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 characteristic of high moisture content is reducing gasification efficiency. Pre-treatment processes, such as drying and pelletizing, are needed to reduce the moisture content. Throated 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 66.30%. 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, throated 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 gasses 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 has been introduced for gasification in India (Jorapur and Rajvanshi, 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 barriers 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 formulae is describing the main oxidation process (BTG, 2004, Higman and Burgt, 2003):

$$C + \tfrac{1}{2}O_2 \Rightarrow CO \qquad -111\ MJ/kmol$$

$$CO + \tfrac{1}{2}O_2 \Rightarrow CO_2 \qquad -283\ MJ/kmol$$

$$H_2 + \tfrac{1}{2}O_2 \Rightarrow H_2O \qquad -242\ MJ/kmol$$

$$C_nH_m + (n/2 + m/4)O_2 \Rightarrow nCO_2 + m/2\,H_2O$$

The CO_2 and H_2O together with the primary char are then converted to producer gas which mainly consists of CO, H_2, and CH_4. The reactions occur in reduction zone are (Higman and Burgt, 2003):

$$C + CO_2 \Leftrightarrow 2CO \qquad +172\ MJ/kmol$$

$$C + H_2O \Leftrightarrow CO + H_2 \qquad +131\ MJ/kmol$$

$$C + 2H_2 \Leftrightarrow CH4 \qquad -75\ MJ/kmol$$

The plus sign in the reaction indicates exothermic reaction where the process generates 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.

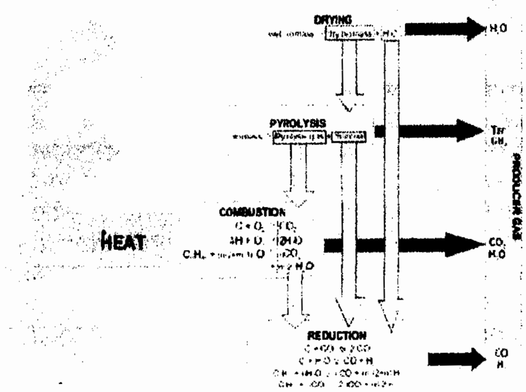

Figure 1 Scheme of gasification process: drying, pyrolysis, oxidation and reduction
Source: (BTG, 2004)

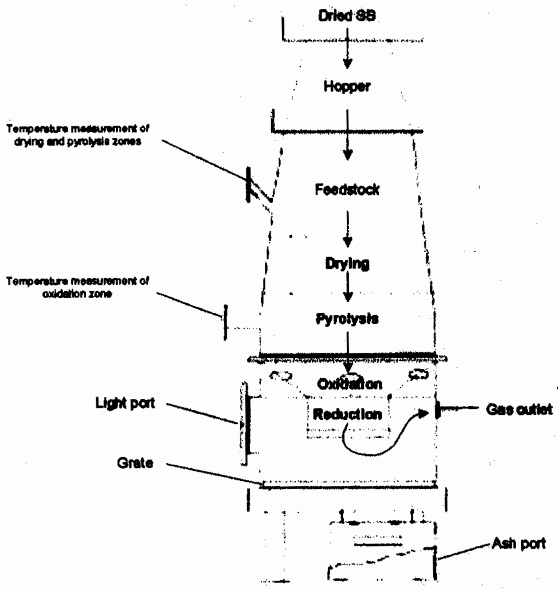

Figure 2 Schematic figures of sewage sludge gasification using downdraft gasifier
Source: modified from Dogru et al (2002)

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 tars 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.

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.

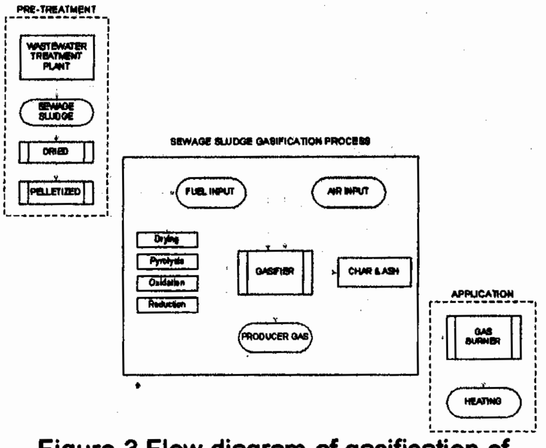

Figure 3 Flow diagram of gasification of sewage sludge

PRE-TREATMENT PROCESS FOR SEWAGE SLUDGE

Sewage sludge gasification requires pretreatment of the feedstock which mainly purpose to reduce water content. The pretreatment process involves drying where sludge is placed on drying beds and will remove 60% of water content (Böhnke, 1969). Other drying methods such as thermal drying can achieve 90% dried sludge but require energy up to 340 kWh (Hassebrauck and Ermel, 1996). It is not feasible for small scale gasification since the heat requirement for thermal drying may exceed the heat produced from the system. In addition, mechanical dewatering of sewage sludge, using belt press, centrifuge, filt press or diaphragm press, was reported for only reducing water content up to 50% (Novak, 2006). Therefore considering the cost and simplicity, conventional method of sewage sludge drying beds is the best option for application in rural area.

Dried sewage sludge with 60 to 65 % of dry solids content is pelletized to ease difficulties on handling and storage due low density of cake-fibrous material. Pelletizing plant should be located near to drying plant to reduce transportation and energy. The dried sludge is processed to form 3 to 5 mm in diameter of pellet (ESRU).

