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FLUIDIZED BED CO-GASIFICATION OF COAL AND SOLID WASTE FUELS IN AN AIR GASIFYING AGENT

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ABSTRACT

The increased need to reduce carbon dioxide emissions to prevent global warming have led to an interest in biomass and solid waste as fuel sources. As a potential renewable energy resource, biomass and solid waste materials are receiving more attention worldwide. A number of techniques and methods have been proposed for reducing gaseous emissions from a fossil fuel conversion thermal system. This paper presents a pilot-scale bubbling fluidized bed gasifier with a diameter of 0.68 m and a height of 1.50 m using an oil burner to heat the bed. This study used four types of biomass materials mixed with coal at different mass composition ratios in an air gasifying agent. The gasification tests were conducted under steady-state at an operating condition that is typical for gasification. The influence that the solid waste and coal ratio had on gasification efficiency was investigated. The gasification efficiency and the carbon conversion efficiency increased when the mass ratio of the solid waste fuels increased.

Keywords: Coal; Co-gasification; Fluidized bed gasification; Solid waste

1. INTRODUCTION

Fluidized bed gasification is a promising technology that can convert energy from low rank calorific solid fuels, such as biomass and solid waste, into a combustible gas whose composition and heating value are greatly dictated by the type of gasifying agents. Due to its simplicity and low-cost operations, air is the most widely used gasifying agent. The high volatile matter (VM) content of biomass and solid waste is an important characteristic of their ability to be used as fuel. Because of the high heat transfer from the bed material to the fuel, VM evolution occurs very rapidly when fuel is fed into the bed. This indicates that the fuels are easier to ignite and burn, although the reaction is expected to be rapid and difficult to control. High VM content is also expected to affect the overall gasification process. The implication of high VM content is that the design and operation principles normally adopted for coal-burning systems might not apply for solid waste fuels. The high moisture and ash content in waste fuels can also cause ignition and combustion problems. Moreover, the melting point of the dissolved ash can be low, which causes fouling and slagging problems (Sami et al., 2001).

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Since waste fuels are categorized as high VM fuels, it is necessary to maintain a thermally stable bed to ensure that the reactor temperature is optimal (Izumiya et al., 1997). In such a case, the provision of heat transfer surfaces in the upper bed zone is needed in order to remove excess heat. To lower the reaction rate, the bed temperature should be reduced from the optimum temperature normally used at 1123 K and the introduction of superficial gas into the bed should be minimized (Fujiwara et al., 1995). Controlling the waste feed rate results in the ability to enhance the mixing of air to the VM (Koyama et al, 1995). In order to suppress rapid VM evolution, a porous bed material that captures hydrocarbons in the pores should be used as a carbon deposit (Franke et al., 1999; Franke et al., 2001; Shimizu et al., 2010; Shimizu et al., 2003; Namioka et al., 2003; Winaya et al., 2008; Werther et al., 2000). This reduces the amount of evolved VM and increases the conversion of carbon in the dense bed. Consequently, this is expected to enhance the horizontal dispersion of carbonaceous materials by solid mixing in the dense bed. It is also expected to inhibit the formation of local fuel-rich zones and high-temperature zones in the freeboard. Using a co-gasification of mixture fuels is another possible way to control the VM feed rate.

Because the lower calorific values of waste fuels are accompanied by flame stability problems, co-gasification currently holds more appeal than any of the single source technologies, including more advanced conversion options such as integrated gasification combined cycles. It is anticipated that the co-gasification of waste fuels with coal will reduce flame stability problems and minimize corrosion effects. The co-gasification of coal and waste fuels has the potential to reduce CO_2 emissions and the amount of pollutants, such as NOx and SOx. The co-gasification process has been widely studied using mixtures of several kind of feedstock, such as waste fuels, with other materials, like coal and biomass and even plastic waste (Storm et al., 1999; Pinto et al., 2002; Wong et al., 2010).

This study aimed to investigate the influence of variations in the mass composition of waste fuels and coal as the gasification fuel in a fluidized bed with an air agent, using quartz sand as the bed material.

