Journal of Natural Resources and Environmental Management
http://dx.doi.org/10.29244/jpsl.15.4.592

RESEARCH ARTICLE

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Evaluation of Hazardous and Toxic Waste Management in the Textile Industry in Karawang, West Java, Indonesia

Sugihhartati Dj Rachmawati, Alya Celiana Dewi, Gina Salsabila

Environmental Engineering, Faculty of Civil Engineering and Planning, Institut Teknologi Nasional, Bandung, 40124, Indonesia

Article History
Received 7 May 2024
Revised
27 September 2024
Accepted
27 December 2024

Keywords
evaluation, hazardous and toxic waste management, hazardous waste, likert, scoring

ABSTRACT

The manufacturing industry in this research was a polyester-producing manufacturing industry generating polyester chips and polyester staple fiber. The production process used raw materials and ancillary materials. Every raw material that was processed would produce products and by-products in the hazardous and toxic waste (HTW) category; in the form of Wastewater Treatment Plant sludge, diethylene glycol, residue from the laboratory test, incinerator ash, spin finish oil, bottles of chemical solutions, and contaminated rags. This research aimed to evaluate the implementation of the HTW management for the key activities based on the relevant regulations to prevent harm to human health and the environment. The implementation of the HTWs management activities was observed on site. The observations were then compared with the regulations, and their conformity was scored using a Likert Scale. The results of the evaluations, covering 5 key activities of the packaging and containment, collection, storing, transportation, and symbolling and labelling, gave the percentage of 90%, 91.70%, 96%, 100%, and 85.20%, respectively. The average conformity of the HTWs management with the regulations was 93% and included in the very good category. Improvements have still to be done by this industry to ensure their HTW management operates properly by reducing their wastes using the suitable methods, such as through raw material substitution, process modification to a more efficient process, and the use of environmentally friendly technology.

Introduction

Polyester is one of the most widely used materials in the fashion, design, and interior industries [1]. One of the leading polyester manufacturers in Indonesia is PT X. Thus, the manufacturing industry was used as a case study for this research. This industry was a textile or manufacturing industry that was one of the leading polyester-producing companies in Indonesia. This company produced polyester chips of 330,400 tons/year and polyester staple fiber of 198,000 tons/year.

The production process at this industry uses raw and ancillary materials, which contain flammable, corrosive, explosive, toxic chemicals, and heavy metals. Every raw material treated forms products and by-products in the form of waste. These wastes can be liquid and solid wastes in the hazardous and toxic waste (HTWs) categories. Therefore, it is necessary to handle the waste appropriately so that it does not harm humans or the environment. Various types of hazardous and toxic industrial wastes that do not meet the quality standards, once they are finally disposed of directly into the environment, are sources of pollution and environmental damage [2].

HTWs' management is expected to minimize the generation of HTWs by first reducing the waste generation at the source through the minimization of the use of raw materials or ancillary materials that were originally HTWs to become non-HTWs, and then selecting and implementing more efficient production processes that employ environmentally friendly technologies. The management covers the reduction, packaging, containment, collection, storage, transportation, and processing of HTWs [3].

Corresponding Author: Sugihhartati Dj Rachmawati rachmawatisdj@gmail.com Environmental Engineering, Institut Teknologi Nasional, Bandung, Indonesia.

Although this industry employed HTWs' management to manage its HTWs, evaluating the industry's HTWs' management was of utmost importance. It is necessary to analyze whether industry's HTWs' management complied with the relevant regulations so that the HTWs produced would not harm humans or the surrounding environment. Thus, this research aims to observe the management of HTWs in this industry, to evaluate it, and then to assess it following several legal bases regarding the management of HTWs, that is, the Indonesian Government Regulation Number 22 of 2021 concerning the Implementation of Environmental Protection and Management [4], Indonesian Minister of Environment and Forestry Regulation No. 12 of 2020 regarding the Storage of HTWs [5], and the Indonesian Minister of Environment Regulation No. 14 of 2013 stating HTWs' Symbols and HTWs' Labels [6].

