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Performance Evaluation of Wastewater Sludge to Energy by a Downdraft Gasification System

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Abstract

Wastewater sludge from wastewater treatment system is considered as a hazardous waste which is harmful to environment and needs a appropriate treatment by using various alternatives technologies such as combustion, gasification, landfill, etc. However, landfill is the most used method to dispose of due to cost saving. Nevertheless, waste water sludge can be used as an alternative fuel to produce heat and electricity. The purpose of this study is to evaluate the efficiency of a 50 kg/hr downdraft gasification so as to produce 50kW of electricity by using wastewater sludge as fuel. The system consists of briquetting machine, downdraft gasification, gas cleaning system and engine generator for electricity generation. In order to find optimized-operating condition, the air flow rate was adjusted to 75, 100, 125 Nm^3/hr. The results of this study were showed that the optimized-condition air flow rate was at 100 Nm^3/hr. At this point, the gasifier could produce fuel gas which the main compositions were 16.31% of CO, 9.05% of CO_2, and 1.13% of CH_4 and the higher heating value of gas was 3.36 MJ/Nm^3. At the optimum condition, the efficiency of gasifier, diesel replacement, engine thermal efficiency and overall efficiency were 36.71%, 72.05%, 28.33%, and 11.22% respectively. This study showed that the wastewater sludge can be used as alternative and renewable energy, in order to reduce the emission of green house gas and diminish the effect of global warming, by using a downdraft gasification technology for sustainable development of hazardous waste treatment.

Key words: Downdraft Gasification, Producer gas, Waste to Energy, Hazardous Waste Treatment

1. Introduction

With the oil crisis situation today, the research trend is focused in developing alternative fuel due to environmental concern and uncertainties involving the future availability of fossil fuel. In this study, wastewater sludge which is once considered as waste will be re-think and use as renewable fuel. It is the by-product from wastewater treatment system which consists of organic, inorganic and toxic substance, heavy metal, and pathogenic [1] which are harmful to the environment and all living organisms [2]. Therefore, the proper treatment technology is needed in order to prevent the impact to environment. The disposal of this waste, nowadays consists of landfill, use as fertilizers, dumping into the sea, and thermal processes [1]. However, there is still energy storage inside the waste, therefore thermal process can be harnessed waste to usable and green energy in the form of heat or electricity [3,4,5]. This study will focus on using gasification technology for converting wastewater sludge as renewable fuel to electrical energy.

The objective of this study has an aim to investigate the potential of wastewater sludge gasification in a 50 kg/hr downdraft gasifier to produce electrical energy of 50 kW. The study includes wastewater sludge properties, producer gas properties, and gasification efficiency in order to find the optimum operating condition.

2. Methodology

2.1 Wastewater Sludge

Table 1 Wastewater Sludge Properties

Properties	As-received basis	Dry ash-free basis
Proximate analysis (%wt)		
Moisture	8.44	-
Ash	24.08	-
Volatile matter	60.34	89.37
Fixed carbon	7.18	10.63
Ultimate analysis (%wt)		
Carbon , C	44.39	65.80
Hydrogen , H	1.81	2.69
Nitrogen , N	0.02	0.03
Sulfur , S	0.02	0.03
Oxygen , O	21.23	31.47
Net calorific value , kcal / kg	4,568.76	5,668.92
Bulk density , kg/m3	579.77	

Wastewater sludge used for the study is in the form of cylindrical briquetting with dimension of Ø1.5 x 2 inch. It's proximate analysis is shown in Table 1

2.2. Gasification System

2.2.1 Downdraft Gasifier

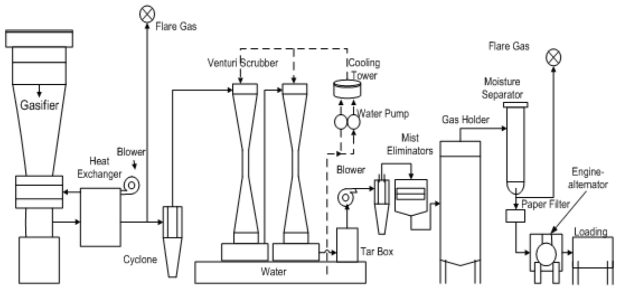

Fig. 1 Schematic Diagram of a 50 kWe Downdraft Gasification System.

The schematic diagram of a 50 kWe downdraft gasification system was shown in figure 1. Feedstock loading is a batch type where can be loaded to gasifier at the top. The hopper chamber uses for keeping feedstock in order to uses in gasification processes which the hopper chamber has to accumulate more than 400 kg of feedstock or it can operate continuously of 8 hours. The combustion chamber is designed as a non-throat type in order to prevent solid fuel block at throat area. The combustion area is designed by reference the hearth load value from Venselaar [1] that is 0.03 (kg/cm^2)/hr for non-throat type. Air supply is exchanged heat with produced gas to increase air temperature for improving combustion performance in combustion zone. Beside, this effect helps to decrease produced gas temperature. Therefore, it can decrease cooling load in gas cleaning system. The grating uses for pushing ash and discharge char drop to ash chamber.