2. OVERVIEW OF THE EXPERIMENT

2.1. Experimental Apparatus

The pilot-scale gasifier reactor that was used to perform the experiments in this work is shown in Figure 1. The gasifier is a bubbling fluidized bed reactor with a diameter of 0.7 m and a height of 1.50 m, which was connected to a cyclone separator for gas de-dusting. The reactor consists of a stainless steel vertical tube with four thermocouples along the height, which allows for good fluidization and a good gasification mode. The gas distributor at the bottom of the bed is used to mix the solids using a motor stirrer. The feedstock, which consists of blends of coal, biomass, and waste, is continuously fed into the bottom of the bed. The fuel feeder is an under-bed tank that is screwed into the reactor. The feed system has one hopper where solid wastes are stored and one screw feeder. A hole, which serves as a pre-heater burner, is on the top of the bed material and the feed system has a large capacity blower with an adjustable valve for air supply gasification.

The air used as the gasifying agent is introduced into the reactor at two locations. The primary air is introduced at the bottom of the gasifier through a distributor plate, while the secondary air enters at the side of the freeboard to remove part of the generated tars and to ensure that the process is auto-thermal.

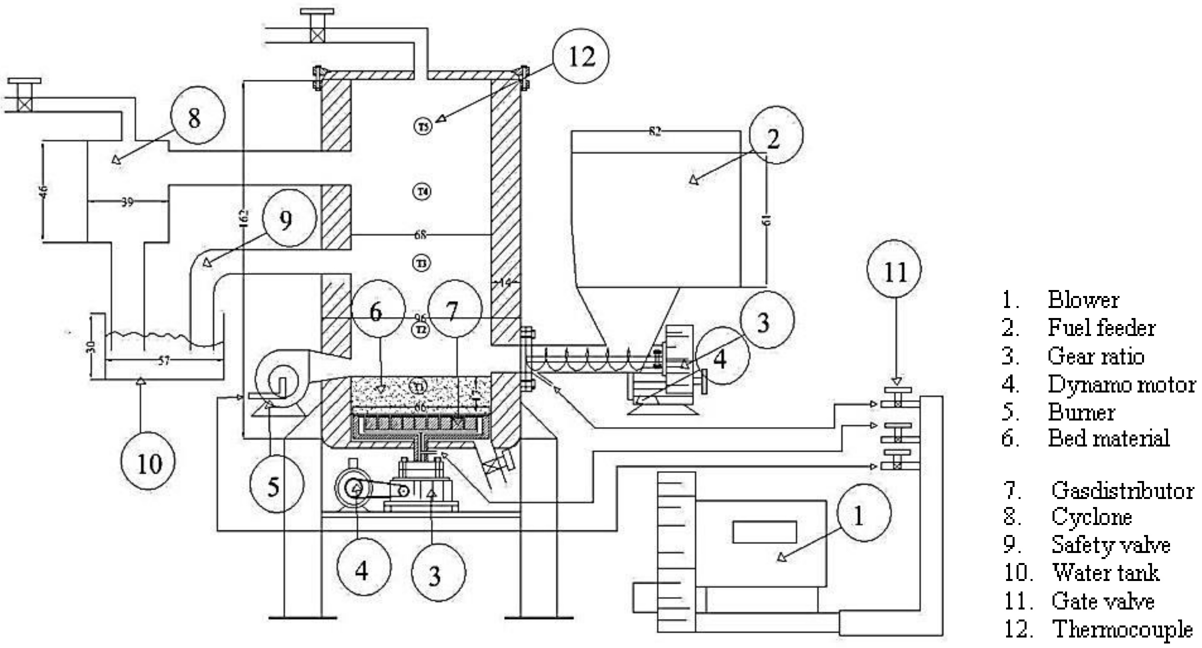

Figure 1 Schematic of the fluidized bed gasifier system

2.2. Experimental Procedure

The gasifier was operated in bubbling mode without recirculation of material/ashes to the bed. The reactor was pre-heated using an oil-burner with a temperature of up to 600^{o}C. Silica sand with a mean size of 0.5 mm was used as the bed material at a bed height of 10 cm. Three waste fuel-to-coal ratios based on percentage of mass were employed: 50%–50% (I), 60%–40% (II) and 70%–30% (III). The blended fuel was continuously inserted into the bed using the screw feeder equipment. The proximate analysis was conducted using thermo-gravimetric measurements to determine the moisture, ash, VM mass and fixed carbon mass, and the ultimate analysis was undertaken using an elemental analyzer to measure the content of carbon, hydrogen, oxygen, nitrogen, and sulfur. The results of the analyses are shown in Table 1.

