Roles of waste pre-treatment unit to support waste to energy sustainability

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Abstract. Improper waste management in big cities, especially DKI Jakarta, causes increasing the burden of the landfill so that it becomes full quickly. It is very troublesome to find land for a new landfill because there has been a lot of land use as residences. The result is an increase in the amount of waste that is discharged outside the landfill causing environmental damage and danger to human health. Waste processing with using thermal technology (Waste to Energy/WtE) is one alternative to overcome these problems. Since the condition of waste in Indonesia is mixed waste and most types of waste are organic waste, it is necessary to pre-process waste before waste enters the incinerator. The waste pre-treatment unit has any significant roles in the sustainability of WtE. There have not been many previous studies that explain this role. The purpose of this paper is to study the significant roles using the study of literature. These roles include: 1) improve the waste quality that will enter the incineration process; 2) reduce the Plant capacity so that it can reduce the WtE’s total costs; 3) facilitate waste hierarchy approach in WtE Pilot Project activities.

1. Introduction

Indonesia is a country that has the fourth largest population in the world. The total population in Indonesian recorded in 2018 was 267,670,543 people with a population increase of 1.1% [1]. An increase in population is proportional to environmental degradation. The increasing population will increase the amount of waste generated. Unproperly waste management will harm the environment and human health. Therefore, we need proper waste management. There is a law governing waste management in Indonesia, namely Law No. 18 of 2008 concerning Waste Management [2], but the application of waste management under the law is still not optimal.

The case has occurred in DKI Jakarta, where the city is most populated in Indonesia. In the city, waste management is still not appropriate because there are still many people dispose of the waste into the landfill without sorting out at the source first. Around 90% of the waste is disposed of in the landfill [3], and around 88.65% of the people have not yet sorted their waste [4]. The inappropriate waste management system will increase the load capacity of the Bantargebang landfill so that the landfill capacity will quickly be fully charged and need another location for the new landfill site. Because DKI Jakarta is a densely populated area [5], finding a location for the new landfill site is very difficult.

An alternative to reduce the volume of waste entering the landfill is to use Waste to Energy Plant.
as a waste processor. There are two types of processes in waste to energy, namely anaerobic digestion and thermal processes [6]. For anaerobic digestion, the processed waste is in the form of organic waste. With a process without oxygen, organic waste will produce energy in the form of biogas [6]. For thermal processes, there are various kinds of technology that can process waste into energy. These technologies include pyrolysis, gasification, incineration, and RDF. If compared with the other technologies, incineration technology is the best choice technology when viewed from terms of the commercial use range, the number of power plants globally, and thermal efficiency [7]. This strength is a consideration using incineration technology for Waste to Energy Plant.

Besides that, there is research that argues that the incineration system is the system that provides the most economic benefits and is the most environmentally friendly [8], but other researchers have different opinions. They argue that the incineration system has not been able to reach a sufficient economic level [9,10]. From the conflicting results of the study, the authors argue that the incineration system costs depend on the waste capacity and Air Pollution Control (APC) system. The function of the APC System is to reduce the number of emissions resulting from the incineration process. It is the reason that makes incineration the best waste management option [11]. For waste capacity, there is a minimum capacity for the incineration process to run efficiently. Small capacity incinerators tend to have higher costs, so they are less efficient [12]. The minimum waste capacity for Waste to Energy Plant can operate efficiently is around 240 tons/day [13]. Government supporting is needed so that people can receive incineration technology to process their waste. It can be form regulations about air pollution control, energy management regulation, and industrial improvement regulation. They function to set environmental standards and provide financial incentives for waste treatment using incinerators [14].

Related to Waste to Energy plant with incineration technology, in Indonesia, there is a waste to energy pilot project located at the Bantargebang Landfill. Waste that goes into the Pilot Project is a waste that originates from DKI Jakarta. The obstacle faced in the application of the Pilot Project is the type of waste produced is still in the form of mixed waste where the organic waste composition as the most component of waste. As a result of this, the heating value of waste is estimated to be lower than the minimum heating value of waste supplies for combustion. Besides that, the condition of mixed waste also has the potential to cause damage to the Waste to Energy Pilot Project equipment due to the presence of large-sized waste. It is necessary to have a waste pre-treatment unit to process waste before entering the incineration process to minimize these possibilities.

