Industrial Waste Treatment Management: A Review

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ABSTRACT

Industrial development is hand-to-hand with economic growth. It has a positive impact on many economic sectors and human living, but also produces hazardous waste which giving a negative impact on the environment and human health. Industrial wastes have a high contribution to climate changes, many human diseases, a mutation on animals and plants. Recently, there are many methods to overcome industrial waste include physical, chemical, and biological treatment. Moreover, waste management also is developed to optimize the treatment using 3R (Reduce, Reuse, and Recycle) and WTE (Waste to Energy). Therefore, this paper tried to discuss many technologies for industrial waste treatment and management includes recent research, benefit, and drawback.

Keywords Treatment Management, Industrial Waste, Liquid Waste, Solid Waste, Gas Waste
Paper type Research paper

INTRODUCTION

Industrial development will cause rapid economic growth in a country. The industry is a vital economic activity that can increase income per capita, job opportunity, and standard of living in an area. Generally, the industry is classified by size, ownership, and raw material for production and one of the important industries to meet people's needs is the chemical industry. This industry uses chemical processes such as synthesis, extraction, distillation, and other methods to make the product. Due to the chemical process, this industry can harm the environment and people's health. Industrial waste commonly can be liquid, gases, or solids which contain inorganic and organic material. It is toxic, carcinogenic, hard to handle, and harmful. There are many kinds of chemical industrial waste based on the industries, processes, and raw materials. The liquid waste generally results from the water uses such as for the cooling process, cleaning, and sanitizing. It contains the amount of toxic organic nitrogen compounds, tars, suspensions, oil, phenols, salts, acids, bases, polycyclic aromatic hydrocarbons, cyanide, and ammonia in varying concentrations. Meanwhile, industrial solid waste comes from raw materials which are used for production. It has different types of materials such as wood, metal, plastic, paper, rubber, glass, and textile. Moreover, the gas waste commonly is exhaust gases from the production process which contain toxic gases such as Carbon Dioxide (CO_2), Carbon Monoxide (CO), Sulfur Dioxide (SO_2), Hydrogen Sulfide (H_2S), etc.

Industrial waste is the most dreadful issue recently. It declines soil, air, and water quality that affects human health. The speedy industrial growth has induced a rapid increase in the environmental problems around the world [1]. Industrial gas waste can affect nerve function, cause respiratory and vision problems. It also affects plant and animal growth. While industrial wastewater and solid waste can cause the death of aquatic micro and macro organism due to the decrease of dissolved oxygen levels. It also causes human diseases, changes in water properties, mutation of animal and plant cells, and changes the chemical equilibrium. Moreover, it decreases the supply of drinking water and increases climatic changes [2]. Therefore, to overcome the environmental problems, industrial waste has to be treated optimally. Waste management also is needed to optimize waste treatment and decrease the amount of industrial waste. Sustainable waste management can have a positive impact in reducing industrial pollution, enhance energy use efficiency, and implementing environmental-friendly materials and industrial processes [3].

Industrial waste treatment and management have been studied in the past two decades. There are many methods to reduce the waste such as coagulation, trickling filters, activated sludge, Rotating Biological Contactors (RBC) [4]. For wastewater treatment commonly use brine treatment, oils removal, solids removal, and biodegradable organics removal [5]. Furthermore, avoidance, reduce, reuse, recycle, and recovery also is used to manage industrial waste treatment [6]. There are many methods to remove waste; it relies on waste contaminants and their characters. Due to the importance of waste treatment, this article highlights the waste treatment and management in industrial liquid, solid, and gas wastes. This review could help to increase a healthy work environment in the industry and designing the solution for waste treatment.

