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Original Research

Material Recovery Facility (MRF) as an Alternative for Specific Waste Management for Hazardous Materials: Evidence from Semarang City, Indonesia

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Abstract

Hazardous and toxic waste (HW) is waste that cannot be decomposed and can have a negative impact on the surrounding environment. Semarang City is one of the large cities in Indonesia that does not yet have specific waste management for hazardous and toxic materials, especially in the residential and office sectors. This research aims to simulate the management of hazardous and toxic waste using a Material Recovery Facility (MRF) in the residential and office sectors. This paper analyzes the current situation of processing facilities and plans the capacity for managing toxic hazardous waste using MRF. This research uses an analysis of existing hazardous and toxic waste management, followed by population projections and the resulting waste generation. Waste in Semarang City in 2031 amounted to 862.65 t/d, which includes all types of city waste, including HWs, which can be recycled at the MRF with an efficiency of 73.03%. The composition of residential waste is dominated by infectious types of B3 waste at 82.9%, followed by toxic types of B3 waste at 6.9%, flammable at 5.8%, and corrosive at 4.4%. Meanwhile, the largest amount of B3 waste from the office sector is generated from corrosive B3 waste, namely 44.9%. This is followed by flammable B3 waste at 20.1%, toxic waste at 19.6%, and infectious waste at 15.4%. The planned MRF will improve waste processing performance and will not impact land in landfills. MRF helps improve development in Semarang City by greatly reducing the burden of waste problems. Apart from that, MRF is a sustainable system that has great economic value for the Semarang City government at the time of its implementation.

Keywords: material recovery facility, hazardous and toxic material, recovery factor, waste generation

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Introduction

Hazardous and toxic wastes (HWs) are wastes, that due to their characteristics (such as toxicity, flammability, carcinogenicity, reactivity, etc.), can cause harm to the environment or health [1, 2]. Hazardous and toxic waste can be defined as waste that cannot be decomposed and can be detrimental to human health or living organisms if disposed of carelessly [3]. HW management is a global problem that occurs in both developing and developed countries [4, 5]. Ichtiakhiri and Sudarmaji [6] explained that the content of hazardous and toxic waste materials such as metals can have negative impacts on health, such as neurotoxicity, and mental, kidney, and liver disorders. Specific waste materials that are hazardous and toxic if included in the MSW composting mixture will produce compost that is not optimal because it will most likely exceed the limits of heavy metals permitted in compost [7]. Apart from that, hazardous and toxic materials also affect the processing of waste with biogas because if they are mixed with metal, iron, or plastic, they can have a negative impact on the production of methane (CH_4) and also on the effectiveness of biogas production.

The hazardous and toxic waste (HMW) management system includes several stages, namely collection, transportation to processing facilities, and proper final disposal. Formal collection is needed to reduce risks and exploit the value of waste [8]. Collaboration between formal and informal parties is really needed to reduce HWs and is an ideal realization, especially in developing countries where informal actors can gain economic benefits while preserving the environment [9]. HMWs handle many classified hazardous wastes with varying properties and characteristics that have different impacts on humans and the environment, thus requiring specific types of processing. Some of the problems that exist in handling HWs are that differences in characteristics will limit certain types of processes [10]. The magnitude of the impact caused will influence the priorities of stakeholders in decision-making on HW management, and finally, even if processed correctly, dangerous processing residues may require further processing [2]. To ensure technical feasibility and safety for society and the environment, the location, technology, and capacity of HW processing facilities need to be carefully selected and calculated. In the planning stage, it is necessary to consider all important aspects of HW management, including preventive measures, proximity, and waste hierarchy.

The city of Semarang is one of the large cities in Indonesia that does not yet have specific waste management for hazardous and toxic materials. Management of hazardous and toxic waste is only specifically for medical waste, while other sectors such as residential and office areas are not yet served [11]. In fact, based on Indonesian Government Regulation Number 27 of 2020 concerning specific waste management, the government needs to plan waste management for specific types of hazardous and toxic materials, which includes five aspects consisting of technical management aspects, regulatory aspects, financing aspects, institutional aspects, and community participation aspects. The waste generated every day in Semarang City is around 1,276.74 t d^{-1} and is processed at the Jatibarang Landfill, including hazardous and toxic waste without any additional processing [11-13]. Even though the percentage of hazardous and toxic waste in municipal waste is relatively small, the negative impacts and relatively long storage period of waste are considerations for the government to build a separate hazardous and toxic waste collection system.

