MUNICIPAL SOLID WASTE GASIFICATION ON DUAL FLUIDIZED BED REACTOR USING DIFFERENT GAS AGENT

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ABSTRACT

Technology for converting municipal solid waste (MSW) into energy has been rapidly growing, one of which is using fluidized bed gasification technology. Dual reactor of fluidized bed (DRFB) is one of the most interesting gasification technics with 2 (two) reactors one as gasifier and the other as combustor. Gasification that separates endothermic and exothermic reaction processes is the focus of the development on current gasification technology. In addition to maximizing the conversion of fuel as well, the dual-reactor system can recirculate combustion gases i.e. CO₂ and H₂O to the gasification reactor as a function of the gasification agent. In this work, the reactor is made of a stainless-steel pipe (SS304) diameter of 4 in (10.16 cm) for the gasification reactor and 2 in (5.08 cm) pipe for the combustion reactor. The study was carried out using MSW as fuel and added a series variation of gasification agent to see the performance of DRFB gasifier using quartz sand as a bed material. The gasification agent of H₂O, CO₂ and O₂ were injected from the bottom of gasification reactor to reach a maximum reaction distribution along vertical direction at a variation of the flow rate of 50 mL/min, 100 mL/min, 150 mL/min and with no addition of a gasification agent (NA) for comparison. The results show that the addition of H₂O and CO₂ agents more dominantly increases syngas production compared to O₂ agent and it is further found that the addition of H₂O provides the greatest syngas and efficiency.

KEYWORDS: Dual reactor, fluidized bed, solid waste, gasification agent

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INTRODUCTION

Global demand for energy is continuously increasing, because of population and economic growth, especially in emerging market economies [1]. The increase in population also causes problems in an increase of a number municipal solid waste (MSW) that has accumulated in landfills. The lack of municipal solid waste (MSW) segregation and treatment in the landfill causes ineffective waste collection in urban areas that pollute the city. The MSW in the landfill should have been managed well, even it could be utilized to be a useful energy. There is an obvious need to minimize the generation of wastes and to reuse and recycle them, the technologies for recovery of energy from wastes can play a vital role in mitigating the problems. Gasification MSW is one of an attractive alternative fuel production process for the treatment of solid waste as it has several potential benefits over the traditional combustion in which it can be utilized as a gas fuel being combusted in a conventional burner or in a gas engine and then connected to a boiler and a steam turbine or gas turbine to utilize the heat or produce electricity [2]. This technology can lead to a substantial reduction in the overall waste quantities requiring final disposal, which can be better managed for safe disposal while meeting the pollution control standards [3].

There are hundreds of different types of gasifiers in the patent which can be divided into two principal types such as fixed bed gasifiers and fluidized bed gasifiers, with variations within each type [4]. The gasification technology to use MSW as fuel has developed rapidly, one of which is applied to a fluidized bed (FB) gasification in which more efficient than other conventional technology. FB technology has been proven as an effective way to convert various wastes into clean energy. Syngas produced from the gasification process in the FB system is a profitable alternative fuel because of its relatively low cost, high efficiency, and a wide variety of syngas applications can be used [5,6].

The most important factor in FB gasification process is an agent gasification which is not only to speed the syngas production but also to increase the quantity and quality of syngas. However, for practical use of this gasification agent is that the gasification process becomes allothermal, which is characterized by the separation of the processes of heat production and heat consumption [7]. A solution for the external introduction of the heat for gasification at an industrial scale can be provided by dual reactor of fluidized bed (DRFB). The dual reactor consists of a combustion and a gasification reactor which is connected in a loop by an intermediate bed material. The combination of bubbling bed and high-velocity circulating bed (riser) ensures the solids movement between the beds [8]. Also, this combination ensures higher fuel residence time for slow gasification and tar reforming reactions compared to the combination where combustion takes place in bubbling bed and gasification in riser. This bed material has a very important role where the combustion reactor is useful for absorbing heat from the combustion which then circulates in the gasification reactor to carry out the endothermic process to produce syngas. The rest of the fuel that has not been converted to gas is then circulated to the combustion reactor and so on.

The performance of the gasification system in DRFB can be improved by the addition of gas gasification agents. Research on two types of steam gasification technic namely high temperature steam and solar assisted steam gasification, results increasing the efficiency [9]. The hydrogen (H_2) gas produced was found to increase by using steam (H_2O), oxygen (O_2), oxygen-enriched air and air as a gasification agent [10]. The CO_2 - O_2 agent gasification from bitumen coal on circulating fluidized bed (CFB) has been investigated and produces an increase in $CO+H_2$ concentrations, product gas calorific value, carbon conversion and cold gas efficiency [11]. Adding CO_2 gas to the gasification agent in a pressurized fluidized reactor can increase CO yield per unit mass of raw material, which makes it possible to reduce oxygen demand from the process [12]. Increased CO_2 content has an effect on the reduction level of CO_2 gasification process, while the increase in O_2 content, oxidation value, the level of reduction of CO_2 gasification on oxidation, and the rate of carbon conversion increases [13]. Research and modeling of fluidized bed gasification systems using MSW as fuel have been extensively studied in order to produce clean energy sourced from waste [14-17]. The addition of a gasification agent is later expected to help improve the efficiency of gasification and syngas production produced from the DRFB system. For the purpose to increase the gasification performance of the DRFB system, this study is conducted comprehensively on variation of gasification agent.

