Chapter 7

Energy Prospects of Hazardous Sludge from Wastewater Treatment Facilities

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Additional information is available at the end of the chapter

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Abstract

Reduced reserves of fossil fuels, global warming issue, population growth rates and consumptive lifestyles trigger awareness of the need to utilize alternative energy sources as a substitute for the use of fossil fuels. The carbon compounds contained in wastewater sludge is one of the materials that has the potential to be an alternative energy source if managed with proper method. In relation to this, the main objective of this research is to identify the prospect of several technologies to treat organic sludge in terms of mass reduction and energy recovery as a basis for feasibility study and further development. Simulations carried out on wastewater sludge from Jababeka's centralized wastewater treatment facilities showed that thermochemical processing methods were quite effective in reducing sludge mass. Reduction of mass occurs due to the decomposition of carbon compounds resulting in changes in the size of sludge particles. In addition, green energy produced can also be used to fulfill some needs in treatment facilities and can be a substitute for the use of fossil fuels. Overall, based on the results of the feasibility study simulation, it can be concluded that the thermochemical processing method can be further considered to develop into the pilot scale.

Keywords: hazardous sludge, energy recovery, renewable energy, sewage, wastewater treatment

1. Introduction

The need for energy source is one of the important things in human life. Fossil fuel, geothermal, water potential, and nuclear energy are some energy sources that have been commonly used. In addition to some of these energy sources, wind energy, solar radiation, ocean waves, biomass, and other renewable energy sources have also been widely researched and developed as an alternative energy source. Nevertheless, until now fossil fuels are still one of the primary energy sources that cannot yet be completely replaced by other types of energy sources. The decrease in availability of fossil fuels as non-renewable energy sources is inversely proportional to the increasing population of the world. Raising awareness of the limited reserves of fossil fuel and of the need for another energy source as alternative energy source is needed. One alternative energy source that can be considered is the biomass content of sludge produced from biological wastewater treatment. Carbon compounds contained in biological sludge (bio-sludge) can be converted into energy through thermal process, bio-digestion, lipid/oil extraction, or other methods that are in accordance with its characteristics [1, 2, 12, 15, 25, 34]. Therefore, the main objective of this research is to identify the prospect of several technologies to treat organic sludge in terms of mass reduction and energy recovery as a basis for feasibility study and further development. The thermal process of converting biomass to energy is also accompanied by a decomposition process of complex carbon into a simpler form of carbon compounds. So that, in this case, not only the conversion of biomass into energy, but also the mass reduction of sludge should be processed and managed to minimize the negative impacts that can be generated from the sludge generated by the wastewater treatment process [11].

Before discussing further the next section, it is necessary to clarify in advance some terms in this paper. What is meant by sewage is liquid waste (in this case, it is wastewater) that flows in the sewer [31]; so, the terms sewage and wastewater will be used interchangeably according to the context of the sentence. Sewage sludge is mud that originated from a sewer, whereas treated sewage sludge means sludge that is produced from the treatment process in wastewater treatment facilities.

2. Hazardous sludge: properties and its potency

The list of hazardous waste from non-specific sources found in Annex 1 of the Republic of Indonesia government regulation No. 101/2014 concerning the management of hazardous and toxic waste stated that sludge produced from integrated wastewater treatment facilities in industrial estate was classified as hazardous waste category 2 [10]. In this category, the waste in question is declared as toxic waste which is harmful to the environment and living things.

2.1. The origin of sludge: case study of Jababeka's wastewater treatment facilities

In a centralized wastewater treatment facility, especially in an industrial estate, wastewater from each factory located within the industrial area will be drained through sewerage. Wastewater generated from the production process should be treated in advance so that it is in accordance with the wastewater quality standards determined by the industrial estate manager. In addition to its characteristics, the volume of wastewater discharge through the sewer should also follow the regulations determined by the industrial estate manager. It is required to ensure that the wastewater that flows to the treatment facility has characteristics that are in accordance with the processing capability and capacity of the existing treatment facilities. The treatment process is generally divided into several stages, among others primary treatment, secondary treatment, tertiary treatment, and other treatment options according to the wastewater characteristics to be treated.

Referring to the regulation of Republic Indonesia environment minister No. 5 year 2014 concerning wastewater quality standards, stated that each type of industry that produces wastewater from the results of its activities and conducts types of treatment activities, it is a mandatory to comply with the applicable quality standards [23]. Likewise, with centralized wastewater treatment facilities located in industrial estates, it is mandatory to comply with the applicable quality standards. One of the centralized wastewater treatment facilities in the industrial estate in Indonesia is the Jababeka's wastewater treatment facility located in Bekasi Regency, West Java. The main process in this treatment facility is a biological treatment process equipped with other treatment process units.

As can be seen in **Figure 1**, there are several treatment stages at the Jababeka's wastewater treatment facilities. Among them are the removal stages of sand, gravel, and rough mud on the grit chamber unit. Furthermore, wastewater will flow due to gravity toward the primary settling tank unit. In this unit, suspended solids will settle, while floating material will be separated with the scum collector and then flow to the sludge treatment unit. The primary settling tank effluent is flowed to the oxidation ditch which utilizes biological process (activated sludge) to decompose pollutants contained in wastewater. This process will produce