Based on current conditions, a separate place for handling hazardous and toxic waste is needed because certain types of waste require storage for three months before being handed over to third parties or hazardous and toxic waste collection officials. Therefore, this research proposes processing hazardous and toxic waste using a material recovery facility. Material recovery facilities (MRF) are an important component of municipal waste management systems because they often determine the percentage of recyclable waste collected [14]. This research carries out a simulation of specific waste processing for hazardous and toxic materials in Semarang City, which takes into account existing conditions by analyzing waste generation, composition collection, and measurements. The creation of waste processing scenarios is carried out by making projections on the number of residents and office facilities. It is hoped that the results of the research can be a consideration for the government in managing hazardous and toxic waste.

Materials and Methods

Study Area and Boundaries

This research was conducted in residential and office areas in the Semarang City area by sampling the residential and office sectors. This sector was chosen because of the unavailability of additional management and processing to handle hazardous and toxic waste. Sampling in the residential sector is based on population density in three categories, namely high, medium, and low density. Adopting Azwar's (2020) research, the determination of population density categories is based on the SPSS program [15]. The determination of this category is based on the assumption that the subject population scores are normally distributed. Meanwhile, waste sampling in the urban sector is carried out randomly at government offices in Semarang City. There are 7 specific waste generation characteristics of hazardous and toxic materials analyzed in both sectors, which can be seen in Table 1.

Data Analysis

Field Survey

A field survey was carried out to collect samples in the form of specific types of hazardous and toxic waste produced by residential areas and offices in Semarang City. Sampling is an initial method that functions to determine the amount and composition of hazardous and toxic waste. Sampling refers to the SNI 19-3964-1994 guidelines regarding methods for collecting and measuring samples of waste generation and composition, which are carried out for eight consecutive days [17]. Apart from that, calculations based on population are also based on the Semarang City Environmental Service (2019) study of Semarang City waste generation 2019, where the calculation for determining the number of samples uses high, medium, and low population density. The formula for calculating the number of settlement samples can be seen in the formula.

$$K = \frac{S}{N}$$

$$S = Cd\sqrt{T_s}$$

Where in formula 1, K is the number of examples of waste generated from housing, S represents the number of samples per person, and N is the number of people per family, assuming that 1 family has 5 members [17]. Meanwhile, for calculating the office sample, S is the number of samples for each type of non-residential building, Cd represents the non-residential building coefficient, which has a value of 1, and Ts is the number of non-residential buildings.

After calculating the number of samples, it is possible to calculate the generation of hazardous and toxic waste in the residential and office sectors produced in Semarang City by calculating the generation carried by carts or three-wheeled vehicles. The sampling method used is based on Damanhuri [18], which calculates waste generation at domestic temporary dumping sites. The unit used to measure the type and characteristics of waste is % of wet weight [18]. Measurement of waste generation samples is carried out by placing the collected waste into a 40 L transport container and weighing it to determine the weight of the waste.

Data Analysis

Data analysis in this research uses software, namely SPSS and Excel, for planning. First, this research conducted secondary collection based on reports from the Central Statistics Agency in Indonesia to determine population growth, GRDP, and existing facilities in Semarang City. Next, the number of offices and population projections are calculated to determine trends in HW waste generation. Based on the calculations, the number of samples to be taken is also analyzed. After that, planning for HW waste management in Semarang City was carried out, and an analysis of the need for processing facilities was carried out.

Analysis of Existing Conditions

An analysis of the existing conditions in Semarang City is used as a consideration in building planning. The analysis takes the form of population analysis, physical conditions, and infrastructure for managing hazardous and toxic waste. Population analysis is needed to determine population density because it influences the generation of hazardous and toxic waste. Physical conditions are used to determine the geographical conditions and characteristics of the planning area.

