A Study of Energy Conversion From Agricultural Residues to Producer Gas Using a Simple Downdraft Gasifier

Ratchaphon Suntivarakorn and Chaiwat Juangtong

Abstract— *This research presents a study of energy conversion from agricultural residues to producer gas by using gasification technology. Four types of biomass, which were sugarcane trash, palm oil shell, longan peel and eucalyptus, were selected to use as a fuel in a downdraft gasifier. The gasifier consists of a cylindrical reactor, two sets of cleaning cycles, insulator and air supply blower. The experiment was conducted by using 10 kg of fuel per batch and varying the air supply velocity from 2.0 – 3.5 m/s. In case of sugarcane trash, a test varying the fuel length from 10 – 40 mm. was also done. Then, the producer gas component, heating value and energy conversion efficiency were studied. The results show that the gasifier can produce the producer gas, and the heating value of sugarcane trash, palm oil shell, longan peel and eucalyptus were 15.3, 9.33, 17.77 and 10.92 MJ/kg, respectively. The energy conversion efficiency was between 53.55 – 93.64%. The suitable condition for the maximum energy conversion efficiency was at 3 m/s of air velocity and 30 mm. of the fuel length. Producer gas from sugarcane trash and agricultural residues can be used as a substitute for fossil energy or charcoal in direct heat application.*

Keywords— **Downdraft gasifier, Producer gas, Heating value, Energy conversion efficiency.**

1. INTRODUCTION

The use of energy is an important factor in the everyday life of people including heat energy from Liquid Petroleum Gas (LPG) used as cooking fuel, automobile fuel and for electric current production etc. At present, the energy demand is rapidly increasing, causing many countries to provide more energy resources to satisfy demand. Each year, Thailand imports a lot of energy from abroad, which results in a loss of money to outside countries and this tendency is increasing. Thus, in order to decrease the amount of imported energy, development of alternative energy resources within the country, such as solar energy, wind energy and energy from biomass, are studied.

Biomass is raw material that can be transformed to produce energy and there is a large amount of biomass in Thailand. Sugarcane trash is one of the agricultural residues that has a high potential for use in the production of alternative energy. Nowadays, sugarcane trash is abandoned in the field and it is seldom used as an energy source. This is because the sugarcane trash has a low density and it is difficult to collect. From an estimation of the one year energy potential of sugarcane trash, it is found that there is about 10 million tons, or 3,800 million liters of crude oil equivalent, which is abandoned in sugarcane farms [1]. For this reason, if there is a supporting or appropriate technology that can convert sugarcane trash into energy, it can be used as a new alternative energy source which can substitute for the disappearing fossil fuel.

R. Suntivarakorn (corresponding author) and C. Juangtong are with Department of Mechanical Engineering, Faculty of Engineering, Khon Kaen University, 123 Moo 16, Mittraphap Road, Khon Kaen, 40002, Thailand. Phone : +66-81-989-1983; Fax : +66-43-347-879 ; E-mail: ratchaphon@kku.ac.th and manpower_10a@live.com.

Biomass can be transformed into a usable gaseous fuel by a technology known as biomass gasification technology. Biomass gasification means the incomplete combustion of biomass resulting in the production of combustible gases consisting of carbon monoxide (CO), hydrogen (H_2) and traces of methane (CH_4). This mixture is called producer gas. Producer gas can be used to run internal combustion engines (both compression and spark ignition), as a substitute for furnace oil in direct heat applications and to produce methanol-an extremely attractive chemical which is useful both as fuel for heat engines as well as chemical feedstock for industries [2]. Since any biomass material can undergo gasification, this process is much more attractive than ethanol or biogas production where only selected biomass materials can produce the fuel. A comparison with other renewable energy options, using the common basis of energy efficiencies and economics, shows that this technology may have significant advantages and deserves serious attention.