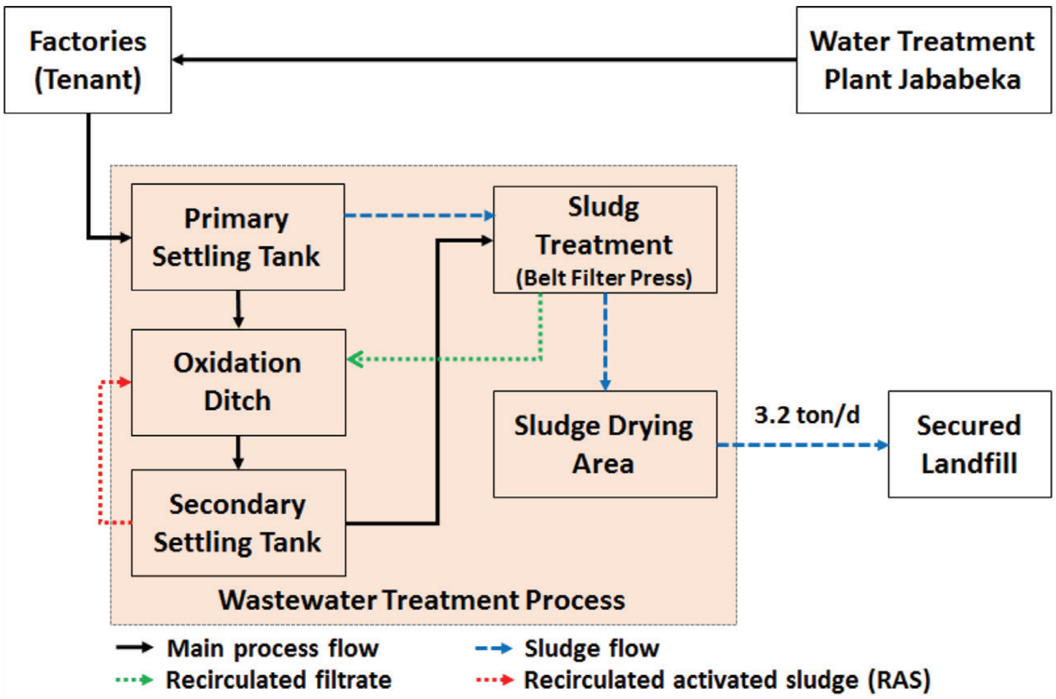

Figure 1. Schematic flow diagram of Jababeka's wastewater treatment facilities.

biological floc which is then deposited in the secondary settling tank unit. A part of the sludge produced in this process is recirculated to maintain the continuity of the process, while other parts are channeled to the sludge treatment unit.

Referring to the process description, it can be identified that there are two types of sludge produced from this treatment facility. Sludge produced from primary settling process mainly is inorganic material (about 55–65%) that comes from heavy suspended solid settled by physical gravity process. The total sludge production from primary treatment was about 500 kg/day for a flow rate of 13,300 m^3/day of wastewater.

The second type of sludge is produced by secondary settling process that mainly contains 60–70% of organic material from organic floc formed in the aeration tank. The quantity of organic sludge is much bigger than inorganic sludge due its relation with biological process control. The management of activated sludge concentration in aeration tank and sludge concentration in recirculation flow by distribution box unit is very significant for maintaining wastewater treatment process properly. In this case, the production of large amounts of organic sludge cannot be avoided. The organic sludge production is about 3200 kg/day (55% dry solid) for a flow rate of 13,300 m^3/day of wastewater with its calorie about 2000–2500 kcal/kg of 100% dry sludge. This quantity contributes a very significant amount in the wastewater treatment operational cost. Reducing quantity or converting the organic sludge to the alternative materials or energy is very helpful in terms of reducing operational cost.

2.2. Sewage sludge and treated sewage sludge properties

Previously, research has been carried out by several researchers regarding the analysis of the characteristics of sludge collected from sewer, as well as sludge generated from wastewater treatment process in wastewater treatment facilities. There are two major groups of sludge types whose characteristics are analyzed, which are municipal and industrial sludge. Municipal sludge is sludge originating from domestic activities in connection with activities in a residential area, while industrial sludge is produced from production processes in various fields of industry.

Most of the previous research studies summarized in **Table 1** are regarding characteristics of sludge from urban/municipal activities [2, 7, 8]. Several reports concerning industrial sludge treatment have also been summarized [4, 5, 19]. Not all of the research studies summarized in **Table 1** are using treated sludge as the feedstock for energy recovery process. Some researchers use organic sludge which is the by-product of the manufacturing process of TFT-LCD and sludge from pulp and textile industries [4]. In addition, there is a review report of various sludge characteristics of each wastewater treatment stage [20].

When compared carefully based on the summary from **Table 1**, it can be observed that organic sludge which has the highest amount of volatile matter is sludge originating from a centralized biological wastewater treatment process. It can be observed that the volatile matter content in the sludge analyzed is in the range of 47.00–77.00%. If it is assumed that the main component of volatile matter is carbon compounds, which in the process will be converted into

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The origin of sludge (feedstock)	C	H	O	N	S	Volatile matter	Fix carbon	Ash
	%	%	%	%	%	%	%	%
Dry treated sewage sludge, digested (municipal) [2]	29.50	4.67	20.20	5.27	1.31	—	—	39.04
Recycling of organic sludge from TFT-LCD manufacturing process [4]	50.00	—	—	9.00	2.10	—	—	—
Pretreated pulp industrial sludge [5]	18.48	1.78	78.82	0.83	—			
Pretreated textile industrial sludge [5]	32.15	5.73	59.04	1.36	1.64			
Dry treated sludge from urban wastewater treatment [7]	38.82	6.19	—	5.78	1.17	64.90	7.90	27.20
Dry treated sludge from urban wastewater treatment [8]	28.50	4.30	22.40	4.10	0.80	47.00	6.40	39.90
Dried sewage sludge [9]	36.45	5.93	25.74	7.03	0.77	59.06	9.36	24.08
Urban sewage plant [18]	36.11	5.25	—	6.50	1.03	57.22	6.09	31.27
Dried sludge from wastewater treatment plant of thermal power plants [19]	32.30	4.90	24.90	5.30	0.57	64.70	—	—
Primary treatment [20]	51.50	7.00	35.50	4.50	1.50	65.00	—	—
Biological treatment (low) [20]	52.50	6.00	33.00	7.50	1.00	67.00	—	—
Biological treatment (low and mid) [20]	53.00	6.70	33.00	6.30	1.00	77.00	—	—
Primary and biological (mix) [20]	51.00	7.40	33.00	7.10	1.50	72.00		
Digested [20]	49.00	7.70	35.00	6.20	2.10	50.00		