LIQUID WASTE TREATMENT

Liquid waste is the most industrial waste which contaminates clean water easily. It becomes a big problem for human life and the environment. To deal with these problems, various methods have been developed to treat wastewater include chemical, physical, and biological treatment. Physico-chemical treatment includes coagulation, ozonation, adsorption, ion

exchange, chemical oxidation, electrochemical, membranes technology, photocatalytic, and advanced oxidation process [2]. This treatment effectively removes toxic organic and inorganic pollutants. The physical or mechanical treatment effectively removes solid contaminant and eliminates larger floating in the wastewater which commonly uses in the first treatment. This treatment includes filtration, sedimentation, separation, centrifugation, drawl, and crystallization [7]. Meanwhile, the biological treatment effectively eliminates toxic pollutants with high biological oxygen demand and chemical oxygen demand [8]. This treatment includes the biodegradation process in aerobic or anaerobic conditions using fungi, bacteria, algae, enzymes, and plants. Each wastewater treatment has a different function, characteristic, advantages, and drawback. They are working in different conditions and types of waste. The kind of treatment should be determined based on wastewater composition and type of contaminant, economic feasibility such as operation cost, material cost, and handling cost, the environmental impact also must be considered, and the technique [9].

Physico-chemical treatment

Physico-chemical treatment is the wastewater treatment that focuses on separating colloidal particles in the water which add some chemicals throughout the process. One of the most common methods that have been used since a long time ago is coagulation. This method can separate colloidal particles through the addition of positively charged ions into the water and leads to destabilization or neutrally charged particles which result in flocculation. The main concept of coagulation is to distract the stability of colloidal particles in the water and make it unstable. The negatively charged ion in colloidal particles will be neutralized by a positively charged ion from metal salt or polyelectrolyte and cause the particles to congregate together [10]. Generally, coagulants are from metallic salts (aluminum sulfate, aluminum chloride, ferric and ferrous sulfate, ferric chloride), or polymers such as melamine-formaldehyde and tannins group. In recent studies, coagulation has been widely used in many industrial waste treatments.

Loloei, et al. had studied the dairy industrial waste treatment using coagulation. They use Ferric Chloride ($FeCl_3.6H_2O$), Aluminum Sulfate ($Al_2[SO_4]_3.6H_2O$), Calcium Hydroxide ($Ca[OH]_2$), Polyacrylamide (PAA), and Polyferric Sulfate (PSF) as coagulants. The inorganic salts were investigated from 100 to 1000 mg/L, while the polymers were used at 20 mg/L. According to the study, it shows that alum and ferrous sulfate can eliminate dairy industrial waste at 68 and 62% respectively with the optimal condition at 100 mg/L and pH 5. Meanwhile, the use of polymer coagulants, PAA can extend Chemical Oxygen Demand (COD) removal efficiency by 86% and reduce alum consumption. Different from PFS, it can reduce alum consumption but can effectively eliminate the contaminants and turbidity in the dairy industrial wastewater [11]. Moreover, coagulation also can be used in textile wastewater treatment according to Merzouk, et al. Their study was focused on decolorization dye wastewater using chemical coagulant with electrocoagulation. It shows that alum chloride can effectively eliminate 90% dye from the water with 40 mg/L. According to the study, chemical coagulation is an easier method in comparison with electrocoagulation although it requires a higher cost [12].

Another coagulation study has been conducted by Zaman who explains the potential of natural coagulants for wastewater treatment. It denotes that plant seed extracts have the potential to remove contaminant and turbidity in industrial wastewater. *Plantago ovata* and *Moringa oleifera* can eliminate turbidity above 90%, whereas *Tamarindus indica* pod seed removes color 60% effectively. The natural coagulant is non-toxic, low cost, and environmentally friendly although it requires many challenges to develop it becomes a more effective coagulant [13]. Coagulation is one of the simple methods to remove many contaminants in industrial wastewater, low cost, and can optimally remove impurities. However, this method is pH-dependent, results in a high amount of sludge from the process, and difficult to handle highly soluble dyes.

Adsorption is a technique that has been widely used in many wastewaters especially in textile waste. Adsorption occurs due to chemical bonds or physical force interaction. Adsorption is defined as a surface process that induces the bonds of molecules on the surface of a liquid or solid [7]. Chemically, activated carbon has been widely used to adsorb pollutants in industrial wastewater. Activated carbon can adsorb organic compounds intimately [14]. It has a spacious surface area, high surface reactivity, large porosity, and high thermal and chemical resistance. The study about effectivity activated carbon shows that this material can decrease COD and biological oxygen demand (BOD) above 90% [15]. Adsorption with activated carbon to good purpose dismisses various kinds of dyes, acid or basic dyes, and azo. However, its pH-dependent, high cost for regeneration, induces adsorbent loss, and pitiful for sulfur dyes [16].