Calculation of Population Projections and Office Facilities

Population projections are calculated based on arithmetic, geometric, and least square method approaches for the next 10 years. Sampling method showed in Table 2.

Table 1. Specific waste generation characteristics of hazardous and toxic materials.

No	Code	Waste description	Danger Category	Characteristics	Waste Type *
1.	B104d	Packaging hazardous and toxic materials	2	Poisonous	Detergent packaging, Dish cleaning packaging Floor cleaner packaging Hand-sanitizer packaging Beauty product packaging Hair oil packaging
2.	B104d	Packaging hazardous and toxic materials	2	Corrosive	Clothing softener packaging
3.	B3371	Pharmaceutical product packaging	2	Poisonous	Medicine packaging
4.	A102d	Battery/batteries	1	Corrosive	Used Battery
5.	B3214	Ink packaging	2	Flammable	Used ink containers and cartridges
6.	B107d	TL lamp	2	Poisonous	Used TL lamp
7.	A3371	Clinical waste has infectious characteristics	1	Infectious	Masks, sanitary napkins, and diapers

Notes: * Based on [16] and Republic of Indonesia government regulation number 22 of 2021

Table 2. Sampling method.

Calculation	Formula or Method	Result
Number of surface samples	$K = \frac{S}{N}$	Population Density (Sample) Height = 112 Sample Medium = 108 Sample Low = 46 Sample
District population density sample	Processed using SPSS Low category = X < 5.18 Medium = 5.18 < X< 9.31 High = 9.31 < X	Category District Low = Tugu Medium = Banyumanik High = Gayamsari
Office sample	$S = Cd\sqrt{T_s}$	13 office samples

The determination of the projection method is carried out through a correlation number test, where the method chosen is the one that has the smallest standard deviation. The results of the projection calculations show the percentage (%) of the annual population growth rate factor. This factor is used to calculate office facility projections. The projected number of offices can be calculated using Formula 3 [11].

$$\frac{Number\ of fices_{n-1}}{Total\ Population_{n-1}} \times = Total\ Population_n$$

Where n is defined as the year to be projected. The results of the projection calculation for office facilities can be multiplied by the average number of Semarang City office employees so that the amount of waste generated in this sector can be known.

Calculation of Projected Public Consumption and Composition of Hazardous and Toxic Waste

People's consumption patterns can be determined based on the GRDP (Gross Regional Domestic Product) per capita figure at constant prices. Economic growth has a big influence on increasing regional income. The higher the regional economic potential, the greater the GRDP value. Meanwhile, the types of hazardous and toxic waste are obtained from sampling results and calculated based on SNI 19-3964-1994 using the waste calculation formula as in Formula 4 [17].

$$\begin{matrix} Generation\ of \\ hazardous \\ and\ toxic\ waste \end{matrix} = Bs\ hazardous\ waste\left(\frac{\frac{kg}{person}}{day}\right) \times U$$

$$\begin{matrix} \%\ Composition\ of \\ Hazaradous\ Waste \end{matrix} = \frac{\begin{matrix} Weight\ of\ hazardous \\ waste\ composition \end{matrix}}{\begin{matrix} Total\ weight\ of \\ hazardous\ waste \end{matrix}} \times 100\%$$

Where Bs hazardous waste is the generation of hazardous waste and U represents the number of units producing hazardous waste. The units in this plan are people (residents) and employees. Then, the generation and composition of hazardous waste are calculated using formula 5. Meanwhile, the calculation of hazardous and toxic waste projections is done using formulas 6 and 7. Q_n refers to the waste generation in the next n years (kg); Q_t is the waste generation in the first year of calculation; C_s is the city improvement/growth; C_i is the growth rate of the industrial sector; C_p is the agricultural sector growth rate; C_{qn} represents the rate of increase in per capita income; and P is the population growth rate.