Table 1. Characteristics of sludge from previous research.

flammable gas and/or flammable oil, it means that volatile matter can be expressed as volatile carbon and can be used as a benchmark in determining the energy content. Furthermore, it can be expressed to determine the calorific value of the flammable gas and/or flammable oil produced from thermal conversion process. In fact, volatile matter contains not only carbon compounds but also volatile components such as nitrogen compounds, sulfur, and other components varying in number depending on the process characteristics and complex compounds involved. It shows that gas produced from the thermal conversion still requires a purification process to minimize the negative impact of emission from combustion (**Figure 2**).

2.3. Conversion method of sludge to energy

Before going further, it is necessary to clarify the terms that will be discussed in this section. What is meant by conversion of sludge to energy, in this context, can be the decomposition process of carbonaceous (organic) sludge into gas/fuel oil which will then be used as an

Figure 2. Treated industrial sludge in Jababeka's wastewater treatment facility. (Source: Kurniawan et al.).

energy source, or it can be in the form of direct conversion of sludge to energy in the form of heat released from combustion.

Organic sludge has the potential to be an alternative sustainable energy source if managed with the proper and efficient method. What needs to be realized is, to convert sludge into an energy source, a certain amount of energy is needed in the conversion process. In **Table 2**, we can observe several methods of converting feedstock into energy sources through various types of process. The sludge to energy conversion discussed in this paper covers the physical, biochemical, thermochemical, and transesterification conversion methods.

2.3.1. Physical conversion method

What is discussed in this section is the method of compacting sludge into a form of pellets or briquettes for later use as solid fuel known as refuse-derived fuel (RDF). It is done to facilitate storage and transport compared to the original form. The compacting process will directly affect the water content. In the direct combustion process, the low water content will increase the ease of solids to burn. It will affect the combustion temperature and heat value generated from combustion, because the heat produced is only used for the oxidation of organic matter rather than vaporizing the water content. Besides being burned directly, RDF sludge can also be applied to the pyrolysis process or gasification to produce synthesis gas or pyrolysis oil (**Figure 3**).

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Conversion method	Feedstock	Main process
Anaerobic digestion	Wastewater sludge from food-processing industry [32].	Fermentation using a clostridium strain to produce hydrogen and methane.
Pelletization	Recycling of organic sludge from TFT-LCD manufacturing process [4].	Characterization of sludge refuse-derived fuel (RDF) and its combustion behavior and properties
Pelletization	Urban wastewater sludge from biological treatment [13].	Combustion characteristics of pure biomass RDF and RDF from sludge-biomass mixture. Comparative study of the energy consumption for pelletization process.
Pyrolysis	Treated wastewater sludge originating from domestic, commercial and industrial activities [13].	Characterization of fundamental properties of the wastewater sludge pyrolysis product in a fixed bed pyrolysis reactor.
Pyrolysis	Wastewater sludge from petrochemical industry; oily sludge from primary decanter [14]	Pyrolysis product characterization of wastewater sludge in a fixed bed pyrolysis reactor.
Pyrolysis	Wastewater biosolids [21].	Pyrolysis product characterization of wastewater biosolid in a fixed bed pyrolysis reactor and its energy comparison for required and resulting energy content.
Pyrolysis	Combination of rice waste and treated sewage sludge [30]	To produce bio-oil in fluidized-bed reactor through fast pyrolysis.
Pyrolysis	Thickened excess activated sludge, dewatered digested sludge, and dried excessive activated sludge [27].	Flash pyrolysis to produce pyrolysis oil in fixed bed reactor.
Gasification	Solar dried-treated wastewater sludge [29].	Syngas production in semi-batch steam gasification reactor.
Gasification	Undigested and dried-treated sewage sludge pellets [22].	Gasification of feedstock pellets in fixed bed downdraft reactor.
Transesterification	Wet activated sludge [17].	Hexane-lipid extraction and non-catalytic biodiesel production in tubular glass transesterification reactor.
Transesterification	Dried sludge of food processing plant [15].	In situ transesterification of sludge in subcritical mixture of methanol and acetic acid.

Table 2. Various conversion methods of sludge to energy source.

2.3.2. Biochemical conversion method

The decomposition of organic compounds using biological processes is one method that can be done to produce alternative energy sources. Biogas which has the main content of methane gas is produced from the decomposition process under controlled anaerobic conditions. Several stages in the biogas production process include the stages of hydrolysis, liquefaction, and fermentation; the formation of hydrogen and acetic acid; and the last is the methane gas formation stage [25]. Each stage of the process that the sludge goes through will involve different types of enzymes produced from the metabolism of anaerobic bacteria. Previous research has reported on critical review along with the biogas production process from wastewater sludge [25].