Two previous studies have been conducted on the management of industrial HTWs. The first is the management of HTWs in Indonesia's shipbuilding industry [7]. The evaluation of HTW management carried out in this research referred to the older regulations, that is, Indonesian Government Regulation No. 101 of 2014, concerning the Management of Industrial HTWs and the company's standard operational procedures (SOPs) [7]. The second is the management of HTWs in many industries in China [8]. In this study, the HTW management evaluation referred to China's Catalogue of Hazardous Wastes, which lists the national and industrial standards issued by the Chinese Government from 2003 to 2018. Compared with both previous studies, this research, even though it used the older regulation of HTWs (Year 2013) for the HTWs' Symbols and HTWs' Labels, has the advantage of using the latest regulations (Year 2020 and Year 2021) to evaluate the implementation of industrial HTWs' management, as previously stated. Moreover, this study employed a Likert Scale to measure the implementation of industrial HTWs' management for each clause of the relevant regulations, while both previous studies [7,8] did not use specific methods to evaluate their implementation of industrial HTWs' management.

This research was thus conducted to evaluate and assess the implementation of HTWs' management at the manufacturing industry based on the related regulations, and by using the Likert Scale for each clause of the relevant regulations, it is therefore expected to provide a more accurate and comprehensive evaluation of the management of HTWs, so that humans and the surrounding environment will not be affected by the negative impacts of HTWs. This study will hopefully benefit research on industrial HTWs' management worldwide.

Materials and Methods

Study Area

The research took place at a polyester production facility located in Karawang, West Java, Indonesia. Covering an area of 50 hectares, the facility focuses on the manufacture of polyester chips and staple fibers. The location of this study is shown in Figure 1. There were three production process plants at this manufacturing industry to produce the polyester chips and the polyester staple fiber: (1) Purified Terephthalic Acid (PTA) Plant, (2) Polymer Plant, and (3) Fiber Plant. The production process plants are described as follows.

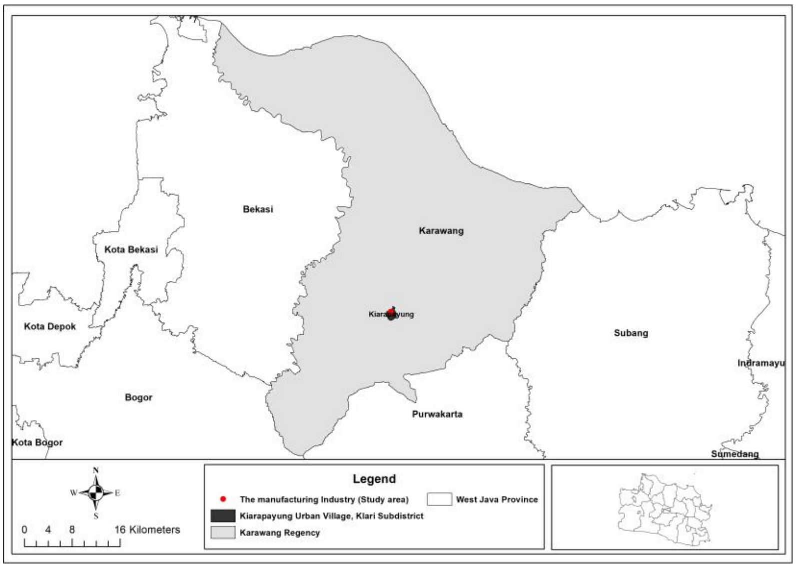

Figure 1. The manufacturing industry location.

Purified Terephthalic Acid Plant

At this stage, the PTA raw material is distributed to the Polymer Plant in two ways. First, the bulk PTA raw material was transferred directly and mechanically from the container to the silo tank for storage. Second, the raw PTA bag material was manually moved to the silo tank.

Polymer Plant

In the Polymer Plant, polyester was produced continuously and gradually (batch process). The technology used was John Brown Deutsche Engineering. The raw materials for the polyester manufacturing process were PTA and ethylene glycol (EG). PTA flour generated from the PTA Plant was fed to the Polymer Plant using a pneumatic conveyor; subsequently, PTA flour was converted into chips. This process will generate diethylene glycol (DEG) waste from the polymerization process.

Fiber Plant

At this stage, synthetic cotton/staple fibers containing 100% polyester were generated. The production stages consisted of the spinning line, the draw line, the extruder, and the recycling process. The spinning process transforms the melted polymer into filaments to form a tow. Next, the tow was treated on the draw line to create a polyester staple fiber. The extruder reprocessed low-grade polyester chips for use as raw spinning materials. The recycling process recycled the downgraded products into popcorn, which was then transformed into a Polymer Plant to be processed to become chips [9]. This process will produce spin finish oil. The spin finish oil is used in production machines within the Fiber Plant to reduce static electricity that occurs during the processing of polyester fibers in subsequent spinning machines.