The membrane is a promising filtration technique to purify wastewater. This technology has attracted enormous attention due to inexpensive, low energy requirements, and without requires the addition of chemicals. The membrane can filter many different materials such as simple carbohydrates, polyvalent ions, dye water, protein, viruses, emulsion, colloids, and bacteria. It can be divided into isotropic and anisotropic. The isotropic membrane is a term of uniform membrane both in composition and physical structure, while anisotropic is a non-uniform membrane. Different compositions and structures of membranes depend on their function. Generally, membrane material can from organic or inorganic. Organic material includes Polyethylene (PE), Polypropylene (PP), Polytetrafluorethylene (PTFE), Cellulose Acetate, etc. [17]. Meanwhile, the membrane can be made from inorganic material such as ceramics, zeolites, or silica.

The type of membrane also can be classified by filtration process includes ultrafiltration, nanofiltration, microfiltration, and reverse osmosis. Their characteristic is explained in Table 1. Usually, it requires pressure, temperature, and optimum concentration to effectively remove wastewater. In many years, membrane technology has been applied in different industrial wastewater. For textile industrial wastewater, Ellouze, et al. explains that nanofiltration can reduce 57% COD,

effectively reduce color 100%, and salinity 30% [18]. Petrinic, et al. studied the potential of ultrafiltration combine with reverse osmosis for the metal finishing industry. It points out that the combination membrane technologies can achieve 90-99% pollutant removal [19]. In addition, ultrafiltration and reverse osmosis also can be used for oily wastewater treatment according to Salahi, et al. The study explains that these membranes can remove 100% turbidity and oils, which also can decline COD around 98% [20]. Meanwhile, ultrafiltration with nanofiltration can be employed for the paper industry to remove phenolic wastewater which can bring down 95.5% COD and phenol contaminant about 94.9% [21].

TABLE I. MEMBRANES CHARACTERISTICS

Type	Nanofiltration	Ultrafiltration	Microfiltration	Reverse Osmosis
Pore size	1-8 nm	10-50 nm	50-10000 nm	Solid
Approximate size of separated molecules	1 nm	2-20 nm	100 nm	0.1 nm
Pressure (MPa)	0.5-3.0	0.3-1.0	0.1-0.3	2.0-5.0
Components that can be filtered	Dyes, polyvalent and monovalent ions.	Proteins, viruses, dyes, polyvalent and monovalent ions.	Colloids, bacteria, proteins, viruses, dyes, polyvalent and monovalent ions.	Polyvalent and monovalent ions.

Advanced oxidation process (AOP) is relative a new method for wastewater treatment. It uses an oxidation process to reduce organic pollutants in the industrial wastewater into biodegradable compounds [2]. AOP is a term of oxidation technique that produces hydroxyl radicals from ozone, photocatalyst, hydrogen peroxide, or ultraviolet radiation. This radical then oxidize organic compounds and breakdown their bond to results in smaller organic compounds and easily degrade. Researches about AOP treatment have been conducted in many years. AOP continues to be developed and becomes a promising wastewater treatment in recent years. In 2015, Iqbal, et. al. had studied AOP with heterogeneous photocatalytic for the textile printing industry. They use $UV/H_2O_2/TiO_2$ to oxidize organic compounds in the textile wastewater. The study shows that these photocatalytic, organic compounds can be degraded 72%, and reduce COD and BOD by 57% and 48%. The optimum condition was found at 0.8 g TiO_2, 9% H_2O_2, UV radiation for 2 hours, and pH 3. H_2O_2 leads to decrease pH which causes an increase in the reaction rate. This study proves that AOP can remove pollutants from textile industrial wastewater [22]. Another research about the use of AOP has been studied by Kim, et al. They study about Fe(II) ion with peracetic acid (PAA) for AOP promoter to eliminate micropollutants. It explains that Fe(II)/PAA AOP has a fast reaction rate with a higher pH range rather than Fe(II) with H_2O_2 which makes this combination can be a promising material for AOP photocatalytic agent [23]. Table 2 explains the advantages and disadvantages of Physico-chemical treatment for wastewater.