In Thailand, during 1980 and 1990 the first studies on the gasification technology of biomass were undertaken at Prince of Songkla University. Emphasis in the studies was placed on the development of small-scale decentralized energy system which could be operated using locally available fuels. The gasification system was developed for gasifying wood block, wood chip, coconut shell corn cob, cassava stalk, rice husk and wood mixture of coconut husk and wood blocks. The gasifier was of the down draft type with a throat and conical fuel container [3]. Charcoal gasifier engine for power generation has been also designed and studies. The system consists of a gasifier unit, purification system, electric generator, small internal combustion engine (6.5 Hp) and water pump. The maximum power generation was found to be 1 Kw at the charcoal consumption rate of 3 kg/hr [4]. Moreover, the municipal solid waste gasification for power generation was also studied. The gasifier was run on a batch mode and has a designed capacity of about 30 kg feed per batch. From the analysis results, the producer gas has the heating value of 5.68 MJ/m3 and it can be used as a fuel for 50 Kw electricity generation [5]. However, even though many types of biomass have been studied, the study on sugarcane trash gasification in Thailand has not been clear yet. In this study, the producer gas production from sugarcane trash will be investigated.

Gasification technology is an appropriate technology for converting sugarcane trash to gaseous fuel. A low-density sugarcane leaves and bagasse gasification system for thermal applications has been developed for commercial scale use [6]. The system was tested for more than 700 hours under laboratory conditions and it was found that the heating value of the producer gas was 3.56-4.82 MJ/Nm^3. However, this system is large scale and quite complex making it unsuitable for use in a household. In this paper, the simple design of a downdraft gasifier will be presented and used to produce the producer gas from sugarcane trash and three other types of agricultural residues, including palm oil shell, longan peel and eucalyptus. The producer gas components, heating value and energy conversion efficiency will be studied in order to know the characteristics of the gasifier. These results will be used to develop a suitable gasifier for utilization of the sugarcane trash as a new alternative source of energy.

2. PRINCIPLE OF GASIFICATION

In the gasification process, combustible gases are formed by burning solid biomass with a restricted air supply. The process of gasification is carried out in a reactor known as a gasifier. Gasifier can be classified, according to the direction of gas flow, into three types : updraft, downdraft and crossdraft as shown in Fig. 1.

So far, the downdraft gasifier has received the most attention as it can be designed to give tar-free gas which is suitable for use as fuel in an internal combustion engine. The updraft gasifier is suitable for large scale process heat application since its efficiency is high. Gasification is a thermo-chemical conversion process and is divided into four process zones. These are combustion zone, reduction zone, pyrolysis zone and drying zone [3].

In the combustion zone the reactions, which are exothermic, are

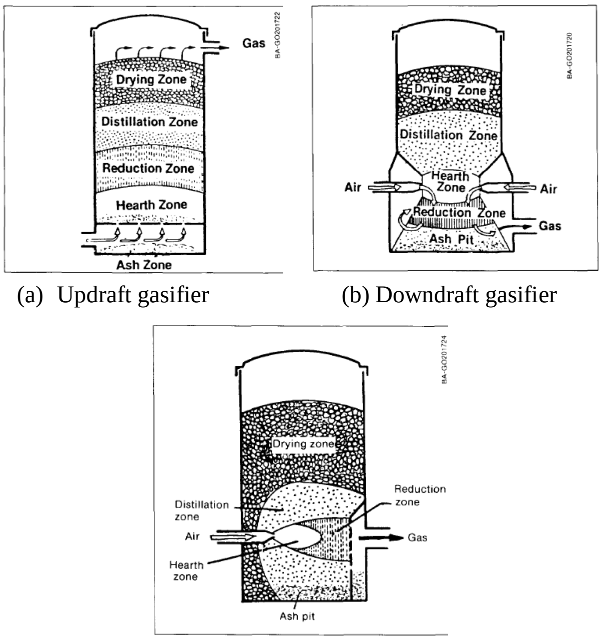
$$C + O_2 \rightarrow CO_2 \quad (1)$$

$$2H_2 + O_2 \rightarrow 2H_2O \quad (2)$$

In complete combustion, carbon dioxide is obtained from carbon in the fuel and water is obtained from the hydrogen, usually as steam. The combustion reaction yields a theoretical oxidation temperature of 1,450 ^{o}C. The products of partial combustion pass through a red-hot charcoal bed where the reduction reactions take place. The main reduction zone reactions are :

$$C + CO_2 \rightarrow 2CO \quad (3)$$

$$C + H_2O \rightarrow CO + H_2 \quad (4)$$



(a) Updraft gasifier (b) Downdraft gasifier

(c) Crossdraft gasifier

Fig.1. Classification of Gasifier [1].