In addition, these production processes generate wastewater, which is treated through a Wastewater Treatment Plant. The treatment plant produces sludge containing heavy metals, biodegradable organic compounds, and organisms that have the potential to become pathogenic. This occurs because, during the wastewater treatment process, physical and chemical processes take place. The production process requires quality control chemical (QCC) and quality control technical (QCT) analyses in the laboratory. These activities generate waste in the form of residues and used bottles from chemical solution packaging. In addition, these processes will generate waste in the form of contaminated rags used during spill incidents, as well as incinerator ash produced from manual incineration of contaminated rags and other hazardous tools that have been exposed during these production activities.

Data Collection

The collected data were primary and secondary data. Primary data on HTWs' management were obtained directly through interviews and field surveys. The secondary data consisted of production processes, HTWs' generation, HTWs' management data, and related regulations and references, which were collected through the desk study.

Data Processing and Analyzing

The data collected on-site regarding the HTW, the source, the state of matter, and the waste characteristics were checked with Appendix IX of Indonesian Government Regulation No. 22 of 2021 to determine the type of waste, waste code, and hazard category, and the data were then analyzed descriptively. Data on the quantity of HTWs were also collected on-site to determine the type of HTW that was generated most frequently, and then they were evaluated descriptively.

The implementation of the HTWs' management activities observed on site was compared with the regulation, and its conformity with the regulation was scored using a Likert Scale. A score of 1 was given to the HTWs' management activity that did not comply with the relevant regulations; 2, to the HTWs' management activity that was less compliant; and 3, to the HTWs' management activity that complied with the relevant regulations [10,11]. The regulations used for comparison were as follows: (1) for packaging and containment, storage was the Regulation of the Minister of Environment and Forestry No. 12 of 2020 [5]; (2) for collection and transportation was the Indonesian Government Regulation No. 22 of 2021 [4]; and (3) for symbols and labels was the Minister of Environment and Forestry Regulation No. 14 of 2013 [6].

There are other methods to evaluate compliance with the regulations, i.e., a Guttman scale and a Thurstone scale; yet, the Likert scale is easier to apply than the Guttman scale, and the Thurstone scale has a relatively high level of reliability [10]. The percentage of the score was calculated using Equation 1 to determine the category of achievement of HTWs' management implementation within the company. The achievement was considered 'very good' for scores of 81–100%, 'good' for 61–80%, 'fair' for 41–60%, 'poor' for 21–40%, and 'very poor' for 0–20% [12].

$$Percentage\ of\ Existing\ Score = \frac{Total\ Existing\ Score}{Ideal\ Score} x100\% \quad (1)$$

Results and Discussion

Results

Waste Generated

Based on the results of field data collection, several sources of HTW were identified in this manufacturing industry. The types of waste and their hazard categories are listed in Table 1. The characteristics of the HTW are shown in Table 2, while the amounts of waste generated from January to June 2020 are presented in Table 3. The HTW the company produces is derived from production and non-production process activities. Based on Indonesian Government Regulation No. 22 of 2021, HTW is categorized into Category 1 HTW and Category 2 HTW, and HTW sources are divided into three types: (1) specific sources, (2) non-specific sources, and (3) other sources. Categories 1 and 2 HTW reflect the danger level of HTW. Category 1 HTW has an acute and direct impact on humans and will have a negative impact on the environment. Category 2 HTW has a delayed effect, no direct impact on humans and the environment, and sub-chronic or chronic toxicity [4].

Table 1. The sources of the HTWs.

Waste	Source	Type of waste*	Hazard categories*
Wastewater Treatment Plant (WWTP) sludge	WWTP decanter area	Specific source	2
Diethylene glycol (DEG)	Polymerization process at the Polymer Plant	Specific source	1
Residue	Sample test of quality control chemical (QCC) analysis in the laboratory	Specific source	1
Incinerator ash	Waste burning in the incinerators	Specific source	1
Spin finish oil	Spinning machine at the Fiber Plant	Non-specific source	2
Used bottles for packaging chemical solutions	Product analysis in the laboratory	Non-specific source	1
Contaminated fabric	Maintenance, repair of machines & workshops at each plant	Non-specific source	2

*Source: [4].

