The prospect of hazardous sludge reduction through gasification process

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Abstract. Biological sludge generated from centralized industrial WWTP is classified as toxic and hazardous waste based on the Indonesian’s Government Regulation No. 101/2014. The amount of mass and volume of sludge produced have an impact in the cost to manage or to dispose. The main objective of this study is to identify the opportunity of gasification technology which can be applied to reduce hazardous sludge quantity before sending to the final disposal. This preliminary study covers the technical and economic assessment of the application of gasification process, which was a combination of lab-scale experimental results and assumptions based on prior research. The results showed that the process was quite effective in reducing the amount and volume of hazardous sludge which results in reducing the disposal costs without causing negative impact on the environment. The reduced mass are moisture and volatile carbon which are decomposed, while residues are fix carbon and other minerals which are not decomposed by thermal process. The economical simulation showed that the project will achieve payback period in 2.5 years, IRR value of 53 % and BC Ratio of 2.3. The further study in the pilot scale to obtain the more accurate design and calculations is recommended.

Keywords: disposal cost, gasification, hazardous sludge, industrial estate, wastewater treatment

1. Introduction

Wastewater treatments involve physical, chemical, or biological process, depend on the wastewater characteristics. According to the Indonesian’s Government Regulation No. 101/2014, the biological treatment will be more efficient for wastewater with high organic content. Biological treatment of industrial wastewater utilizes microorganism activities that release an amount of hazardous sludge as a product. On other hand, disposing hazardous substance requires great effort thereby it accounts for additional cost for waste water treatment process [1]. In Indonesia, typical method for hazardous sludge treatment is either by land deposition (landfill) or by reusing it as additional fuel in the industry. The amount of hazardous sludge produced is directly proportional to the cost. Moreover, the increasing number of industries will increase the amount of hazardous sludge produced and it will have an impact on the availability of landfilling area. An additional attempt is required to reduce the amount of hazardous sludge to be managed by landfill method. Gasification technology was chosen for reducing the volume of sludge while as much as possible recover some of its energy content. Gasification is a partial combustion process of solid substance that was optimized for maximum production of gaseous fuel, known as synthesis gas (syngas). Gasification is a faster method for volume reduction compared to biochemical options and it offers advantages over direct combustion method [2], [3]. Gasification was initially developed for converting coal into syngas [3]. With the increasing concern of global warming, gasification research has been focused on the gasification of biomass to produce renewable energy [4],
There are but few who have discussed the treatment of hazardous sludge by using gasification technology. Researcher [9] conducted the analysis of bio-sludge as an energy source, while [10] performed a study on biofuels from pyrolysis of sewage sludge, and [11] researched on steam gasification of sewage sludge to produce hydrogen and syngas. However, the sludge produced from different treatment plants will certainly have different characteristics. It will have an impact on the effectiveness of gasification unit performance. Therefore, the development of gasification unit based on the characteristics of hazardous sludge is necessary. This preliminary study encompasses initiatory characterization, lab-scale trial, and economic simulation to calculate the feasibility of gasification process.

2. Research Method
As mentioned earlier, this preliminary study aims to estimate the prospect of hazardous sludge (which released from Jababeka’s centralized WWTP) reduction through the gasification process. Jababeka has being managed 3000 ha of industrial land in Bekasi Regency that have already occupied by more than 1700 industries. A lab-scale trial has been conducted at Environmental Engineering Research Laboratory, President University, while sludge characterization has been carried out at Jababeka’s Environmental Laboratory.

2.1. Hazardous sludge characterization
Hazardous sludge characterization is the early stage of this study to analyze the chemical composition of sludge, especially to measure the organic content. Volatile organic compounds as raw materials for gasification process will be converted into syngas through the thermochemical process. Moreover, other impurities should be recognized to determine the syngas purification unit.

2.2. Lab-scale pyrolysis
There are several simultaneous processes occurred, i.e., redox reaction, pyrolysis, and drying treatment. Pyrolysis process yields syngas that is formed by thermochemical conversion of the organic complex to be less complex compounds. The lab-scale trial focuses on the pyrolysis process as an estimation to find out how the conversion works. A flare test has been conducted to determine the syngas formation. The reactor configuration used in this study consists of a closed-system stainless steel vessel, a bunsen burner that generates heat from butane combustion, flare test equipment, and other required tools.