Related to the waste pre-treatment unit for the Waste to Energy Pilot Project, there have been previous studies that discussed various ways of managing waste before entering the incineration process, which includes the basics of separation, reduction in size, and thermal and biological treatment [15]. The studies have not yet discussed the importance of waste pre-treatment units in improving the quality of waste supply for the incineration process. Therefore, this study will discuss the waste pre-treatment unit important roles for Waste to Energy Pilot Project. The purpose of this study is to explore the waste pre-treatment unit roles to support the Waste to Energy Pilot Project activities by sorting waste that will enter the incineration process. This study will provide insight into Waste to Energy Plant stakeholders regarding the importance of the pre-treatment unit for mixed waste before entering the incineration process.

2. Materials and Methods
This study uses a mixed method. The quantitative method used is the calculation of the calorific value and the estimated composition of waste to the quality standard product. Table 1 is the data used for the analysis of the waste pre-treatment unit roles for Waste to Energy Pilot Project activities. The qualitative method used is in the form of a survey result from the waste pre-treatment unit in the Waste to Energy Pilot Project. The results of this survey are observations related to equipment, processes, and conditions that exist in the waste pre-treatment unit. There are two types of data in this study, namely primary data and secondary data. Primary data come from survey results, while secondary data come from various literature studies that provide data needed.
3. Theory

3.1. Waste hierarchy

The waste hierarchy is a waste management framework that prioritizes waste reduction, reuse, and recycling activities [16]. The waste hierarchy provides the most preferred waste management options up to the one rarely preferred. The purpose of the hierarchy is to strive for material circulation to increase the product's useful life and reduce material extraction from nature to reach sustainability [17,18]. Solid Waste Framework can be seen in figure 1.

| No. | Waste Type         | Waste Composition (%) | Heat value of the waste type (kJ/kg) |
|-----|--------------------|-----------------------|--------------------------------------|
| 1   | Organic Waste      | 52                    | 1,920                                |
| 2   | Paper              | 17                    | 8,082                                |
| 3   | Plastic            | 17                    | 20,932                               |
| 4   | Wood               | 1                     | 8,256                                |
| 5   | Textiles           | 1                     | 6,795                                |
| 6   | Metal              | 1                     | 0                                    |
| 7   | Glass              | 2                     | 0                                    |
| 8   | leather            | 0                     | 10,550                               |
| 9   | Construction waste | 0                     | 0                                    |
| 10  | Hazardous Waste    | 0                     | 0                                    |
| 11  | Others             | 9                     | 0                                    |
|     | Total              | 100                   |                                      |

Table 1. Waste composition in DKI Jakarta [19,20]

Figure 1. Waste management options in the waste hierarchy [21]
3.2. Waste to Energy Plant using incineration technology

Waste to Energy Plant with incineration technology is a waste processing unit that can convert waste into energy by combustion at 850°C so that the energy produced can be used as heat energy and electric power sources [6,22].

The waste to energy plant consists of five main parts, namely: the waste receiving and handling unit, the combustion unit, the energy recovery unit, the combustion gas emission cleaning unit, and the bottom ash handling unit [23]. Although incineration technology can process mixed waste [24], the waste receiving and handling unit is still needed, at least to homogenize the waste composition to achieve combustion efficiency [25]. The homogenized waste then enters the combustion unit. There are three stages of the combustion process in the combustion unit, namely the pyrolysis stage at temperatures less than 200°C, the gasification stage at 200-700°C, and the oxidation stage at 850°C [23]. The process of burning waste will produce three products, namely heat, gas, and ash. The heat will be converted into electrical energy by the energy recovery unit. The gas will be cleaned in the combustion emission cleaning unit, so it is safe for the environment. The ash will enter the ash handling unit. Ash consists of two types, namely bottom ash and fly ash. Bottom ash is classified as non-hazardous waste so that it can be directly managed by the Waste to Energy Plant. Fly ash is classified as hazardous waste, so it needs special handling from an agency appointed by the government to manage hazardous waste [23].