HTW from specific sources is that left over from industrial processes or activities that can be specifically determined. HTW from non-specific sources is that of HTW, which is generally not generated from the main process, but from activities such as equipment maintenance, washing, corrosion prevention or corrosion inhibitors, scale dissolution, and packaging [4,13,14]. HTW from other sources is expired, spilled, does not meet product specifications, to be discarded, and/or used packaging [4].

Table 1 shows that the produced HTWs were generated from either a specific or a non-specific source. The HTWs that originated from specific sources were Wastewater Treatment Plant (WWTP) sludge, diethylene glycol (DEG), residue, and incinerator ash, which were produced by the WWTP (decanter area), polymerization process at the Polymer Plant, quality control chemical (QCC) analysis of each product sample test in the laboratory, and waste burning in the incinerators. QCC analysis in the laboratory uses chemicals to analyze each product sample from the Polymer Plant and the activities related to the production process. The HTWs that resulted from non-specific sources were those of spin-finish oil, used bottles for packaging chemical solutions, and contaminated fabric, which were generated from the spinning machine at the Fiber Plant, product analysis in the laboratory, and maintenance, repair of machines, and workshops at each plant. No HTW was obtained from the other sources. These HTWs were categorized based on Appendix IX of Indonesian Government Regulation No. 22 of 2021. It was revealed that DEG, residue, incinerator ash, and bottles used for packaging chemical solutions were included in Category 1 HTW. WWTP sludge, spin-finish oil, and contaminated fabric belong to Category 2 HTW.

Table 2. The characteristics of HTW.

Waste	State of matter	Waste code*	Characteristics	Hazard categories*
WWTP sludge	Solid	B305-5	Dangerous to the environment	2
DEG	Liquid	A305-2	Easy to light	1
Residue	Liquid	A338-3	Poisonous	1
Incinerator ash	Solid	A347-2	Dangerous to the environment	1
Spin finish oil	Liquid	B105D	Easy to light	2
Used bottles for packaging chemical solutions	Solid	A106D	Poisonous	1
Contaminated fabric	Solid	B110D	Easy to light	2

*Source: [4].

Table 2 presents the state of matter, waste code, and characteristics of each waste produced by this manufacturing industry. There are two states of matter: solid and liquid. HTWs classified as solid were those of WWTP sludge, incinerator ash, bottles used for packaging chemical solutions, and contaminated fabric. The DEG, residue, and spin-finish oil were liquid matter. It is shown that there are three characteristics of HTWs: (1) they are dangerous to the environment (for WWTP sludge and incinerator ash); (2) they are easy to light (for DEG, spin finish oil, and contaminated fabric); and (3) they are poisonous (for residue and used bottles for packaging chemical solutions). The waste code was based on Indonesian Government Regulation No. 22 of 2021 (Appendix IX).

Table 3. Monthly HTW generation.

Month	Waste							
	WWTP sludge (tons)	DEG (tons)	Residue (tons)	Incinerator ash (tons)	Spin finish oil (tons)	Used bottles for packaging chemical solutions (tons)	Contaminated fabric (tons)	Total waste
January	58.09	3.75	NA	NA	8.80	NA	2.90	73.54
February	65.90	7.50	NA	0.48	4.40	NA	2.30	80.58
March	53.89	11.25	NA	-	17.59	NA	2.10	84.83
April	62.66	3.75	24.29	0.48	13.19	NA	NA	104.37
May	28.89	NA	NA	NA	NA	NA	NA	28.89
June	64.49	NA	NA	0.48	NA	2.33	NA	67.30
Total waste	333.92	26.25	24.29	1.44	43.98	2.33	7.30	439.51
Monthly average	55.65	4.38	4.05	0.24	7.33	0.39	1.22	

NA: Not Available.

Table 3 displays the monthly average waste generation of this industry in January–June 2020. The total number of HTWs generated during that period was 439.51 tons. The highest HTW produced during that period was the WWTP sludge (333.92 tons, with a monthly average of 55.65 tons), whereas the incinerator ash produced 1.44 tons, with a monthly average of 0.24 tons. The residue, the liquid produced from the QCC analysis in the laboratory of each product sample test from the Polymer Plant and activities related to the production process, was only measured once (24.29 tons). Similarly, the bottles used for packaging chemical solutions generated from the product analysis in the laboratory were only weighed once (2.33 tons).

