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Physicochemical Treatment and Disposal of Hazardous Waste

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Abstract - *Since massive urbanization occurs, more and more waste is produced in yearly bases; a situation that drives sanitation facilities exceeding their capacities. On top of that with increased industrialization activity significantly more hazardous waste is produced and disposed as contaminated water or hazardous solid waste. This is a problem, both developed and developing states face and it can dispute the biogeochemical cycles and has side effects in human health and environment. In this report we review in detail physicochemical propertiesof the hazardous chemicals released to the environment and provide an overview of the various hazardous waste treatment technologies. The goal is encourage government to implement policies to ensure water pollution is controlled and enforced by law.*

Keywords – *Physicochemical properties, hazardous waste, wastewater, industrial waste, policy implementation.*

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1. Introduction

Clean water is essential to the livelihood of people across the world. Many developing nations struggle with access to clean drinking water and implementation of government regulations to ensure the safety and cleanliness of water supplies. Since the second industrial revolution and the massive extraction of fossil fuels, human kind introduced large amounts of hazardous gases in the atmosphere [37]. Another phenomenon that causes a myriad of problems is the highly increasing population and its concentration in urban areas. Proper and sustainable sanitation has become more urgent than ever. Though important, the ever-increasing urbanization causes existing sanitation plants overcome their capacity. In addition, some low-income developing states are unable to provide their citizens even with the basics of sanitation. Legislations are of high importance in those countries since they lack them completely. It is also vital to identify the reason that causes the environmental and human hazards in waste. Those properties called physicochemical and require our attention for a handful of reasons. The physicochemical properties of hazardous waste are of high importance, since by analyzing them, we are able to categorize them and therefore apply different techniques of treatment. Hazardous waste can be solid, in the form of landfill waste from domestic sector mainly. In addition it can be fluid, mainly wastewater which contains hazardous chemicals that are found to be harmful for flora and fauna as long as humans. In the case of Papua New Guinea, the current garbage services are mainly municipal solid wastes. As to the hazardous wastes generated by hospitals or industry are directed to be treated by the Polluter Pay Principle of the country. Nevertheless, a huge gap is noted in policy and regulation of the country for disposal and treatment technologies [36].

The following report outlines the effects of water pollution and hazardous waste treatment technologies and provides compelling evidence to encourage the Papua New Guinea government to implement necessary water pollution controls that will protect people and the environment.

Water pollution control. A guide to the use of water quality management principles

In the developing world and in industrialized countries, the absence of adequate expertise to properly manage and control water pollution is a major issue. Inadequate legislations and pollution control measures often result in escalating issues related to diseases, environmental degradation an economic stagnation. Under the UN umbrella, world leaders in 1992 and 1993 agreed to a global effort in assisting developing countries to achieve better water quality through water pollution control and management techniques. Implementing policies to avoid water contamination is the first and most vital step required to ensure water quality and safety. To reach a situation that political intentions have a real impact on the management of water resources, a water pollution control policy, should become constitutional and must be applied by all the appropriate ministries. A properly implemented policy should follow some guiding principles, including taxes on polluters, applying realistic standards and regulations, balance economic and regulatory instruments (e.g. discharge fees) and allow private investments assisting pollution awareness. Apart from political framework, a scientific framework needs to be implemented. The substances it contains quantify water quality. There are also certain chemicals or materials that are prohibited like DDT or mercury as highly toxic. Protection of aquatic life is also taken into account. Certain chemicals or even water itself, if disposed in higher temperatures, may disrupt the local aquatic environment. Globally there are minimum water quality standards that each country should follow; however, each country may have individual standards that are implemented.

A major asset in successfully managing waste and water is technology advance. In recent years significant breakthroughs in technology, driven by economic advances, provide us with adequate solutions for wastewater treatment. It is vital, though, technological advances to come together with public awareness. The latter, is equally important as most of wastewater, comes from domestic use.