Table 1 Proximate and ultimate analysis and High Heating Value (HHV)

	Municipal waste	Rice husk	Sawdust	Palm residue	Coal
Proximate analysis					
Moisture (%)	13.46	22.00	8.49	10.00	40.59
Ash (%)	9.00	14.87	5.88	2.73	27.00
Volatile matter (%)	77.38	62.25	85.28	70.67	32.29
Fixed carbon (%)	13.62	22.58	8.85	26.60	40.71
Ultimate analysis					
C (%)	64.46	37.65	49.08	48.67	86.14
H (%)	11.50	6.25	6.83	6.93	0.75
O (%)	18.03	39.43	43.21	41.82	1.54
N (%)	0.52	0.97	0.1	0.31	1.12
S (%)	0.05	0.06	*	0.01	0.56
Calorific value					
MJ/kg	16.08	17.72	14.70	14.6	20.24
Btu/lb	6.91	7.62	6.32	6.28	8.70

The experiments were conducted using standard operating procedures for gasification. Fuel was inserted through the screw feeder with a capacity rate of 25 kg/hr. The fluidization velocity was set at 0.253 m/s using an adjustable valve. Four thermocouple temperature sensors were mounted onto the wall side of the reactor, and then connected to data logger software, which was able to record the temperature changes at each reactor position (T_1, T_2, T_3, and T_4). The sampling point was located after the cyclones, before the heat exchanger. Samples of the major gas components were collected and analyzed using gas chromatography.

3. RESULTS AND DISCUSSION

3.1. Effect of Fuel Composition on Gas Yield

The composition of mass feedstock impacts the gas yield and the working performance. Figure 2 shows the effect that the waste fuel content (municipal waste, sawdust, rice husks, and palm residue) had on co-gasification with coal. It was observed that, as the amount of waste composition increased, which was indicated as the ratio of I to III, the amount of gas yield as CO and H_2 increased, but it was almost equivalent to the amount of CH_4.