HTW Management

This manufacturing industry implemented HTW management activities in both nontechnical and technical aspects. The non-technical aspects of the industry's HTW management were the legal regulations used, institutions, financing, and work instructions for handling the HTW. The technical aspects include HTW reduction, packaging, storage, reduction, collection, transportation, symbolling, and labelling [15,16]. The HTW management activities of transportation, utilization, and disposal were executed by third parties in collaboration with this industry.

HTW Reduction

The HTW reduction of B3 waste was only carried out for bottles used for packaging chemical solutions. Bottles that no longer contained chemical solutions were not thrown away, but were reused for laboratory needs, such as storage of blank solutions in large quantities, storage of solution stocks, and as containers for taking sample fluids from Polymer Plants, Fiber Plants, and utility plants. Before the bottles were used, they were washed in the washing area. The bottles that were transported to the temporary storage area (TSA) could no longer be used because they were cracked or broken. Thus, the HTW reduction of the used bottles could reduce the total HTW generated, thus minimizing the effects on humans and the environment. However, in this study, HTW reduction was not analyzed, as the reduction was only carried out for the used bottles.

HTW Packaging and Containment

HTW plays a major role in environmental pollution; therefore, management of HTW, especially HTW packaging and containment, is very important [17]. HTW packaging was performed by each department and plant of this industry that produced HTW. Before putting the HTW into a TSA, the HTW was packaged initially [18] so that it would not pollute the environment, harm humans, or cause the mixing of different types of waste that would eventually result in negative impacts to humans or the environment [19]. A drum [20] and a jumbo bag [21] were used in this industry. The WWTP sludge, DEG, residue from the laboratory, incinerator ash, and spin-finish oil were placed in drums [20]. The bottles used for packaging the chemical solutions and contaminated fabrics were contained in jumbo bags. Generally, HTW in liquid form and in large quantities is packaged in drums [20,22]. Before use, the drum must be cleaned and not contain explosive or hazardous materials [23]. Bags or jumbo bags are usually used for HTW types, such as waste from textile activities, waste containing chemicals, infectious and anatomical waste, sharps, and household refuse [24,25].

The suitability of packaging and containment activities was determined using 10 parameters. Seven parameters, that is, knowledge of waste producers or collectors, packaging form, packaging materials, suitability between HTW, packaging capacity, packaging reuse, and supervision, complied with the related regulations; hence, each parameter's score was 3. Three parameters, safety parameters, conditions, and packaging markings, each scored 2, because there were several existing safety parameters, conditions, and packaging markings that did not conform to the regulations. For safety parameters, for example, several storage drums do not have lids. For the condition parameters, some storage drums were corroded, whereas for the packaging marking, some packaging was not yet labelled. Based on the evaluation results, the total score obtained was 27 out of 30, which is an ideal score. The percentage of the existing score of the suitability level of HTW packaging in this industry was 90% (Equation 1), which was included in the very good category.

HTW Collection

HTW is collected first by the waste-producing department or plant. The material store department would next provide an HTW handover form to be filled out by the waste producer and inform the Health, Safety and Environment (HSE) department about the HTW that would be stored at the TSA. If the HSE department had received the information and had permitted the HTW to be stored at the TSA, the material store department would then transport the HTW using a forklift and submit the HTW handover form to the HSE department as an archive and be put into the database collection of the *Sistem Informasi Real-time Pengelolaan Sampah Jaringan* (SIRAJA) website.

Conformities of the HTW collection activities with relevant regulations were observed onsite and evaluated. The results showed that three parameters, HTW collection activities, prohibitions, and mixing of collected HTW, complied with the regulations. Thus, each participant was assigned a score of three.

The HTW segregation parameter was given a score of 2 because there were several pieces of packaging that did not label the type and characteristics of waste, so they did not conform to the regulations. The total score obtained was 11, out of the ideal score of 12. The suitability level of HTW collection in this industry was 91.70%, which was classified as a very good category.