Another significant contributor is the industrial sector that disposes large amounts of non-biodegradable compounds on water environments. Due to pesticide use, the agricultural sector is another major contributor of phosphorous and nitrogen. The proper technology selection depends on wastewater characteristics and components as long as the desired effluent quality. Generally, sanitation solutions differ as changes of population density happen. For rural areas with low population density, on-site sanitation is preferred as a cheaper and effective solution, while in urban areas off-site sanitation is applied, due to lack of space. The selection criteria for a technology are, average efficiency, manageability, financial sustainability and application in reuse schemes. As a renewable source within the hydrological cycle, water needs to be efficiently used, and recycled. When treated but still not appropriate for human consumption, wastewater can be reused in sectors like agriculture or in fire protection and public sector (decorative water, fountains, toilet etc.). The industrial sector can use wastewater as cooling medium, boiler-feed water or process water. Recycling though, advances with the advance of technology, as mentioned before, and the techniques have to be economically feasible in order to be able to apply in greater scale. Being able to assess the progress achieved, sufficient data must be generated in yearly bases. For the generation and processing of those data environmental quality standards are implemented along with water quality objectives. In this way, estimations and predictions for potential environmental risks and even for progress monitoring, is becoming easier. Along with all the above, appropriate, measures for sustainable wastewater management, comes, law enforcement mechanisms. Violation of an environmental law has to lead to court action. Aside from infiltrating in fresh water deposits, wastewater also affects ground water and requires special efforts to protect from pollution. Any activity taking place on the surface land has an effect on ground water quality; however, being out of sight the damage is not always apparent. In order to preserve its quality, preventive measures need to take place for harmful substances released by agricultural or domestic activity. Another form of pollution is trans boundary pollution. By definition, is when pollutants carried from one country to another by rivers? This situation may cancel significant progress of one country due to wastewater-imported form its neighbors. National bodies like EU and UN need to take action for cross-border agreements to eliminate this issue and promote international cooperation. Urban sanitation, as noted before, is a major and priority issue in the increasingly urbanized societies. One of the problems is inadequate capacities of the already installed plants and financing issues for expanding. Low-income and Lower middle-income countries face low access to basic sanitation with scarce water treatment and severe water pollution issues while Upper middle-income countries enjoy access to all the above. Progress has been achieved since 1980 for middle and high-income households. Lastly, public engagement is an important measure for promoting wastewater management [22].

Physicochemical properties of interest

For the purpose of this report, physicochemical properties are defined as, physical properties, solvation properties related to interactions with different media and reactivity. The physicochemical properties involved in chemical alternatives assessment can be used to identify physical hazards, predict a chemicals environmental fate, human toxicity or Eco toxicity as presented in Figure.1.

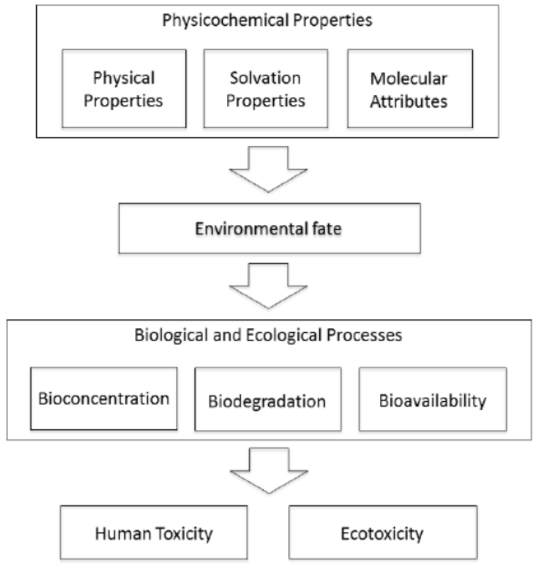

Figure 1. Three primary types of physicochemical properties assessed in this report

<u>Physical Properties</u>

Physical properties include freezing point, boiling point, melting point, infrared spectrum, electronic parameters, viscosity, and density. Some of these physical properties (e.g., electronic parameters, molecular weight, boiling/freezing point) are directly associated with environmental fate and health effects.

<u>Solvation Properties</u>

Solvation properties describe a chemicals interactions with different phases and its partitioning between phases. Solvation properties of interest in alternatives assessment can be divided into three main types:

(a) phase partitioning, (b) solubility, and (c) colligative properties:

Phase partitioning: A partition-coefficient or distribution-coefficient is defined mathematically, as the ratio of concentrations of a given compound across two mixed, immiscible phases at equilibrium. In the context of a chemical alternatives assessment, important partition coefficients are often measured in the liquid phase. Though partitioning can be measured across a range of solvents and phases, the phase partition coefficient most often encountered when, assessing physicochemical properties, is from a system where one solvent is water or an aqueous phase and the second is organic and hydrophobic, such as 1 octanol/water partition coefficient [Kow] represented by P)

Solubility: This chemical property refers to the ability of a given substance (the solute) to dissolve in a solvent. The primary measurement of interest in chemical alternatives assessment is solubility in water.