METHODELOGY

This research was conducted using a dual reactor of fluidized bed (DRFB) unit as shown in Figure 1. The reactor is made of stainless-steel schedule, SS 304 which can withstand the conditioned temperature. The gasification reactor (reactor 1) has a diameter size of 15.2 cm and the combustion reactor (reactor 2) has a diameter size of 5.1 cm with a height of 100 cm and 150 cm respectively. At the top end of the combustion reactor there is a solid separator which functions to separate solids and gases while also helping the solid materials to circulate to the gasifier. This separator has a large size

of 15.2. cm in diameter, so that the remaining unburned fuel is circulated again until the fuel is optimally converted. The DRFB unit is equipped with a safety system to maintain a positive pressure in the form of a water filled tube. The fuel feeder is located in the upper side of gasifier reactor in order to maintain the fulfillment of the fuel. In the combustion reactor, eight (8) pressure gauges and ten (10) thermocouples are installed to see the pressure and temperature horizontal distribution while four (4) pressure gauges and four (4) thermocouples are installed in the gasification reactor. Each reactor is equipped with a thermostat which is used to control the operation temperature. In this study, gasification agent of H_2O , CO_2 and O_2 were injected from the bottom of gasification reactor to reach a maximum reaction distribution along vertical direction. at a variation of the flow rate of 50 mL/m, 100 mL/m, 150 mL/m and with no addition of a gasification agent (NA) for comparison.

Figure 1: Schematic of the DRFB Gasifier Unit

RESULT AND DISCUSSIONS

Characteristic of MSW Fuel

In this study, municipal solid waste (MSW) from the town of Denpasar city has previously been treated undersize of 0.5 mm with a content of 95% organic and 5% inorganic, weighing 600 grams per test. The bed material as a heat carrier between the reactors was quartz sand (99.4-99.9% SiO_2) having the particle density of 2.18 gr/cm^3 and a small specific heat of $0.20 \text{ cal/gram}^\circ\text{C}$ with a size of between 0.4 mm to 0.5 mm [18,19]. The photo of MSW feed stock and bed material quartz sand is found from Figure 2. In order to smoothen the circulation, a moisture of MSW is conditioned under 10% as seen in Table 1.

Figure 2: Photo of dried MSW (left) and bed material of quartz sand (right)

The characteristics of MSW can be known after conducting several tests such as proximate, ultimate, and caloric value analysis. The proximate analysis test was carried out using a thermogravimetric analyzer (TGA 701, Leco) unit to determine the physical property content of MSW which includes fixed carbon (FC), volatile matter (VM), moisture (M), and ash (A). balance Leco TGA-701, according to CEN/TS14774-14775.

Figure 3: TGA diagram test for MSW in nitrogen flow rate

The technical test from TGA analysis were performed with a flow of nitrogen of 3.5 L/min, to reproduce the conditions of the pyrolysis process. The sample was put in a ceramic crucible covered from top and heated from ambient temperature to 750°C for about 340 minutes. The amount of the sample used in this study was 1.0 g. The experimental data as mass change, operation time and furnace temperature of MSW sample were recorded as seen in Figure 3. In the early stages of the pyrolysis process occurs slowly due to a small loss of mass. Furthermore, with the increase in temperature, the mass loss of MSW increases rapidly. This occurs due to chemical reactions that release tar and volatile products. The data analysis can be performed in Table 1.

The ultimate analysis was performed using a Leco TruSpec CHNO analyzer, according to ASTM D5373 which aims to determine the chemical elements of MSW such as of Carbon (C), Hydrogen (H), Oxygen (O) Nitrogen (N), and Sulfur (S). Furthermore, the MSW calorific value (CV) test was carried out using a bomb calorimeter of Parr Instrument 6400 according to ASTM D240, to determine the amount of heat released in the complete combustion of a material. From the summary results in Table 1, it is shown that MSW has a high VM content of 79.81% with Carbon content of 64.46%. The calorie meter value for the sample of MSW has been tested at high of 16.083 MJ/kg.

Table 1: Property of MSW consisted of proximate, ultimate and calorific analysis on dry base (db)

Proximate Analysis	Carbon (C)	vol.-% _{db}	64.46
	Hydrogen (H)	vol.-% _{db}	11.50
	Oxygen (O)	vol.-% _{db}	18.03
	Nitrogen (N)	vol.-% _{db}	0.52
	Sulfur (S)	vol.-% _{db}	0.05
Ultimate Analysis	Fixed Carbon (FC)	vol.-% _{db}	3.38
	Volatile Matter (VM)	vol.-% _{db}	79.81
	Moisture (M)	vol.-% _{db}	8.65
	Ash (A)	vol.-% _{db}	8.16
Calorific Value	CV	kJ/kg	16.083

Syngas Production

Figure 2 below shows the relationship between the effects of 3 types of gasification agents such as H₂O, CO₂ and O₂, with varying flow rates of 50, 100, 150 mL/m and NA (no addition) agent to syngas concentrations (CO, H₂ and CH₄). Based on the graph, it is obtained an increase in the value of syngas concentration for each increase in the rate of volume of agent gas. The addition of CO₂ and H₂O gasification agents more dominantly increases syngas production compared to O₂ and it is also seen that the addition of H₂O provides a greater value than the addition of CO₂ and O₂ agent gases. The highest syngas production of CO and H₂ was at a flow rate of 150 mL/min with a composition of 15.048% CO and 12.046% H₂.