HTW Storage

The HTW was stored in an internal HTW TSA, covering an area of 12 × 9 m. HTW is stored temporarily before entering the next stage [18,26]. This internal HTW TSA was used specifically for the HTW produced by the company, both from production and non-production activities [27]. The HTW TSA has a dividing wall consisting of six compartments. Each compartment stores HTWs that match each other's characteristics. TSA provided emergency response equipment and drainage channels. TSA operations received a permit from the related local government that was valid for five years.

Based on on-site observations, the suitability of storage activities was evaluated. Two parameters, namely, the HTW storage location and emergency vehicle handling equipment (such as fire extinguishers and other appropriate emergency response equipment), complied with the standard. Thus, they were given a score of 3. Similarly, for the parameters of HTW storage facilities, that is, first aid facilities, loading and unloading, suitability of design, storage space area, design, and construction; ventilation system; lighting system, waterproof and non-wavy floors; the presence of drainage channels; and the presence of a spill collection bank, they conformed with the regulation; thus, they were each scored 3. The HTW storage parameters using drums, storage time, monitoring, and reporting complied with the regulations; thus, they received a score of 3. The parameter of completeness of symbols got a score of 2. The spill-handling equipment had a score of 1.

The parameter of completeness of symbols received a score of two because the symbol of the TSA still needs to be completed according to the HTW characteristics. Meanwhile, the spill-handling equipment had a score of 1 because it was not yet available. The total score obtained was 72 out of the ideal score of 75; thus, the level of suitability of HTW storage at this industry was 96%, which was categorized as very good.

HTW Transport

Transporting HTW from the TSA to the treatment and utilization locations was performed by third parties [18]. Third parties collaborating with this manufacturing industry received the supervision card and were permitted to transport HTW goods from the Indonesian Ministry of Transportation. In addition, third parties also obtained recommendations for HTW transportation and electronic manifests from the Indonesian Ministry of Environment and Forestry, which were used if an accident occurred during transportation. The generation of HTW influenced the number of HTW transportation activities. The more waste that is produced, the more frequently HTW transportation activities are executed [28,29]. The conformity of HTW transportation activities with the regulation was 100% and belonged to the very good category [4].

The conformities of HTW transport activities with regulations were evaluated based on on-site observations. The results showed that six parameters, i.e., HTW transportation, management permit, documents, reporting, type and number of transportation equipment, and manifest/estrogenic, complied with the regulation. Thus, they were assigned a score of three. The total score obtained was 18 out of the ideal score of 18; thus, the level of suitability of HTW transport at this industry was 100%, which was included in the very good category.

HTW Symbolling and Labelling

The compliance of HTW symboling and labelling activities with the regulations was analyzed based on on-site observations and Likert Scale. For the HTW symbol and label, some containers in the TSA still need to be labelled or given symbols. Thus, they did not comply with the regulations and were given a score of 2. The HTW symbol attachment for the container and storage place was scored as 2, and the HTW vehicle scored as 3. The HTW symbol shape and color were assigned a score of 3. The HTW symbol size (on the packaging, vehicle, and distance of symbol visibility) was scored 3. HTW symbol material (resistance to scratches and chemicals received a score of 3 and adhesion resistance was given a score of 2). The HTW symbol and label type were assigned a score of three. HTW label attachment (on filled containers and closing instructions received a score of 2, and on empty containers were given a score of 1) and label size (minimum size and closing instructions label were given a score of 3).

The total score of compliance with HTW symboling and labelling activities obtained was 46 out of an ideal score of 54. The suitability level of HTW symboling and labelling at this industry was 85.2%, which belonged to the very good category. This was because there were still some instances of noncompliance to the regulations, such as those of the HTW storage containers that did not have symbols and labels attached, and/or the symbols and labels attached were damaged and had to be replaced with new ones. The presence of symbols and labels in HTW storage containers is very important because the most appropriate way to identify waste based on its category is to sort waste based on packaging color, labels, and symbols [30]. In addition, labels were used to indicate the type of hazardous substances in the stored HTW [31].

Discussion

Waste Generated

The results show that this manufacturing industry produced HTWs that belong to Category 1 HTW (Table 1), meaning that they have an acute and direct impact on humans and will harm the environment. The HTWs were DEG, residue, incinerator ash, and bottles for packaging chemical solutions. The DEG was the by-product of the formation of polyester in the Polymer Plant; residue was produced from the quality control chemical (QCC) analysis in the laboratory; incinerator ash was generated from HTW burning in the incinerators; bottles used for packaging chemical solutions generated from the product analysis in the laboratory contained hazardous and toxic solutions; thus, all these HTWs, based on the regulation, were included in Category 1

HTW. QCC analysis in the laboratory uses chemicals to analyze each product sample from the Polymer Plant and the activities related to the production process.

