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Industrial Waste Management, Treatment, and Health Issues: Wastewater, Solid, and Electronic Wastes

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Abstract

The research centered on the management and treatment of industrial wastewater, solid waste, and electronic wastes, as well as their associated health issues and environmental impacts. Industrial waste can be solid, liquid, or gas and each type has different methods of disposal and management. Industrial waste management deals with all types of wastes relating to industries, including industrial, biological and household, before, during, or after production, and even after usage by consumers. In some cases, waste can pose threat to

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human health. The underlying principles on the guide for industrial waste management ensures Protecting human health and the environment, Tailoring management practices to risks, Affirming state and tribal leadership, and Fostering partnerships. Waste characterization plays an important part in any treatment of waste which may occur. Industrial wastes can be characterized to be absolute non-hazardous, mirror entries, or absolute hazardous. The steps involved in risk assessment of industrial wastes include hazard identification and characterization, exposure assessment, and risk characterization. Treatment levels of wastewater are often identified as primary, secondary and tertiary. Primary treatment involves separating a part of the suspended solids from wastewater. Secondary treatment involves further treatment of effluent. Biological processes accomplish the removal of organic matter and residual suspended solids. Tertiary treatment is the third, advanced level of wastewater treatment which include unit operations and processes such as coagulation, filtration, activated carbon adsorption, electrodialysis, reverse osmosis, ozonation, advanced oxidation processes etc. Solid wastes from industries are source of toxic metals, hazardous wastes, and chemicals. Due to improper waste disposal systems, wastes heap up and become a problem. Methods of solid waste management include sanitary landfill, recycling and recovery, composting, pyrolysis, incineration, etc. Used electronics destined for refurbishment, resale, reuse, salvage recycling via material recovery, or disposal are considered e-wastes. Informal processing of e-wastes in developing nations can result in environmental pollution and adverse human health effects. Electronic scrap components, like CPUs, contain potentially harmful materials such as cadmium, beryllium, brominated flame retardants, or lead. Recycling and disposal of e-wastes may involve significant risks to the health of communities and workers in developed and developing countries.

Key words: Industrial waste management, wastewater treatment, solid waste management, electronic waste management, Environmental impacts of industrial waste, Health effects of industrial waste

1. INTRODUCTION

Industrialization has brought lots of advantages and disadvantages as well. One of the negative impacts of industrialization is the creation of wastes. Industrial waste can be solid, gas, or liquid and each type has different methods of management and disposal. Industrial waste management deals with all types of wastes relating to industries, including industrial, biological and household, before, during, or after production, and even after usage by consumers. In some cases, industrial waste can pose threat to human health. Waste in general is produced by human activity, for instance, extraction and processing of raw materials. Industrial waste management is intentionally done to reduce the adverse effects of waste on the environment and human health. Industrial waste management examines the broader context of waste treatment for wastes directly or indirectly originating from industries, and may include corporate sustainability, environmental impact, consideration of government policy and regulations, recycling, containment, handling and transport, centralized compared to on-site treatment, technologies, economics, avoidance and reduction.

Industrial wastewater treatment deals with the processes used for treating wastewater (liquid wastes) produced by industries as undesirable by-products. After treatment, the treated industrial wastewater (or now called effluent) might be reused or released to sanitary sewer or to surface water in the environment either directly or through water canal. Most industries produce large volume of wastewater continuously which after treatment (effluent) is released to the aquatic environment (Awuchi and Awuchi, 2019a; Awuchi and Awuchi, 2019b). Recent trends have been to reduce such production (waste reduction) or to recycle treated wastewater (recycling or reuse) within the production process.

Solid waste management refers to the methods or process of collecting, managing, and treating solid wastes. Solid waste management offers solutions for recycling the items which do not belong to trash or garbage. As long as people and industries have been living and sited in settlements, residential and industrial areas, solid wastes have been an issue. Solid waste management is about how solid wastes can be changed and used as valuable resource or discarded efficiently if no other use is possibly with little or no impact on the environment and human health. Currently, plastic waste (a kind of solid waste) is a global concern due to its negative impacts on the environment, aquatic life, and human health (Awuchi and Awuchi, 2019a; Awuchi and Awuchi, 2019b). Solid waste management ought to be embraced by each and every industry and household including business owners around the world. Solid-waste management can also be seen as the collection, treatment, and disposal of solid materials because they have served their purpose or are not useful anymore. Improper disposal of municipal or industrial solid waste can create unsanitary conditions, which in turn can result in pollution of the environment and in the outbreaks of vector-borne disease (i.e., diseases spread by insects and rodents). Rodents, insects, ants, and other disease causing creatures thrive on solid waste dumps.

Electronic waste (e-waste) describes the discarded electrical or electronic devices. E-waste is among the types of waste plaguing the world currently. Used electronics which are destined for reuse, refurbishment, salvage recycling through material recovery, disposal, or abandonment are also considered e-waste. The informal processing of e-waste in developing nations can result in adverse effects on human health and lead to environmental pollution. Scrap components of electronics, such as CPUs, contain potential harmful materials such as cadmium, lead, beryllium, and brominated flame retardants. The recycling and disposal of e-waste can have significant risks to health of workers and the communities in developed and developing countries (Sakar, 2016).

Many industries have a requirement to treat water to obtain high quality water for demanding purposes such as boiler feed water or pure chemical synthesis. Many water treatments generate organic and mineral sludge from sedimentation and filtration. Ion exchange using synthetic or natural resins removes calcium, carbonate ions, and magnesium from water, usually replacing them with chloride, sodium, hydroxyl and/or other ions. The regeneration of ion exchange (IE) columns with strong alkalis and acids produces a wastewater rich in hardness ions that are readily precipitated out, mostly when in admixture with other components of wastewater.

Areas with developing economies usually experience exhausted waste collection services and uncontrolled and inadequately managed dumpsites. The problems are worsening (Dao-Tuan *et al.,* 2018; Chinaza, *et al*., 2020). Problems with governance make the situation more complicated. Waste management in these countries and their cities is an ongoing challenge because of weak institutions, rapid urbanization, and chronic under-resourcing. All these challenges, together with lack of understanding of the different factors that contribute to hierarchy of waste management, affect waste treatment (Abarca *et al.,* 2013). On the other hand, industrial waste management is still a challenge in developed world, although almost all the developed countries and cities have well established and functioning waste management systems and regulations. This research expanded and made available the current methods and techniques for the management and treatment of industrial wastewater, solid waste, and electronic wastes, and the associated health issues and environmental impacts due to poor management of Industrial Waste.

1.1. Waste characterization

Waste characterization is process by which the composition of different streams of waste are analyzed (Awuchi and Igwe, 2017; Chinaza, *et al*., 2020). Waste characterization plays important role in any waste treatment; industrial or non-industrial. Developers of new waste technologies and treatment specialists must take into account the exact components of waste streams consist of so as to fully treat the waste. Biodegradable element of waste stream is critically important in the use of systems such as anaerobic digestion or composting (Awuchi and Igwe, 2017). Using the European Waste Catalogue as Case Study, the first step in characterizing waste is to determine the composition and assign the appropriate categorization. There are three categories; absolute hazardous, mirror entries, and absolute non-hazardous. Absolute hazardous entries are hazardous not because of the composition of the wastes but by virtue of process that produced them, the same is true for the non-hazardous absolute entries. The mirror entries can either be nonhazardous or hazardous depending on the waste composition.