As reductions (3) and (4) are endothermic, the temperature will decrease during the reduction process. Apart from reactions (3) and (4), other reactions may also take place in the reduction zone as follows:

$$C + 2H_2 \rightarrow CH_4 \quad (5)$$

$$CO_2 + H_2 \rightarrow CO + H_2O \quad (6)$$

$$C + 2H_2O \rightarrow CO_2 + 2H_2 \quad (7)$$

$$CO + H_2O \rightarrow CO_2 + H_2 \quad (8)$$

$$CO + 3H_2 \rightarrow CH_4 + H_2O \quad (9)$$

The temperature in the reduction zone is normally 800 – 1,000 ^{o}C. Pyrolysis, which takes place between 280 – 500 ^{o}C, produces large quantities of tar and gases containing carbon dioxide. Finally in the drying zone, the main process is the drying of biomass. The temperature in the drying zone is between 100 – 200 ^{o}C. Producer gas is therefore a mixture of the gases i.e. CO, H_2, CH_4, C_xH_x, N_2, CO_2, H_2O and the combustible components of the gas are CO, H_2, CH_4 and C_xH_x. The percentage of these combustible gases should be made as high as possible. The heating value of producer gas is calculated from the components of the gas and varies from 3 MJ/Nm^3 to 6.5 MJ/Nm^3 depending on the types of feedstock (biomass), heat loss from the gasifier and the moisture content of the feedstock used. The gasification characteristics depend on particle size, void space, bulk density, moisture content and ash content of the fuel and the temperature in the combustion and reduction zones.

Gasification is an energy conversion method and the ability of the energy conversion is indicated by the energy conversion efficiency which is defined as [7]

$$\eta_{Gas} = \frac{\text{Calorific value of gas per kg of fuel}}{\text{Average calorific value of 1 kg of fuel}} \qquad (10)$$

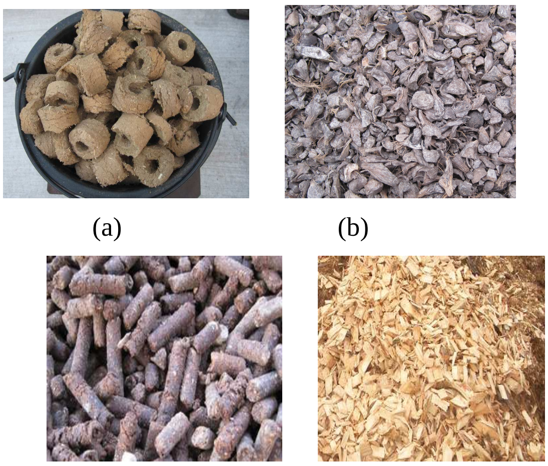
3. EXPERIMENT

3.1 Raw Materials

Four different types of biomass were selected for use as fuels in the combustion experiment. These were sugarcane trash, palm oil shell, longan peel and eucalyptus. The initial humidity of the fuels was between 1-15% and their characteristics are shown in Fig. 2. In the cases of sugarcane trash and longan pell, both were shredded and compressed into a cylindrical shape with a diameter of 49 and 10 mm, respectively. The compressed sugarcane trash was tested by varying four sizes of length, which were 10, 20, 30 and 40 mm. All fuels were tested in the reactor in order to produce producer gas and to determine the energy conversion efficiency. The heating values and properties of the fuels are shown in Table 1.

Table 1. Heating Value and Properties of Biomass.