The factory also generated HTWs that were included in Category 2 HTW (Table 1), which has a delayed effect, has no direct impact on humans and the environment, and has sub-chronic or chronic toxicity. These HTWs consisted of WWTP sludge, spin-finish oil, and contaminated fabric. The sludge was produced from the WWTP decanter area, spin finish oil was generated from the spinning machine at the Fiber Plant, and contaminated fabric resulted from the maintenance and repair of machines and workshops at each plant.

It is shown that there are three characteristics of HTWs (Table 2): (1) they are dangerous to the environment (for WWTP sludge and incinerator ash); (2) they are easy to light (for DEG, spin finish oil, and contaminated fabric); and (3) they are poisonous (for residue and used bottles for packaging chemical solutions). Solid WWTP sludge, that was produced from the WWTP decanter area, if it is just disposed without being treated can enter to and/or mix with the soil where plants grow, so it can harm the plants, animals and/or humans via the food chain. If exposed to rainwater, the hazardous and toxic materials contained within the sludge can infiltrate and percolate into the soil and pollute the groundwater and once the ground water is not treated properly, they can contaminate the drinking water; which in the end can harm animals and/or humans who consume it. Even though sludge is classified as solid matter, it still contains liquid, so the level of danger will be multiplied as liquid can disperse faster into other solid and liquid materials. However, due to the sludge is more consisted of solid than liquid; and due to the pathway of the hazardous and toxic materials through the solid matters (soil/land) and liquid matters (rain water infiltration and percolation, ground water, drinking water) is considered requiring more times to affect humans, animals and the environments [13]. Thus, the WWTP sludge is classified as Category 2 HTW that has a delayed effect, has no direct impact on humans and the environment, and has sub chronic or chronic toxicity. Nevertheless, WWTP sludge remains dangerous to the environment (and finally to animals and humans through the food chain) [32].

Solid incinerator ash generated from HTW burning in incinerators can harm humans and/or animals if inhaled. As this ash is generally easy to disperse and transport via its air pathway, it can be easily inhaled by humans and/or animals within a short time [33]. Thus, this HTW is included in Category 1 HTW, which has an acute and direct impact on humans [33]. In addition, if this ash is deposited on land without being treated, it will have a similar effect on the environment (land/soil, groundwater) and finally harm animals and/or humans via the food chain through the pathway of land and water, as previously explained by the WWTP sludge. Thus, this ash is dangerous to the environment (and finally to animals and humans through the food chain) [34].

The DEG, which is a by-product of the formation of polyester in the Polymer Plant, is liquid, will easily disperse through the environment through the pathway of land/soil, and/or of water, and will finally harm humans and/or animals in a short time, and is thus considered to be a Category 1 HTW. In addition, with liquid HTW, the DEG is considered easy to light.

On the other hand, the spin finish oil is as liquid as that of the DEG, so it will easily disperse through the environment through the pathway of land/soil, and/or of water, and will finally harm humans and/or animals [35], and is considered to belong to Category 2 HTW. This is because the oil generated from the spinning machine at the Fiber Plant is considered to be an auxiliary material that does not directly harm humans or the environment as that of the DEG. As liquid HTW, spin-finish oil is also considered to be easy to light.

The solid contaminated fabric results from the maintenance and repair of machines and workshops at each plant; if it is disposed without being treated properly, it will harm the environment through the pathway of land/soil, or of liquid/water, which will ultimately affect humans and/or animals via the food chain [36]. However, as the effects are considered to take more time to occur, this HTW is included in Category 2 HTW. Because it contains carbon, the fabric is deemed easy to light.

The residue, which was a liquid and produced from the QCC analysis in the laboratory of each product sample test from the Polymer Plant and activities related to the production process, is believed to be included in Category 1 HTW. Being liquid and generated from each product, the residue will be easily dispersed into solid and/or liquid matter and will harm humans, animals, and/or the environment within a very short time; thus, it is considered to belong to Category 1 HTW. In addition, the residue is believed to be poisonous because it is generated from the Polymer Plant and activities related to the production process.

