SEWAGE SLUDGE GASIFICATION CASE STUDY IN RURAL INDIA

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ABSTRACT

Gasification is emerging technology for converting biomass to combustible gas that can be used for heating or electricity generation. Various types of biomass can be used for gasification, including sewage sludge. Sewage sludge characteristics of high moisture content is reducing gasification efficiency. Pre-treatment processes, such as drying and pelletizing, are needed to reduce the moisture content. Throttled downdraft gasifier is selected for processing sewage sludge considering the efficiency of converting char to gas and low ash production. Reactor diameter is 0.5 m at the gasification zone and 3 m in height. The overall thermal efficiency of the system is 65.30%. Technical barrier is mainly to monitor ash formation and maintain the emission of producer gas. Non-technical barrier is coming from the initial cost which quite expensive but still affordable for rural community.

Key words: sewage sludge, throttled downdraft gasifier, pellet, drying

INTRODUCTION

Gasification is emerging technology in particular for small scale system with the purpose of electricity and heating in some developing countries. Partial oxidation gets the main interest over the other processes since it can use pure oxygen as the oxidant and suitable for various feedstocks, solid, liquid, and gas. The producer gas, mainly consist of carbon monoxide, carbon dioxide, hydrogen, methane, and nitrogen gases can be burned directly for space heating, used for driving gas turbine for electricity generation, or for drying material.

In India particularly, about 35 MW of total gasifier capacity has been installed in 2002 (REN21, 2006). Various feedstock such as sugar cane, leaf bagasse, and coal have been introduced for gasification in India (Jorapuk and Rajavanshi, 1997), while no commercial application of sewage sludge gasification. Sewage sludge gasification technology is potential for renewable energy approach in the future since the sludge production is increasing. The growth is relating to the increasing of improved wastewater treatment facilities (Dubey et al., 2006).

This paper is aiming to design a sewage sludge gasifier for heating purpose in India. The gasifier will have 200 kW heating capacity for 8 hours use per day. It is the followed by a discussion with regard to cost of design and barrier on the implementation of the design in India.

BIOMASS GASIFICATION

Gasification is a thermal conversion of biomass to produce combustible gas. The conversion occurs in an elevated temperature which reflects segments of the process, drying, pyrolysis, oxidation and reduction. Drying process is simply evaporation of moisture content in the biomass substrate. Pyrolysis is a thermal conversion of organic matters to produce primary char, oil, and primary gas. The primary gas is underwent an oxidation process where the substance is partially oxidized to form carbon dioxide and water, the following reaction formulate is describing the main oxidation process (BTG, 2004, Higman and Burgt, 2003):

\[ C + \frac{1}{2}O_2 \rightarrow CO \quad -111 \text{ MJ/kgmol} \]
\[ CO + \frac{1}{2}O_2 \rightarrow CO_2 \quad -283 \text{ MJ/kgmol} \]
\[ H_2 + \frac{1}{2}O_2 \rightarrow H_2O \quad -242 \text{ MJ/kgmol} \]
\[ C + \text{H}_2 + (\text{O}_2 + \frac{\text{mH}_2\text{O}}{2}) \rightarrow n\text{CO}_2 + \text{mH}_2\text{O} \]

The CO2 and H2O together with the primary char are then converted to producer gas which mainly consists of CO, H2, and CH4. The reactions occur in reduction zone are (Higman and Burgt, 2003):

\[ C + \text{CO}_2 \rightarrow 2\text{CO} \quad +172 \text{ MJ/kgmol} \]
\[ C + \text{H}_2\text{O} \rightarrow \text{CO} + \text{H}_2 \quad +131 \text{ MJ/kgmol} \]
\[ C + 2\text{H}_2 \rightarrow \text{CH}_4 \quad -75 \text{ MJ/kgmol} \]

The plus sign in the reaction indicates exothermic reaction where the process generate heat, whereas the minus

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sign shows endothermic reaction where the process requires heat. The scheme of all reactions that occur in gasification process is illustrated in Figure 1.