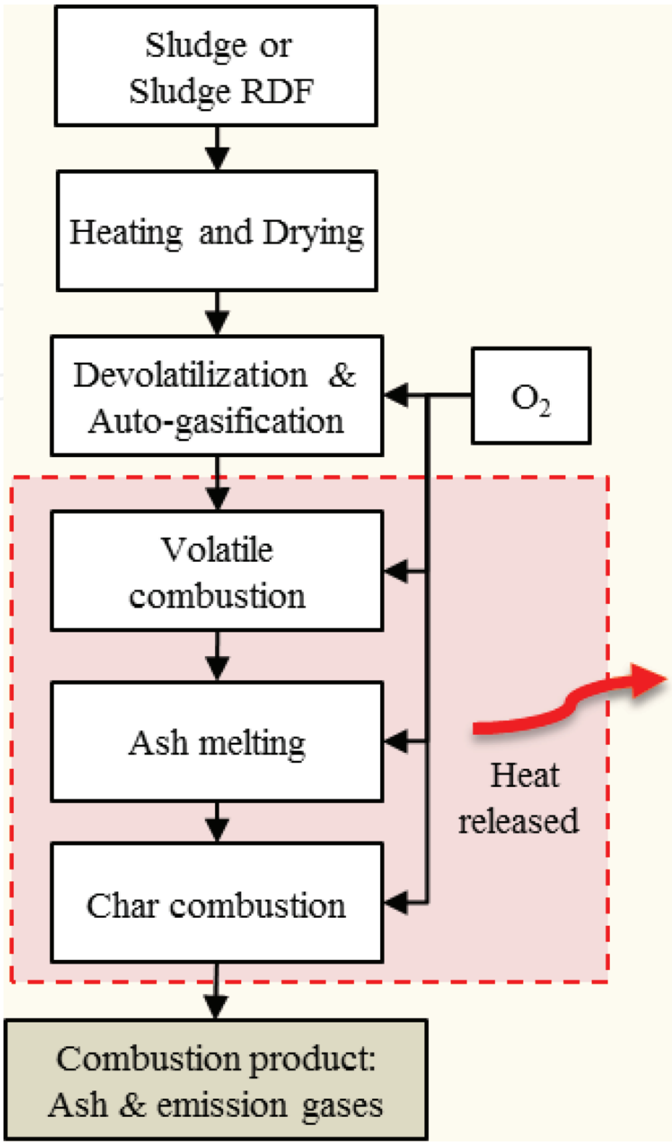

Figure 3. Pathway of sludge combustion process (Source: Kurniawan et al.).

2.3.3. Thermochemical method

In the thermochemical method, combustion process is one part that cannot be separated. Heat is produced from chemical reactions that occur due to the decomposition of organic compounds through oxidation process. Some types of treatments classified as thermochemical methods include direct combustion, incineration, pyrolysis, and gasification. The combustion process takes place in a compartment, which is usually known as combustion chamber. In this compartment, several types of configuration are known based on the type of working fluid flow pattern (updraft and downdraft) and the type of solid bed (fixed and fluidized bed) (**Figure 4**).

In the fixed bed type, solid bed is on the screen or perforated plate in fixed position. As for the type of fluidized bed, solids are suspended in the working fluid flow. Updraft and downdraft flow show the pattern of working fluid in the bed reactor. Combination of solid bed types and the types of working fluid flow pattern can be applied to pyrolysis and gasification reactor according to needs.

