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Research Paper

Comparative Study of Municipal Solid Waste Fuel and Refuse Derived Fuel in the Gasification Process Using Multi Stage Downdraft Gasifier

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Abstract

Municipal solid waste (MSW) is a type of general waste that includes households, traditional markets, commercial areas, and the rest from public facilities, schools, offices, roads, and so on. Refuse Derived Fuel (RDF) is obtained from the remnants of MSW which cannot be used anymore, which is flammable waste and is separated from parts that are difficult to burn through the process of chopping, sifting, and air classification. RDF has potential as an alternative energy source. In this study, RDF fuel was compared with MSW fuel both by proximate and calorific value, then the gasification process was carried out using a multi-stage downdraft gasifier to see gasification performance indicators such as syngas composition, LHV, cold gas efficiency, and tar concentration. The results showed that the gasification performance indicator for MSW biomass resulted in the syngas composition of CO = 19.08% v, H_2 = 10.89% v, and CH_4 = 1.54% v. The calorific value (Low Heating Value, LHV) of syngas is 4,137 kJ/kg, cold gas efficiency is 70.14%, and tar content is 57.29 mg/Nm^3. Meanwhile, RDF obtained the composition of CO gas: 18.68% v, H_2: 9.5446% v, and CH_4: 0% v. The maximum LHV syngas is 3365.08 kJ/kg, cold gas efficiency is 57.19 % and the smallest tar content is 80.24 mg/Nm^3. When compared to RDF, MSW produces a better gasification performance indicator. However, RDF can still be used as an alternative energy source using the gasification process. The results of this study can be used to optimize the further RDF gasification process.

Keywords: MSW; RDF; Gasification; Downdraft gasifier; Syngas.

Abstrak

Sampah kota (MSW) adalah jenis sampah umum yang meliputi rumah tangga, pasar tradisional, kawasan komersial, dan sisanya dari fasilitas umum, sekolah, perkantoran, jalan, dan sebagainya. Refuse Derived Fuel (RDF) diperoleh dari sisa-sisa MSW yang sudah tidak dapat digunakan lagi yaitu limbah yang mudah terbakar dan dipisahkan dari bagian yang sulit terbakar melalui proses pencacahan, pengayakan, dan klasifikasi udara. RDF berpotensi sebagai sumber energi alternatif. Pada penelitian ini bahan bakar RDF dibandingkan dengan bahan bakar MSW baik secara proksimat maupun nilai kalor, kemudian dilakukan proses gasifikasi menggunakan multi stage downdraft gasifier untuk melihat indikator performansi gasifikasi seperti komposisi syngas, LHV, efisiensi gas dingin, dan konsentrasi tar. Hasil penelitian menunjukkan bahwa indikator unjuk kerja gasifikasi biomassa MSW menghasilkan komposisi syngas CO = 19,08% v, H_2 = 10,89% v, dan CH_4 = 1,.54% v. Nilai kalor (Low Heating Value, LHV) syngas adalah 4,137 kJ/kg, efisiensi gas dingin 70,14%, dan kandungan tar 57,29 mg/Nm^3. Sedangkan RDF diperoleh komposisi gas CO: 18.68% v, H2: 9.5446% v, dan CH4: 0% v. LHV syngas maksimum 3365.08 kJ/kg, efisiensi cold gas 57.19% dan kandungan tar terkecil 80.24 mg/Nm^3. Jika dibandingkan dengan RDF, MSW menghasilkan indikator kinerja gasifikasi yang lebih baik. Namun demikian, RDF tetap dapat digunakan sebagai sumber energi alternatif melalui proses gasifikasi. Hasil penelitian ini dapat digunakan untuk mengoptimalkan proses gasifikasi RDF selanjutnya.

Kata kunci: MSW; RDF; Gasifikasi; Gasifier downdraft; Syngas.