The addition of H₂O gasification agent into the reactor triggers a char reforming reaction ($C + H_2O \rightarrow H_2 + CO$), a water gas shift reaction ($CO + H_2O \rightarrow CO_2 + H_2$) which produces more H₂ gas (13.192%) than other gasification agents of 11.002% and 9.646% for CO₂ and O₂ agents respectively. In line with the use of high temperature gasification agents, steam (H₂O) is the best choice of agent that can produce more H₂ gas [9,10]. It has also been reported that the heat content of H₂ syngas is greater when using steam than air [20]. The addition of a gasification agent also causes a significant increase in CH₄ syngas compared to using only air (NA). This increase was obtained from the methane cracking reaction ($C + 2H_2 \rightarrow CH_4$) due to the emergence of H₂ from the MSW fuel. However, the addition of H₂O allows a decrease in CH₄ if the methane reforming reaction ($CH_4 + H_2O \rightarrow 3H_2 + CO$) occurs.

The addition of O₂ gasification agent has a pattern similar to that of H₂O and CO₂ agent, where the syngas production of CO and H₂ has increased and the highest concentrations occur at flow rates of 100 mL/min at 9.433% and 9.726% respectively. This additional oxidation reaction ($C + O_2 \rightarrow CO_2$) produces more CO₂ which then reacts with MSW fuel and results in an increase in syngas CO through the Boudouard reaction ($C + CO_2 \rightarrow 2CO$). Meanwhile, if the flow rate is added to 150 mL / m, syngas production actually decreases slightly. The decrease in the amount of syngas at the O₂ flow rate due to excessive O₂ agents triggers a complete combustion in which O₂ gas reacts with fuel to help the oxidation reaction so that the oxidation gas in the form of CO₂ tends to pass through the gas output without having time to react with the fuel carbon.

Figure 4: The concentration of syngas CO (a), H₂ (b) and CH₄ (c) at variation of gas agent at different flow rate

Cold Gas Efficiency

Cold gas efficiency is defined as the ratio between the chemical energy produced by syngas which is obtained by multiplying the mass flow rate with the lower heating value of the gas with the chemical energy from the fuel obtained by multiplying the mass flow rate of MSW with the lower heating value of MSW [9]. Based on MSW test data and syngas flow rate measurements at the time of testing, the cold gasification efficiency (η_g) can be found in the following ways:

$$\eta_g = \frac{\text{flow rate of syngas} \times \text{LHV syngas}}{\text{MSW mass flowrate} \times \text{LHV}} \times 100\%$$

As seen from Figure 3 below, for the addition of H₂O and CO₂ gas agents a higher efficiency was obtained at a flow rate of 15 mL / m at a value of 52.76% and 51.51% respectively. This is because the syngas with the addition of the gasification agent has the highest value which then results in higher LHV. The increase in the agent gas flow rate from 100 to 150 mL/min was smaller than the increase in efficiency from 50 to 100 mL/min as for 4.2% and 1.3%, respectively. This shows that an increase in the amount of gasification agent does not lead to an increase in efficiency linearly but will decrease at a certain point.

Figure 3: Cold gas efficiency at different flow rate of gas agent

However, with the addition of O₂ gasification agent the highest efficiency was obtained at a flow rate of 100 mL/min at 38.99%, then decreased at a flow rate of 150 mL/min. Increasing the flow rate from 100 to 150 mL/min does not cause an increase in efficiency because more oxidation reactions occur than reduction processes so that the syngas yield is lower. It can also be seen that the addition of O₂ gasification agent gives a lower efficiency value compared to other agents but better than NA gasification.

CONCLUSIONS

The research has demonstrated the effect of flow rate variations of gasification agents on the performance of dual reactor of fluidized bed (DRFB) gasifier. Based on a series experiment using MSW as fuel, it can be concluded that:

- The addition of H₂O and CO₂ gasification agents more dominantly increases syngas production compared to O₂ agent and it is also seen that the addition of H₂O provides a greater value than the addition of CO₂ and O₂ agent gases. The addition of O₂ gasification agent has a pattern similar to that of H₂O and CO₂ agent but the higher flowrate of the agent did no cause the higher syngas concentrations. The water gas shift and the Boudouard reaction have more dominantly effect than other reactions.
- The highest efficiency is also found by the addition of H₂O and CO₂ gas at a flow rate of 150 mL/min. The addition of O₂ gasification agent shows a lower efficiency value compared to other agents.

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