Colligative properties: Colligative properties are properties of solutions that are not dependent on the chemical species but instead on the ratio of the number of solute particles to the number of solvent molecules in a solution. Examples of colligative properties include lowering of vapor pressure, elevation of boiling point, and depression of freezing point. Colligative properties generally do not play a significant role in alternatives assessments and are not discussed further in this report.

The other properties that was also discuss in this chapter are also molecular attribute, which is used to describe properties related to molecular shape and size and environmental partition coefficients that can provide valuable information about environmental fate such as chemical phase coefficient in soil and water.

Physicochemical properties and environmental fate

National Research Council, in its 2014 report, outlines in detail the required steps for a reader to acquire in depth knowledge of the physicochemical properties of potentially hazardous chemicals. There are two basic outlines in the chapter. The inherent hazard of a chemical, such as its capacity to intervene in normal biological processes, is the first, while, its physical hazards and environmental fate (degradation time, persistence), is the second. Those outlines, factors are determined by the intrinsic physicochemical properties of the chemicals and the interacting system.

For both organic and inorganic chemicals, those intrinsic parameters are characterized by the molecular structure of the chemical and by the material which is composed. Their hazardousness is then a factor of their size, composition and morphology. The toxicological and physical hazards of the chemicals can be prevented if the physicochemical properties that cause those hazards removed in their initial stage. This procedure is inexpensive but it has to be quickly implemented.

In this report, a general background on physicochemical properties of hazardous chemicals is provided and methods (computational or experimental) to determine them are reviewed. Finally, the committee provides additional instructions on the implementation of the framework as presented in Figure.2.