1.2. Risk assessment and building partnership in waste management

Risk assessment in waste management is the systematic process of evaluating the potential risks which may be involved in a projected waste management activity or undertaking (Awuchi and Igwe, 2017). Environmental risk communication skills are crucial to successful partnerships between companies, the public, state regulators, and other stakeholders. As more environmental management decisions are made based on risk, it is increasingly imperative for all interested stakeholders to understand the science behind the risk assessment. Encouraging the public participation in environmental decision-making means making sure that all the interested parties understand the basic risk assessment principles and can converse equally on development of assumptions which underlie the analysis. Residents located near units of waste management and sources of waste always want to understand the management activities in place within their neighborhoods (Awuchi and Igwe, 2017). They want to be assured that waste is being managed safely and reliably, without danger to the environment and public health. This requires an understanding of basic principles of risk assessment and the science and rationale behind it. Opportunities for dialogue between states, tribes, facilities, and concerned citizens, including discussion of risk factors, have to take place before decisions are made. Successful partnerships are an ongoing activity, subject to reviewing at intervals.

Steps Involved in Risk Assessment

a) Hazard Identification: the identifying and characterizing of the source of the potential risks (e.g., chemicals managed in waste management unit).
b) Exposure Assessment: the determination of the exposure pathways and the exposure routes from the source to an individual.
c) Risk Characterization: the integration of the results of exposure assessment with information on the individual or

group of individuals who is/are potentially at risk (e.g., body weights, location of the person, gender) and chemical toxicity information.

1.2.1. Hazard identification: identifying and characterizing source of the potential risk (for example, chemicals managed in waste management unit). The source of the potential risks has already been identified: a waste management unit. However, there must be release of chemicals from the waste management unit for exposure and risk to come to be. Chemicals can be released from the waste management units by a range of processes, including leaching to ground water, volatilization, particulate emission, and runoff and erosion. To consider these releases in risk assessment, the information characterizing the waste management units is required. Critical parameters include the unit's size and location. For example, larger units have potential to produce larger releases; the units located close to water table may produce greater releases to ground water than the units located further from water table. Units located in hot, windy, and dry climate can produce greater volatile releases than the units in cool, non-windy, and wet climate.

1.2.2. Exposure assessment (Routes, Pathways, and Estimation): determining exposure routes and pathways from the source to individual. People and populations can come in contact with environmental pollutants by a range of exposure processes and mechanisms. The mere presence of hazard, such as toxic chemicals in waste management units, does not denote existence of any risk. An exposure is the bridge between what is regarded as a hazard and what in reality presents a risk. Assessing exposure involves evaluating potential or actual pathways for and extent of humans contact with toxic chemicals. The frequency, duration, magnitude, and route of exposure to any substance must be considered when collecting all the data required to construct complete exposure assessment. Steps for performing exposure assessment include identifying potentially exposed population (receptors); the pathways of exposure; the environmental media that transport the contaminant; the contaminant concentration at a receptor point; and the receptor's exposure time, duration, and frequency (Awuchi and Igwe, 2017). In a deterministic exposure assessment, some single values are assigned to every exposure variable. For instance, the length of time an individual lives in same residence adjacent to the facility may be assumed to be 30 years. Alternatively, in probabilistic analysis, single values can often be replaced with the probability distribution functions that represent range in real-world variability and uncertainty. Using the time in residence as example, it may be found that 10% of the individuals adjacent to the facility live in their homes for less than three years, 50% less than six years, 90% less than 20 years, and 99% less than 27 years.

1.2.3. Risk characterization: In risk-characterization process, the health standard information (i.e., reference concentrations, cancer slope factors, and reference doses) and the results of exposure assessment (estimated dose or intake by potentially exposed populations) are integrated and critically analyzed to arrive at quantitative estimations of non-cancer and cancer risks. To characterize potential non carcinogenic effects, comparisons are often made between reference concentration (or reference dose) values and projected intake levels of substances. To characterize potential carcinogenic effects, the probabilities that individual will develop cancer over lifetime are estimated from the projected intake levels and chemical-specific cancer slope factor values. This procedure is final calculation step. The step determines who can be likely affected and what likely effects could be.

2. INDUSTRIAL WASTE TREATMENT METHODS, TECHNIQUES, ENVIRONMENTAL IMPACTS, AND HEALTH ISSUES

2.1. Industrial wastewater

The composition of industrial wastewater varies by types of industries.

2.1.1. Sources of industrial wastewater

2.1.1.1. Food industry

Wastewater generated from the agricultural and food processing operations have distinctive characteristics that set them apart from the common municipal wastewater managed by the public or private sewage treatment plants all over the world: it is non-toxic and biodegradable, but has high concentrations of Biological Oxygen Demand (BOD) and suspended solids (SS) (European Environment Agency, 2001). The components of food and agriculture wastewater are usually complex to predict, because of the differences in pH and BOD in effluents from fruit, vegetable, and meat products and because of the seasonal nature of post-harvesting and food processing. Processing of food from raw materials needs large volumes of high quality water. Vegetable washing alone generates water with high loads of particulate matters and several dissolved organic matters. It may also contain surfactants. The dairy processing plants produce conventional pollutants (SS, BOD) (U.S. Environmental Protection Agency, 2018). Animal slaughter and processing generate very strong organic wastes from body fluids, such as gut contents and blood. Pollutants generated include BOD, coliform bacteria, oil and grease, SS, ammonia, and organic nitrogen. Processing foods for sale produces wastes from cooking which are usually rich in plant organic materials and may also contain salt, colouring material, flavourings, and or alkali. The sweeteners used to flavor beverages such as sugars, aspartame, sugar alcohols, etc. (Awuchi and Echeta, 2019; Awuchi, 2017) may wash off during manufacturing process and end up as part of the components of wastewater. Very significant amounts of fats and oil may be present. The food processing activities such as material conveying, plant cleaning, bottling, and product washing generate wastewater. Many food processing facilities need on-site treatment before operational wastewater may be applied on land or discharged to a sewer or a waterway system. High SS levels of organic particles increase the BOD and can lead to significant sewer surcharge fees. Sedimentation, rotating belt filtration (microscreening), or wedgewire screening are commonly used methods to lessen suspended organic solids loading before discharge.

2.1.1.2. Iron and steel industries

Iron production from its ores involves strong reduction reactions in blast furnaces. The cooling waters are certainly contaminated with products especially cyanide and ammonia. Production of coke from coal in the coking plants also requires cooling with water and the use of water in the by-products separation. The contamination of waste streams includes the gasification products such as naphthalene, benzene, anthracene, ammonia, phenols, cyanide, cresols along with a variety of more complex organic compounds collectively called polycyclic aromatic hydrocarbons (PAH) (Environmental Protection Agency, 2002). The conversion of steel or iron into wire, sheet, or rods needs hot and cold mechanical transformation stages regularly employing water as coolant and lubricant. Contaminants include hydraulic oils, tallow and the particulate solids. The final treatment of products of iron and steel before sale into manufacturing includes the *pickling* in strong mineral acid to get rid of rust and prepare the surface for chromium or tin plating or for other surface treatment such as painting or galvanization. The two acids commonly used are sulfuric acid (H_2SO_4) and hydrochloric acid (HCl). Wastewaters include acidic rinse waters along with waste acids. Although several plants operate acid recovery plants (mostly those using HCl), where the inorganic acid is boiled away from iron salts, there remains large volume of highly acid ferrous chloride or ferrous sulfate to be disposed of. Numerous steel industry wastewaters are contaminated with hydraulic oil, known as soluble oil.