1. Introduction

In 2016, the results of the population census in Indonesia reported that Indonesia was the fifth largest country in the world with a population growth of 26.1 million. This population growth is not matched by good waste management, causing social and environmental problems, such as municipal solid waste [1], cooking oil waste [2], rubber [3], and plastic waste [4]. As much as 69 % of the waste is only piled up in landfills and the remaining 10% is just piled up without further processing. Refused Derived Fuel (RDF) is a product of processing Municipal Solid Waste (MSW) which is flammable and is separated from parts that are difficult to burn through the process of counting, sieving and air classification [5]. To produce RDF, waste must first be chopped and then carefully sorted to remove all non-combustible materials such as glass, metal and plastic [6]. Thus a technological breakthrough is needed to deal with these problems.

One of the technologies that can be used to convert biomass into alternative energy without producing emissions is gasification [7]. Gasification is the process of converting solid or liquid raw materials into gas thermochemically [8]. The gasification process consists of several successive stages, namely the drying, pyrolysis, partial oxidation, and reduction stages. Gasification requires a medium such as air, oxygen or water vapor. The gas produced from the gasification process or what is commonly called synthetic gas (syngas) consists of combustible syngas (CO, H_2, and CH_4) and non-combustible gases (remaining CO_2, N_2, and O_2). One type of gasifier that is widely used is downdraft. Downdraft gasifier has the advantages of high carbon conversion rates, low tar production, and simple construction compared to other types [9]. Air, generally used as a gasifying agent, is only entered into the partial oxidation zone. However, based on several recent studies, the addition of air intake in the pyrolysis and reduction zones can affect the increase in gasification performance [10].

The addition of an ash sweeping mechanism so that the residue removal process can run more smoothly so that a more stable temperature will be achieved in each gasification zone and get good syngas quality [11]. The result of syngas production which is inhibited by ash in the reactor will decrease the quality of the syngas, especially CO and H_2 compounds. This is because the two compounds will react/oxidize again in the oxidation zone or the reduction zone to form CO_2 and H_2O compounds. [12], modified a single bed downdraft type reactor by adding a fin-shaped sweeper made of Round Bar AISI 310s (heat resistant), which is heat resistant stainless steel on a scale of 1100-1250 °C. From the research, it was explained that the addition of an ash sweeper was able to maximize the removal of ash under the reactor with a residual discharge rate of 0.45 gram/s.

Via biomass gasification, the development of 2nd generation bio-automotive fuels, such as synthetic fuels like methanol, ethanol, DME, FT-diesel, SNG, and hydrogen, appears to be promising. Synthetic fuel processing technology is well developed and focused on fossil fuels. However, biomass is a relatively new technology, and the technology is still being developed. Syngas processing is highlighted, implying a gasifier design that is appropriate for high-quality syngas production. The development of syngas from biomass is widely recognized as a key platform for 2nd generation automotive biofuels. Aside from gas fuel or gas biomass gas products for power generation, syngas is characterized by two chemical components: CO and H_2, with the unwanted CH_4 component present in the gas at 5% to 10%. The application of syngas to transportation in the form of synthetic liquid fuels has progressed well. Syngas fuels are a commercially viable fossil-based technology [13].

SNG, EtOH (bioethanol), MeOH (biomethanol), biogas, RME (rapeseed oil biodiesel), H_2, DME, and FTD (FT-diesel) can all be made from biomass gas. The question is, which fuel would be the most appropriate for incorporation into the transportation industry. Biomass-based transportation fuels should be assessed against four criteria before being introduced to the fossil-fuel transportation market on a wide scale: quality, economy, environmental impact, and end use. In tropical developing countries, first-generation bio-automotive fuels including bioethanol and biodiesel derived from food crops will continue to be the preferred fuels. Methanol, ethanol, DME, FT-diesel, SNG, and hydrogen are examples of 2nd generation bio-automotive synthetic fuels (BTS) derived from forest and agricultural gas. In the transportation market of industrialized countries, biomass residue is poised to make a breakthrough, especially in countries with a strong forest industry [13].