**Figure 1** Scheme of gasification process: drying, pyrolysis, oxidation and reduction
Source: (SIG, 2004)

**DESIGN OF SEWAGE SLUDGE GASIFIER**

**THEORY OF SEWAGE SLUDGE GASIFICATION**

The gasification of sewage sludge can be determined as a series of chemical and thermal process where sludge goes through a complex physical and chemical change. The downdraft gasifier is selected because it produces tar-free gas as a result from the cracking of most of the tar by the pyrolysis gases that pass through hot char bed. Moreover Dogru et al. (2002) asserts that the downdraft gasifier produces few ash, converts char efficiently, responsive to change in different load, and simple easy to build. The downdraft gasifier is illustrated in Figure 2.

**Figure 2** Schematic figures of sewage sludge gasification using downdraft gasifier
Source: modified from Dogru et al. (2002)

Sewage sludge gasification runs firstly by drying up the sludge and then pyrolysed to produce condensable and non-condensable vapours and char. In the drying zone, moisture content in the substance is evaporated using the heat generated in the oxidation zone, about 70 – 200 °C. Dogru et al. (2002) suggests that this zone can completely evaporate sewage sludge with 15% of moisture content. In the pyrolysis zone, the substance undergoes thermal decomposition using thermal energy (350 – 500 °C) from oxidation zone. Pyrolysis products are then gasified under oxidation reaction in the throat zone (oxidation zone) with temperature raise rapidly up to 1000 and 1100 °C, and followed by reduction reaction to generate producer gas at the reduction zone (Dogru et al., 2002). The producer gas leave the reduction zone with temperature about 700 °C, but leave the gasifier at temperature between 200 and 300 °C due to heat loss. For heating purpose the producer gas can be directly used in a gas burner since the appliances can run in gas. The flow diagram of sewage sludge gasification is illustrated in Figure 3.
the gasification is designed to have maximum 5 mm in diameter.

SEWAGE SLUDGE CHARACTERISTICS

Sewage sludge main characteristic is high water content which is approximately 99.6% wet basis (Aye and Yamaguchi, 2006). For downdraft gasifier, the maximum moisture content of feedstock is 30% wet basis. The fuel, pelletized sewage sludge, has moisture content of 7.3% dry basis, thus it is suitable for the type of reactor. However the high ash content is the main barrier for using this type of biomass. Physical characteristics of sewage sludge are presented in Table 1. Bulk density of the dried sewage sludge is 207.5 kg/m³. High bulk densities requires smaller reactor and make handling and storage easier. Ash content in the dried sludge is quite high and this is potential to hinder the gasification process. High ash content results in lower quality of producer gas and lower efficiency of gasifier.

Table 1 Physical characteristics, proximate, and ultimate analysis of dried sewage sludge

<table>
<thead>
<tr>
<th>Proximate</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>%</td>
<td>50.5</td>
</tr>
<tr>
<td>Ash</td>
<td>%</td>
<td>7.1</td>
</tr>
<tr>
<td>Fixed carbon</td>
<td>%</td>
<td>23.9</td>
</tr>
<tr>
<td>Volatile matter</td>
<td>%</td>
<td>28.6</td>
</tr>
<tr>
<td>Fixed carbon % dry basis</td>
<td></td>
<td>70.4</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>%</td>
<td>5.6</td>
</tr>
<tr>
<td>Oxygen</td>
<td>%</td>
<td>21.5</td>
</tr>
<tr>
<td>Carbon</td>
<td>%</td>
<td>46.8</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>%</td>
<td>1.2</td>
</tr>
<tr>
<td>Ash</td>
<td>%</td>
<td>7.1</td>
</tr>
<tr>
<td>Lower heating value (LHV)</td>
<td>MJ/kg</td>
<td>10.9</td>
</tr>
</tbody>
</table>

Source: (Dogru et al., 2002, Petersen and Werther, 2005)