Type of Fuel	Properties of Biomass		Heating Value (MJ/kg)
	Moisture (%)	Size	
Sugarcane trash	4.55	Diameter 49 mm	18.88
Palm oil shell	1.62	12x6x3 mm^3	17.84
Longan peel	14.55	Diameter 10 mm	18.98
Eucalyptus	1.14	15x15x8 mm^3	18.56

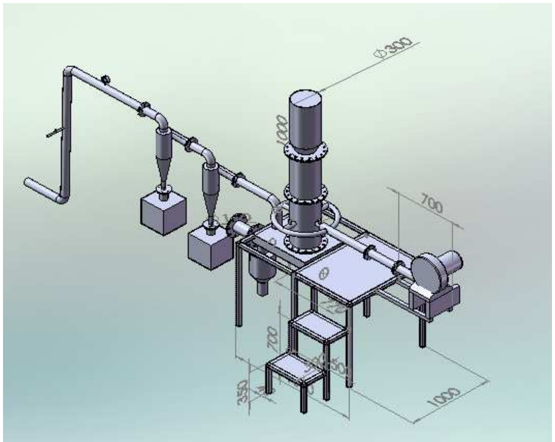


(a) (b) (c) (d)

Fig. 2. Characteristic of five different biomass tested in the experiment: a) sugarcane trash, b) palm oil shell, c) longan peel and d) eucalyptus.

3.2 Experimental equipments

The schematic of the experimental apparatus is shown in Fig.3. The simple down draft gasifier was designed and used in this experiment [8]. The gasifier consisted of a reactor, gas cleaning cyclone, insulator and air supply system. The reactor was designed and constructed as a cylindrical reactor without a bottle neck. The diameter and length of the reactor were 20 cm. and 120 cm., respectively. Two sets of cyclones were installed at the exit of the reactor in order to trap dust particle. A blower was used to supply air for combustion. The air was blown into the reactor through four inlets with a 10 mm diameter. The amount of air used in the gasification process was about 30% of the stoichiometric air. Stoichiometric or Theoretical Combustion is the ideal combustion process during which a fuel is burned completely. Thus, the experiment was conducted by controlling the air velocity in the range from 2.0 – 3.5 m/s.



(a) Schematic of the experiment apparatus

(b) Picture of developed downdraft gasifier

Fig. 3. Experiment apparatus.

3.3 Procedure

The biomass gasification tests were done with fuel supplied as 10 kg per batch. All fuels were tested in the reactor in order to produce the producer gas. In each experiment, the velocity of the supply air was varied as 2.0, 2.5, 3.0 and 3.5 m/s which were related to 22.2%, 27.65%, 33.19% and 33.88% of stoichiometric air, respectively. Then, the heating values and the components of the obtained producer gas were investigated. The experimental procedure was as follows:

(1) The sugarcane trash was prepared with about 10 kg for each batch of the experiment.

(2) The fuel was entered and arranged in the reactor.

(3) The blower was started and the air velocity was adjusted to 2.0 m/s

(4) A fire was lit and the outlet valve at the exit of the reactor was opened.

(5) The velocity of the producer gas was measured for calculation of the energy conversion efficiency.

(6) The producer gas was collected in order to analyze the heating value and gas components.

(7) When the fire was extinguished, the combustion time was recorded in order to know the amount of producer gas per kilogram of fuel.

(8) The air velocity was varied from 2.0 to 2.5, 3.0 and 3.5 m/s, respectively, and then experimental steps (3) – (6) were performed again.

The fuel was changed from sugarcane trash to palm oil shell, longan peel and eucalyptus, respectively and experimental steps (1) – (8) were performed again. In the case of sugarcane trash, an additional experiment was conducted by varying the length of the fuel from 10 – 40 mm.

4. RESULTS AND DISSCUSSIONS

4.1 Producer gas component and heating value

From the experiment, it was found that the designed downdraft gasifier could produce the producer gas and a firing test of the obtained producer gas was tested as shown in Fig. 4. The maximum quantity of producer gas was obtained at an air velocity of 3 m/s. This velocity was converted to an air flow rate equal to 0.01 Nm^3/s. This value was about 33.19 % of stoichiometric air. For one kilogram of the fuel, the volumes of the producer gas obtained from sugarcane trash, palm shell, longan peel and eucalyptus were 2.46, 2.45, 2.3 and 2.4 Nm^3/kg, respectively. The heating value of each fuel was calculated from the component of the producer gas which are shown in Table 2. The results revealed that longan peel had the maximum heating value which was 7.73 MJ/Nm^3 or 17.77 MJ/kg. The next highest values were from sugarcane trash, eucalyptus and palm shell which had heating values of 15.3, 10.92 and 9.33 MJ/kg, respectively. (see Fig. 5)

Fig. 4. Firing of teh obtained producer gas.

