Study on potency of municipal solid waste conversion into renewable energy by thermal incineration and bioconversion: case study of Medan city

To cite this article: Maya Sarah and Erni Misran 2018 IOP Conf. Ser.: Earth Environ. Sci. 126 012130

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Study on potency of municipal solid waste conversion into renewable energy by thermal incineration and bioconversion: case study of Medan city

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Abstract. Municipal solid waste (MSW) in Medan City is facing problems either with the quantity and management of MSW. Local authority only dumped approximately 73.9% MSW in the landfill over the years. Spontaneous phenomena of methane formation in dumping site indicates the potency of MSW conversion into energy by biochemical conversion. On the contrary, the presence of plastics, woods, papers, etc. in the MSW show the potency of MSW to be treated by thermal conversion. Both thermal incineration and anaerobic digestion may convert MSW Medan City into energy. This study evaluates potency of MSW conversion into renewable energy using proximate and ultimate analysis. Overall, MSW of Medan City has the opportunities to be converted into energy by both thermal and biochemical conversion with a special requirement such as pre-dry the MSW prior incineration process and degrade organic MSW in a bioreactor.

1. Introduction
Medan is the capital city of North Sumatera Province covers an area of approximately 265.10 km² with 21 Districts. As the 3rd largest cities in Indonesia with a total population of 2.2 million, Medan is facing several social problems [1]. Municipal solid waste (MSW) management is crucial issue in Medan. Total daily MSW in Medan is approximately 1,975 ton in average but only 73.9% of total MSW is taken to the landfill [2]. Nowadays the only Landfill of Terjun operated to receive MSW from Medan after Landfill of Namo Bintang closed several years ago. Landfill of Terjun covers areas of approximately 14 Ha locates at Terjun Village District of Medan Marelan. Open dumping treatment in Landfill of Terjun is far from effective because it utilizes several heavy types of equipment, requires transportation inside the landfill area [2]. Other disadvantages of open dumping treatment are pollution on the surface area by rain off, land and ground water, and emits 30 to 40% of methane from open dumping treatment release directly into the atmosphere which contributes to global warming.

MSW in Medan originally come from daily activities such as households, restaurants, fresh/traditional markets, industries, tradings, constructions, etc. Fig 1 shows the average composition of MSW in Landfill of Terjun. Overall, organic waste (77.3%) and plastic (8.56%) dominate MSW composition in Medan. Others MSW component are papers, metals, woods, diapers, linens, etc. [3]. Fundamentally, MSW conversion into energy carries out by several processes such as incineration or pyrolysis, anaerobic digestion and sanitary landfill [4]. Refer to MSW compositions and existing
conditions, incineration and anaerobic digestion are proposed to study. High organic content in MSW indicates the potency of MSW to be converted into energy by anaerobic digestion, while plastic, paper and linen in MSW show opportunities to use MSW as fuel in incineration and pyrolysis to produce thermal heat.

![Figure 1. Average daily MSW composition in Landfill of Terjun [3]](image)

2. Methods
This study investigates potency of MSW conversion into energy by thermal process and bioconversion (anaerobic digestion) process. This study carried out investigation in both landfill and laboratory. Waste collection (sampling) and sample preparation (characterization of waste and size reduction) were carried out in the landfill while proximate and ultimate analysis conducted in the laboratory.

2.1. Sampling of MSW at the landfill or dump site
Fresh MSWs taken from various places in Medan were dumped in the landfill and mixed several times by an excavator. The mixed MSW were lifted by the excavator, put it in the small dump truck and weighed 200 kg by weight bridge. The MSW sampling was carried out for three days, each conducted in triplicates [5].

2.2. Sample preparation
MSW sample was put in the roofed dry place, spread, and separated into 4 piles of MSW (each weight of 50 kg). Two of fourth parts of MSW were sorted and mixed into smaller MSW pile. Repeated this procedure until 25 kg of sorted MSW sample obtained. The sample was then reduced using crusher, and dried under the sun. The dried sample put into the container and sent for proximate and ultimate tests [5].

2.3. Proximate and ultimate test
Proximate analysis in this study consist of determination of moisture content, fixed carbon, volatile matters and residue. We also determined parameters such as carbon, nitrogen, sulfate, ash and chlor content by ultimate analysis method. Ash analysis carried out to determine parameters of SiO₂, Al₂O₃, Fe₂O₃, CaO, MgO, SO₃, P₂O₅, K₂O and Na₂O in MSW. Methods for the proximate and the ultimate analysis in this study are shown in Table 1.