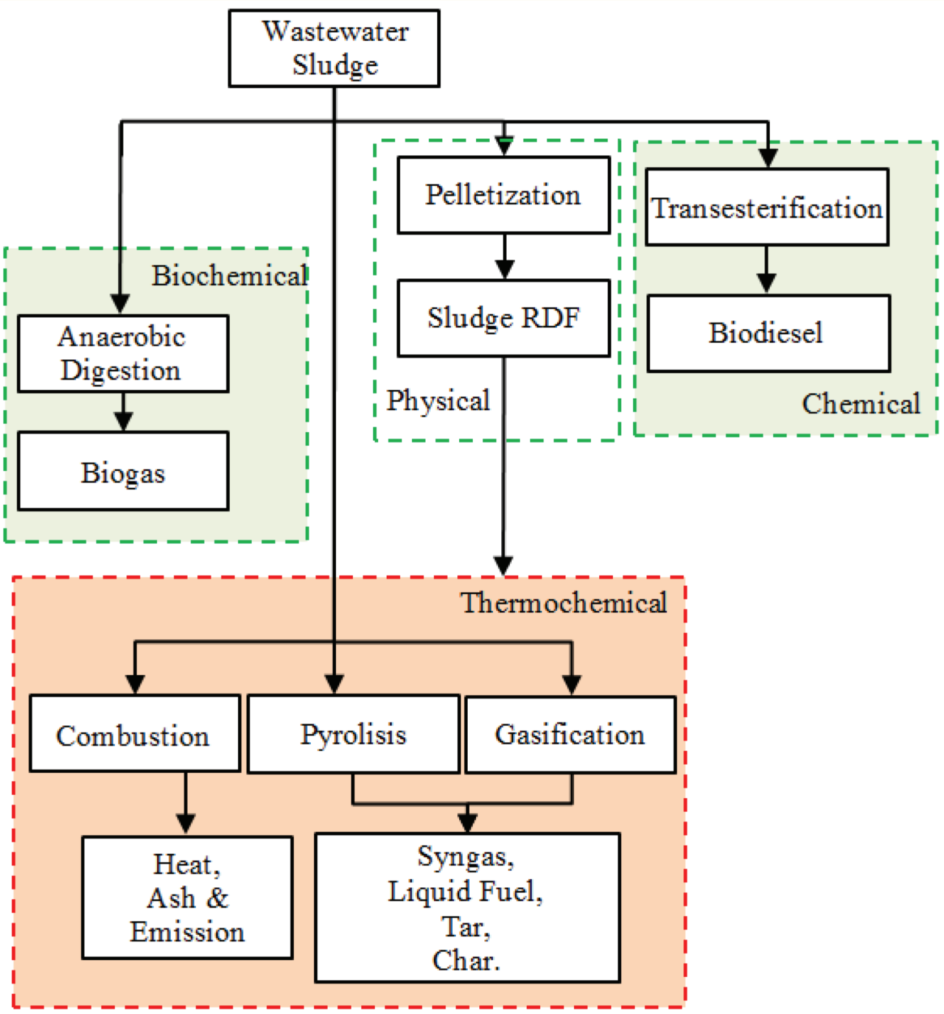

Figure 4. Sludge-energy conversion pathway (Source: Kurniawan et al. with modification).

The most fundamental difference between direct combustion with pyrolysis/gasification is the amount of oxygen used in the oxidation process. A certain amount of oxygen with sufficient stoichiometric concentration (even in excessive condition usually) is required in direct combustion, so that carbonaceous compound will be completely oxidized to carbon dioxide and water vapor. An imbalance in the amount of stoichiometric oxygen will result in incomplete combustion, indicated by the production of volatile compounds other than carbon dioxide. This phenomenon occurs in the gasification process, the supply of oxygen to the combustion chamber is intentionally limited in such a way that it does not meet the stoichiometric equilibrium as occurs in the complete combustion of carbonaceous compounds. In this process, flammable synthesis gas will be produced. In the context of the shortness of the duration and stages of the mass reduction process, and the flexibility of renewable energy that can be produced, gasification is a viable option compared to direct combustion or anaerobic digestion method .

Typical oxidation medium in combustion is air, whereas in gasification, it can be air, pure-oxygen, steam, or other substances [29]. In gasification, the energy released from decomposed solid fuel is packed into chemical energy in the form of gas fuel . On the contrary, combustion decomposes solid fuel and releases as much as possible the energy content in the form of heat. There are four stages of gasification process, heating and drying, devolatilization, gas-gas reaction, and char gas reaction [3]. At the drying stage, there is an increase in temperature of carbonaceous sludge which results in evaporation of sludge-water content. At the devolatilization stage, thermal cracking process occurs that produces light gas products such as H_2, CO, CO_2, CH_4, H_2O, and NH_3. This devolatilization stage is also known as pyrolysis stage. In the gasification process, a gasification medium is required in the form of air, oxygen, or steam. In contrast to pyrolysis, no medium is required, but heat is required as a driving force to release the volatile compounds. Based on the explanation, it can be said that gasification is a pyrolysis process that is optimized to convert solid fuel into synthesis gas. The next two stages are the chemical reaction stage between gas-gas and char-gas which will eventually produce synthesis gas (syngas).

Gasification process for pellets made from sewage sludge (sludge RDF) has been carried out by several previous researchers [22, 26, 28]. Research shows that the use of fixed bed and fluidized bed gasifiers is quite promising. The results of this study were obtained from several types of sludge which have different characteristics, so they cannot be compared with each other. The total heating value generated in the use of a fixed bed-type gasifier is around 4 MJ/m^3 with hydrogen concentration around 10–11% v/v [22]. Other studies on uncompressed sewage sludge gasification showed that the higher the oxygen content and the temperature of compressed air, the higher heating value produced [6, 33]. In addition, it can be observed that the higher the sludge humidity, the higher the hydrogen concentration and its heating value [33]. This phenomenon occurs because the water content in the form of moisture on the sludge evaporates into steam which involves a water-gas shift reaction, in this case, the equilibrium of the reaction shifts to the right due to excess concentration of carbon components and water molecule in the form of steam on the side of reactant. This is in line with the previous research which shows that high-quality syngas can be obtained from steam-gasification of wet sludge which results in higher hydrogen-carbon ratio than air-gasification or oxygen-gasification [24]. Other studies on the type of gasification using water in supercritical conditions indicate that the higher and the longer detention time will increase the yield of hydrogen and methane [1].

2.3.4. Transesterification

In addition to anaerobic digestion, direct combustion, pyrolysis, and gasification, another option for organic sludge energy recovery is the transesterification process. It involves the reaction between triglycerides and methanol under controlled conditions, either with or without the presence of a catalyst. The use of homogeneous catalyst is relatively cheap compared to the use of heterogeneous catalysts. However, homogeneous catalysts are very sensitive to free fatty acids and the water content in oil, and can trigger saponification and hydrolysis reactions [17]. The first stage of the process is to extract the oil contained in the sludge that will be reacted with methanol to produce crude biodiesel; then the refining process is carried out by separating the biodiesel fraction from the glycerin layer. Several studies on sludge energy recovery through transesterification process have been carried out in lab-scale experiments or only in the form of simulation or process review. Research about transesterification on lab scale has been carried out in a quart-tubing tubular reactor equipped with gas sensors, heaters, and other equipment to produce controlled process conditions [17]. The products resulting from esterification reaction in the form of biodiesel, which is still mixed with glycerin, are then allowed to settle for 2 hours to be separated and then analyzed by gas chromatography. Another research has analyzed challenges in terms of process commercialization, including sludge collection, optimization of biodiesel production process, maintaining quality of product, formation of soap as a by-product and its purification method, proper design of bioreactor, pharmaceutical chemical in sludge, regulatory concerns, and economics of biodiesel production [15].