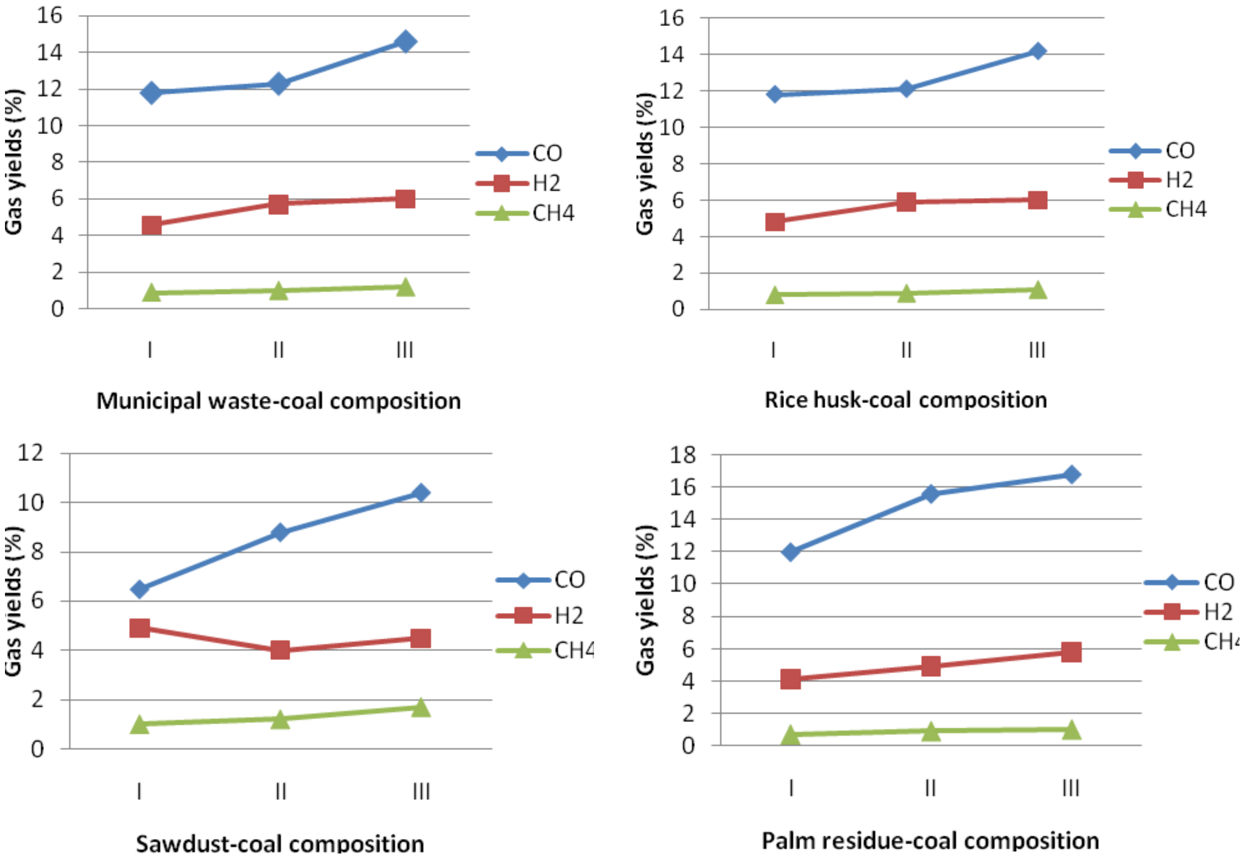

Figure 2 Gas yield of the co-gasification of coal combined with municipal solid waste, rice husk, sawdust, and palm residue

The most important gases produced from the gasification process are CO, H_2, and CH_4. The gas yield results from the endothermic reaction, which is supported by the heat produced from the combustion reaction. There are four major gasification reactions.

The water-gas reaction is a reaction of partial oxidation of carbon by water vapor, which can be derived from solid fuel:

$$C + H_2O \rightarrow CO + H_2 - 131.38 \text{ kJ/kg mole of carbon} \tag{1}$$

The carbon dioxide present in the gasifier reacts with char to produce CO according to the following endothermic reaction, which is known as the Boudouard reaction:

$$CO_2 + C \rightarrow 2CO - 172.58 \text{ kJ/mol} \tag{2}$$

The water-gas shift results in an increase in the ratio of hydrogen to carbon monoxide in the gas producer, as follows:

$$CO + H_2O \rightarrow CO_2 + H_2 - 41.98 \text{ kJ/mol} \tag{3}$$

A methanation reaction is a reaction to the formation of methane (CH_4), according to the following equation:

$$C + 2H_2 \rightarrow CH_4 + 70.90 \text{ kJ/mol} \tag{4}$$

The CO content indicates an increase in the amount of waste in the co-gasification process, which ranges between 20–30% for all types of waste fuels. The highest CO content (26.62%) was produced from palm residue that had a 70%–30% composition ratio with coal (III).

3.1. Effect of Fuel Composition on Gas Yield

The performance of a gasifier is often expressed in terms of its efficiency. Carbon conversion efficiency (CCE) and cold gas efficiency (CGE) are two important parameters of efficiency. Carbon conversion efficiency (CCE) can be calculated as:

$$\text{CCE} = \frac{\text{carbon total reacting in the system (kg)}}{\text{carbon total inserted to the system (kg)}} \tag{5}$$

Cold gas efficiency (CGE) can be calculated as:

$$\text{CGE} = \frac{\text{LHVfuelgas}\left(\frac{\text{kJ}}{\text{Nm}^3}\right)\text{xfuelgasproduction}\left(\frac{\text{Nm}^3}{\text{kg}}\right)}{\text{LHVbiomassoffeedinthesystem}\left(\frac{\text{kJ}}{\text{kg}}\right)} \tag{6}$$

In general, a similar efficiency trend occurred during the co-gasification process. When the ratio of the waste fuel-coal composition increased, the efficiency (CGE and CCE) also increased. The highest efficiency was obtained when the ratio of 70% palm oil and 30% coal (III) was used. Gasification efficiency is determined by comparing the ratio of energy contained in the fuel with the amount of energy produced from the gasification process. The amount of energy from the gasification process is the amount of energy output of gases, such as CO, H_2, and CH_4 (MJ/kg of fuel).