2.2.2 Gas Cleaning System

The gas cleaning system is used to eliminate dust, moisture, and tar which contaminated in producer gas. The gas cleaning equipments consist of cyclone, ventury scrubber, tar adsorption, mist eliminator, moisture separator, and paper filter.

2.2.3 Engine-Generator

An engine is a compression ignition engine of 4 stocks 4 cylinders which is modified to use as dual fuel mode. There is 65 kW of power output. A generator is 48 kWe of power output which is 3 phases type, 380/400 V, and 50/60 Hz. The engine specification was showed in table 2.

Table 2 Engine specification.

Type	Direct injection, four cylinder, vertical, four stroke engine
Engine model	CUMMINS 4BTA 3.9-G2
Engine Speed (rpm)	1500 (Constant)
Cylinder bore (mm)	102
Stroke (mm)	120
Cubic capacity (l)	3.9
Compression ratio	16.5:1
Specific Diesel consumption rated (g/kWh)	220
Generator rating (kW)	48 (base output power)

2.3 Performance Evaluation Procedure

Wet sewage sludge is treated by solar drying and controlled size as briquetting. The 300 kg of sludge briquettes are weighed and loaded into gasifier's hopper. During loading, a kilogram of sludge samples is picked up from loader, so that the moisture content can be measured in a laboratory. Next, the gasifier is ignited by pilot burner until sludge is ignited. Then the pilot burner is switched off, and air flow rate is introduced. At the same time, data logger and computer are switched on to record parameters which consist of temperature, pressure, air flow rate and produced gas flow rate. When the temperature of produced gas is stable, the produced gas is directed through the cleaning system to eliminate contamination and through the engine for electricity generation. The engine is ignited by diesel oil until the engine becomes stable. After that, the diesel is replaced by produced gas, and also electrical load is connected, that the variation of engine loads consist of 10%, 20%, 30%, 45%, 55%, 65%, and 75%. Moreover, the pollutant and rate of diesel replacement are measured, and the experiments need to be run for three various air flow rates which is consisted of 75, 100, and 125Nm^3/hr.

3. Results and Discussion

3.1 Reaction Zone's Temperature

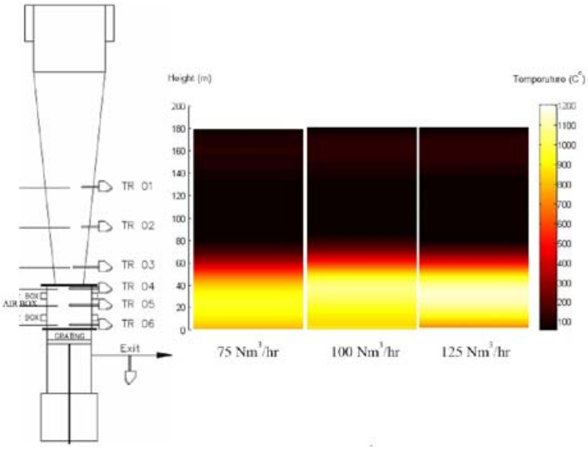

Fig. 2 Typical temperature distribution along the height of the gasifier.

The typical temperature distribution along the height of the gasifier is as shown in Figure 2, it can roughly indicate the reaction zones as drying devolatilisation, combustion and reduction zone. The drying zone occurs at position of TR2 at temperature less than 200 ºC. The devolatilisation zone occurs at position of TR3 at temperature in the range of 200ºC. The combustion zone occurs at position of TR4 to TR5 while the reduction occurs at position of TR4 at the temperature of 900-1200 ºC and 800-900 ºC, respectively. The effect of temperature fluctuation could be observed in all experimental cases, especially in combustion zone, which is thought likely to be due to bridging and collapsing of fuels. This is thought to be an effect of fuel collapsing, which can cause the drop of temperature (when no fuel was being burned) and the rise of temperature due to the sudden movement of large amount of fuel into the combustion zone.