$$Q_n = Q_t(1 + C_s)n$$

$$C_s = \frac{[1 + (C_i + C_p + C_{qn})/3]}{1 + P} \times 100\%$$

Planning for Hazardous and Toxic Waste Management

Planning for hazardous and toxic waste management using MRF technology. Operational technical aspects of waste management for specific types of hazardous and toxic materials include collecting points for the residential sector, containers for the office sector, and transportation to collection points for hazardous and toxic waste. Hazardous waste management with MRF goes through two stages of analysis, namely feasibility analysis and initial planning [19]. Feasibility analysis includes waste management plans, concept design, economic considerations, ownership and operations, and business systems. The initial planning stage includes process flow diagrams, recycling material calculations, material balance, loading rate, layout, and final planning. In calculating the MRF design stages using Formula 8, the loading rate is used to determine the amount of waste entering the MRF facility and to determine the capacity of the equipment used for operations. The amount of waste that can be recovered can be calculated using formula 9 [20].

$$Loading\ rate\left(\frac{ton}{hours}\right) = \frac{Garbage\ weight\ (ton/day)}{Processing\ time\ (hours/day)}$$

$$Recovery\left(\frac{ton}{day}\right) = n(\%) \times Waste\ generation\ (ton/day)$$

Results and Discussion

In general, the pattern of handling specific waste for hazardous and toxic materials in Semarang City currently still applies the old pattern or paradigm, namely that waste from the source (no sorting) is collected directly at the TPS by cleaning staff and then transferred into waste containers. There are two methods of transfer, namely manual and mixed. Manual transfer is used in direct individual collection patterns, while mixed transfer is used in indirect individual collection patterns. At the transfer location, or TPS, no sorting is carried out, but they are transported directly to the Jatibarang TPA. The Jatibarang final waste processing location still applies an open dumping system so that it does not sort hazardous and toxic waste.

The Existing Condition of Hazardous Waste Treatment in Semarang City

Based on the Semarang City Central Statistics Agency in 2020, the total population in 2019 was 1,814,110 people, with a GRDP value of IDR 140,326.26 (million rupiah) and a growth rate of 5.89%. The largest GRDP contributor was in the processing industry sector, with a value of IDR 35,950.86 million in 2019. Meanwhile, the smallest GRDP contributor was in the water supply, waste management, waste, and recycling sectors, with a value of IDR 120.68 million. From 2016 to 2019, the GRDP value of the city of Semarang experienced an increase every year, which shows that the level of economic growth, regional income levels, per capita income, changes or shifts in economic structure, inflation rates, and the welfare or prosperity of the residents of Semarang City are increasing.

Hazardous Waste Processing Scenario in Semarang City

Population and GRDP Projections

Population size is one of the factors that influences waste generation [21]. Population projections are needed to determine predictions of population growth at the end of the planning year, namely 2031. The selected population projection method is the one with the smallest standard deviation after calculating existing data. The population projection results can be seen in Table 3, which presents the total population, GRDP per capita, and industrial GRDP.

The amount of waste generated is considered to be in line with community consumption patterns and regional economic growth. In his calculations,

Table 3. Population, GRDP of business services, and economic growth rate of Semarang City from 2015–2019.

Year	Total Population	Based on current price (million rupiah)	On the basis of constant prices (million rupiah)	Growth rate (%)
2015	1,701,114	134,205.84	191,547.22	5.82
2016	1,729,083	147,049.32	115,542.56	5.89
2017	1,757,686	159,622.73	123,107.02	6.55
2018	1,786,114	159,622.73	131,137.26	6.52
2019	1,814,110	191,547.22	140,326.26	6.86

Table 4. Population and GRDP Projection.

Year	Total Population (people)	GRDP Per Capita (Million Rupiah)	Industrial GRDP (Million Rupiah)	Agricultural GRDP (Million Rupiah)
2020	1,842,359	113.57	38,024,766.21	1,105,642.40
2021	1,870,608	122.16	40,218,305.35	1,121,716.18
2022	1,898,857	131.39	42,538,383.44	1,137,789.96
2023	1,927,106	141.33	44,992,300.14	1,153,863.74
2024	1,955,355	152.01	47,587,776.22	1,169,937.52
2025	1,983,604	163.50	50,332,977.83	1,186,011.30
2026	2,011,853	175.87	53,236,542.21	1,202,085.08
2027	2,040,102	189.16	56,307,604.84	1,218,158.86
2028	2,068,351	203.46	59,555,828.23	1,234,232.64
2029	2,096,600	218.84	62,991,432.26	1,250,306.42
2030	2,124,849	235.39	66,625,226.38	1,266,380.20
2031	2,153,098	253.18	70,468,643.60	1,282,453.98

the increase in agricultural and industrial GRDP is in line with the projected increase in annual waste generation. This shows that increasing activity in the agricultural and industrial sectors increases waste generation [22]. Population and GDRP Projection presented in Table 4.