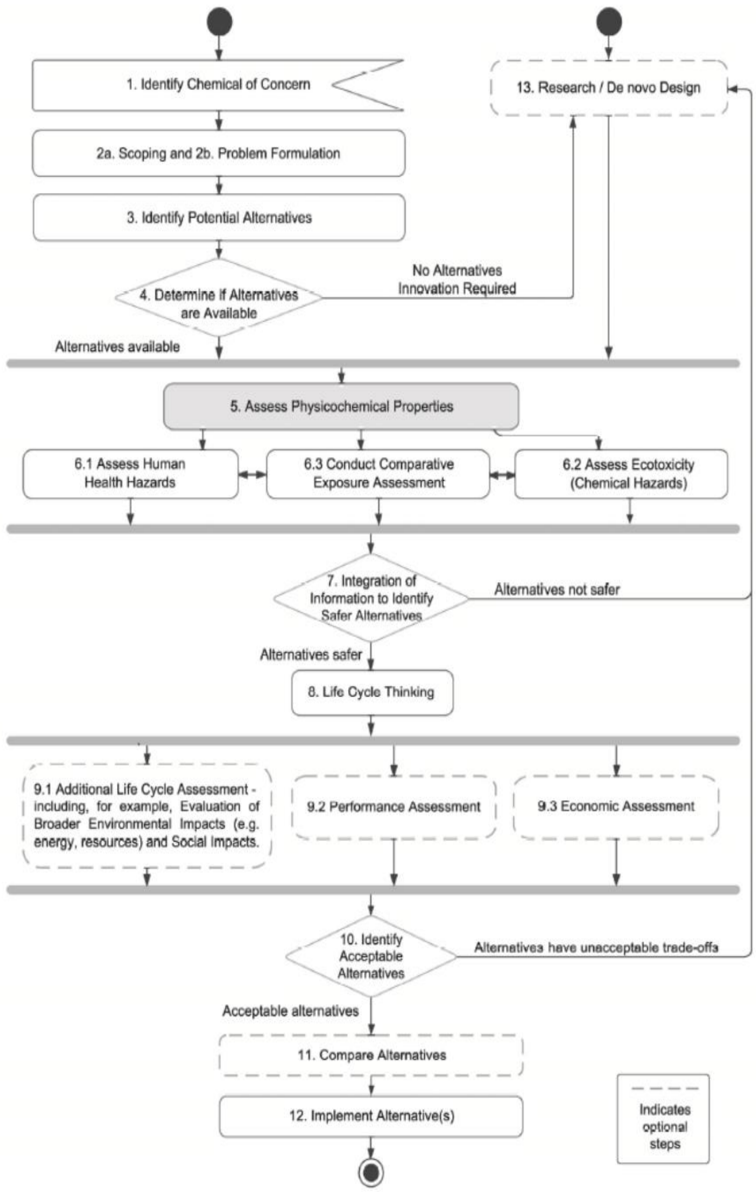

Figure 2. Algorithm representation for assessing physicochemical properties

Hazardous waste treatment technologies

The purpose of hazardous management is to mitigate the harm that may be caused by waste to humans and the environment. This can be achieved by converting waste materials into less harmful or environmentally friendly by physical, chemical or biological processes followed by the disposal or dispersal of solid or gaseous products or residues under properly managed or monitored conditions.

Hazardous Waste Management converts the waste material into less harmful or environment benign chemicals by biological, physical, chemical, and thermal processes followed by solid, liquid, gaseous, or residue disposal or dispersal under managed conditions. Hazardous waste can be classed into the following main categories: physical processes, physicochemical processes, chemical processes, biological processes, and thermal processes. The general scheme for the allocation of treatment technologies to different types of hazardous waste is shown below.

Processes in this section are something of a hybrid, in so far as the process relies on the exhibition and use of both physical and chemical properties for the process to operate successfully.

Solvent extraction is a process in which an aqueous system containing dissolved or suspended organic material is mixed with an immiscible solvent which then dissolves the organic material. The two immiscible phases may then be separated.

A solvent extraction process is that where a membrane is placed between the phases so that the organic solvent and aqueous phases do not come into direct contact.

Stripping and desorption, is a process in which volatile components of a liquid mixture can be removed by passing a stream of gas through the liquid which is the Ammonia rich aqueous wastes, containing phenolic wastes, or any aqueous waste with volatile organic components/contaminants.

Membrane-based processes, separate solutes/contaminants from the liquids in which they are present by the use of semi-permeable membranes. Semi-permeable membranes function by selectively rejecting certain species, based on factors such as size, ionic valence, and polarity.

Leaching, is a process in which waste gas streams or liquid wastes are subjected to a cleaning process by contacting them with a washing liquid or slurry, or in some cases, a solid powder.

Scrubbing, occurs when components of waste gas streams, both gaseous and entrained solid matter, and droplets can be removed to varying degrees by scrubbing processes which contact the gas stream with (usually) an aqueous washing medium.

UV Irradiation/Ozonolysis, is a process in which molecules are broken down by a combination of ozone and energy inputted to the system via UV irradiation applicable to assisting the breakdown of halogenated and stable organic molecules, even when dispersed in a medium such as soil.

Ion Exchange, is a reversible process in which dissolved ionic constituents of a solution may be, when in contact with a suitable resin, exchanged with other ionic species on the resin.

Immobilization Techniques have to be considered when other processes cannot be used. The term is used to cover several processes which share the principle of "conditioning" a waste so as to minimize the possibility of release into the environment at large.

Solidification, is a cement-based process which seeks to convert waste into a solid, inert mass, preventing its release or dispersion into the environment

Encapsulation is a process in which waste is enclosed within a casing or layer of some inert and resistant substance so as to prevent the escape of that substance into the wider environment.

Because of the widely physical and chemical characteristics of hazardous waste, treatment technologies have to be carefully matched into each waste type, taking into consideration the nature of waste, the degree of waste reduction and of hazardous reduction (i.e., the nature of the residue class) together with economic and other factors.

Advances in biological processes have resulted in and allow faster degradation rates and treatment of higher level of contamination by raising treatment temperature and increasing oxygen transfer rates during treatment processes. Useful physicochemical processes have been developed over the years by researchers that used a combination of chemicals often aided by the addition of electrical current to oxidize as well as to recover the constituents in the waste from aqueous solution.