2.1.1.3. Mines and quarries

The major wastewaters associated with the mines and quarries are slurries of the rock particles in water. These come from rainfall washing the exposed surfaces and the haul roads as well as from rock washing and grading processes. The volumes of water can be very high, particularly rainfall related arising on big sites. Many specialized separation operations, such as the coal washing to separate coal from the native rock using density gradients, can generate wastewater contaminated by fine particulate surfactants and hematite. Oils and hydraulic oils are also some common contaminants. Wastewater from the metal mines and ore recovery plants are unavoidably contaminated by the minerals in the native rock formations. After crushing and extraction of desirable materials, undesirable ones may enter the wastewater streams. For metal mines, this often include unwanted metallic elements such as zinc and other materials like arsenic. Extraction of high value metals, e.g. silver and gold, may generate slimes containing very fine particles in which physical removal of contaminants becomes difficult. In addition, the geologic formations that harbor economically valuable metals such as gold and copper very often contain sulphide-type ores. The processing entails grinding rock into fine particles and extracting the desired metal(s); the leftover rock is referred to as tailings. The tailings consist of a combination of undesirable leftover metals and sulphide components which subsequently form sulphuric acid (H_2SO_4) upon exposure to water and air which unavoidably occurs when tailings are disposed in large impoundments. Resulting acid mine drainage that is usually rich in heavy metals (since acids dissolve metals) is among the many environmental impacts of mining.

2.1.1.4. Battery manufacturing

Battery producers specialize in fabricating small devices for portable equipment (e.g., power tools) and electronics, or larger, highly powered units for trucks, cars, and other motorized vehicles. The pollutants generated at battery manufacturing plants includes lead, manganese, mercury, nickel, chromium, cobalt, copper, cadmium, cyanide, iron, oil and grease, silver and zinc (U.S. Environmental Protection Agency, 2017), which out to be treated (recycled).

2.1.1.5. Organic chemicals industries

The specific pollutants discharged by the organic chemical manufacturers widely vary from plant to plant, depending on types of products manufactured, such as resins, pesticides, bulk organic chemicals, plastics, or synthetic fibers. Some organic compounds that may be discharged include napthalene, phenols, benzene, chloroform, vinyl chloride, and toluene. Biochemical oxygen demand (BOD), a gross measurement of a variety of organic pollutants, might be used to measure effectiveness of a system of biological wastewater treatment, and is used as regulatory parameter in various discharge permits. Metal pollutant discharges can include lead, nickel, zinc, chromium, and copper.

2.1.1.6. Electric power plants

Fossil-fuel power stations, especially coal-fired plants, are major source of industrial wastewater. Many electric power plants discharge wastewater with significant amounts of metals such as lead, cadmium, chromium, and mercury, as well as arsenic, nitrogen compounds (nitrites and nitrates), and selenium. Wastewater streams include fly ash, flue-gas desulfurization, bottom ash, and flue gas mercury controls. Plants with the air pollution controls such as wet scrubbers normally transfer the captured pollutants to wastewater stream (U.S. Environmental Protection Agency, 2015).

Ash ponds, types of surface impoundment, are widely used treatment technology at the coal-fired plants. These ash ponds employ gravity to settle out huge particulates (measured as total suspended solids, TSS) from the power plant wastewater. The technology does not treat the dissolved pollutants. Power stations use more technologies to control pollutants, depending on particular waste streams in the plant. These include closed-loop ash recycling, dry ash handling, biological treatment (such as activated sludge process), chemical precipitation, evaporation-crystallization systems (U.S. Environmental Protection Agency, 2015). Technological advancements in the ion exchange (IE) membranes and electrodialysis systems have enabled high efficiency in treatment of the flue-gas desulfurization wastewater to meet current discharge limits set by some recognized bodies such as the U.S. EPA (Power Mag. Electric Power, 2017). The treatment approach is similar for the other highly scaling industrial wastewater.

2.1.1.7. Textile industries

Textile industries, including carpet manufacturers, create wastewater from a wide range of processes, including yarn manufacturing, wool cleaning and finishing, and fabric finishing (such as bleaching, waterproofing and flame-proofing, , dyeing, resin treatment). Pollutants generated by textile mills include SS, oil and grease, BOD, sulfide, phenols and chromium (Environmental Protection Agency, 2017). Insecticide residues in fleeces are particular problem in treating wastewater generated in wool processing. Also, animal fats might be present in the wastewater, which if uncontaminated, can be recovered and recycled for further rendering or for the production of tallow.

The textile dyeing plants generate wastewater containing natural and synthetic dyestuff, gum thickener (i.e., guar) and various wetting agents, dye retardants or accelerators, and pH buffers. Following treatment with the polymer-based flocculants and settling agents, common monitoring parameters include COD, BOD, color (ADMI), oil and grease, phenol, sulfide, TSS and heavy metals (lead, copper, chromium, zinc).

2.1.1.8. Petroleum refining and petrochemicals industries

Pollutants discharged at the petroleum refineries and petrochemical plants include the conventional pollutants (BOD, oil and grease, COD, SS), ammonia, phenols, sulfides, and chromium.

2.1.1.9. Paper and pulp industries

Effluents from the paper and pulp industries are generally high in BOD and suspended solids. Plants that bleach wood pulp for the manufacturing of paper may generate dioxins (including 2,3,7,8-TCDD), chloroform, furans, COD, and phenols (Environmental Protection Agency, 2000). Stand-alone paper mills using an imported pulp may only need simple primary treatment, such as dissolved air flotation or sedimentation. Increased COD or BOD loadings, as well as organic pollutants, might require biological treatment such as upflow anaerobic sludge blanket reactors or activated sludge processing. For mills with high inorganic loadings such as salt, tertiary treatments may be necessary, either general membrane treatments such as ultrafiltration or reverse osmosis or the treatments to remove some specific contaminants, such as nutrients.

2.1.2. Industrial oil contaminations

Industrial applications where oil pass into the wastewater stream may include workshops, fuel storage depots, vehicle wash bays, power generation, and transport hubs. The wastewater is often discharged into the local sewer or trade waste system and must meet the local environmental specifications. Typical contaminants include solvents, grit, lubricants, detergents, and hydrocarbons.

2.1.3. Wood preserving

Wood preserving plants create conventional and toxic pollutants, including COD, copper, chromium, arsenic, abnormally high or low pH, SS, phenols, oil & grease (Environmental Protection Agency, 2018).

2.1.5. Treatment of industrial wastewater

The several types of contamination of wastewater need a range of strategies to remove the contamination (Tchobanoglous *et al.,* 2003).

Levels of wastewater treatment

Treatment levels of wastewater are usually identified as primary, secondary and tertiary advanced level).

Primary treatment is often the first treatment level which involves separating a portion of suspended solids (SS) from the wastewater. Sedimentation and screening usually accomplish the separation process in primary treatment. The effluents from primary treatment will normally contain considerable organic materials and will have relatively high BOD.

Secondary treatment is the next level of treatment which involves further treatment of the effluents. Biological processes generally achieve the removal of the residual suspended solids and the organic matter. The effluents from secondary treatment often have little BOD (average of 30 mg/l) and a low suspended solids (SS) value (average of 30 mg/l). Most readily biologically degradable organic materials are removed during biological treatment, however from 40 to 100 mg/l dissolved and biologically resistant (called "refractory") organic materials remain in the effluents. These materials might be end products of normal biological decompositions or artificial products, such as oils, chlorophenols, PCB, nitro-compounds, TCE, synthetic detergents, pesticides, PCE, etc.

Tertiary treatment is the third and the advanced level of wastewater treatment. The unit operations and processes in tertiary treatment include precipitation, activated carbon adsorption, coagulation, filtration, electrodialysis, reverse osmosis, advanced oxidation processes, ozonation, etc., and, at the same time, are often used for local treatment og industrial effluents. These unit operations and processes are applied in treatment of specific components of waste such as refractory organics removal, heavy metal removal, etc.