The development of office facilities is adjusted to population growth. In 2020, there will be 407 office facilities, and after being projected for the next 10 years, in 2031, office facilities in Semarang City will increase to 468.

Projection of Hazardous Waste Generation

The percentage of waste generation is usually multiplied by the population to determine domestic waste generation because there is a linear relationship between waste and population [23]. The greater the population, the more domestic waste is produced. Table 5 shows that the positive correlation with the amount of HW waste is in line with income. For example, the production of HW waste in high-income settlements is greater than in low-income settlements. This is supported by research by Otoniel [24], which states that generational studies show that there are variations in container types according to income, where HW packaging in high income communities is greater than in low income communities. The sampling results show that the composition of hazardous and toxic waste that is mostly produced in the residential sector is infectious type waste, which reaches 82.87% of the total waste. The waste with the second highest composition is toxic, amounting to 6.91%. Then followed hazardous and toxic waste, flammable, and corrosive types. Meanwhile, in the office sector, the dominant waste is the corrosive type at 44.91%, which generally comes from used batteries. Table 6 shows the composition of hazardous and toxic waste in Semarang City.

Based on the results of predictions of the population of Semarang City for 10 years using arithmetic methods and analysis of the composition of waste produced in Semarang City, the volume of waste stored in the MRF until 2031 is presented in Table 7. Predictions of waste generation are used because they are directly proportional to the increase in population and economic growth in a region. It is estimated that in 2031, waste in the residential and office sectors will reach 0.022 kg/person/day and 0.0078 kg/person/day, respectively.

Scenario: Hazardous and Toxic Material Waste Processing

Material Recovery Facility

Sorting is the beginning of all forms of waste management because sorted waste has different treatments and a higher selling value [25, 26]. MRF is one of the technology choices for sorting waste in landfills at 3R temporary disposal sites. MRF is a component of municipal waste (MSW) systems that is considered because it often determines the percentage of recyclable waste collected [27]. Research conducted by [28] analyzed the impact of MRF on the environment and economic sustainability. This technology is useful for

Table 5. Results of the sampling of hazardous and toxic materials for the residential and office sectors.

Description Weight (kg)		Average Waste Generation (Volume/day)		Average Waste Generation (Volume/person/day)	
		Volume (l)	Weight (kg)	Volume (l)	
Domestic Sector	High	11.242	67.042	0.008	0.0498
	Medium	9.944	52.954	0.007	0.0393
	Low	1.531	18.01	0.001	0.0134
	Average	7.572	46.002	0.005	0.034
Office Sector		1.666	6.607	0.007	0.0267

Table 6. Composition of hazardous and toxic waste in the residential and office sectors.

Composition	Domestic sector		Office Sector	
	Kg	%	kg	%
Flammable	10.54	5.8	2.68	20.09
Corrosive	8.02	4.41	5.99	44.91
Infectious	150.61	82.87	2.05	15.37
Poisonous	12.57	6.91	2.62	19.64
Total	181.74	100	13.33	100

Table 7. Projection of hazardous and toxic waste generation in the residential and office sectors.

Year	Domestic Sector				Office Sector			
	kg/day	kg/person/day	L/day	L/person/day	kg/day	kg/person/day	L/day	L/person/day
2021	31.5	0.017	191.7	0.102	32.9	0.0067	130.6	0.027
2022	32.8	0.017	199.1	0.105	34.5	0.0068	136.7	0.027
2023	34.1	0.018	206.9	0.107	36.0	0.0069	142.8	0.028
2024	35.4	0.018	215.1	0.11	37.6	0.0071	149.2	0.028
2025	36.8	0.019	223.6	0.113	39.3	0.0072	155.8	0.028
2026	38.3	0.019	232.4	0.116	41.0	0.0073	162.5	0.029
2027	39.8	0.020	241.7	0.118	42.7	0.0074	169.5	0.029
2028	41.4	0.020	251.3	0.122	44.5	0.0075	176.6	0.030
2029	43.0	0.021	261.4	0.125	46.4	0.0076	183.9	0.030
2030	44.8	0.021	271.9	0.128	48.3	0.0077	191.5	0.030
2031	46.6	0.022	282.9	0.131	50.2	0.0078	199.2	0.031