DESIGN ASSUMPTION

According to Dogru et al (2002) the hot gas efficiency of sewage sludge gasification using throated downdraft gasifier is 63% to 81%. Mitigan (1995) in Jayah (2002) suggests that the range of heat loss for downdraft gasifier is 6 to 16%. Thus for sewage sludge downdraft gasifier design, 85% of hot gas efficiency is selected with consideration of 15% heat loss from gasifier wall.
Air fuel ratio and turndown percentage are 2.26 N m⁻³/kg and 94.15% respectively. The air fuel ratio is chosen by considering the formation of cinder and bridging in the throat region. The selected air fuel ratio is suggested by Dogra et al. (2002) as it was observed to have no cinder formation and bridging phenomenon as well. It is said that the temperature in oxidative zone was so high so it burn out the cinder and slag. For the 2.26 N m⁻³/kg of air fuel ration, the specific gasification rate is 497.74 N m⁻³ h⁻¹. The ratio of H₂/CO is about 0.18 kg H₂/kg CO and the flow rate of the producer gas is around 7 N m⁻³/h (Appendix D). These numbers are the maintained operating parameter for the downdraft gasifier of sewage sludge.

**Table 2 Operating parameters of throated downdraft gasifier for sewage sludge**

<table>
<thead>
<tr>
<th>Operating parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Fuel Ratio N m⁻³/kg</td>
<td>2.26</td>
</tr>
<tr>
<td>Specific Gasification Rate N m⁻³ nm⁻³</td>
<td>497.74</td>
</tr>
<tr>
<td>Turndown ratio %</td>
<td>94.15</td>
</tr>
<tr>
<td>Temperature fuel zone °C</td>
<td>200</td>
</tr>
<tr>
<td>Pyrolysis zone °C</td>
<td>500</td>
</tr>
<tr>
<td>Throat zone °C</td>
<td>100</td>
</tr>
<tr>
<td>Ambient temperature °C</td>
<td>45</td>
</tr>
<tr>
<td>Pressure atm</td>
<td>1</td>
</tr>
</tbody>
</table>

**REACTOR DESIGN**

The fuel consumption rate is important for designing the reactor. It is defined from design purposes, 200 kW heating capacity for 8 hours per day usage. From calculation, the fuel consumption rate for sewage sludge downdraft gasification is 85 kg per hour or 67 A kg per day. The approximate volume of baffled sewage sludge required is 0.41 m³ per hour or 3.3 m³ per day. Detail of calculation is presented in appendix A.

The calculation of diameter of throat zone and the superficial velocity result 0.5 m and 0.81 m/s. The gasification length is designed of 22 cm which results in 50% of conversion efficiency and 14 % of heat loss. Wider zone will give the similar conversion efficiency while narrower zone will affect its smaller output gas. Diameter of pyrolysis zone is twice that of throat zone (SERI, 1983) which is 1.22 m. Reduction zone is designed twice that of throat zone, 45 cm. The throat angle affect the conversion efficiency wherein bigger angle results in smaller efficiency and vice versa (Iyay, 2002). It is also affecting bridging phenomenon where smaller angle will reduce the likely of bridging at the throat zone. For the design, 90° of throat's angle is selected to achieve the highest efficiency and avoid bridging.

![Figure 4 Design of downdraft gasifier for sewage sludge](image)

Material for constructing the reactor is aluminous silicate which can withstand in temperature up to 1500 °C. Perry (1973) asserts that compared to firebrick aluminous silicate insulation demonstrates a better performance in durability and heat flow resistance (SERI, 1983). The suggested thickness of cylindrical gasifier ranges from 2 to 5 cm and additional ceramic matel to shape the corner of reactor. Auxiliary appliances such as air intake pipe that is not requiring high heat resistance, can utilize PVC pipes. Outlet gas pipe requires high heat resistance, thus it should use steel or aluminous silicate.

**Overall thermal efficiency** is thermal capacity generated from the sequential process which is including the efficiency of gasifier and gas burner. Recalculating the overall thermal efficiency is 86.20%.

**ESTIMATED COST**

The cost of using sewage sludge is assumed as free but the initial cost of i. aluminizing sewage sludge is assumed 35%
of gasifier. Initial cost of gasifier is US$23,000 (Jayah, 2002), thus the cost of drying and pelletizing sewage sludge is US$8,050. In total energy cost is US$31,050 or equal to Rs 1,270,000. According to Aye (2007) cost of gasifier for heating purpose is AU$25-75 kW. Therefore cost of 200 kW, from sewage sludge is used to create heat. The annual cost of gasifier is AU$5,000 - AU$15,000 or approximately equal to Rs 170,000 - Rs 50,000.