2.4. Pyrolysis of treated wastewater sludge from Jababeka's treatment facility

This section is an extended article from a paper entitled "The prospect of hazardous sludge reduction trough gasification process," which was presented in scientific forum. The study of the topic originated from consideration of disposal cost of biological sludge to secure landfill. The energy produced is a by-product of the process of reducing the organic sludge mass which, if optimized, can also be an alternative energy source and it is hoped that more or less can be utilized as a substitute for fossil fuels in the area of treatment facilities.

2.4.1. General considerations

From several options of sludge to energy conversion method discussed in the previous section (see part 2.3), it can be observed that conversion technology is not a major problem, considering that up to now there are quite a number of conversion method options that have been developed. However, in the context of its implementation, it is necessary to consider several aspects including technical, economic, environmental, and other aspects that are interrelated with this.

Technically, the selection of the conversion method should conform to the characteristics of the sludge. In sludge with high oil/fat content, the extraction options for oil/fat content followed by transesterification (extraction-transesterification) are possible. The oil extracted from sludge still has carbonaceous solid, which can be treated by thermal or biochemical processing methods, whereas for sludge with low oil/fat content, the extraction-transesterification method is certainly not the proper option considering the yield will also be very low.

Another technical aspect that needs to be considered is the ease of operation. The complexity of the technology used will directly affect operational ease and will also affect the operational and energy costs. Environmental impacts that may result from the advanced treatment of sludge carried out also need to be considered. In the thermal conversion method that involves the combustion process, it must be ensured that the resulting flue gas is treated first before being released into the atmosphere. Improper treatment of flue gas can be a source of pollutants for the earth's atmosphere and may even be a contributor of gaseous pollutants, which in large quantities can exacerbate the greenhouse effect. In addition, reviews of economic aspects are also an aspect that needs to be considered, including investment cost, operational cost, energy cost, and other costs that are related to this process.

2.4.2. Simulation based on experimental data

Experiments of the pyrolysis process are carried out on a laboratory scale using pyrolysis reactor in the form of a closed stainless steel vessel equipped with a gas-fired heating system. The reactor is also equipped with a gas-liquid separator made of polypropylene and several valves to regulate the fluid flow involved in the process, as illustrated in **Figure 5**.

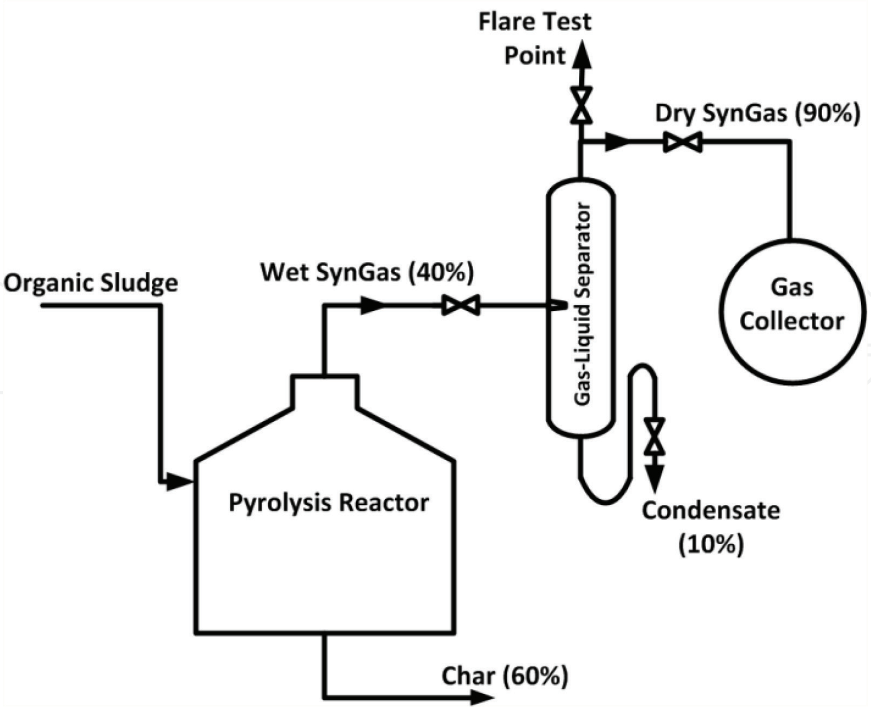

Figure 5. Simplified schematic diagram of organic sludge pyrolysis process.

Treated wastewater sludge which contain 66% of carbonaceous compound has the potential that can be used as an alternative energy source if it is managed by the appropriate method. The amount of water contained in the wet sludge (43% of the total wet basis) is removed through the belt filter press unit and then dried with sunlight in the sludge drying area, until the water content is around 10% (dry basis).

In addition to organic matter and water, there are also contents of sulfur and other minerals which amount to 4% of the dry weight.

Sludge which has reduced in its water content by about 10% is then put into a fixed-bed pyrolysis reactor so that the mass of solids is reduced by 40%. Mass loss occurs due to the decomposition process of organic matter into simpler matter. The measurement results show that the decomposition process occurs at reactor temperature up to 550°C. The fraction that is converted to gas will then flow to the gas-liquid separator which is equipped with a carbon filter layer to reduce the amount of gas impurities carried to the gas collector.

Not all gas produced from thermal decomposition process flows into the gas collector, the heavier fraction will condense in the separator because of the difference in temperature and pressure inside the reactor with those on the inside of the separator.