2.1.5.1. Brine treatment

Brine treatment involves the removal of dissolved salt ions from the waste streams. Although similarities to brackish water or seawater desalination exist, brine treatment in the industries may contain unique combinations of the dissolved ions, such as the hardness ions or other metals, requiring specific equipment and processes. Brine treatment systems are normally optimized to either maximize the recovery of the fresh water/salts or reduce the volume of final discharge for more economic disposal. Brine treatment systems can also be optimized to reduce chemical usage, physical footprint, or the consumption of electricity. Brine treatment is usually encountered when treating produced water from the steam assisted gravity drainage (SAGD), cooling tower blowdown, produced water from the natural gas extraction such as frac flowback water, coal seam gas, acid mine or acid rock drainage, reverse osmosis reject, pulp and paper mill effluent, chlor-alkali wastewater, and waste streams from the food and beverage processing. Brine treatment technologies include: ion exchange processes such as electrodialysis or weak acid cation exchange; membrane filtration processes, such as reverse osmosis; or evaporation processes, such as the brine concentrators and crystallizers employing the mechanical vapour recompression and steam.

The reverse osmosis may not be effective or viable for brine treatment, because of the potential for fouling caused by the hardness salts or organic contaminants, or the damage to reverse osmosis membranes from hydrocarbons. The evaporation processes are the most widely used for brine treatment as they facilitate the highest degree of concentrations, as high as solid salt. Also, they produce the highest purity effluent, even the distillate-quality. Evaporation processes are more tolerant of organics, hardness salts, or hydrocarbons. However, there is high energy consumption and corrosion might be an issue as the concentrated salt water is the prime mover. Consequently, evaporation systems typically employ duplex stainless steel materials or titanium.

2.1.5.2. Hydrocyclone oil separators

The hydrocyclone oil separators operate on processes where the wastewater enters cyclone chamber and is spun under extreme centrifugal forces above 1000 times the force of gravity. The force causes the droplets of water and oil to separate. Separated oil is discharged from the one end of the cyclone while treated water is discharged via the opposite end for additional treatment, discharge, or filtration.

2.1.5.3. Oils and grease removal

Effective removal of the oils or grease depends on the oil characteristics with respect to its suspension state and size of droplets, which in turn will affect the choice of separator technology. The oil in industrial wastewater may be the free light oil, the heavy oil, which has a tendency to sink, and the emulsified oil, usually referred to as the soluble oil. Soluble oils (or emulsified oils) will typically require cracking to free the oils from their emulsion. In most circumstances this is accomplished by lowering pH of the water matrix.

Many separator technologies have optimum range of oil droplet sizes which can be effectively treated. Analyzing the oily water to determine the droplet size can be performed using video particle analyzer. Each separator technology has its own performance curve outlining the optimum performance based on the oil droplet size. Most common separators are the gravity tanks or pits, chemical treatment via DAFs, centrifuges, API oil-water separators or plate packs, hydrocyclones and media filters.

2.1.5.4. Solids removal

Most solids are removed using simplified sedimentation techniques with solids recovered as sludge or slurry. Very fine solids and the solids with densities close to density of water constitute special problems. In such case, ultrafiltration or filtration may be required.

Though, flocculation may be applied by the addition of polyelectrolytes or using alum salts. Industrial wastewater from food processing often needs on-site treatment before it is discharged to reduce or prevent sewer surcharge fees. The specific operational practices and type of industry determine what kinds of wastewater are generated and what kinds of treatment are required. Reducing solids such as waste products, sand, and organic materials is always a goal of industrial wastewater treatment. Most common ways to reduce solids include Dissolved Air Flotation or (DAF), primary sedimentation (clarification), drum screening, and belt filtration (microscreening).

2.1.5.5. API separators

Many oils can be recovered from the open water surfaces by skimming device. Considered a cheap and dependable way to remove grease, oil, and other hydrocarbons from water, oil skimming devices can sometimes accomplish the required level of water purity. At some other times, skimming is also cost-efficient method to remove most oil before using chemical processes and membrane filters. Skimmers will prevent the filters from premature blinding and retain chemical costs down as there is less oil to process. As grease skimming involves higher viscosity hydrocarbons, the skimmers must be well equipped with heaters sufficiently powerful to keep grease fluid for proper discharge. If floating grease forms solid clumps or mats, an aerator, a spray bar, or mechanical apparatus may be used to facilitate removal (Hobson, 2004). However, hydraulic oils and majority of oils that degraded to some extent will also have emulsified or soluble component that will need further treatment to eliminate. Emulsifying or dissolving oil using solvents or surfactants usually intensifies the problem instead of solving it, generating wastewater that is more challenging to treat. The wastewater from large-scale industries such as chemical plants, natural gas processing plants, oil refineries, and petrochemical plants usually contain gross amounts of oil and SS. Those industries use device known as API oil-water separator, designed to separate the oil and SS from their wastewater effluents. The name is originated from the fact that the separators are designed according to the standards published by American Petroleum Institute (API) (American Petroleum Institute, 1990).

The API separator is gravity separation device designed using Stokes Law to define rise velocity of oil droplets basing on their size and density. The design is based on the difference in specific gravity between the wastewater and the oil because the difference is much smaller than specific gravity difference between the water and suspended solids. The suspended solids settles at the bottom of the API separator as sediment layer, the oil rises to the top and the cleansed wastewater is middle layer between the solids and the oil layer. Normally, the oil layer is skimmed off, subsequently disposed of or re-processed, and the bottom sediment layer removed by a chain and flight scraper (or other similar device) and sludge pump. The water layer is led to additional treatment for further removal of any residual oil, then to some type of biological treatment units for removal of undesirable dissolved chemicals.

Parallel plate separators are similar to the API separators, however they include tilted parallel plate assemblies (parallel packs). The parallel plates offer more surface for the droplets of suspended oil to coalesce into larger globules or balls. Such separators still depend on the specific gravity between the water and the suspended oil. However, the parallel plates improve the degree of oil-water separations. The result is that parallel plate separator needs significantly less space than conventional API separator to accomplish the same degree of separation.

2.1.5.6. Biodegradable organics removal

Biodegradable organic materials of animal or plant origin is usually likely to treat using the extended conventional sewage treatment process such as trickling filter or activated sludge (Tchobanoglous *et al.,* 2003). Problems can arise if wastewater is highly concentrated (such as undiluted milk or blood) or is excessively diluted with washing water. The presence of disinfectants, pesticides, antibiotics, or cleaning agents can have detrimental impacts on the treatment processes.

Trickling filter process

A typical trickling filter (often called a *trickling biofilter*, *biofilter*, *trickle filter*, *biological filter* or *biological trickling* *filter*) consists of bed of rocks, peat moss, gravel, slag, or plastic media above which wastewater flowing downward contacts a film or layer of microbial slime covering or wrapping the bed media. Aerobic conditions are maintained by natural convection of air or by the forced air flowing via the bed. The process involves the adsorption of organic compounds in wastewater by microbial slime layer, and air diffusion into the slime layer to give the oxygen necessary for the biochemical oxidation of organic compounds. The end products are water, carbon dioxide gas, and other products of the oxidation process. As slime layer thickens, it becomes more difficult for air to penetrate the layer leading to the formation an inner anaerobic layer.

The fundamental components of a whole trickling filter system include:

- Bed of filter medium on which a microbial slime layer is promoted and developed.
- Enclosure or container which houses a bed of filter medium.
- System for distributing flow of wastewater over filter medium.
- System for removing and disposing any sludge from treated effluent.

The sewage or other wastewater treatment with trickling filters is one of the oldest and best characterized treatment technologies.

Activated sludge process

Activated sludge is a biochemical process used for treatment of industrial wastewater and sewage using microorganisms and air (or oxygen) to biologically oxidize organic pollutants, generating a waste floc or sludge containing the oxidized material. Generally, a typical activated sludge process includes: *aeration tank* where the air (or oxygen) is injected and mixed thoroughly into the wastewater; *settling tank* (commonly known as a settler or clarifier) to allow the waste sludge to properly settle. Portion of the waste sludge is recycled into the aeration tank and remaining waste sludge removed for additional treatment and final disposal.