2.3. Particle size analysis
The reduction of hazardous sludge amount is determined by particle size measurements at the initial and final thermochemical treatments. Particle size measurements were conducted using Fiji-ImageJ software ver. 20151222-1. The sizes of random-shape sludge particles are expressed in Feret diameter, obtained from 2D digital objects that have been adjusted so that they can represent the actual 3D forms.

2.4. Simulation of economic feasibility
The economic aspect is an important parameter to be simulated. Economic feasibility relates to investment cost, profit, and duration of the payback period. Simulation of the economic aspect is based on the analysis results, laboratory experiments, and some required assumptions to calculate the value of PP, IRR, BC ratio and NPV which are commonly used as economic feasibility indicators. The NPV (net present value) leads to better investment decisions than other criteria. In the opportunity-cost concept should identify financial assets with risks equivalent to the project under consideration. In this term, estimation of IRR is needed to calculate the opportunity cost [18]. The value of IRR was very interesting compared to the financial banking interest of 6%. The financial analysis as analyzing estimates possible returns is needed by the investors to determines how certain the expected rate of return on an investment [19].

3. Results and Discussion
The study of pyrolysis as an estimation for gasification process will be the basis of designing the gasification system, including the reactor, separator unit, as well as the mass and energy balance
calculation in ideal condition to determine the typical process parameters. The initial characterization of hazardous sludge is required as a preliminary approximation in lab-scale trial design. The reduction of sludge particles is related to the subtracted amount of hazardous sludge. Moreover, an economic simulation should be conducted as a preliminary calculation for pilot-scale trial.

3.1. Hazardous sludge characteristics
Initial and final chemical compositions were analyzed to determine the configuration changes as the results of the thermochemical treatment. Theoretically, several parameters that are supposed to alter following the thermochemical process are organic content as well as water and sulfur content. Organic materials consist of fixed carbon and volatile carbon that will be converted into syngas and other volatile products. Sulfur content that will be transformed into the gas phase and contained in the syngas is an impurity that should be removed to cleanse the syngas. Moreover, sulfur content will release sulphur oxide (SO\textsubscript{x}) to the emission. Analytical results show that the organic materials equal to 66% of dry-sludge basis, the water content equals to 43% of the total sludge mass, while sulfur concentration and other minerals content is about 4% of dry-sludge basis.

**Table 1. Initial composition of hazardous sludge.**

| Components     | Units | Amount  |
|----------------|-------|---------|
| TSS            | mg/L  | 7,168.0 |
| MLVSS          | mg/L  | 4,732.0 |
| SO\textsubscript{4} | mg/g  | 594.0   |
| Ammonia        | mg/g  | 14.2    |
| Organic content| %     | 66.0    |
| H\textsubscript{2}O | %     | 43.0    |

3.2. Hazardous sludge pyrolysis
Pyrolysis process can reduce the amount of hazardous sludge up to 40% of the total sludge mass basis (in a condition that 10% of the total sludge mass is water content). Several stages occurred the inside fixed-bed pyrolysis reactor are as follows: (1) heating process inside the vessel (the measured temperature is up to 550°C); (2) water content evaporation; (3) when the moisture content decreases, the thermochemical conversion begins. Moreover, it has been known that not all of the top product will be stable as a gas when it reaches room temperature. There are some fractions of the top product that will be condensed because of the temperature difference between the inside and outside part of the reactor. A gas-liquid separator unit is required to prevent the condensate carried along with the syngas. This modified separator is equipped with a carbon filter to prevent other impurities contained in the syngas. A sudden drop in gas-velocity leads to the formation of aerosols, then the phase separation occurs. A gas having a lower density tends to move to the top of the separation tank (top product), while the condensate moves to the bottom of the tank (bottom product). The simplified mass balance can be seen in Figure 1.