TABLE II. THE ADVANTAGES AND DISADVANTAGES OF PHYSICO-CHEMICAL TREATMENT

Technique	Advantages	Disadvantages
Coagulation	Satisfactory reduce BOD and COD, cheap technology	Results in a high amount of sludge, depending on pH.
Adsorption	Highly reduce BOD and COD, simple method, inexpensive technique	Problem with the utilization of waste, the effectiveness depends on the time.
Membranes Technology	High efficiency to remove dyes and micro contaminants, easy to handle and operate.	Fouling effects require pressure, expensive equipment, should be precisely controlled.
Advanced Oxidation Process	Fast reactions do not require a large land area and remove heavy metals and hazardous organic components.	Complex operating, high cost, need chemical oxidation addition.

Physical treatment

Physical or mechanical treatment is commonly used as wastewater pretreatment to remove solid pollutants. Filtration is a mechanical treatment that has been widely used in industry to remove solid contaminants due to its simple method, low energy consumption, and economically friendly. During the filtration process, the solid pollutant will be trapped by porous filter media. On the other hand, sedimentation is also the easiest technique to separate solid particles. Due to gravitation force, solid pollutants will fall to the bottom and become sediment, then wastewater without sludge can be separated easily. Another physical treatment is crystallization. This technique has been studied for a long time ago to separate solid and liquid waste. The solute crystallizes from liquid waste will be a pure solid crystalline phase and can easily separate [24]. Crystallization becomes a promising wastewater treatment to recovery useful substances such as NaCl, Na_2CO_3, NH_4OH, phosphates, and removing Ca^{2+}, Mg^{2+}. Mechanical treatment is an important method because it can increase the efficiency of the primary treatment process to reduce pollutants in industrial wastewater.

Biological treatment

Biological wastewater treatment is used to reduce pollutants in the wastewater by using biological compounds such as bacteria, yeast, fungi, enzyme, etc. The technique commonly is divided into aerobic (with oxygen) and anaerobic (without oxygen) wastewater treatment. The main purpose of biological treatment is to degrade organic substances in the wastewater to become non-harmful compounds. Both of these biological treatments result in a high reduction of COD and BOD and produce lower sludge but it has a high operating cost and complicated technique. Many studied have been developed to make this technique turns into an economically friendly and simple process. Goswami, et al. had studied the use of biological treatment to remove Polycyclic Aromatic Hydrocarbons (PAHs) such as naphthalene, phenanthrene, and fluoranthene from refineries and biomass gasification industrial wastewater. This study employs Rhodococcus opacus to degrade PAHs. The results show that the bacteria can remove naphthalene, phenanthrene, and fluoranthene until 91.6%, 82.3%, and 80.7%, respectively [25]. Halim, et al. also studied biological wastewater treatment using Aerobic Granular Sludge (AGS). The effect of temperature and nutrients removal was studied. The results explain that AGS at 50oC achieves COD removal rates in the range of 85-98% and 94-97% ammonia removal [26]. Furthermore, the biological treatment also can be used to treat petroleum industrial wastewater such as aerobic and anaerobic treatment to eliminate hydrocarbon pollutants [27]. Figure 1 shows the difference between aerobic and anaerobic processes.
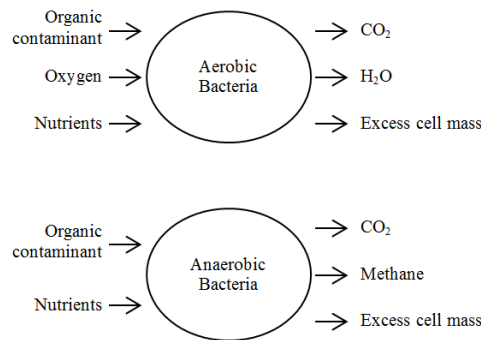