2.1.5.7. Removal of other organics from industrial wastewater

Synthetic organic materials including paints, pharmaceuticals, products from coke production, solvents, pesticides, and so forth may be very difficult to treat. The treatment methods are usually specific to the material under treatment. Methods include distillation, ozonation, advanced oxidation processing, vitrification, incineration, adsorption, chemical immobilisation or landfill disposal. A number of materials such as various detergents may have the capability for biological degradation and in such circumstances, a modified form of treatment of wastewater can be used.

2.1.5.8. Removal of alkalis and acids

Alkalis and acids can often be neutralized under controlled conditions. Neutralization frequently generates a precipitate which will need treatment as solid residue that can be toxic too. In most cases, gases can be evolved necessitating treatment for the gas streams. Some other treatment forms are often required following neutralization. Waste stream rich in hardness ions as from de-ionization processes can readily and freely lose the hardness ions in buildup of precipitated magnesium and calcium salts (Awuchi and Igwe, 2017). This precipitation process can result in severe furring of the pipes and, in extreme cases, can result in blockage of disposal pipes. Treatment is by concentration of de-ionization wastewater and landfill disposal or by careful pH management of released wastewater.

2.1.5.9. Removal of toxic components

Toxic components including metals (such as cadmium, thallium, lead, silver, etc.) acids, alkalis, many organic materials, non-metallic elements (such as selenium or arsenic) are in general resistant to biological processes except very dilute. Metals are often precipitated out by treatment with other chemicals or by changing the pH. Many, however, are resistant to mitigation or treatment and may need concentration followed by recycling or landfilling. Dissolved organics may be incinerated within the wastewater using advanced oxidation process.

2.1.6. Use of smart capsules

Molecular encapsulation technology has the potential to provide system for recyclable removal of lead and some other ions from polluted sources such as industrial wastes. Milli-, micro-, and nano-capsules, with sizes in the ranges of >1mm, 1μm-1mm, and 10 nm-1μm, respectively, are the particles that have active reagent (core) enclosed by carrier or shell. The three types of capsule under investigation include carbon nanotubes, polymer swelling capsules, and alginate-based capsules. These capsules provide likely means for remediation of contaminated water (Tylkowski and Jastrząb, 2017).

2.2. Solid waste

Tons of solid waste is disposed at many landfill sites daily, majority of which are often industrial sources, either directly or disposed of after use. The wastes come from homes, industries, offices, and various agricultural related activities. The landfill sites generate foul smell if the wastes are not properly stored and treated, and can pollute the surrounding air which can severely affect human health, wildlife, and the environment (Rinkesh, 2018).

2.2.1. Sources of solid waste

The main sources of solid waste can be:

Agricultural: Crop farms, vineyards, feedlots, orchards, and dairies are also sources of solid waste. The wastes they produce include spoiled food, pesticide containers, agricultural wastes, and other hazardous materials (Rinkesh, 2018).

Commercial: Commercial facilities and buildings are another source of solid wastes. Commercial facilities and buildings in this context refer to restaurants, go downs, hotels, markets, stores and office buildings. Some solid wastes generated from these facilities and buildings include plastic wastes (Awuchi and Awuchi, 2019a; Chinaza, *et al.*, 2020; Awuchi and Awuchi, 2019b), food wastes, wood, cardboard materials, metals, paper, glass, special wastes and other hazardous wastes (Rinkesh, 2018).

Institutional: The institutional centers such as colleges, prisons, schools, military barracks and other government centers produce solid waste (Rinkesh, 2018). Some of the common solid wastes generated from these places include plastics, food wastes, wood, glass, rubber waste, paper, metals, electronics, cardboard materials, and various hazardous wastes.

Demolition and construction sites: Construction and demolition sites contribute to the solid wastes generation. Construction sites include the road repair sites, new construction sites for roads and buildings, building demolition sites, and building renovation sites (Rinkesh, 2018). Some of the solid wastes generated in these places include concrete, wood, steel materials, plastics, copper wires, dirt, rubber, and glass.

Biomedical: Hospitals, chemical manufacturing firms, and biomedical equipment are sources of solid wastes. There are different kinds of solid wastes produced in hospitals, including syringes, drugs, paper, plastics, bandages, used gloves, food wastes and chemicals (Rinkesh, 2018). All these require appropriate disposal or else they may cause a huge problem to human and the environment.

Residential: Residential areas and homes where individuals live are among the major sources of solid wastes. Garbage from these places include paper, food wastes, plastics, glass, metals, yard wastes, ashes, leather, cardboard, and special wastes such as bulky household items, e.g. electronics, old mattresses, used oil, tires, and batteries. Most homes have garbage bins in which they throw their solid wastes in and the bin is later emptied by garbage collecting firm or individual for treatment.

Industrial: Industries are one of the biggest contributors to solid wastes. They include heavy and light manufacturing industries, fabrication plants, canning plants, construction sites, chemical plants, power plants, etc. These industries produce solid wastes in form of food wastes, packaging wastes, plastic wastes, housekeeping wastes, ashes, construction and demolition materials, medical wastes, special wastes, and other hazardous wastes (Rinkesh, 2018).

Municipal services: The urban centers contribute hugely to the solid wastes generation in most countries. Some solid wastes brought about by the municipal activities include street cleaning, wastewater treatment plants, wastes from parks and beaches, landscaping wastes, the wastes from recreational areas, and sludge.

2.2.2. Methods of solid waste management

There are different methods of managing solid wastes. Proper solid waste management is an important and integral part of environmental conservation which should be observed by industries, individuals, and recognized agencies worldwide to keep the environment clean as well as reduce health and settlement issues.

The following are some of the common methods:

Recycling and Recovery: The recycling or the recovery of resources is one of the common methods of solid waste management. Conventionally, these items are cleaned and processed before recycling. The process aims at reducing the energy loss, reduction of landfills, and consumption of new material.

Sanitary Landfill: This is the most common solid waste disposal method used today. Garbage is mainly spread out in thin layers, compacted or compressed and covered with plastic foam or soil. Modern landfills are designed in a way the landfill bottom is covered with impervious liner which is often made of many layers of thick plastics and sand (Rinkesh, 2018). The liner protects ground water from contamination due to percolation or leaching. When the landfill is completely filled, it is covered with layers of clay, sand, gravel, and top soil to prevent water seepage.

Composting: Owing to the lack of sufficient space for landfills, the biodegradable yard wastes are allowed to decompose in medium designed for such purpose. Only the biodegradable wastes are used in composting. Quality environmentally friendly manure is made from the compost and are used for agricultural purposes. Composting is a good green method of waste management.

Pyrolysis is a method of solid waste management where solid wastes are chemically decomposed through heating without presence of oxygen. Pyrolysis usually takes place under pressure and at temperatures of about 430^{o}C. The solid waste is converted into gasses, small amounts of liquid, and solid residue.

Incineration: Incineration of solid wastes involves burning of them at high temperatures until the waste materials turn into ashes. Incinerators are made in a way that they do not generate extreme heat when burning solid wastes. This method reduces the volume of the solid waste up to 20 to 30% of the original volume or more. As a method of solid waste management, incineration can be done by industries, municipalities, individuals, and (or) institutions (Rinkesh, 2018).