Experimental studies regarding the effect of pyrolysis, oxidation and reduction air ratios on the performance of the gasification process with MSW pellet raw materials have been carried out [14]. There are six variations in the ratio of air (AR) entering the reactor, namely 0: 10: 0, 1: 8: 1, 2: 7: 1, 1: 6: 3, 2: 6: 2, 3: 6: 1 with a constant ER of 0.4. The results of this study indicate that the AR 1: 8: 1 variation is the optimum variation. At the optimum variation, the composition of combustible gas CO, H_2, and CH_4 is 19.08 vol%, 10.89% vol and 1.54 vol%, respectively. Then, cold gas efficiency and tar content are valued at 70% and 57.9 mg/Nm^3, respectively. All the results of these studies indicate that multi-stage intake air can improve the performance of the gasification process. Experimental research on gasification using a multistage downdraft gasifier with RDF as raw material has not been carried out. So that in this study RDF is used as raw material for multistage downdraft gasification.

In this study, RDF fuel is compared with MSW fuel both by proximate test and calorific value then the gasification process is carried out using a multi-stage downdraft gasifier which has been carried out by Saleh, et al. [14], to see gasification performance indicators such as composition syngas, LHV, chilled gas efficiency, and tar concentration. The results of this study can be used to optimize the further RDF gasification process.

2. Method

2.1. *Material*

RDF briquettes are MSW that have undergone sieving, filtering, and separation with a percentage of 60% and 40% organic and inorganic materials. Metals and inerts are removed, while light fractions with high heating values (plastics, textiles, and paper) remain. RDF biomass is then briquered to have a higher density and lower moisture. Before being used, biomass is analyzed first by proximate analysis and heating value. The following are the results of the MSW and RDF analysis as presented in **Table 1**.

2.2. *Instrument Configuration*

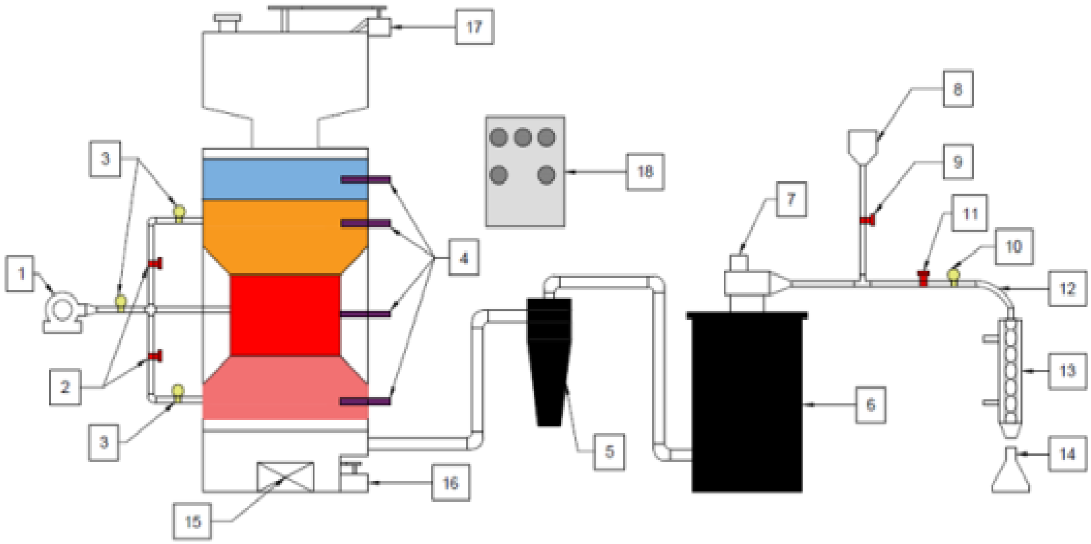
The experimental reactor used a downdraft gasifier with a reactor length of 90 cm. The modified reactor uses three stages of air intake with each air inlet being placed into the pyrolysis, oxidation, and reduction zones. Configuration of the experimental instrument was showed in Figure 1.