Waste thermal treatment is once again attracting attention as a viable alternative to landfill disposal. Thermal treatment reduces the volume of solid waste significantly but suffers from a bad reputation with the public, representing one of the top industries no-one wants 'in their backyard'. Some of this fear stems from a lack of information about the process, but more justified concerns over emissions remain. With high efficiency to improve destruction of hazardous waste with inert ash product.

Alternatively, waste can be contained or immobilized so as to minimize or limit the dispersion of waste mass and exposure of the receptors to the hazards. In addition to the degradation, destruction or disposal technologies, the term 'treatment' represents processes for the recycling or recovery of waste, the effect being to remove these materials from the disposal chain so that humans and the environment are not exposed to them anymore.

However, it was found that recovery and recycling processes also produce residues which are hazardous waste in nature and which would therefore have to be directed to other treatment or disposal options to render them safe.

Wastewater treatment available technologies in industrial and agricultural sector

Development of wastewater treatment technologies became a basic need in the last few decades, as urbanization moved populations from rural regions to large urban cities. Along with this high concentration of people in some regions, came the industrialized areas that provide the massive populations with their increasingly high amenities. Both people and industries constantly infiltrate in the natural water cycle with the disposal of their byproducts. The urgent need for high efficient, economically and environmentally sustainable wastewater treatment solutions brought forward.

The most widely known and applied way of wastewater treatment is distillation. This is the process where multi components are separated into pure components, based on their difference in boiling points. The distillation setup consists of large columns that contain the contaminated water. By heating, the water becomes vapor and is driven from several membranes to a condenser to liquefy again. Those membranes prevent the particles that contaminate the water to pass. Typical examples of distillation are separation of ethanol from water and distillation of petroleum products. A similar technique is stripping columns. Stripping is essentially a distillation process where the heavy product is water/liquid and the lighter product is generally mixture of organic volatile materials. The heating source in the column is steam.

Wastewater is entered at the stripping tower at the top while, steam is introduced at the bottom and makes contact with the liquid. Liquid proceeds down while vapor rises up and collects organic material. In this way clean water is collected at the bottom. A typical example of Stripping distillation is Benzene separation from wastewater [1].

In different industries different treatment procedures are applied due to the specific characteristics of wastewater. In the chemical industry, the characteristics and the compounds of wastewater, determine the adequate treatment system. Those characteristics may be, solubility, toxicity and biodegradability of the pollutants. A widely used technology with adequate results in oil and other organic wastes removal, is the rotating biological contractor, a technology is simple in operation and management [2].

Another industry sector that produces large amounts of wastewater is the energy sector. Especially coal-fired power plants dispose wastewater enriched with significant levels of metals such as lead, mercury, cadmium, as well as arsenic and nitrogen. This concentration has a lot of hazardous effects in the environment and is the major contributor on the disruption the normal cycles of nitrogen and sulfur [3]. Flying ash and large sulfur emissions are also pollutants. To reduce ash emissions water is applied to capture the particles. The ash-contaminated water stream also belongs to the wastewater disposed or needs treatment [4]. Ash ponds are widely used in treatment technology at coal-fired power plants. This is a technique that uses gravity to settle out large particles (ash particles) from power plant wastewater but no treatment is applied for dissolved pollutants [5]. Additionally, ion exchange membranes and electrodialysis are widely applied techniques, with high efficiency in neutralizing and treat wastewater from power plants.

A water intensive industry is also the plump and paper one. Conventional wastewater treatment technologies like, sedimentation and coagulation lack sustainability and increase the environmental impact of the industry. The most widely used physicochemical method is coagulation separation technique as it removes dissolved solids and organic matter from pulp and paper wastewater [6]. In this method, chemical coagulants (like aluminum sulfate and ferric chloride) introduced to the effluent which results in the aggregation and settling of the contaminants and clarification of the wastewater. The large volume of inorganic coagulants comes together with high environmental impact due to the creation of disposals problems and increased metal concentration in treated water [7]. Microbial fuel cells, seem to be the technology of the future. Not only they treat wastewater but they produce clean energy as well. The energy production from wastewater feed is still low and ranges from 0.2 W/m^3 to 2.8 kW/m^3. Microbial fuel cells found to adequately remove metals, drugs, dyes and petrochemical products [8].