Differences in temperature and pressure occur due to decomposition of some solid sludge into gas accumulated in pyrolysis reactor. The wet gas fraction as a top product from pyrolysis reactor will be flow to the gas-liquid separator that allows the decrease in gas velocity so that the separation process of the gas fraction and heavier fractions can be occur. The top-most product of pyrolysis reactor that enters the separator will be separated into 90% dry gas and

10% condensate (see **Figure 5**). Another parameter analyzed is the particle size of the sludge that is treated. The initial treatment carried out in laboratory experiments is the drying process with an oven, and then reducing the lump of sludge into particle which has an average size of 11 mm. Sludge, which has been reduced in solid size, is then processed thermally so that it produces char, the remaining solid sludge that does not decompose and remains in a solid form with an average size of 4 mm (see **Figure 6**). The results of these observations indicate that the heat treatment given results in decrease in sludge particle size by about 36%, this is directly proportional to the decrease in sludge mass up to around 40%. The decrease in sludge mass and the decrease in sludge particle size indicate that decomposition of the sludge component has occurred. Components classified as volatile heat-sensitive matter are evaporated, while fixed carbon and other unevaporated components remain in the solid form (**Table 3**).

As mentioned in the previous paragraph, the decomposition process of solid sludge is indicated by a decrease in sludge particle size. And the decrease in sludge particle size also affects the total mass of sludge. The cost of managing treated wastewater sludge comes from the energy cost used to reduce the water content, in this case using a belt filter press unit. Besides that, there are sludge disposal costs involving third parties who have permits. In connection with this, a simulation of economic feasibility is carried out as one consideration to expand this research to the pilot scale.

The economic feasibility simulation was carried out to compare solid sludge management by secured landfill (existing) methods with the thermal process method. In its existing condition, the industrial estate manager issues around US $ 7020/month for sludge disposal to secured landfill through third-party services [11]. Also, about US $ 26,492/month is issued for the use of electrical energy in Jababeka's wastewater treatment facilities [11], as illustrated in **Figures 7 and 8**. In the proposed business model, the cost incurred for the disposal of sludge is estimated to decrease to US $ 2808/month, while the cost of electricity consumption fell to US $ 25,560/month [11]. It is related to the calculation of green energy resulted from the process is assumed to be able to substitute energy requirements as much as that produced from the gasification process [11]. In total, based on the simulation results, it is estimated that there will be a reduction in costs of up to 40% if the proposed business model is actually implemented.

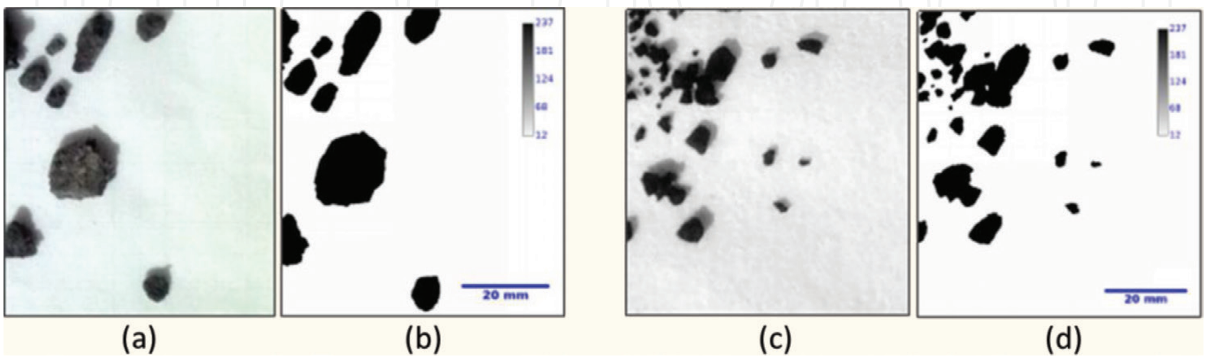

Figure 6. Average sludge particle size (a) & (b) size before pyrolysis: about 11 mm;(c) & (d) size after pyrolysis: about 4 mm (Source: Hakiki et al. [11]).

No	Items	US $/month
1	Revenue	
	Sludge disposal cost saving (to PPLI) (55% dry solid)	2808.0
	Green energy produced (expressed in US $ 0.08/kwh)	932.4
	Employment cost saving (2 people)	512.0
	Total revenue	**4252.4**
2	COGS/expenses	
	Employment cost (4 people)	1024.0
	Electricity consumption	38.5
	Fuel for start up	80.0
	Generator maintenance	400.0
	Reactor maintenance	400.0
	Miscellaneous expenses	160.0
	Depreciation on investment	886.9
	Total cost	**2989.4**
3	**Profit**	**1263.4**
4	**% Profit to revenue**	**30%**

Table 3. Benefit cost analysis of the proposed business model (Source: Hakiki et al. [11] with modification).