Table 2. Component and Heating Value of Producer Gas.

Type of Fuel	Component of Producer gas (%)					Heating Value (MJ/Nm^3)
	CO	H_2	CH_4	CO_2	N_2	
Sugarcane trash	17.3	14.9	4.5	8.4	54.9	6.22
Palm shell	14.7	11.8	0.8	21.4	51.3	3.81
Longan peel	21.3	20.8	5.3	21.4	31.2	7.73
Eucalyptus	19.6	7.6	2.3	16.2	54.3	4.53

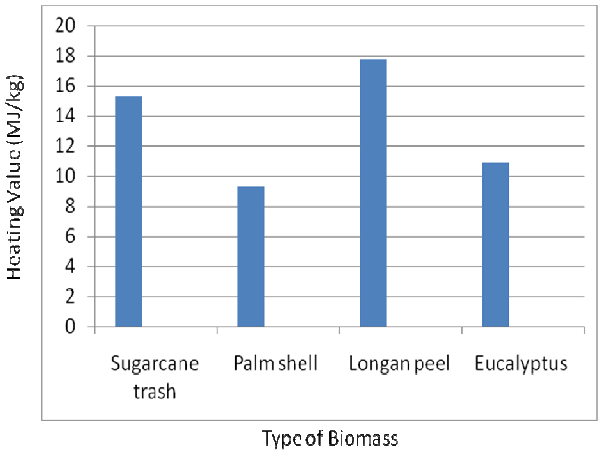


Fig. 5. Heating value of producer gas from each biomass.

Considering the producer gas production from sugarcane trash, it was found that the best condition for producer gas production was at 3 m/s of air velocity and 30 mm. length of the compressed sugarcane trash. The producer gas was composed of CO, CH_4, H_2, CO_2 and N_2 with volume ratios of 17.31%, 4.47%, 14.85%, 8.40% and 54.37%, respectively. Moreover, the results revealed that the heating value of producer gas was 6.22 MJ/Nm^3 or 15.3 MJ/kg. The heating values of the obtained producer gas, which varied according to the air velocity and the length of the fuel, are shown in Fig. 6 and Table 3. The results also revealed that the maximum heating value of the producer gas was obtained at the air velocity of 3.0 m/s for all lengths of the compressed fuel. The component of producer gas at 3 m/s for all lengths of the fuel are shown in Fig. 7.

From the experimental results, it was found that suitable conditions for producing the producer gas from sugarcane trash were at the air velocity of 3.0 m/s and the sugarcane trash length of 30 mm. These conditions can be applied to implement in the practical industry.

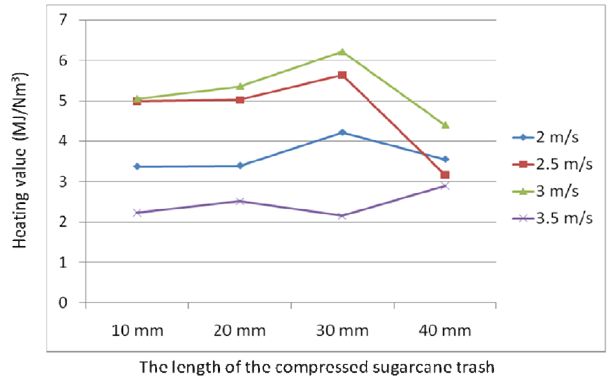


Fig. 6. Heating value of producer gas from each length of compressed sugarcane trash.

Table 3. Heating Value of Producer Gas from Sugarcane Trash at air velocity of 3 m/s.

Sugarcane trash length	Producer Gas Flow rate (Nm^3/kg fuel)	Heating Value (MJ/ Nm^3)	Heating Value (MJ/kg fuel)
10 mm.	2.42	5.05	12.22
20 mm.	2.81	5.36	15.06
30 mm.	2.46	6.22	15.30
40 mm.	2.3	4.40	10.12

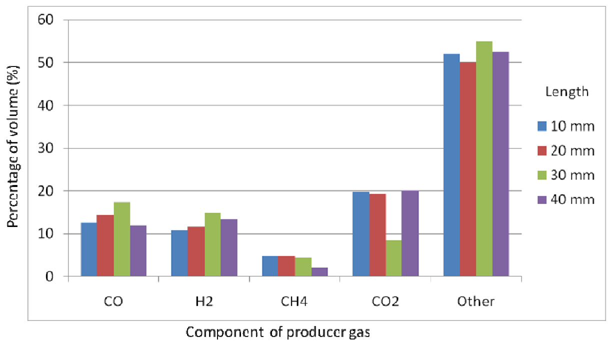


Fig. 7. Component of producer gas.