2.3. *Experimental procedure*

RDF briquettes are prepared in advance with the intention of increasing their density and reducing their moisture content. The blower is operated and the amount of air is adjusted for each zonebased air-ratio (AR) with the total air according to ER 0.4. The air intake ratio is varied using a valve attached to the pipe. The amount of air in each pipe is measured using a manometer, which is used as a reference for data variation. The variation used is the air-ratio (AR) which shows the ratio between the valve openings in the pyrolysis, oxidation, and reduction zones. In this study, nine variations of AR were used, namely the variations of each pyrolysis: oxidation: reduction as follows, 0: 10: 0 (1); 1: 8: 1 (2) ; 2: 7: 1 (3) ; 1: 7: 2 (4); 1: 6: 3 (5); 2: 6: 2 (6); 3: 6: 1 (7) , 2: 5: 3 (8); and 3: 5: 2 (9). For example, 1: 7: 2 represents 10% of the total mass of air entering the pyrolysis zone, 70% in the oxidation zone, 20% in the reduction zone, and so on.

Table 1. Characteristics of MSW and RDF

Analysis	Contents	MSW	RDF
		% Mass	% Mass
Proximate	Fixed carbon	14.16	15.1
	Volatile	77.76	54.23
	Moisture	2.36	3.25
	Ash	5.94	27.42
High heating value (kJ/kg)		15.149	
Heating value (kal/gr)			5.293



1	Force draft fan, supply gasifier agent	10	Pitot tube
2	Inlet valves, controlling air flow	11	Syngas valve, controlling syngas
3	Pitot tubes, measure pressure differintial	12	Sample tube, gas sampling tube
4	Thermocouples, temperature sensor	13	Tar sampling set
5	Cyclone, dask collector	14	Tar container, collecting tar
6	Dry filter, syngas filter	15	Ash box
7	Induced draft Fan, pulling syngas	16	Ash sweeper motor, ash transport
8	Flare stack, syngas flare	17	Hopper motor, controlling feed stock
9	Stack valve, controlling syngas	18	Control Panel and Temperature logger

Figure 1. Configuration of the experimental instrument

The gasification process begins by entering the biomass into the reactor until it is full. Then it is ignited using a burner by passing an inlet in the oxidation zone until the biomass inside the rector is burned. The ID fan is operated to extract gas from the gasifier. After the oxidation temperature is above 600 ° C, the syngas at the flare point is ignited, which means that when it is burned, the syngas can be used. Grate sweepers and ash/charcoal screw conveyors are actuated. After the syngas burns and all temperature distributions in the drying, pyrolysis, oxidation and reduction zones are in a stable state, the tar and gas samples are collected. Gasifier temperature measurement uses a type K thermocouple in the drying, pyrolysis, oxidation, and reduction zones.

3. Results and Discussion

3.1. Syngas composition

Syngas consists of two chemical components, flammable and non-flammable components. The flammable components consist of CO, H_2, and CH_4, while the non-flammable components mainly consist of CO_2, N_2, and O_2. These components are categorized based on their calorific value. The flammable component has a heating value, while the non-flammable component has no heating value. **Figure 2** shows the volumetric percentage of the chemical components contained in the syngas produced.

In the pyrolysis zone, where usually thermal decomposition reactions occur in the absence of air, when air enters the zone, partial oxidation occurs, producing heat, and additional CO gas composition. With the addition of heat, the temperature increases, which increases the thermal decomposition reaction, thereby increasing the composition of the volatile gases. Higher temperatures also increase the rate of charcoal conversion reaction, increase gas production, and reduce char production. The tar decomposition reaction is also better at higher temperatures, reducing the tar content, which will improve syngas quality.

Variation 1: 7: 2 has the greatest CO composition and has a high enough H_2. However, all the variations in the composition of CH4 are so small that they cannot be read on gas chromatography tools. This is in accordance with

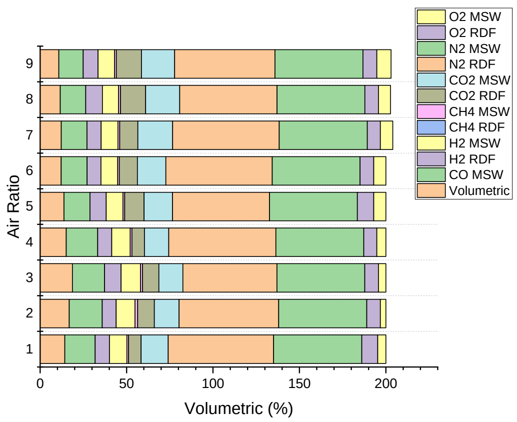


Figure 2. Syngas Composition

research conducted by Haydary [15], where when using ER more than 0.35 the value of CH_4 will be close tozero. The addition of the flammable composition shows that the addition of air in the reduction zone and pyrolysis zone causes a partial oxidation reaction which increases the rate of biomass conversion. However, after 1: 6: 3 variation, the flammable composition began to decline. In an oxidative state, oxygen tends to react with char, causing partial oxidation which produces CO which can increase the calorific value of syngas because CO is a flammable component.