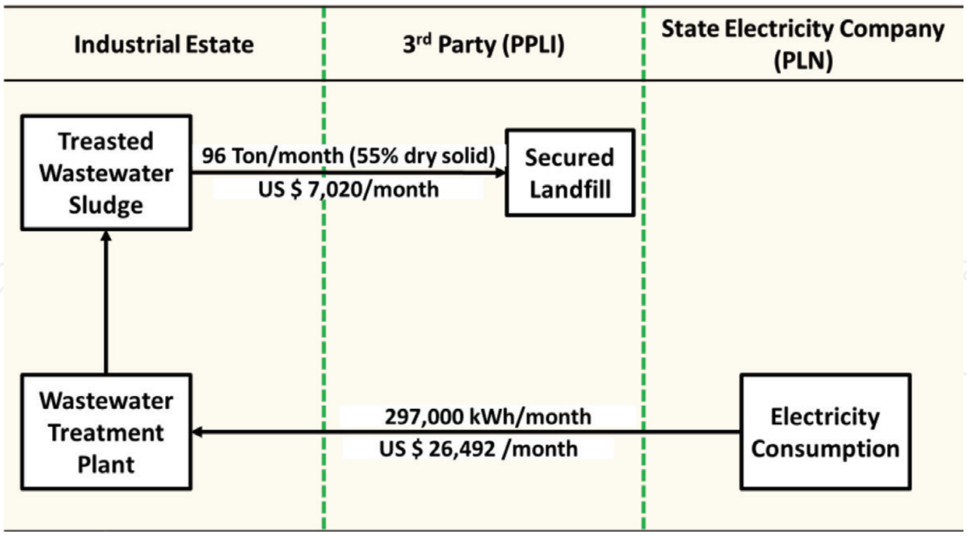

Figure 7. Existing business model (Source: Hakiki et al. [11] with modification).

In calculating and analyzing economic feasibility in the simulation, the following assumptions are made[11]: (1) The disposal costs of sludge will increase by 5% per year; (2) electricity consumption costs will increase by 3% per year; (3) employee salary costs will increase by 10% per year; (4) fuel costs will increase by 10% per year; (5) maintenance costs will increase by 10% per year; (6) miscellaneous costs will increase by 10% per year; (7) inflation rate is 6%

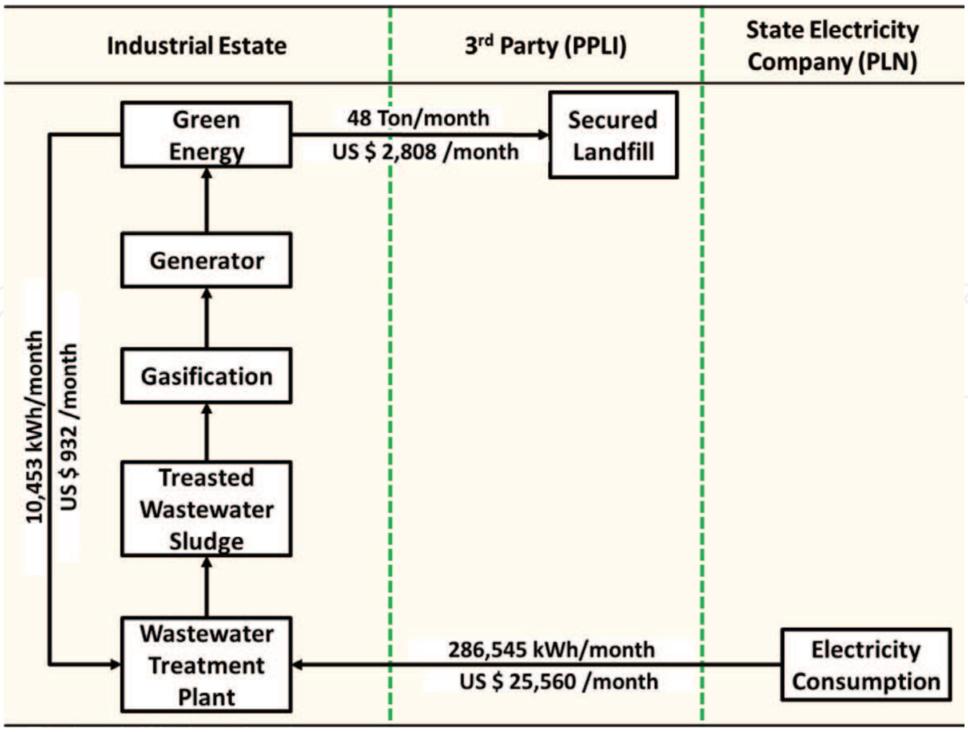

Figure 8. Proposed business model (Source: Hakiki et al. [11] with modification).

Items	Units	Value
Capacity (70% dry solid)	tons/month	75
Investment	US $	62,080.0
Lifetime of gasification unit	years	5
Profit to revenue	%	30%
Payback period	years	2.8
IRR	%	42%
NPV	US $	32,625,4
BC ratio	—	2.1

Table 4. Summary of economic simulation based on the proposed business model (Source: Hakiki et al. [11] with modification).

per year. All assumptions are based on data valid in March 2017. The summary of economic simulation can be seen in **Table 4**.

3. Conclusion

Management of wastewater sludge originating from wastewater treatment facilities can be done in several ways, including physical process (compacted into briquettes), biochemical process (anaerobic digestion), thermochemical process (pyrolysis/gasification), and extraction-transesterification (sludge as an alternative feedstock to produce biodiesel). In addition to these management methods, the last option has been commonly used in disposal to secured landfill. The last option is still seen as the best choice in terms of practicality and ease of process. In this option, the producing party utilizes the services of third parties who already have permission to manage the sludge produced. Along with increasing awareness about the decreasing reserves of fossil fuels and the increasing popularity of global warming issues, the secured landfill option needs to be reviewed further, considering that organic sludge still has the potential as an alternative energy source if managed with the proper method. Simulations carried out on wastewater sludge from Jababeka's centralized wastewater treatment facilities showed that thermochemical processing methods were quite effective in reducing sludge mass. In addition, green energy produced can also be used to fulfill some needs in treatment facilities and can be a substitute for fossil fuels. Overall, based on the results of the feasibility study simulation, it can be concluded that the thermochemical processing method can be further considered to develop into the pilot scale.

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