3. Results and Discussions
This study observed the fresh MSW entering the landfill from 21 Districts with average bulk density ranged between 352 to 408 kg/m³ [5]. Discussion on potency of MSW conversion into energy by thermal and biochemical conversion describe comprehensively in section 3.1 and 3.2.
Table 1. Methods for the proximate and the ultimate analysis in this study [5]

| Parameters       | Units | Methods                        |
|------------------|-------|--------------------------------|
| Water            | %     | Xylol distilation              |
| Ash              | %     | AOCS Ca 11-55                  |
| Oil              | %     | MPOB kl.3.2004                 |
| Carbohydrate     | %     | Volumetric                     |
| Fibers           | %     | SNI 01.0008.1987               |
| Protein          | %     | Volumetric                     |
| SiO<sub>2</sub>  | %     | Gravimetry                     |
| Cl               | %     | Chlorimetre                    |
| Al<sub>2</sub>O<sub>3</sub> | % | Spectrofotometry               |
| Total moisture   | %     | Spectrofotometry               |
| Fe<sub>2</sub>O<sub>3</sub> | % | AAS                            |
| CaO              | %     | AAS                            |
| MgO              | %     | AAS                            |
| P<sub>2</sub>O<sub>5</sub> | ppm | Spectrofotometry               |
| K<sub>2</sub>O    | %     | AAS                            |
| Na               | ppm   | AAS                            |
| Ni               | %     | Volumetric                     |
| S                | %     | Gravimetry                     |
| C                | %     | Gravimetry                     |

3.1. Thermal conversion of MSW

Proximate analysis provides initial information needed to determine caloric value of MSW. This caloric value indicates commercial potency of MSW to be converted into biogas by incineration and/or pyrolysis. Proximate and ultimate results from MSW sample during this study are shown in Fig 2 to Fig 6. Fig 3 shows content of fixed C (FC) and volatile matter (VM) used to estimate fuel quality that expresses as fuel ratio. Proximate analysis shows high ratio of FC to VM between 6 to 10 which indicates high portion of unburned C in MSW. Fundamentaly, FC/VM ratio exceed 1.2 causes ineffective burning process and decrease burning rate.

Ash content as depicted in Fig 2 expresses fly ash of approximately 80% which emitted with fuel gas through the burning chamber. High fly ash causes fouling and corrosion in equipments. Ratio of FC to water and moisture in MSW ranged between 0.209 to 0.325 and 0.204 to 0.315 respectively. This ratio indicates high water and moisture content should be considered before MSW is converted into thermal energy and/or electricity by incineration process. Caloric value of MSW varied from 6900 to 11400 kJ/kg as shown in Fig 3. This caloric value quite similar with caloric value of MSW in China that ranged between 2000 and 14000 kJ/kg [6].

Other consideration of MSW conversion by incineration is air pollution that emits dioxin, NO<sub>x</sub> and SO<sub>x</sub> into the atmosphere. Contents of Cl, N and S in the MSW as depicted in Fig 4 indicates the presence of dioxin, NO<sub>x</sub> and SO<sub>x</sub> in the atmosphere during incineration process. The estimated NO<sub>x</sub> and SO<sub>x</sub> contents in this study are varied depends on the fresh MSW composition per day. Refering to Indonesia standard for emission of Thermal Power Generator, the predicted emission of NO<sub>x</sub> and SO<sub>x</sub> in this study were lower as compared to threshold value (NO<sub>x</sub>= 50 ppm and SO<sub>x</sub>=170 ppm). On the contrary, dioxin emission somehow higher (dioxin emission standard according to US Federal Emission Limit is 0.02 ppm) [7].
Figure 2. Water, ash, volatile matter, total moisture and fixed C in MSW Medan City

Figure 3. Caloric value of MSW Medan City

Figure 4. Chlor, nitrogen, and sulfur C content of MSW in Medan City

Ash analysis as depicted in Fig 5 shows content of Fe₂O₃, CaO, MgO, K₂O Al₂O₃, P₂O₅, SiO₂ and Na in MSW Medan City quite high. It indicates residue of MSW after incineration process may dispose directly into the environment to enrich soil composition.
3.2 Biochemical conversion of MSW
The facts that MSW in Medan City contains high organic materials (77.3%) and phenomena spontaneous methane formation occurred in dumping site area some years ago until recently, indicates potency of MSW conversion into energy by biochemical conversion. Biochemical conversion actually anaerobic digestion process which depends on involvement of consortium of microorganism hydrolytic, acidogens and methanogens. Hydrolytic microorganism such as various enzymes degrade the complex organic compounds into simple ones such as glucose, amino acid and glycogen. The acidogens convert simple organic compound into acetate acid and by methanogens it will convert further into methane and CO₂. Fig 6 shows C content of MSW Medan City while detailed organic composition of MSW Medan City is shown in Fig 7.

The presence high amount of water (70 – 80%) in MSW enhances digestion of organic compound in MSW especially in preliminary stage of anaerobic process. Water facilitate hydrolysis process of complex organics especially for carbohydrate. Fundamentally carbohydrate (15 to 20%) will be the first to degrade via tricarboxylic acid (TCA) cycle to form glucose. Fibres, oil and fat, and protein require more time to be hydrolyse into their simple compounds. Fibres which mainly dominate by cellulosic materials require delignification process prior hydrolysis and degradation via TCA cycle. Oil and fat will be oxidized via β-oxidation to form glycerol prior entering the TCA cycle. Acidogens will convert further the simple products of hydrolysis into acetic acid, and by methanogen it will be converted further into methane and CO₂.
4. Conclusion and Recommendation

MSW of Medan City has the potency to be converted into energy by both thermal and biochemical conversion with respect to their proximate and ultimate test results. Special treatment is required to burn the MSW such as pre dry the MSW to achieve optimum incineration process. For biochemical conversion, a bioreactor should be constructed and MSW sorting prior biochemical conversion is required. Overall, it is recommended to study the incineration of MSW and anaerobic digestion of MSW separately in laboratory scale.

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