In the reduction zone, a syngas formation reaction occurs to form other types of flammable gases, H_2 and CH_4. In the oxidative state, partial oxidation occurs, which generates heat, increasing the zone temperature as seen in the temperature profile data, especially when the intake air is high. Increasing the temperature is favorable for tar breakdown reactions, but also favorable for endothermal gasification reactions, such as the Boudouard and Water-Gas reactions, which is why the CO and H_2 compositions peaked during the peak temperatures of the reduction zone. Although in some variations it does not seem so, for example, variation AR 1; 7; 2 and 2; 7; 1 has almost the same temperature reduction zone, but the two have very different amounts of combustible composition. This suggests that the flammable composition can be affected by other factors, such as temperature of other zones, or external factors, such as heat loss, and uneven distribution of oxidants.

The composition of N_2 tends to consistently have a volumetric percentage above 50% for each variation. This happens because N_2 has a high percentage of air in the atmosphere, around 78%, besides N_2 is a gas that cannot react with other chemical components, so its volumetric percentage tends to be constant.

The CH_4 content in all variations is very low due to high temperatures making endothermal reactions more dominant in the reduction zone, rather than the formation of CH_4 (methanation) reactions.

3.2. *Low Heating Value (LHV)*

Low Heating Value (LHV) for syngas is influenced by its composition, because each component of the flammable gas has its own. As shown in **Figure 3**, LHV starts to increase from 0 : 10 : 0 AR until the peak of LHV is reached at 1 : 7 : 2 AR variation is 3365.08 kJ/kg, then continues to decrease in the last variation with the lowest LHV is reached at 2 : 5 : 3 AR is 2187.73 kJ/kg. This figure corresponds to the change in the operating temperature graph, which means that the temperature significantly affects the gasification reaction which directly affects the syngas composition and the final calorific value.

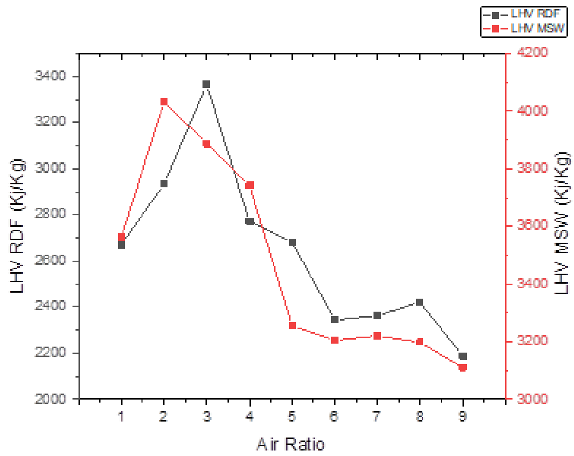


Figure 3. LHV Syngas

3.3. *Cold gas efficiency*

The Cold Gas Efficiency is a measure of efficiency using energy input rather than potential energy output. **Figure 4** shows that increasing the amount of air entering the pyrolysis and reduction zone can increase the efficiency of cold gas from 43.517% at variation 0 : 10 : 0 to the highest efficiency of 57.896% in variations 1 : 7 : 2. Whereas in the last variation the Efficiency of Cold Gas decreases due to an increase in the combustion reaction stimulated by an increase in the concentration of oxidants in the pyrolysis and reduction zone, as stated in the previous section, which reduces the flammable syngas content. The cold gas efficiency is influenced by many factors, especially syngas composition, LHV, syngas mass flow, biomass mass flow, and biomass LHV.