Pellet size 3.5 x 1 x 0.5 cm on average basis, which is equal to 1.5 cm of spherical diameter, is suggested by Dogru et al (2002) to suitable for downdraft gasification. The maximum particle size for feedstock to downdraft gasifier is one-eight of the reactor diameter, as suggested by Earp (Dogru et al., 2002). Pellet size which will be used in 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 99wt% 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 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/m^3. 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

Parameter	Unit	Value
Physical properties		
Size	cm	3.5x1x0.5
Absolute density	kg/m3	314.33
Bulk density	kg/m3	207.5
Proximate analysis		
Volatiles	wt% (db)	83.4
Combustibles	wt% (raw)	50.6
Water	wt% (raw)	7.3
Ash	wt% (raw)	42.1
Ultimate analysis % dry basis		
Carbon	wt% (db)	50.5
Hydrogen	wt% (db)	6.6
Oxygen	wt% (db)	34.5
Sulfur	wt% (db)	1.2
Nitrogen	wt% (db)	7.1
Lower Heating Value (LHV)	MJ/kg (raw)	10.0

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%. Milligan (1994) in Jayah (2002) suggests that the range of heat loss for downdraft gasifier is 6 to 16.6%. 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 2.28 N m^3/kg and 94.15% respectively. The air fuel ratio is chosen by considering the formation of clinker and bridging in the throat region. The selected air fuel ratio is suggested by Dogru et al (2002) as it was observed to have no clinker formation and bridging phenomenon as well. It is said that the temperature in oxidation zone was so high so it burn out the clinker and slag. For the 2.28 N m^3/kg of air fuel ration, the specific gasification rate is 497.74 N m^3/m^2 h. The ratio of H_o/C_o is about 0.18 kg H_2/kg C 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

Operating parameters	**Unit**	**Value**
Air Fuel Ratio	N m^3/kg	2.28
Specific Gasification Rate	N m^3/m^2 h	497.74
Turndown ratio	%	94.15
Temperatures:		
Drying zone	°C	200
Pyrolysis zone	°C	500
Throat zone	°C	1100
Ambient temperature	°C	25
Pressure	Atm	1

REACTOR DESIGN

The fuel consumption rate is important on designing the reactor. It is defined from design purpose, 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 678 kg per day. The approximate volume of palletized sewage sludge required is 0.41 m^3 per hour or 3.3 m^3 per day. Detail of calculation is presented in appendix A.

The calculation of diameter of throated 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 to smaller output gas. Diameter of pyrolysis zone is twice that at the throat (SERI, 1988), which is 1.22 m. Reduction zone is designed twice that of throated zone, 45 cm.

The throat angle affect the conversion efficiency wherein bigger angle results in smaller efficiency and vice versa (Jayah, 2002). It is also affecting bridging phenomenon where smaller angle will reduce the likely of bridging at the throat zone. For the design, 30° of throat's angle is selected to achieve the highest efficiency and avoid bridging.

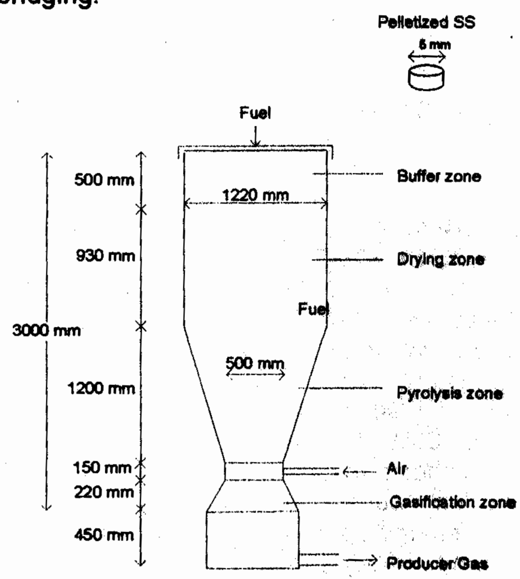

Figure 4 Design of downdraft gasifier for sewage sludge

Material for constructing the reactor is alumino-silicate which can withstand in temperature up to 1500 °C. Perry (1973) asserts that compared to firebrick, alumino-silicate insulation demonstrate a better performance in durability and heat flow resistance (SERI, 1988). The suggested thickness of cylindrical gasifier ranges from 2 to 5 cm and additional ceramic mold 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 alumino-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 68.30%.

ESTIMATED COST

The cost of using sewage sludge is assumed as free but the initial cost of palletizing sewage sludge is assumed 35%

of gasifier cost. Initial cost of gasifier is US$23,000 (Jayah, 2002), thus the cost of drying and palletizing sewage sludge is US$ 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_{th} from sewage sludge throated downdraft gasifier is AU$5,000 – $15,000 or approximately equal to Rs 170,000 – Rs 508,000.

Using case study of gasifier operation in Ideal Crumb, Kerala, the operational and maintenance and labour costs of gasifcation 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 doubling in 20 years. Detail calculation of benefit cost ratio of the designed system is presented in Appendix A.

APPLICATION OF SEWAGE SLUDGE GASIFICATION CASE STUDY OF INDIA

Seasonal weather of India is highly influenced by the Himalaya which isolates the land from the res of Asia 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 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 (CensusofIndia). 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 sensibility of the system. On the contrary the 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 throated downdraft gasifier by considering the less tar production and ash, effectively convert 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 throated area and 3 m in overall height. Height of throated zone is 22 cm as recommenced 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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