processing aluminum, high density polyethylene, plastic film, and PET. These waste management facilities can also produce solid recovery fuels used in power generation and biocells from organic fractions for composting and creating safe landfills [28].

Waste that goes to the landfill before being landfilled will go to the MRF for sorting. The MRF selection aims to sort hazardous waste that is mixed with other domestic waste when it enters the landfill and separate waste that still has recycling value. The percentage of total waste recycled at MRFs is generally between 50%–70% [29]. The recovery value is determined by the waste recycling potential of each component during the waste management process [30]. The recovery factor is calculated by multiplying the percentage of recovery factor for each type of waste by the amount of waste produced per day [20, 31]. The recovery factor is a value factor that determines the percentage of each type of waste that can be reused and is also a measure of the efficiency and effectiveness of the MRF in extracting valuable recyclable materials from incoming waste. This shows the proportion of materials that have been successfully sorted, separated, and prepared for recycling or reprocessing [32]. The remaining waste that is recovered is a residue that cannot be processed or disposed of in landfills. Each waste composition has a different recovery factor [33]. The recovery factor values are listed in Table 8.

Table 9 shows that the mass of waste that can be recycled is 630.38 t d^{-1} out of 862.65 t d^{-1} of waste collected, with a recycling percentage of 73.07%. The amount of waste is calculated as the sum of waste generation and hazardous waste. The remaining mass that cannot be processed can be burned or thrown into a landfill. A recycling percentage of 73.07% is enough to extend the life of the landfill. Overall, hazardous and toxic waste was collected at the waste disposal site for hazardous and toxic materials and then processed through an incinerator, amounting to 37.29 tonnes day^{-1}. The incinerator yield was 25% of the total input, namely 9.32 tonnes day^{-1}.

Table 8. Recovery factor values for types of waste.

Waste	Percentage
Organic	80%
Plastic	72.9%
Paper and Cardboard	64.42%
Glasses	45.1%
Fabric	0
Metal	83.63%
Rubber	34.84%

MRF loading rates can vary depending on several factors, including the size and capacity of the facility, equipment, and technology for sorting and processing, and specific recycling program requirements or regulations. The loading rate is higher if several materials are processed within a certain time period [34]. In 2031, the volume of waste produced per day is estimated to reach 10,903,767 L d^{-1} or 10903.77 m^3 /d. By knowing the level of MRF loading, the total land area required and the number of MRF operational facilities can be determined, as presented in Table 10. The processing layout at the MRF is adjusted to prioritize hazardous waste incinerators for maximum operational efficiency [35]. The MRF layout is also designed with operational efficiency in mind by considering the logical flow of materials and minimizing the movement of materials and labor in the area [36].

Storage and Hoarding

Hazardous waste from the MRF, Collecting Point, and office sector transportation will then be stored at a temporary disposal site for hazardous and toxic waste.

Table 9. Waste composition and processing recovery in 2031.

Composition	Percentage (%)	Waste mass (ton/day)	Volume (m^3/day)	Recovery factor (%)	Recovery Mass (ton/day)	Recovery volume (m^3/day)	Residual mass (ton/day)	Residual Volume (m^3/day)
Organic(1)	58.57%	505.28	6576.08	80.00%	404.20	5260.86	101.05	1315.22
Paper and Cardboard(2)	10.10%	87.14	1134.12	64.42%	56.13	730.60	31.00	403.52
Plastic(2)	16.20%	139.72	1818.49	72.90%	101.85	1325.68	37.86	492.81
Glassses(2)	2.27%	19.54	254.34	45.10%	8.81	114.71	10.73	139.63
Fabric(2)	2.24%	19.31	251.39	0.00%	-	-	19.31	251.39
Metals(2)	1.39%	12.01	156.34	83.63%	10.05	130.75	1.97	25.59
Rubber(2)	0.91%	7.83	101.92	34.86%	2.73	35.53	5.10	66.39
Other	2.92%	25.20	328.01	0.00%	-	-	25.20	328.01
HWs	5.40%	46.62	283.08	0.00%	46.62	283.08	-	-
Total	100	862.65	10903.7	-	630.38	7881.20	232.23	3022.56

Note: [31]1* [20]2*

Table 10. Land requirements for MRF planning for hazardous and toxic materials.