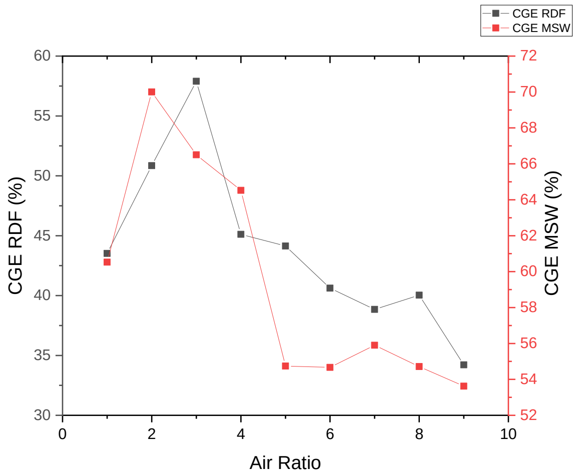


Figure 4. Cold Gas Efficiency

3.4. *Tar content*

Tar content is the amount of tar contained in a given volume of syngas. As shown in **Figure 5**, the highest tar content was produced at the AR variation 0 : 10 : 0 with 154.01 mg/Nm³, while the lowest tar content was achieved at 1 : 8 : 1 AR, with 80.24 mg/Nm³. When compared with temperature data, this result is in theory, because the tar breaking process starts at 500 °C , and the higher the temperature in the gasifier, the more active the tar breaking reaction that occurs. Primary tar begins to crack at about 500 °C, secondary tar at 600 °C, while tertiary tar begins to crack at 800 °C. Since 1: 8: 1 variation has the highest pyrolysis temperature, the tar can be cracked so that its tar content is the lowest among all variants.

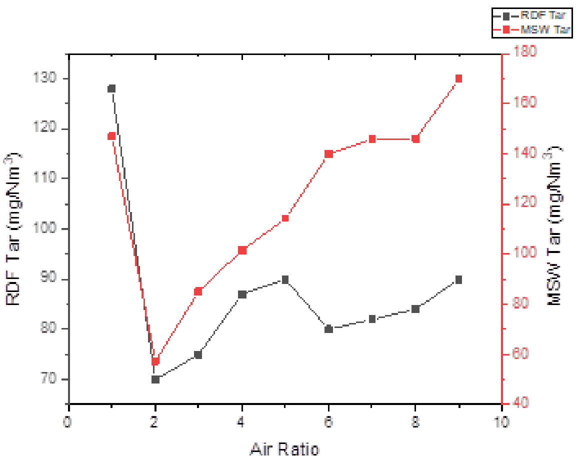


Figure 5. Tar content

While in variation 1 : 7 : 2 has the highest oxidation zone temperature of 850,25 °C, but the tar from other zones is thought to have not completely cracked. Whereas the 0 : 10 : 0 variation has the lowest pyrolysis temperature at 425.5 °C. This causes a high tar content in the AR 0 : 10 : 0 variation. Judging from the tar content in this study, the variation 0 : 10 : 0; 2 : 5 : 3; 2 : 7 : 1; 1: 6: 3, and 3: 5: 2 which cannot be used because the combustion motor in the maximum limit is 100 mg/Nm³ [8].

4. Conclusion

The results of the study show that the best indicator of RDF biomass gasification performance is the composition of CO gas: 18.68% v, H2: 9.5446% v, and CH4: 0% v. The maximum LHV syngas is 3365.08 kJ/kg, Cold gas efficiency is 57.19% and the smallest tar content is 80.24 mg/Nm³. This is obtained in AR 1 : 7 : 2. The results showed that the best gasification performance indicator for MSW biomass was the syngas composition of CO = 19.08% v, H2 = 10.89% v, and CH4 = 1.54% v. The calorific value (LHV) of syngas is 4,137 kJ/kg, cold gas efficiency is 70.14%, and the tar content is 57.29 mg/Nm³. This happened in AR 1: 8: 1. Meanwhile, when compared to RDF, MSW produces a better gasification performance indicator.

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Author's Declaration

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

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Availability of data and materials

All data are available from the authors.

Competing interests

The authors declare no competing interest.

Additional information

No additional information from the authors.

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