3.3. Waste supply requirements for combustion

The waste treatment process using Waste to Energy Plant has requirements for waste that will enter the combustion process. These requirements include: 1) waste has no potential to damage equipment and safe for the environment; 2) waste has a minimum calorific value for the incineration process of 7 MJ / kg [26]. The purpose of the heating value is so that the waste can do self-combustion to minimize operating costs [13]. Besides the heating value, incinerator capacity is another factor that can minimize costs. Smaller plant capacity has lower total incinerator costs.

The assessment of the achievement of waste requirements is by the heat value amount and rate of product quality (Q). Rate of product quality is part of the Overall Equipment Effectiveness (OEE) measurement [27]. The Q formula is as follows [27]:

\[
Q = \frac{\text{Proceeded a Nount} - \text{Defect a Nount}}{\text{Proceeded a Nount}} \times 100\% \tag{1}
\]

4. Results and Discussion

4.1. Overview of waste pre-treatment unit in the waste to energy pilot project

In general, a waste pre-treatment unit is a unit that processes waste so that waste is eligible to enter the Waste to Energy Pilot Project. In the process phase of the waste to energy plant, this unit is part of the waste reception and handling unit [23]. Add to the previous theory [22] the waste receiving and handling unit also conduct waste sorting so that the quality of the waste that enters the incineration process is following the permitted waste requirements [26]. The explanation applies to regions where the waste management system is not yet right, like in Indonesia.

Based on field surveys in 2019, the waste sorting process in the waste pre-treatment unit is semi-manual sorting. The initial stage for waste that has entered the waste pre-treatment unit is the separation of bulky waste from the waste to be processed. This waste is usually furniture waste [28]. This sorting of waste is done manually by workers. By using an excavator, the waste-free of bulky waste enters trommel through a conveyor. A trommel is a tool used to separate waste by size. This trommel serves to separate the waste-free of bulky waste from organic waste. Organic waste is waste that falls from trommel because of its smaller than the trommel screen. Waste with size larger than the trommel screen will pass and enter the advanced sorting process, namely manual sorting done by
workers. In this process, waste is sorted according to size and type so that waste following the requirements, as explained in theory [26].

The size of the waste used for waste sorting is adjusted to the size of the pusher space when the waste feeding to the incineration process. If the waste size exceeds the pusher space, there will be a blockage, so inhibit the flow of waste that enters the incinerator and reduces the potential for tool damage. The explanation is following the waste requirements as described in the theory [26]. For the Waste to Energy Pilot Project, the maximum size of the pusher space is around 30 cm, so that the waste that is allowed into the incinerator is the waste that is less than 30 cm. The size varies depending on the distance of the pusher in each incinerator.

As explained earlier, the sorting waste purpose by type is to obtain a decent quality of waste. Organic waste, glass waste, B3 waste, and PVC waste are waste that is not allowed into the incinerator. Sorting the type of waste has influences in the combustion process. The reduction of organic waste serves to increase the calorific value of waste, the reduction of glass waste serves to minimize the amount of slag, the reduction of hazardous and PVC waste serves to reduce the harmful content of combustion [29]. In addition to these waste types, recyclables and reusables material are also sorted in the waste pre-treatment unit. Examples are plastic bottles and plastic cups. After sorting the waste manually by the employee, then the waste is taken to the bunker by truck.

4.2. Effect of Waste Pre-treatment Unit on Waste Quality

The main objective of the existence of a waste pre-treatment unit is to improve the waste quality Waste to Energy Pilot Project. Following the literature, the quality of waste base on the calorific value of waste, the content of hazardous materials that are in the garbage, and the composition of large-sized waste that can cause damage to the Waste to Energy Pilot Project equipment. This section will explain the potential for improving the quality of waste supply thanks to the presence of a waste pre-treatment unit.