2.2.3. Effects of improper solid waste management

Due to poor waste disposal systems mostly by municipal waste management teams; the wastes stockpile and become problematic. This type of dumping waste materials makes the biodegradable materials to decompose under improper, unhygienic and uncontrolled conditions (Rinkesh, 2018). After few days of decomposition, foul smell is generaed and becomes breeding ground for many disease causing insects and infectious organisms. In addition, it also spoils aesthetic value of the area. Solid wastes from industries are source of toxic metals, harmful chemicals, and hazardous wastes. When released to the environment, solid wastes can cause physicochemical and biological problems to the environment and human, and may affect the soil productivity and fertility. Plastic wastes have been linked to human exposure to endocrine disruptors, such as bisphenol A, phthalates, etc., and have also been reported to cause the death of many marine species (Awuchi and Awuchi, 2019a; Awuchi and Awuchi, 2019b). These endocrine disruptive effects are due to the chemical additives added to plastics during manufacturing to confer some desirable characteristics and functions. Toxic chemicals and other harmful materials may seep into soil and pollute ground water. In the course of collecting solid waste, hazardous wastes often mix with ordinary garbage and inflammable wastes making the process of disposal even harder and risky (Rinkesh, 2018; Awuchi and Igwe, 2017). When hazardous wastes such as pesticides, cleaning solvents, batteries containing lead (zinc or mercury), e-waste, radioactive materials, and plastics are mixed up with paper and some scraps are burned they produce gasses and dioxins. These toxic gases have potential to cause many diseases and have been reported to be carcinogenic.

2.3. Electronic waste (E-waste)

2.3.1. Environmental impact of e-waste

The dismantling and disposing processes of electronic waste in developing countries resulted in many environmental impacts. The atmospheric and liquid releases end up in water bodies, groundwater, air, and soil, and therefore in sea and land animals – both wild and domesticated, in crops consumed by both human and animals, and in drinking water (Frazzoli *et al.,* 2010). A study of environmental impacts in Guiyu, China reported that the levels of the carcinogens in rice paddies and duck ponds exceeded international standards for the agricultural areas and cadmium, nickel, lead, and copper levels in rice paddies were above the international standards; heavy metals detected in road dust (copper over 100 times and lead over 300 times that of the control village's road dust); airborne dioxins (a type found at 100 times levels measured previously). A separate study at Agbogbloshie e-waste dump in Ghana found presence of lead levels as high as 18,125 ppm in the soil (Caravanos, 2013). US EPA standard for lead levels in soil in play and non-play areas are 400 ppm and 1200 ppm respectively. Scrap workers at the Ghanaian Agbogbloshie e-waste dump frequently burn electronic components as well as auto harness wires for the recovery of copper (Chasant, 2018), releasing toxic chemicals such as lead, furans, dioxins into the environment. These practices are also commonly done in many parts of Nigeria with little or no government regulations.

Table 1: The environmental impact of the processing of different electronic waste components

E-Waste Component	Potential Environmental Hazard	Process Used
Cathode ray tubes (used in ATM, TVs, video cameras, computer monitors, etc.)	Barium, lead, and other heavy metals leaching into ground water and release of toxic phosphor	Breaking and the removal of yoke, then dumping
Printed circuit board	Air emissions and discharge into the rivers of glass dust, lead, brominated dioxin, tin, beryllium, mercury, and cadmium	Removal of computer chips and de-soldering; open burning and acid baths to remove metals after chips are removed.
Chips and the other gold plated components	Heavy metals, PAHs, brominated flame retardants directly discharged into rivers acidifying fish/flora. Lead and tin contamination of ground and surface water. Air emissions of brominated	Chemical stripping using nitric acid and hydrochloric acid and the burning of chips

	dioxins, PAHs, and heavy metals	
Plastics from keyboards, printers, monitors, TVs, radios, etc.	Emissions of brominated dioxins, hydrocarbons, and heavy metals	Shredding and the low temperature melting to be reused
Computer wires	PAHs released into air, soil, and water.	Open burning as well as stripping to remove copper

2.3.2. E-waste recycling

Recycling is essential for management of e-waste. If done properly, it should significantly reduce leakage of toxic materials into environment and mitigate exhaustion of the natural resources. However, it needs to be supported by local authorities and also through community awareness or education. One of the main challenges is recycling printed circuit boards from electronic wastes. Circuit boards contain precious metals such as gold, tin, platinum, silver, etc. and base metals such as copper, aluminum, iron, etc. Conventional method employed includes mechanical shredding and separation however the recycling efficiency is low. One way electronic wastes are processed is by melting the circuit boards, open-pit acid leaching for separating valuable metals, and burning the cable sheathing to recover copper wire. Alternative methods like cryogenic decomposition have been examined for printed circuit board recycling (Yuan *et al.,* 2007), and some are still under research. Proper reusing or disposing of electronics can help reduce greenhouse-gas emissions, prevent health problems, and create more jobs (Fela, 2010). Reuse and refurbishing offer more socially and environmentally friendly conscious alternative to the down-cycling processes. Many sizes of button and coin cells with 2 9v batteries as size comparison are all recycled in some countries as they contain lead, cadmium, and mercury.

E-waste Processing techniques

In some developed nations, processing of e-waste often first involves the dismantling of the equipment into several parts (power supplies, plastics, circuit boards, metal frames), often by hand, but then increasingly by automated shredding equipment. Typical instance is the NADIN e-waste processing plant in the Novi Iskar, Bulgaria; the largest facility of this kind in the Eastern Europe (Sofia News Agency, 2010). The advantages of the process are the ability of human to recognize and save the working and repairable parts, including transistors, RAM, chips, wires, etc. The disadvantage is that labor is cheapest in the countries with lowest health and safety standard. In alternative bulk systems, a hopper conveys the materials for shredding into unsophisticated mechanical separator, with granulating and screening machines to separate component plastic and metal fractions, which are sold to plastics recyclers or smelters. These kind of recycling machineries are enclosed and employs dust collection system. Some emissions are caught by screens and scrubbers. Magnets, Trommel screens, and eddy currents are employed to separate plastic, ferrous and nonferrous metals, and glass, which can be separated further at a smelter. Leaded glass from the CRTs is reused in car batteries, lead wheel weights, and ammunition, or sold to foundries as fluxing agent in the processing of raw lead ore. Gold, palladium, silver, tin, and copper are valuable metals sold to the smelters for recycling. The hazardous smoke and gases are caught, contained and treated to mitigate the environmental threat and impacts. These methods allow safe reclamation of all the valuable computer construction material.

The benefits of e-waste recycling

Recycling raw materials from the end-of-life electronics is the major effective solution to the growing problem cause by e-waste. Most electronic devices contain some materials, including the metals which can be recovered and recycled for future use. By dismantling and providing reuse possibilities, the intact natural resources are often conserved and the water/air pollution caused by the hazardous disposal is prevented. In addition, recycling reduces the levels of greenhouse gas emissions caused by manufacturing of new products. Another benefit is that a lot of the materials can be recycled, recovered, and reused again. The recyclable materials include iron-based (ferrous) and non-iron-based (non-ferrous) metals, glass, and several types of plastics. Non-ferrous metals, mostly copper and aluminum can all be re-smelted as well as re-manufactured. Ferrous metals such as iron and steel can also be reused (Zero Waste, 2016). Due to the recent surge in the attractiveness in 3D printing, some 3D printers are designed (FDM variety) to produce wastes that can be recycled easily which decreases the levels of harmful pollutants in atmosphere. The excess plastics from these printers which comes out as byproducts can also be reused to make new 3D printed creations (Plasticscribbler, 2016). In Europe, the metals that are recycled are often returned to the companies of origin at reduced cost (Sea Columbia, 2016). In Japan, through a committed recycling system, manufacturers are pushed to make more sustainable products. As many companies are responsible for their products recycling, this imposed responsibility on the manufacturers necessitating many to redesign their infrastructures. Consequently, manufacturers in Japan have added option to sell recycled metals.