![Figure 1. Mass balance of gasification process (lab-scale).](image)

3.3. Particle size reduction
Figure 2 shows the processed image for the particle size determination. The lab-scale gasification trial
can reduce sludge particle size of up to 60%. It is in line with the results of sludge weighing where there is mass difference (mass reduction occurred is up to 50%) between the initial and final sludge mass after the process. Based on both data, it can be said that the sludge amount reduction occurs due to the thermal degradation, resulting in volatilization of volatile carbon, water content, and other thermal sensitive matters.

![Figure 2](image)

**Figure 2.** Feret diameter of particles: (a) sludge before the process (11 mm) and (b) slag after the process (4 mm).

3.4. Economic feasibility

The economic feasibility simulation is based on analysis data, lab-scale trial results, and assumptions required in the calculation. There will be a new proposed business model to be compared with the existing scheme. Figure 3 and Figure 4 show the comparison of both models.

![Figure 3](image)

**Figure 3.** The existing business model.

In the existing business model, the industrial estate spends about 87 million Rupiah/month for sludge disposal and pays out about 331 million Rupiah/month for the electricity consumption. As seen in the proposed business model depicted in Figure 5, the expenditures are only about 43 million Rupiah/month for sludge disposal and 319 million Rupiah/month for electricity consumption. The comparison between both business models shows a cost reduction of up to 40%.

![Figure 4](image)

**Figure 4.** The proposed business model.

Several assumptions taken into account to simulate the economic feasibility and to develop the proposed business model are as follows: (1) The increment of sludge disposal cost is about 5% per year;
(2) The increment of electricity cost is about 3% per year; (3) The increment Increase of employee salary is about 10% per year; (4) The increment Accretion of fuel cost is about 10% per year; (5) The increment Increase of maintenance cost is about 10% per year; (6) Accretion of miscellaneous expenses is about 10% per year; and (7) Inflation rate of about 6% per year. (8) All assumption rate and cost of energy, man power, sludge disposal, mechanical & electrical maintenance, inflation rate were based on data in March year 2017.

Table 2. The financial profit and loss analysis of the proposed business model.

| No | Items                                      | Rp/month      |
|----|--------------------------------------------|---------------|
| 1  | Revenue                                   |               |
|    | Sludge disposal cost saving               | 35,104,457    |
|    | Green energy produced (expressed in Rp1115/kwh) | 11,657,317    |
|    | Employment cost saving (2 people)         | 6,400,000     |
|    | **Total in revenue**                      | **53,161,774**|
| 2  | COGS/Expenses                             |               |
|    | Employment cost (4 people)                | 12,800,000    |
|    | Electricity consumption                    | 481,680       |
|    | Fuel for start up                         | 1,000,000     |
|    | Genset maintenance                        | 5,000,000     |
|    | Reactor maintenance                       | 5,000,000     |
|    | Miscellaneous expenses                    | 2,000,000     |
|    | Depreciation on investment                | 10,371,528    |
|    | **Total Cost**                            | **36,653,208**|
| 3  | Profit                                    | 16,508,566    |
| 4  | % Profit to total cost                    | **45%**       |

Based on several assumptions above, the financial profit and loss analysis is presented in Table 2. Table 3 shows the summary of economic simulation results for the proposed business model.

Table 3. Summary of economic simulation based on the proposed business model.

| Items                        | Units     | Value            |
|------------------------------|-----------|------------------|
| Capacity                     | tons/day  | 2.5              |
| Investment                   | Rp        | 775,000,000      |
| Lifetime of gasification unit| years     | 5                |
| Profit percentage            | %         | 45%              |
| Payback Period               | years     | 2.5              |
| IRR                          | %         | 56%              |
| NPV                          | Rp        | 574,569,163      |
| BC ratio                     | -         | 2.3              |

4. Conclusion
The results showed that the gasification process is quite effective in reducing the volume of hazardous sludge which then lowers the disposal cost without causing an adverse impact on the environment. The reduced mass contains moisture and volatile carbon which are decomposed by the thermal process, while the residues are fixed carbon and other minerals which are not degraded by the thermal process. The economic simulation shows that the project will achieve payback period in 2.5 years, IRR value of 53%, and BC Ratio of 2.3. The value of IRR was very interesting compared to the financial banking interest
of 6%. The further study in the pilot-scale is highly recommended to obtain a more accurate design and calculation.

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