The solid bottles used for packaging chemical solutions, which were generated from the product analysis in the laboratory, are also viewed as Category 1 HTW, as the remaining hazardous and toxic chemical matters were still believed to be attached to the bottles' wall and/or were still in the bottles. In addition, as the bottles contained the main products, they were considered to be acute, have a direct impact on humans, and harm the environment; as such, they were also poisonous.

Both Category 1 and Category 2 HTWs can be managed to lower their impact on humans and the environment through HTWs' reduction and/or HTWs treatment [37]. HTWs can be reduced through a) material substitution, b) process modification, and/or c) environmentally friendly technology application. Substitution of materials can be achieved by selecting raw materials and/or auxiliary materials that originally contain HTWs to be replaced with raw materials and/or auxiliary materials that do not contain HTWs. Process modification can be performed by selecting and implementing a more efficient production process [4].

The treatment of HTWs can be performed using: a) thermal, b) stabilization and solidification, and/or c) other methods in accordance with the development of science and technology [4]. HTWs treatment must be carried out considering the a) availability of technology and b) environmental quality standards [4].

Although WWTP sludge is classified as a Category 2 HTW that has a delayed effect, has no direct impact on humans and the environment, it has sub-chronic or chronic toxicity, and is still dangerous to the environment, and eventually to animals and humans through the food chain; thus, being the most HTW produced (Table 3), the sludge has to be carefully and properly managed by reducing and/or treating it using previously described methods [38] to reduce the impacts on humans, animals, plants, and/or the environment. For the incinerator ash, even though it was the least produced, it was included in Category 1 HTW, and the incinerator ash must be carefully and properly managed, just like the WWTP sludge, to minimize its effects on humans, animals, plants, and/or the environment.

HTW Management

A recapitulation of the results of observations on the conformity of HTW management in this manufacturing industry shows that the packaging and containment, collection, storage, transportation, and symboling and labeling activities received compliance scores of 90%, 91.70%, 96%, 100%, and 85.20%, respectively—all of which are categorized as 'very good.' The average score was 93%, which is also categorized as 'very good'. Nurbayti et al. [39] obtained the score of 84.09% for the HTW management of the public hospital in Indonesia; yet, they were using 4 scales of the Likert Scale, and they studied the reduction, collection, storage, transportation, and treatment system. The highest score of 100% was for the transportation activity, and the lowest score of 85.20 was for the symboling and labelling activities. Although this industry had achieved a very good score in their HTW management, meaning that they had treated the HTW properly in accordance with the HTW management regulations, improvements are still required in HTW management, so that HTW management will be even better in the future and will not harm humans, plants, animals, or the environment. Some improvements can be made in HTW management by starting to reduce the HTWs through a) material substitution, b) process modification, and/or c) environmentally friendly technology application, as described previously in the Waste Generated Discussion Section. Although this industry did not treat their HTWs, actions can be taken to ensure that the third parties that treat their HTWs perform their treatment processes properly in accordance with the regulations and/or standards. This can be achieved through effective communication with third parties.

As this research used the Likert Scale to evaluate the HTW management, this study is expected to provide a more accurate and comprehensive evaluation of the implementation of the HTW management, which in turn will be beneficial for implementing the HTW management in the industrial world. By applying the same methods used in this study, other industries could conduct similar research to manage their HTWs so that their operations could be more efficient in terms of time and finances. It is hoped that other industries can implement HTW management through applicable regulations to avoid environmental pollution, improve occupational safety and health, and reduce the risk of accidents and fires.

Conclusions

Based on the observations of the HTW management at this manufacturing industry, the evaluations were performed for the key activities from packaging and containment to transportation, based on the Indonesian Regulation and using the Likert Scale. The average HTW management obtained was 93% that put the HTW management of the company in the "very good" category. To maintain and enhance its performance, the industry can adopt more advanced technologies, conduct regular audits, and continually improve its waste handling procedures. Strengthening these areas will ensure operational sustainability and minimize environmental risks in the future.

Author Contributions

RSD: Conceptualization, Writing - Review & Editing; **ACD**: Conceptualization, Methodology, Writing - Review; **GS**: Conceptualization, Writing - Review & Editing.

Conflicts of Interest

There are no conflicts to declare.

Acknowledgments

Thanks are due to PT X for facilitating this research.

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