2.3.3. E-waste constituents

Some computer components are reused in assembling new computer products, whereas others are simply reduced to metals which are reused in applications as varied as flatware, jewelry, and construction. Substances found in large amounts include fiberglass, PCBs, epoxy resins, PVC (polyvinyl chlorides), lead, tin, copper, thermosetting plastics, silicon, beryllium, iron, aluminum, and carbon. Elements found in small quantities include mercury, thallium, and cadmium. Elements found in trace amounts include arsenic, barium, bismuth, americium, antimony, boron, cobalt, europium, gold, indium, lithium, manganese, gallium, germanium, nickel, niobium, platinum, rhodium, palladium, ruthenium, selenium (Hieronymi, 2012), terbium, thorium, titanium, vanadium, yttrium, silver, and tantalum. Almost all electronics contain tin and lead (as solder) and copper (as wire as well as printed circuit board tracks), although the use of lead-free solder is currently spreading rapidly. Table 2 shows ordinary applications:

Hazardous

Table 2: Adverse health and environmental effects of e-waste components

E-Waste Component	Adverse Health Effects	Electric Appliances in which they are found
Americium	Known to be carcinogenic.	The radioactive source in smoke alarms.
Beryllium oxide	Occupational exposure associated with lung cancer. Beryllium sensitization, acute beryllium disease, and chronic beryllium disease.	The filler in some thermal interface material such as thermal grease used on heat-sinks for the CPUs and power transistors, X-ray-transparent ceramic windows, magnetrons, gas lasers, and heat transfer fins in vacuum tubes.
Brominated Flame Retardants (BFRs)	Health effects include impaired nervous system development, liver problems, thyroid problems. The environmental effects are similar to the effects in animals and humans.	Used as flame retardants in the plastics in most electronics. Includes PBDE, DecaBDE, PBBs, OctaBDE, PentaBDE.
Cadmium	The inhalation of cadmium cause severe lungs damage and is known to cause kidney damage. Also, cadmium is associated with deficits in cognition, behavior, learning, and neuromotor skills in children. When improperly recycled it may leach into soil, harming microorganisms and disrupting soil ecosystem.	Found in light-sensitive resistors, nickel-cadmium batteries, and corrosion-resistant alloys for aviation and marine environments. The most common cadmium form is found in the Nickel-cadmium rechargeable batteries. The batteries tend to contain between 6 and 18% cadmium.
Hexavalent chromium	Known carcinogen after occupational inhalation exposures. There is evidence of genotoxic and cytotoxic effects of various chemicals, which have been reported to inhibit cell proliferation, cause DNA single-strand breaks, elevate Reactive Oxygen Species (ROS) levels, and cause cell membrane lesion.	Used in metal coating to protect from corrosion.
Lead	Adverse effects of lead exposures are behavioral disturbances, attention deficits, impaired cognitive function, hyperactivity, lower IQ, and conduct problems. These effects are most damaging to the children whose developing nervous systems are more susceptible to damage caused by lead, mercury, and cadmium.	Solder, lead-acid batteries, CRT monitor glass some PVC formulations. A 15-inch cathode ray tube can contain 1.5 pounds of lead, however other CRTs have been shown to have up to 8 pounds of lead.
Mercury	Health effects of mercury are memory loss, muscle weakness, sensory impairment, and dermatitis. Exposure in-utero results in fetal deficits in motor function, verbal	Found in fluorescent tubes, tilt switches (thermostats, mechanical doorbells), and ccfl backlights in the flat screen monitors.

	domains, and attention. Environmental effects in animals are death, slower growth, slower development, and reduced fertility.	
Perfluorooctanoic acid (PFOA)	In mice health effects include hepatotoxicity, developmental toxicity, hormonal effects, carcinogenic effects, and immunotoxicity. In human; increased risk of spontaneous abortion (i.e., miscarriage) and stillbirth. Increased maternal perfluorooctanoic acid levels are also associated with reductions in mean gestational age (preterm birth), mean birth length (i.e., small for gestational age), mean birth weight (low birth weight), and mean APGAR score.	Used as antistatic additive in industries and found in electronics and in non-stick cookware (PTFE). Perfluorooctanoic acids are synthetically formed through environmental degradation.
Polyvinyl chloride (PVC)	In the production phase, toxic and hazardous raw materials, including dioxins are released. The PVC such as chlorine have a tendency to bioaccumulate. With time, the compounds that contain the chlorine can become pollutants in air, soil, and water, posing a problem as human as well as animals can ingest them. In addition, exposures to toxins can cause developmental and reproductive health effects.	Often found in electronics and is used as insulation for electrical cables.
Sulfur	Health effects are kidney damage, heart damage, liver damage, eye irritation, and throat irritation. When released into environment, it can generate sulfuric acid via sulfur dioxide.	Found in lead-acid batteries.

Generally non-hazardous

Table 3: Non-hazardous e-waste components and the processes used

E-Waste Component	Process Used
Zinc	Plating for steel parts.
Tin	Solder, coatings on component leads.
Silicon	Glass, ics, transistors, printed circuit boards.
Nickel	Nickel-cadmium batteries.
Lithium	Lithium-ion batteries.
Gold	Connector plating, primarily in the computer equipment.
Germanium	1950s to 1960s transistorized electronics (the bipolar junction transistors).
Copper	Component leads, copper wire, printed circuit board tracks.
Aluminium	Almost all electronic goods using more than few watts of power (heatsinks), electrolytic capacitor.

2.3.4. Notable human health and safety concerns due to e-waste

2.3.4.1. Prenatal exposures and health of neonates

Prenatal exposures to e-waste has found to have some adverse effects on the human body burden of pollutants of neonates. In one of the most well-known e-waste recycling sites, Guiyu, in China, it was reported that the increased cord blood lead concentrations of neonates was associated with the participation of parents in e-waste recycling processes, and also how long the mothers live in Guiyu and in electronic waste recycling workshops or factories during pregnancy (Grant *et al.,* 2013). In addition, a higher placental metallothionein – small protein marking the toxic metals exposures – was found among neonates from the Guiyu as due to Cd exposure, while the higher level of Cd in Guiyu's neonates was connected to the involvement in their parents e-waste recycling (Li *et al.,* 2010). High PFOA exposures of mothers in Guiyu is correlated with adverse effects on the growth of their new-born and prepotency in this area (Wu *et al.,* 2012). Prenatal exposures to informal e-waste recycling can lead to many adverse birth outcomes, such as still birth, low Apgar scores, low birth weight, etc., and long-term effects such as learning and behavioral problems of neonates in their future life (Xu *et al.,* 2012).

2.3.4.2. People living near e-waste recycling sites

Individuals living around e-waste recycling sites, even though they do not involve in the e-waste recycling activities, may face the environmental exposures as a result of the food, environmental, and water contaminations caused by e-waste, as they can easily make contact with e-waste contaminated water, dust, soil, air, and food sources. Generally, three main exposure pathways are ingestion, inhalation, and dermal contact (Grant *et al.,* 2013). Studies have shown that people living very close to e-waste recycling sites have higher daily intakes of heavy metals and more serious body burden. The potential health risks include impaired cognitive function, general physical health damage, and mental health (Song and Li, 2015). DNA damage was found more prevalent in all e-waste exposed populations (neonates, children, and adults) than the populations in control area (Song and Li, 2015). DNA breaks can increase likelihood of wrong replication and consequently mutation, and also lead to cancer if damage is to tumor suppressor gene.