Effect of waste pre-treatment unit on waste calorific value. One of the parameters to measure the quality of waste as a raw material for combustion is the heating value. As explained earlier that the heating value of waste in Indonesia, especially in DKI Jakarta, is lower than the standard heating value for the combustion process. The composition of the type of waste influence the heating value. The waste composition and heating value in DKI Jakarta are in Table 1.

Based on the data in Table 1, the heating value of DKI Jakarta mixed waste can be calculated in the amount of 6.08 MJ / kg. When compared with the minimum standard heating value of the combustion process's waste [26], the waste heating value is still below the minimum standard heating value of the combustion process's waste. That means that DKI Jakarta's waste does not meet the requirements of the waste for the combustion process. In Table 1, 52% of the waste is organic waste. When compared with other waste types, organic waste has the smallest heating value. The dominance of organic waste makes DKI Jakarta's waste have a heating value below the minimum heating value of the combustion process's waste.

4.2.1. Sorting by the waste type in the pre-treatment unit can increase the waste heating value. That known from simulating calculations. The assumptions used in the simulation calculation namely: 1) waste pre-treatment unit sort organic waste completely; 2) the recyclables & reusables material which sorted is plastic cups and plastic bottles, the amount of which is about 14% of the total amount of plastic [30]; 3) The amount of the PVC waste sorted is 3% of the total amount of plastic [31]. Based on these assumptions, the output waste heating value of the pre-treatment unit is13.5 MJ / kg. This value is higher than the waste heating value before waste entering the pre-treatment unit, and the heating value of the waste output of the pre-treatment unit also exceeds the minimum heating value of the combustion process's waste. That is following the theory, which explains that the reduction of organic waste can increase the heating value of waste supply for combustion [29]. The results of this simulation reinforce that the waste pre-treatment unit has an important role in increasing the heat value of waste that will enter the Waste to Energy Pilot Project incineration process.
4.2.2. Effect of waste pre-treatment unit on waste composition that potentially causes damage to incinerator equipment. As has been explained in the overview of the waste pre-treatment unit, several things can make incinerator equipment damage, namely the waste that exceeds the size of the equipment and the presence of glass waste in combustion. Adding to the theory [29], melt resulting from the combustion process of glass at operating temperatures above the melting point of glass can clog the furnace grate [32]. The potential damage of incinerator equipment can be seen by the Rate of Quality tools, by looking at the waste composition caused damage. From the value of a product that meets the standard quality [27], the potential damage value due to the large size and the glass waste is 0.1%. When compared with the composition data of waste types in Table 1, the amount of glass waste that needs to be reduced to obtain a standard quality is 1.99%. In contrast to glass waste, the amount of large-size waste reduction cannot be known yet because there is no preliminary data on the composition of large-sized waste. Nevertheless, the maximum composition of large-sized waste has been determined following the Rate of Quality tools is 0.1%.