3.2 Producer Gas Composition

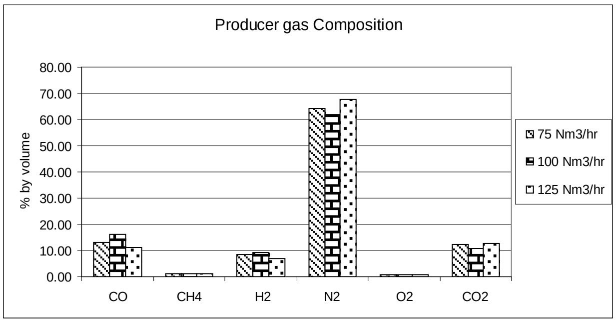

Fig. 2 Producer gas composition with different air flow rate

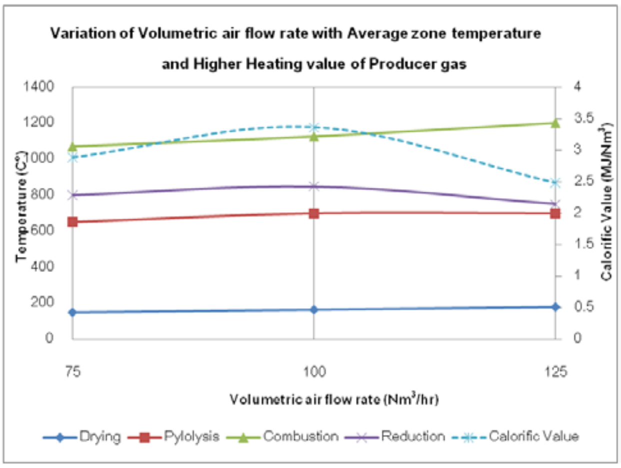

Fig. 3 The variation of heating value of producer gas with air flow rate

Effect of operating conditions on the compositions of the producer gas is also investigated in figure 2, since the heating value of producer gas determines the gasification efficiency. The main compositions are H_2 concentration which varied from about 7 to 9 %, CO concentration varied from about 11 to 16 % and CH_4 concentration was slightly difference. At 100 Nm^3/hr of air flow rate, the higher heating value was found to reach maximum which was shown in figure 3.

3.3 Gas Cleaning System

Producer gas from gasifier will pass through gas cleaning system by using water for reducing gas temperature and remove dust and tar before passing clean and cold gas to engine. It is indicated that at the optimum operating point where the amount of air flow rate of 100 Nm^3/hr, there is no dust in the producer gas and the tar is reduced as minimal of about 26 mg/Nm^3.

3.4 Diesel Replacement

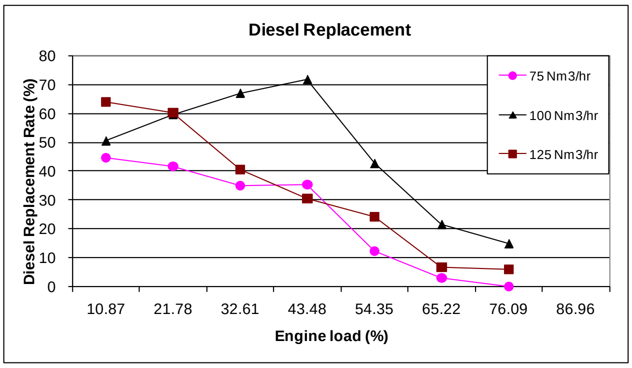

Fig. 4 % of diesel replacement by producer gas at various air flow rate

The clean producer gas will pass through the engine-generator for electricity generating. The engine was running with diesel oil and has been replaced with producer gas in order to reduce the fuel consumption. The % of diesel replacement by producer gas at various air flow rate is shown in Figure 4. Again, it is cleared that at the optimum operating point give the maximum diesel replacement of about 70%

3.5 Gasification efficiency

Table 4 Efficiency of gasifier system

Air flow rate (Nm^3/hr)	Producer gas (Nm^3/hr)	Fuel consumption rate (kg/hr)	Ash rate (%)	Efficiency of the Gasifier(%)	Efficiency of the Engine(%)	Overall Efficiency of System(%)	Specific consumption rate of Sludge (kg/kW)
75	86.45	36.58	32.73	35.59	3.61	9.36	5.12
100	124.9	59.71	27.56	36.71	23.65	11.21	3.57
125	153.36	70.94	34.73	27.99	22.61	4.84	12.03

Efficiency of gasifier system is counted between energy input in wastewater sludge and energy output in the form of electricity. It is shown in Table 4 that, at the optimum operating condition, the wastewater sludge can be used as renewable fuel to produce electricity with the overall efficiency of 11.21% with sludge specific consumption of 3.57 kg/kW.

3.6 Economic Consideration

The gasification system of this study can treat wastewater sludge about 157 tons/year. The investment cost of system costs about 3 Million Bath with the operating and maintenance cost of 544,292 Bath/year. Income of the system is come from the treatment cost of sludge and the electricity (generated from the system) about 1,394,732 bath/year, so the profit margin is about 850,440 bath/year. The economic analysis shows that the system can be return the investment within 3.53 years.

4. Conclusion

A 50 kg/hr of gasification equipped with gas cleaning system for dust and tar removal and dual-fuel diesel engine with generator has been used by using wastewater sludge as fuel for evaluating its performance. From the field-experiment, the inlet air with the flow rate of 100 Nm^3/hr has been shown to be the optimum operating point of the downdraft gasifier. The temperatures investigated in the combustion zone were around 1,150°C while the reduction zone were around 1,000°C. From the analysis on results of performance testing, the producer gas composition consists of 16.31 %CO, 0.90 %O_2, 1.13% CH_4, and 9.05% H_2. The calculated higher heating value was 3.36 MJ/Nm^3. The optimum operating point for electric power generation was about 24 kW, with a specific fuel consumption of 2.94 kg/kWh at fuel consumption rate of 59.71 kg/hr, 27.56% of ash removal rate and the total plant efficiency of 11.12%. The economic analysis has been shown that the system is self-economic and can return on the investment within 3.53 years which shown the sustainability of the system.

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