Fig. 1.   Illustration aerobic and anaerobic process

SOLID WASTE TREATMENT

Industrial solid waste is a result of industrial production and waste treatment. This industry includes heavy manufacturing, construction sites, chemical plants, power plants, textile, and canning plants which result in construction and demolition waste materials, heavy metals, packaging waste, plastic waste, ashes, and other harmful wastes. This waste can be classified into organic (paper, textiles, plastic, and wood) and inorganic waste (ceramics, metals, glasses) which can be combusted or composted [28]. The type of solid wastes is shown in Table 3. To reduce their effect on humans and the environment, solid waste should be treated and managed properly. There are various methods of solid waste treatment include composting, pyrolysis, combusting, recycling and recovery, and also sanitary landfill. Composting is a solid waste method only for biodegradable wastes. The waste can be composed using some biological material and can be used for agricultural purposes. Pyrolysis is a term of solid waste treatment through heating with vacuum conditions under pressure and high temperatures. This method leads to solid waste become liquid, gasses, or solid residue. Meanwhile, combusting is also known as incineration is one of solid waste treatment at high temperature to convert solid waste into ashes [5]. Recycling and recovery are the greeners of solid waste treatment due to low energy consumption, low cost, and reduce the use of landfills [5]. Solid waste treatment is a complex challenge with requires many processes to face. Industrial solid wastes contain much harmful material, toxic chemicals, and hazardous metals which can result in environmental problems, human diseases, and many biological problems.

TABLE III.   INDUSTRIAL SOLID WASTES TYPE

Industrial Type	Solid Wastes
Mineral and Non-metallic	Wood, metal, box, paper, glass
Metal	Iron, aluminum, copper, chromium, lead,
Food and Beverage	Plastic, paper, box, food waste
Medical	Plastic, aluminum, titanium, glass, box, paper
Textile	Textile, paper
Chemical	Metal, glass, wood, mineral, plastic, box, paper
Machinery	Metal, paper
Rubber	Rubber wastes, plastic, paper, metal, box
Electrical and Electronic	Glass, metal, box, plastic, steel, paper

The solid waste treatment has been developed in many techniques depends on the type of waste. Leather industrial waste for example, due to the tanning process, leather industry results in Chromium-tanned Solid Wastes (CTSWs). This waste harms the environment and can be a water pollutant, and one of a type of carcinogenic waste. To outgrow this issue, Jiang, et al. had conducted researches to manage CTSWs. They use direct treatment of the CTSWs which can remove chromium and collagen from the CTSWs [30]. Another technique also has been studied by Jiang, et al. They use the oxidation dechroming process with utilized peroxide compounds such as H_2O_2, O_3, Na_2CO_3, or $NaHCO_3$ [30]. CTSWs also can be treated by hydrolysis dechroming using enzymes, acid hydrolysis dechroming, and alkaline hydrolysis dechroming. Moreover, electronic waste also solid waste that has a different treatment. Chip and gold plated contain heavy metals, lead, tin, and brominated flame which can be treated using open burning and chemical peeling using hydrochloric acid and nitric acid. Meanwhile, cathode ray tubes that contain barium, lead, phosphor, and other metals can be eliminated by breaking and dumping [5]. Each solid waste has a different treatment technique and considers many factors such as affordability, economic feasibility, land use, environmental effect, residential area, etc.