4.2.3. Effect of waste pre-treatment unit on waste composition which produces hazardous gas emissions. Sorting waste types that have the potential to produce harmful gas emissions is one way to reduce the number of hazardous gas emissions, besides using Air Pollution Control (APC), as explained by theory [23]. Of the various types of waste, waste that has the potential to produce harmful gas emissions is hazardous waste and PVC waste. Reducing the hazardous waste can reduce the content of heavy metals, Cl, and Br, while reducing PVC can reduce the chlorine content [29]. Several articles explained that heavy metals, Cl, and Br have adverse effects on human health. Exposure to heavy metals can enter the human body through various means, namely through oral, inhalation, or contact with skin. Long-term exposure to some heavy metals can cause brain, lung, liver, and kidney damage [33]. Such as heavy metals, Cl and Br, can also adversely affect human health. Cl and Br will form dioxins/furans at high combustion temperatures in the presence of oxygen [34]. The combustion temperature of 600°C is the combustion temperature which produces the most dioxin/furan [35]. The condition is very likely to occur in the waste incineration process because, in the incineration process, there are three stages of combustion, one of which is in the range of 200-700°C [23]. The effect of dioxin on human health is the occurrence of hormonal disorders, the occurrence of genetic mechanism modification, the onset of cancer, nervous system disorders, miscarriages, and birth defects [36]. Hazardous and PVC waste sorting in the waste pre-treatment unit is a technical solution to reduce the adverse effects of various substances contained in hazardous waste and PVC waste. Based on the composition of DKI Jakarta waste in Table 1, the type of hazardous waste is zero. The might have happened because in DKI Jakarta there were temporary storage and hazardous waste management sites following The Republic of Indonesia Government Regulation Number 101 of 2014 concerning Management of Hazardous and Toxic Waste Material [37] or perhaps because, at the time of the waste composition research, the community did not produce hazardous waste. Further research is still needed to answer the certainty of these possibilities. Hazardous waste sorting in the waste pre-treatment unit is a preventive effort in case hazardous waste enters Waste to Energy Pilot Project because the sorting system in the community is still not well. With the waste pre-treatment unit, hazardous waste can be controlled with a minimum of 0.1% of waste that can enter Waste to Energy Pilot Project. This is consistent with the theory [27], which explains that the minimum value of a product meets the standard quality is 99.9%. The theory applies also to PVC waste. Table 1 shows that the composition of plastic waste is 17%. From the theory [31], around 3% of the total plastic waste is PVC waste. Base on the study, it can be seen that the amount of PVC waste is 0.51% of the total waste amount. As with hazardous waste, the minimum allowable composition is 0.1%, plastic waste is also the same. Based on this, the potential reducing PVC waste is 0.41%.
4.3. Effect of waste pre-treatment unit on waste capacity entering the waste to energy pilot project

The theory [13] shows the relationship between incinerator costs and plant capacity. A large amount of waste will increase plant capacity so that the total cost of incinerators increases. A proper waste management system produces the amount of waste supply for incinerator smaller than a system without sorting. In this case, the waste pre-treatment unit plays a role in reducing the amount of waste through the sorting process. As explained previously, organic, glass waste, B3 waste, PVC, and waste that can be recycled/reused are the waste that is separated in the waste pre-treatment unit. If the assumptions used are the same as the assumptions used in calculating the output waste heating value of the pre-treatment unit, then the amount of waste reduction is 57.89%. Based on the theory [13], the reduction of the amount of waste will affect the decrease in the incinerator capacity so that it can save the total incinerator cost.

4.4. The role of the waste pre-treatment unit in the waste hierarchy

Sustainability can be reached through waste management based on the Waste Management Hierarchy [17][18]. Figure 1 shows that incineration is a waste management options after the reduction, reuse, and recycle waste activities. That is consistent with the theory [16], which explains that the reduction, reuse, and recycle waste activities are the main activities in the waste hierarchy. If they are not running optimally, the waste hierarchy is also less effective in achieving sustainability.

In the case of DKI Jakarta, waste segregation has not yet run optimally. That illustrates that the main activities of the waste hierarchy are not going well. If mixed waste from the community directly enters incineration without a sorting process for recycling/reuse in the waste pre-treatment unit, the waste hierarchy is less effective in achieving sustainability. The waste pre-treatment unit plays a significant role in this case. With the presence of a waste pre-treatment unit, the sorting activities for recycling and reuse activities will be more optimal so that the waste hierarchy becomes more effective compared with activities without a waste pre-treatment unit. In this case, the waste pre-treatment unit functions to facilitate the waste hierarchy approach in Waste to Energy Pilot Project activities [37].

5. Conclusion

The Waste to Energy Pilot Project with mixed waste raw materials requires the presence of a waste pre-treatment unit. This unit plays a significant role in the sustainability of the Waste to Energy Pilot Project. The waste pre-treatment unit can improve the waste quality, include the waste heating value, the waste composition that has the potential to damage the equipment, and the waste composition that has the potential to produce harmful gas emissions. The other important role of the waste pre-treatment unit is reducing the capacity of incinerators to reduce the total cost of incinerators. In addition to these roles, the waste pre-treatment unit also facilitates activities that support the waste hierarchy in Waste to Energy Pilot Project activities.

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