In nuclear industry, water is mainly used for cooling the reactors as well as for steam production. In many cases though, water disposed is enriched with significant amounts of uranium and other substances produced by nuclear fission. WHO set up the limit of Uranium concentration in drinking water at 0.05 mg/L, while, the permissible discharge for the nuclear power plants (according to US Environmental Protection Agency) is from 0.1 to 0.5 mg/L [9]. Traditional treatment technologies include, nitrification, a procedure that stabilizes waste in order not to react nor degrade for long periods by calcinating it to remove water from waste and de-nitrate the fission products. Novel techniques, like absorption using polymer grafted biomaterials still require further research [10].

Much controversy has been expressed for oil industry wastewater treatment. Petroleum refining process unavoidably generates large volumes of oily wastewater causing a myriad of problems in the environment like groundwater affection, endangering human health etc. Therefore wastewater treatment has become an urgent problem [11]. Conventional treatment techniques for oily wastewater include flotation, a method that pours into the oily water tiny air bubbles, that due to density difference with oil they absorb and separate oil particles. There are four types of flotation, Peeling flotation, dissolved air flotation for COD removal, dissolved air flotation for oil removal and classic flotation [17]. Other techniques include, biological treatment using membrane bioreactor, up flow anaerobic sludge blanket for COD removal and biological aerated filter reactor for oil removal [12]. Membrane separation technologies are also applied like microfiltration, dynamic membrane, and UF for oil removal [13, 14] and nano-porous membrane for COD removal [15]. All the above technologies result in high removal efficiency of more than 90% for most of them. Due to the complexity of oily wastewater, using a single method is difficult to reach the national emissions standards and therefore many combined technologies are applied. Wang et al. [16] developed an electrochemical processing technology. The process is: petrol stations runoff, electrical resistance scale flocculator liquid multiphase pump flotation device, double filter canister for detection and concentration of oil, water disinfection station. This technique is found to be highly efficient in removing COD from wastewater.

Depending on their spatial context, wastewater treatment plants can contribute as local energy source and minimize their environmental impact as well. Wastewater is disposed at significantly high temperatures. By taking advantage of the temperature difference, wastewater can generate heat if passed through specially designed heat exchangers. Assisted by PV modules, reduces even further the environmental impact and carbon footprint of the technology [18]. This setup is only locally applicable and not of high capacity but is a way for the industry to make a leap towards sustainability.

The agriculture sector, as mentioned before, is a major contributor of wastewater that infiltrates groundwater and risks disturbing the biogeochemical cycles. The main source of pollution comes from nonpoint source from farms due to rain storms. The main technique to combat this runoff is erosion controls [19]. Some techniques include crop rotation, planning perennial crops and install of riparian buffers. Those techniques are preventive in order not to end up as wastewater in sediment. Nutrient runoff belongs to the same category of water pollution. Nitrogen and phosphorous are key pollutants that come from atmospheric deposition or pesticide use [20]. The other major category of wastewater production is point source pollution. Factory farms are the major source of this type of pollution. Animal waste that contains antibiotics high nitrate and phosphorous levels as well as hormones may be disposed in water. An anaerobic lagoon is a solution that is applied for wastewater treatment. Other technologies or methods applied include, sewage treatment for dairy farming wastes and slaughtering wastes and filtration for vegetable washing water [21].

Medical radioactive waste

Radioactive waste includes any material that is intrinsically radioactive or has been contaminated by radioactivity and has no further use. Radioactive waste, depending on the half-life of the radionuclide, [23] is categorized in:

- Low-level, radioactivity does not exceed 4 GBq/t and is generated from hospitals and industry as well as from nuclear fuel cycle,
- Intermediate-level is produced by reactor decommissioning or chemical sludge's and it has high levels of radioactivity and requires shielding,
- High-level waste comes from used fuel that has been designed as waste or by separated waste from reprocessing of used fuel. For its disposal, cooling and shielding is required.

The radioactive materials emit α, β and γradiation which has hazardous effect on humans, animals and plants. Radioactive liquid waste is also generated from the use of radioactive materials and should be, as well, treated to avoid further exposure of human and environmental hazards [24]. Judging from the facts, safe disposal of radioactive waste is of high priority and thus the development of secure engineered barriers need to be paid with high attention.