GAS WASTE TREATMENT

Industrial waste not only liquid and solid but also can be gas, dust, and small grains. This underrated industrial waste is highly dangerous for human health, especially for human respiratory and vision. Commonly, waste gas is released by the high chimney to prevent negative impacts on human health. However, it can avoid climate change. Industrial waste gas treatment should be performed to prevent the environmental problem and human health. In general, waste gas treatment is focused on the reduction of vapors of volatile liquid substances, air contaminants, odors, and particulates. There are many different methods for waste gas treatment, and it can be classified into two main groups include non-biological and biological treatment. Non-biological treatment like adsorption, chemical scrubbing, membrane processes, non-thermal plasma, condensation, and other methods. While, biological treatment includes Biofilter (BF), Bioscrubber, and Biotrickling Filter (BTF). These treatments currently have attracted huge attention for industrial waste gas treatment due to their green operation. Bioscrubber is a biological technique consist two steps include physical absorption using a column and a regenerator for biological regeneration [31]. Conventionally, bioscrubber is an effective method for polar pollutants because of its wet operation and it is not effectively working at a non-polar component. Biofilter is a method to adsorb gas pollutants and mineralize them using fungi or bacteria. Different from bioscrubber, biofilter has a dry operation mode that can effectively remove lipophilic compounds [31]. Giri and Pandey had been reported the use of biofilter for gaseous waste containing dimethyl sulfide from the pulp and paper industry. *Bacillus sphaericus* culture was employed to degrade dimethyl sulfide gas. The result shows that these bacteria could eliminate the dimethyl sulfide with an efficiency of 71% for a contact time of 360 seconds [32]. Furthermore, biotrickling filter is an intermediate method that contains two steps includes absorber and swamp. These techniques can both effective for polar and non-polar waste gas compounds. Another study related to biological treatment for industrial waste gas has been conducted by Ma, et al. They point out that bioreactor with granular activated carbon (GAC) can detach high concentration hydrogen sulfide (H_2S) in waste gas. The maximum removal efficiency was achieved above 98%, and the average removal efficiency in different GAC concentrations was 96.8% [33].

In addition, a recent method to remove industrial waste gas is using humid acid (HA). HA is a compound from animals and plants breakdown due to microorganism activities. This compound generally contains alcohol, ether, and carboxylates groups which are composed of C, H, O, N, and S elements [34]. According to recent researches, HA can be employed to remove industrial exhaust gasses such as SO_2, H_2S, CO_2, and NO_x using dry or wet processes depend on the type of gasses. Sun, et al. had studied the utilization of HA for the adsorbent. HA was used with sodium and Al_2O_3 for composite adsorbent of HA-Na/αAl_2O_3 by impregnation method. The adsorbent shows an effective method to remove SO_2 and NO_2 at 100% and 80%, respectively [34]. HA is a promising material to remove industrial waste gas. Another method for waste gas treatment use activated cokes with homogeneous granulates. This method has been used for incineration plants to remove SO_2 and Hg. According to Jastrzab, activated cokes can eliminate SO_2 and Hg vapor depends on the surface area. The higher surface area of activated cokes leads to higher effectivity of vapor removal [35]. Waste gas treatment is a crucial technology for air purification. Each treatment has different removal efficiency depending on its condition and waste gas. It also has different advantages and disadvantages for the waste gas treatment process.

WASTE MANAGEMENT

Waste treatment is an important process to reduce and remove industrial waste. It gives a positive impact on the environment, human health, and the industry. Nevertheless, waste treatment should be optimized by a waste management system. A sustainable waste management system is hand-to-hand with optimum waste treatment. It can reduce industrial waste more effectively and efficiently. Generally, a waste management system consists of two terms namely 3R (Reduce, Reuse and Recycle) and WTE (Waste to Energy). According to Farizal, et al. 3R and WTE aim to manage and utilize waste both from industrial waste and domestic waste. 3R has a purpose to decline the number of waste before it is accumulated to landfills. On the other hand, the main purpose of WTE is to convert waste from landfills to become energy [36]. 3R is a waste management system that was launched in 2005 in Japan. According to waste management, the lower level of waste treatment is disposal, followed by energy recovery, recycle, reuse, reduce, and avoidance [6]. Figure 2 shows the illustration of waste management. Reduce and reuse is important activities for industrial waste management

because it can reduce waste treatment cost, enhance profit, and have many social benefits for the company. These activities can be obtained by modifying the production process and technology, minimize or substitute material, etc.
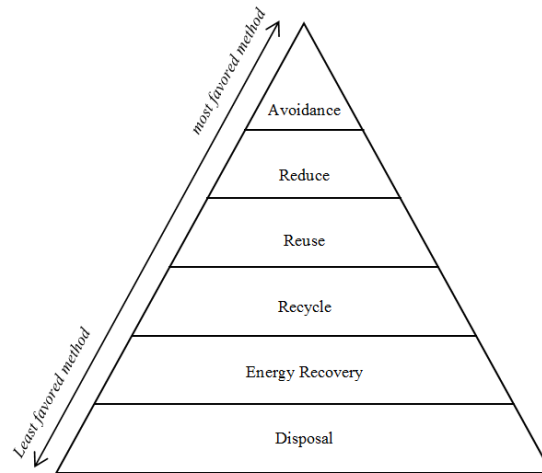