Considering the reactor temperature for sugarcane trash, it was found that the range of the reactor temperature was between 100 – 930 ^{O}C as shown in Table 4. The temperature of the combustion zone was between 900 – 930 ^{O}C. The maximum temperature of the combustion zone occured at a length of 30 mm. This indicated that a lot of carbon dioxide, which occurred in this zone, was decomposed into carbon monoxide in the reduction zone, with the result that the heating value for this condition was higher than that of the other conditions.

Table 4. The Reactor Temperature.

Sugarcane trash length	Temperature (^{O}C)			
	Drying zone	Pyrolysis zone	Combus -tion zone	Reduction zone
10 mm.	100	250	900	850
20 mm.	120	340	920	870
30 mm.	120	250	930	890
40 mm.	130	460	920	870

4.2 Energy Conversion Efficiency

To find the energy conversion efficiency, equation no. (9) was used. The conversion efficiencies of sugarcane, palm oil shell, longan peel and eucalyptus were 81.08%, 66.53%, 93.64% and 53.55%, respectively. (See Table 5.) These results were considered when the air velocity was 3 m/s. In the case of the compressed sugarcane trash, it was found that the energy conversion efficiencies were 65.0%, 80.05%, 81.38% and 56.22% for fuel lengths of 10, 20, 30 and 40 mm, respectively.

Table 5. Energy Conversion Efficiency for Sugarcane Trash.

Type of biomass	Heating Value (MJ/kg)	Gas Flow rate (Nm^3/kg)	Heating Value (MJ/Nm^3)	η_{Gas} (%)
	A	B	C	(BxC)/(A)x100
Sugarcane trash	18.88	2.46	6.22	81.05
Palm oil shell	17.84	2.45	3.81	66.53
Longan peel	18.98	2.3	7.73	93.64
Eucalyptus	18.56	2.4	4.53	53.55

5. CONCLUSSION

Four types of biomass: sugarcane trash, palm oil shell, longan peel and eucalyptus, were tested as fuels in the designed downdraft gasifier. The gasifier was able to produce the producer gas for using all fuels. The amount of obtained producer gas and its heating values and components were investigated. From the experiment, it was found that sugarcane trash, palm shell, longan peel, eucalyptus and coconut shell could produce the producer gas in amount of 2.46, 2.45, 2.3 and 2.4 Nm^3/kg, respectively. The heating values of each fuel were 15.3, 9.33, 17.77 and 10.92 MJ/kg, respectively. These values were the maximum heating values for each fuel which occurred when the air velocity was 3 m/s. The amount of producer gas produced from the gasifier depended on the air flow rate and the size of the fuel. The flow rate of supply air, which was optimal for this gasifier, was found to be 0.01 Nm^3/s or 33.19 % of stoichiometric air. In the case using sugarcane trash, the optimal size of the compressed sugarcane trash was found to be 30 mm. Furthermore, the energy conversion efficiency was also determined and it was found that the energy conversion efficiency was between 53.55 – 93.64%. The producer gas obtained from sugarcane trash and agricultural residues can be used as a substitute for fossil fuel or charcoal in direct heat applications. If this gasifier was used in a household instead of a charcoal brazier or LPG stove, it could reduce the energy expenses for the household and reduce the overall imported energy costs for the country.

The advantages of the gasifier used in this study were easy to construct, low cost of production and maintenance. It can also be used to produce the producer gas from various types of biomass, and due the method of use is not complicated, it can be simplified to utilize in the household. On the other hand, using of some biomass, it needs to grind and compress the biomass which causes the high energy consumption. Since, the gasifier was run on the batch mode, the usability time should be long enough for maximum benefit.

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