Using case study of gasifier operation in Ideal Crumb, Kerala, the operational and maintenance and labour costs of gasification process are designed Rs 0.1/kg/h and Rs 0.15/kg/h respectively (Dasappa et al., 2004).

Price of thermal energy is assumed Rs 1 to Rs 2 per kWh. The price is still affordable for rural population. Interest rate of more than a year is 8%, according to Bank Baroda India. If the thermal energy from gasifier can supply 50 houses in rural area, it is predicted that the benefit from the system will double in 20 years. Detail calculation of benefit cost ratio of the designed system is presented in Appendix A.

APPLICATION OF SEWAGE SLUDGE GASFICATION CASE STUDY OF INDIA

Seasonal weather of India is highly influenced by the Himalaya which isolates the large region of Asia known as continent. Climate in this country is highly diverse but it can be classified into four seasons in a year: winter (January to February), hot weather summer (March to May), rainy south western monsoon (June to September), and post-monsoon known as northeast monsoon in the southern Peninsula (October to December).

India is ranked as the second largest country in the world with more than 70% of its population live in rural area and considered as one of the fastest growing countries of the world through its agriculture, tourism, commerce, power, communications, science and technology. However, the unemployment rate is quite significant, 9.1% as of September 2005 and during 1999 to 2000, 26.1% of population under poverty line. The gross domestic product as per September 2005 accounted for US$ 543 per capita and IMF reported that five states were classified as poor state (Purfield, 2006). With regard to population, rural area accounted for approximately 290 million or more than a quarter of total population (Census of India). Concerning sewage sludge generation, sewage sludge treatment plant in urban area can produce about 37,000 kg of sludge in a year. Therefore feedstock supply can be accessed from the urban area.

TECHNICAL AND NON-TECHNICAL BARRIERS

Technical barrier for installing sewage sludge gasification is mainly the high formation of ash due to fuel characteristics. Ash is useful for protecting the grate from high temperature, but excessive amount of ash will require regular maintenance. Another concern is excessive or fugitive emission of NOx and CO from producer gas. Gas treatment is required if it use as fuel for electricity generation since the solubility of the system. The contrary this heating appliances can work with impurities gas. Nevertheless, preventive action such as locating the gasifier in the outside is agreeable. Lack of knowledge from the operators is also a barrier. This may lead to faulty in system and damage on the equipment. Installing this system in India area is possible but the initial cost is quite high. Hence it needs funding from the government. Regarding government support, some projects were initiated by some departments to construct biomass gasifier in the entire country. The program is entitled National Biomass Gasifier Programme (NBGP). This program is aiming to build up to 16 GW biomass gasifier for thermal, mechanical, power, and industrial purposes. However sewage sludge is not included in the proposed feedstock. Sewage sludge gasification is still need to proof the capability and feasibility to be implemented in larger scale. Solution for initial investment of the system would be fund gathered from the residents. By investing to the system, residents or consumers will have benefit from the thermal energy generated and the knowledge and technology used in the system. People might maintain the system carefully and get knowledge from that.

CONCLUSION

Design selected for sewage sludge gasification is threatened downdraft gasifier by...
considering the less tar production and ash, effectively convect char, and easy to build. Feedstock for the system is pelletized sewage sludge with 5 mm in diameter to achieve optimum combustion in the oxidation zone. Fuel consumption rate of the system is 85 kg/h and the overall thermal efficiency of the system is 66.30%. Reactor is designed with 0.5 m in diameter of throat area and 3 m in overall height. Height of throat zone is 22 cm as recommended for the optimum gasification process with highest conversion of fuel to gas.

Technically the system produces ash and tar which need regular maintenance. Tar contain in the producer gas is not necessary to remove since the purpose of the design is for heating.

Considering the availability of feedstock sewage sludge gasification system is feasible to be installed in rural area of India. On the other hand sewage sludge is not likely to be selected for biomass fuel since it requires energy intensive pre-treatment to reduce its water content. Moreover the lack of knowledge from the rural people may hinder the development of this technology.

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