2.3.4.3. Health of children

Children are mostly sensitive to the e-waste exposures because of many reasons, such as their higher metabolism rate, smaller size, larger surface area relative to their weight, and also multiple exposure pathways (e.g., hand-to-mouth, take-home exposure, and dermal) (Bakhiyi *et al.,* 2018; Song and Li, 2015). They were measured to have 8-time potential health risks compared to adult e-waste recycling workers (Song and Li, 2015). Studies have reported significant higher a blood lead level (BLL) and blood cadmium level (BCL) of children living in the e-waste recycling areas compared to those living in the control area (Huo *et al.,* 2007). For example, a study found that average BLL in Guiyu was approximately 1.5 times compared to that in control site (15.3 ug/dL compared to 9.9 ug/dL) (Huo *et al.,* 2007), while the US CDC has set reference for blood lead level at 5 ug/dL (Centers of Disease Control and Prevention, 2019). The highest concentrations of lead levels were found in children of the parents whose workshop dealt with the circuit boards and the lowest was among those who recycled plastic (Huo *et al.,* 2007). Exposure to e-waste can result in serious health problems to the children. Children's exposure to the developmental neurotoxins contained in e-waste such as cadmium, chromium, PBDEs, lead, and mercury can result in higher risks of impaired cognitive function, lower IQ, and other adverse effects (Chen *et al.,* 2011). In some age groups, decreased lung functions of the children in e-waste recycling sites have been found. Also, some studies found associations between e-waste exposures of children and impaired coagulation (Zeng *et al.,* 2018), decreased vaccine antibody tilters (Lin *et al.,* 2017), and hearing loss (Liu *et al.,* 2018) in e-waste recycling area.

2.3.4.4. Health of e-waste recycling workers

The Occupational Safety and Health Administration (the OSHA) has summarized many potential safety hazards of recycling workers generally, such as toxic metals, crushing hazards, and hazardous energy released.

Table 4: The hazards applicable to recycling in general

Hazards	Details
Crushing hazards	There can be traffic accident when transporting e-waste. Workers can be crushed or stuck by the e-waste or the machine. Using machines which have moving parts, such as the conveyors and rolling machines may cause crush accidents, resulting in amputations, crushed hands or fingers.
Lacerations and cuts	Hands, eye, or body injuries can occur when dismantling the e-wastes that have sharp edges.
Hazardous energy released	Unexpected machine startup may cause injury or even death to workers. This may happen during the maintenance, installation, or repair of machines, processes, equipment, or systems.
Noise	Working overtime near the loud noises from hammering, drilling, and other tools which can make great noise result in hearing loss.
Slips, trips, and falls	They can happen during collection and transportation of e-wastes.
Toxic chemicals (dusts)	Burning the e-waste to extract metals emits some toxic chemicals (e.g. lead, cadmium, PAHs) from e-waste to air, which may be inhaled or ingested by the workers at recycling sites, leading to illness from toxic chemicals.

The OSHA has also specified several chemical components of electronics which can potentially harm e-waste recycling workers' health, such as mercury, PCBs, asbestos, lead, refractory ceramic fibers (RCFs), as well as radioactive substances. In the US, most of these chemical hazards have stipulated occupational exposure limits (OELs) set by the OSHA, ACGIH (American Conference of Governmental Industrial Hygienists), and NIOSH (National Institute for Occupational Safety & Health).

Table 5: Occupational exposure limits (OELs) of some hazardous chemicals

Hazardous chemicals	OELs (mg/m^3)	OELs Type
cadmium	0.005	OSHA permissible exposure limit (PEL), time weighted average (TWA)
hexavalent chromium	0.005	OSHA PEL, TWA
Lead	0.05	NIOSH recommended exposure limits (REL), TWA
Mercury	0.05	NIOSH REL, TWA
sulfur dioxide	5	NIOSH REL, TWA

2.3.5. Formal and informal industries e-waste recycling

Formal e-recycling industry refers to the regular e-recycling facilities sorting the materials from e-waste with manual labor and automatic machinery, where personal protective equipment (PPE) and pollution control are common (Ceballos and Dong, 2016). On the other hand, informal e-recycling industry refers to the small e-waste recycling workshops with a few (if any) personal protective equipment (PPE) and automatic procedures. Sometimes the formal e-recycling facilities dismantle e-wastes to sort the materials, then distribute them to other downstream recycling departments to further recover the materials such as metals and plastic (Ceballos and Dong, 2016).

Health impacts of e-wastes recycling workers working in informal and formal industries are expected not to be similar in the extent (Ceballos and Dong, 2016). Studies in 3 recycling sites in China reported that the health risk of workers from the formal e-recycling facilities in Shanghai and Jiangsu were lower compared to workers in informal e-recycling sites in Guiyu. Also, in another study of e-wastes recycling in India, some hair samples were collected from the workers at e-wastes recycling facility and e-waste recycling slum community (an informal industry) in Bangalore (Ngoc *et al.,* 2009). Levels of Mn, Mo, Sn, Tl, Pb, V, and Cr were reported to be significantly higher in workers at e-waste recycling facility compared to e-waste workers in slum community. However, Ag, Cd, Hg, and Co levels were significantly higher in slum community workers compared to their facility workers counterpart. Even in the formal e-recycling industry, the workers can be exposed to excess pollutants. Studies in formal e-recycling facilities in Sweden and France found overexposure of workers (compared to the recommended occupational guidelines) to cadmium, mercury, lead, and some other metals, and BFRs, PCBs, furans, and dioxin. Workers in the formal industry are exposed to more brominated flame-retardants (BFRs) than the reference groups (Ceballos and Dong, 2016).

3. CONCLUSION

Industrial waste can be solid, liquid, or gas and each type has different methods of disposal and management. Industrial waste management deals with all types of wastes relating to industries, including industrial, biological and household, before, during, or after production, and even after usage by consumers. In some cases, wastes can pose a threat to human health. The underlying principles on the guide for industrial waste management ensures Protecting human health and the environment, Tailoring management practices to risks, Affirming state and tribal leadership, and Fostering partnerships. Waste characterization plays an important part in any treatment of waste which may occur. Waste characterization is the process by which the composition of different waste streams is analyzed. Industrial wastes can be characterized to be absolute non-hazardous, mirror entries, or absolute hazardous. The steps involved in risk assessment of industrial wastes include hazard identification and characterization, exposure assessment, and risk characterization. Risk assessment is systematic process of evaluating potential risks which may be involved in industrial waste management projected activity and undertaking. Industrial wastewater treatment involves the processes used for treating the wastewater produced by industries as an undesirable by-product. Treatment levels of wastewater are often identified as primary, secondary and tertiary. Primary treatment involves separating portion of suspended solids from the wastewater. Screening and sedimentation usually accomplish this separation process. Secondary treatment involves the further treatment of the effluent. Biological processes generally accomplish the removal of the organic matter and the residual suspended solids. The effluent from secondary treatment usually has little BOD (30 mg/l as average) and low suspended solids value of 30 mg/l as average. Tertiary treatment is the third, advanced level of wastewater treatment. The unit operations and processes in tertiary treatment include coagulation, filtration, activated carbon adsorption, electrodialysis, reverse osmosis, ozonation, advanced oxidation processes etc. Solid wastes from the industries are source of toxic metals, chemicals, and hazardous wastes. Methods of solid waste management include recycling and recovery, composting, sanitary landfill, pyrolysis, incineration, etc. E-wastes refer to discarded electronic or electrical devices. Used electronics that are destined for resale, refurbishment, reuse, salvage recycling via material recovery, or disposal are considered e-wastes. Informal processing of e-wastes in developing countries can result in adverse human health effects as well as environmental pollution. The electronic scrap components, like CPUs, contain potentially harmful materials such as cadmium, beryllium, lead, or brominated flame retardants. Recycling and disposal of e-waste often involve significant risk to health of workers and the communities in developed and developing countries. Effective industrial waste management and treatment systems need to be put in place and adequately sustained to protect the environment and the health of humans and animals.

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