Fig. 2. Waste management hierarchy

In New Zealand, 3R and WTE are performed to reduce waste. Several conjectures have been used to optimize waste management in this country include a levy practice for waste disposal in the landfill, regulations, and laws for waste disposal, apply waste assessment, involve a waste advisory board [37]. Moreover, waste management system also is applied food industry in Japan. According to Babalola, the Multi-criteria Decision-making (MCDM) approach is recognized as a suitable evaluation for food and beverage waste treatment. MCDM is tools that focus on ecological assessment include sociocultural, technical, financial, economic consideration, and environmental concerns. From MCDM analysis, it shows that anaerobic technology for food and beverages industrial waste is the most compatible waste treatment in Japan [38]. Another waste management also has been reported by Lu, et al. They studied waste management systems especially electronic waste in China. It is known China is one of the biggest electronic manufacturers which produce a huge number of wastes. To overcome this problem, China upholds a legal regulation and system to manage e-wastes. The integrated system is done to make sustainability of e-waste management. This includes innovative regulations, effective e-waste collection, improve research and development on e-waste treatment technology [39].

CONCLUSION

To conclude, industrial wastes include liquid, solid, and gas are hazardous waste that harms human life and the environment. Liquid waste can be found in the water easily results in water pollution and can be dangerous for animals, plants, and humans. Solid waste commonly takes the form of heavy metals, plastic, food, wood, and other organic or inorganic matters involve a reduction in a residential area which also harms health and ecological system. Meanwhile, waste gas is harmful to the human respiratory, affects mutation in plant and animal growths, and contributes to climate changes. Therefore, industrial waste should be treated to minimize the negative impact. Liquid waste or wastewater can be eliminated by many treatments include physical treatment as a pre-treatment, chemical, and biological treatment for primary treatment. Solid waste can be handled by combusting, composting, pyrolysis, 3R activities, and disposing on the landfill. Waste gas is treated by biological and non-biological techniques. Different type of waste has different treatment depending on their characteristic, economic feasibility, methods, and conditions. Each type of waste treatment also has different advantages and disadvantages which are mentioned in Table 4.

TABLE IV. THE ADVANTAGES AND DISADVANTAGES INDUSTRIAL WASTE TREATMENTS

Waste Type	Technique	Advantages	Disadvantages
Liquid	Physico-chemical Treatment	High COD and BOD reduction, easy operation, short retention time.	Use many chemical additives, high sludge production.
	Physical Treatment	Simple process, cheap technology	Only can be used for pre-treatment
	Biological Treatment	High reduction of COD and BOD, low sludge production, possibility to recover energy.	Complicated technologies, high cost, difficult to handle.
Solid	Composting	Environmentally friendly, easy to handle, benefit for soil structure.	Only for biodegradable wastes, physical work required, odor disturbance.
	Pyrolysis	Degrade harmful components, convert solid waste into small amounts.	High pressure and high temperature required, high cost, complex process.

	Combusting	Cheap technology, can convert waste to release energy.	Release carbon dioxide and water, bigger molecules require higher oxygen to burn.
	Sanitary Landfill	Easy method, cheap technology.	Require large space, need to manage properly.
Gas	Non-biological	Easy-to-use, inexpensive, highly eliminates contaminants.	Require chemical treatment.
	Biological	Environmentally friendly.	High cost, complex method

Furthermore, to dealing with the waste problem, waste treatment should be optimized with a sustainable waste management system. 3R and WTE are the common management system to minimize industrial waste. Innovative public design and waste assessment also should be applied to complete the waste management system.

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