Plan	Area
Waste Receiving Room	1,620 m^2
Hazardous Waste Sorting Room	972 m^2
Waste Screening Room	270 m^2
Inorganic Waste Sorting Room	1,350 m^2
Waste Press Room	810 m^2
Total	5,022 m^2

The requirements for hazardous waste storage containers are adjusted according to the Minister of Environment Regulation Number P.12/MENLHK/SETJEN/PLB.3/5/2020 of 2020 concerning Storage of Hazardous and Toxic Waste, which states that hazardous waste storage containers must have a design and storage area [37]. Which is in accordance with the type, characteristics, and amount of hazardous waste to be produced/mixed. Solid, hazardous, and toxic waste stored in storage areas is placed in packages or drums with a capacity of 200 liters. Drum stacking is a maximum of three layers, with each layer provided with a pallet base measuring 1.5 m × 1.5 m.

Inertization is the process of solidifying waste using cement and other materials before the waste is landfilled in a sanitary landfill, controlled landfill, or final landfill facility for waste specifically for hazardous and toxic materials. Inertization can be carried out on waste ash/residue from incinerator combustion. Landfilling of specific waste for hazardous and toxic materials must be carried out in locations that meet the requirements. Location requirements that must be met in selecting a final landfill location for specific hazardous and toxic waste as determined by the Decree of the Head of the Environmental Impact Control Agency Number Kep-04/Bapedal/09/1995 concerning Procedures and Requirements for Landfilling Processing Results, Requirements for Ex-Processing Locations, and Locations of former landfills for hazardous and toxic waste and Government Regulation Number 27 of 2020 concerning Specific Waste Management [37, 38]. The type or category of landfill design for specific waste storage sites is adjusted to the type and characteristics of specific hazardous and toxic waste. The base layer used in landfilling specific hazardous and toxic waste is a category I, or secure landfill double liner. Drainage planning in landfills for hazardous and toxic materials is used to drain or pass rainwater that falls on the area around the landfill for hazardous and toxic materials.

Conclusion

Based on research carried out, planning through existing analysis is able to provide an illustration that the management of hazardous and toxic waste in Semarang City is not running optimally. MRF planning helps reduce the waste problem in Semarang City because the projected waste in 2031 is 862.65 t/d, which includes all types of municipal waste, including HWs, which can be recycled in the MRF with an efficiency of 73.03%. The composition of residential waste is dominated by infectious types of B3 waste at 82.9%, followed by toxic types of B3 waste at 6.9%, flammable at 5.8%, and corrosive at 4.4%. Meanwhile, the largest amount of B3 waste from the office sector is generated from corrosive B3 waste, namely 44.9%. This is followed by flammable B3 waste at 20.1%, toxic waste at 19.6%, and infectious waste at 15.4%. The planned MRF will improve waste processing performance and will not impact land in landfills. MRF planning helps improve development in Semarang City, reducing the burden of waste problems so that the city development budget allocation is better felt by the community. Facility location and capacity are the most important pieces of information generated in planning. Apart from that, MRF is a sustainable system that has great economic value for the Semarang City government at the time of its implementation. The benefits of building integrated facilities are proven and should be considered by decision-makers when outlining HW management strategies. One of the limitations of this research is that the projection of waste generation until 2031 does not take into consideration the separation of infectious waste, which has increased due to the pandemic and allows for a decrease in the following year. Therefore, it is hoped that future research can consider separation scenarios for HW waste, taking into account several conditions, such as the presence of a pandemic and normal conditions.

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Conflict of Interest

The authors declare no conflict of interest.

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