of combustion zone of gasifier (1200 K),
- T\(_2\) temperature of the top of gasifier (800 K),
- U fluidization velocity (=1.4ms\(^{-1}\)),
- \(n_1\) the lowest load of gasifier (40%, from our experience),
- \(n_2\) ratio of \(N_2\) in inlet and outlet of gasifier (79/50, from our experience),
- \(H_0\) height of feeding point (1.8 m),
- \(t\) gas residence time (4 s).

The main parameters of the gasifier are shown in Table 3.

![Fig. 2: Schematic of 1 MW rice husk gasification & power generation system.](image)

### Table 3: The main parameters of the gasifier

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed rate (kg h(^{-1}))</td>
<td>1500</td>
</tr>
<tr>
<td>Gas heating value (kJ N m(^{-3}))</td>
<td>&gt; 4400</td>
</tr>
<tr>
<td>Gas yield (m(^3) h(^{-1}) (m(^3) kg(^{-1}))</td>
<td>3300 (2.2)</td>
</tr>
<tr>
<td>Gasification efficiency (%)</td>
<td>65</td>
</tr>
<tr>
<td>Gasification rate (MW m(^{-2}))</td>
<td>2.58</td>
</tr>
<tr>
<td>Dimension (outer) (m)</td>
<td>2 × 2 × 8</td>
</tr>
<tr>
<td>Dimension (inner) (m)</td>
<td>1.25 × 1.25</td>
</tr>
</tbody>
</table>

![Fig. 3: Key parameters of a CFB gasifier.](image)
B. Power Output

Fig. 4 shows the relationship between rice husk consumption and the power output. At low loads such as 200 kW the rate is 3.5 kg kW h\(^{-1}\) while at outputs ≥800 kW the rate is 1.7 kg kW h\(^{-1}\). Under these optimum conditions the cold gas efficiency of the gasifier has been estimated at 65%, while the efficiency of the engines is 26.5% for a total system efficiency of 19%. The power output of the BGPG plant could be adjusted from 200 to 1000 kW according to the power demand through slowly increasing feed-in and air flow rate, but the temperature of the gasifier should be kept within 700–850\(^{\circ}\)C during the period.

![Graph showing the relationship between power capacity and rice husk consumed.](image)

IV. CONCLUSIONS

With an emphasis on the practicability, this project can meet the demand of most of the rice mills. The price of rice husk is 10 US$ t\(^{-1}\), value of the purchased electricity is 7 cents kW h\(^{-1}\), person-hours: 8 hours per day, a defined number of staffs: 10 persons per day. According to the above base, the total investment of this system is 51000 US$, the unit investment is about 370 US$ kW\(^{-1}\), the operation cost is 0.032 US$ kW\(^{-1}\), and the payback period is not more than two years. It is suggested that the BGPG system for rice husk is also adapted to other biomass, such as waste wood, straw etc., only little change is needed. There are good existence conditions and developing space for BGPG technology and its technical and economic superiority can be embodied to a maximal extent in India.

REFERENCES