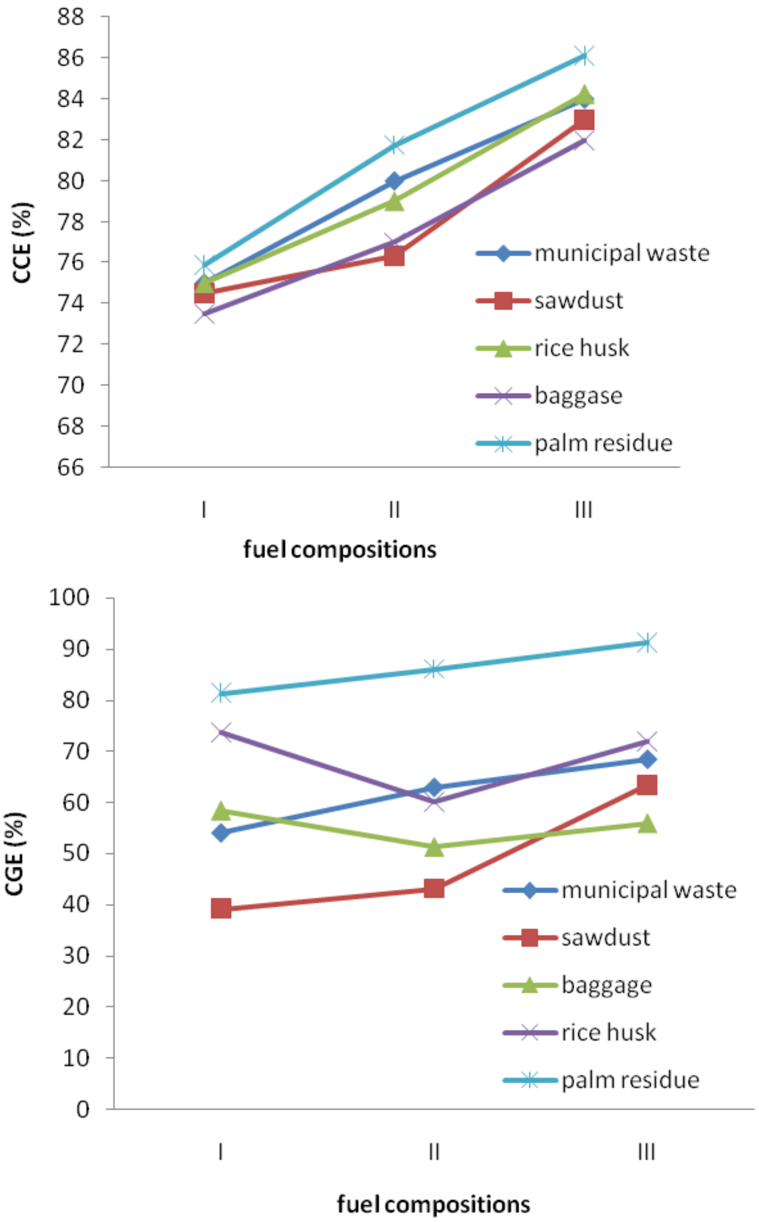

Figure 3 Gasification efficiency (CCE and CGE) of co-gasification on the waste and coal combinations

4. CONCLUSION

The high oxidation rate caused by the high VM content in waste fuels in the co-gasifier resulted in an increase in the CO_2 concentration, whereas if carbon reacts with CO_2, the CO content increases. The highest CO content (26.62%) was produced from the palm residue and coal combination with a ratio composition of 70%–30% (III). The highest gasification efficiency was also produced from the same composition of palm residue and coal. The gasification efficiency and the carbon conversion efficiency increased when the composition ratio of the waste fuels also increased.

5. ACKNOWLEDGEMENT

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