Varying radioactive wastes need different treatment techniques. The most common way of radioactive waste manipulation is cement. Although, mechanisms for achieving proper immobilization have to do with cementing agents or service environments [25]. In general, treatment involves operations intended to change the characteristics and composition of the waste, like reducing its volume, ion exchange to remove radionuclide content. Conditioning is applied to allow safe handling and transportation or storage of this waste. Storage of waste takes place in any stage during the management process and ensures that the waste will not come in contact with the external environment [26]. Recycling of radioactive waste is another form of treatment. Medical radioactive waste that belongs to the low-level waste is much easier to recycle. It helps conserving the storage capacity, where space is an issue, conserving natural resources by using slightly radioactive material instead of new and contributes to sustainable development [27].

In particular for medical wastes treatment, commonly used techniques include:

- Reverse osmosis, a technique that is composed of a pressure chamber, a separation membrane and a piston. The piston pressures the liquid waste through the membrane that beholds the radioactive wastes. The later, then stored, as mentioned before, and decay [28].
- Solvent extraction, which is a method that applies graphene aerogel, a solution with high absorption capacity, found to be able to adequately remove uranium from solutes [29].
- Ion exchange [30].

Sustainable landfill waste disposal

Anaerobic digestion is the natural decomposition of organic material that takes place in absence of oxygen. The product of this reaction is methane which can be further collected and used as a fuel. This procedure takes place in landfills, where waste is buried and left to be digested. Methane though, is a greenhouse gas with significant ozone depletion potential and therefore emissions from landfills need to be controlled. The main advantages of proper treatment of landfill waste, is that the organic wastes have considerably high-energy potential. This potential can be extensively used for electricity production as, waste feedstock is available in low prices, does not require new infrastructure in collection procedure and on top of all that, emissions from anaerobic digestion are avoided [31]. Apart from clean energy, clean fuels can also be produced by applying methods like fermentation that generates bioethanol [32]. An extensive research from Scarlat et al. [33] proposed a pathway for energy generation from waste. The municipal waste is collected. It is either disposed to the landfill which is recovered and through the appropriate techniques is transformed to fuel, heat or electricity, or it passes through separation procedure. There, waste is separated in inert, organic and recyclable. The recyclable materials can end up being metal, plastic, glass or paper while inert materials end up in landfill. The organic materials can undergo incineration, anaerobic digestion or landfill recovery, which all lead, with higher efficiency, again in fuel, heat and electricity production. Anaerobic digestion also leads to biogas and fertilizers production. In that way, with an initial investment, landfills become from greenhouse gas emitters, sustainable development promoters with low cost electricity production.

Not only is the environmental impact significant with implementations of technologies of this kind, but the economic as well. Many development states that face urbanization issues have large waste to energy potential. Huge landfills can be turned to low cost power plants with immediate positive results for the environment and communities [34].

2. Discussion and Conclusions

Hazardous waste is responsible for a myriad of problems; both for humans and for the environment. It is essential that all hazardous waste be properly treated and disposed appropriately to preserve environmental health. Procedures to treat hazardous waste can be complex depending on the varying physiology of the waste and the classification can be defined by analyzing the physicochemical properties. The physiochemical properties are distinguished by viscosity, boiling, melting point and in solvation properties like phase partitioning and solubility. A proper assessment of hazardous waste can direct us to more accurate treatment technology application. Technologies may include ion-exchange, solidification, immobilization, solvent extraction, deposition or membrane-separation. Wastewater is a subcategory of the hazardous waste. It requires special treatment that varies based on the disposal source.

The largest contributor of hazardous and toxic wastewater in Papua New Guinea is the industrial sector. Treatment technologies include ash ponds, ion-exchange and electrodialysis. Flotation, biological treatment using membranes and up flow anaerobic sludge blankets are also highly efficient treatment technologies applied in the petroleum industry. In other industrial sectors, such as the pulp industry, sedimentation and coagulation technologies are used; however, these technologies result in a large environmental footprint. More sustainable solutions include microbial fuel cells that detoxify wastewater and produce electricity. Sustainable landfill disposals management is crucial for reducing their environmental impact as a major polluter. Landfills can take advantage of the methane emissions for energy production; there is also huge thermal energy and biofuels potential.

For the implementation of successful and effective wastewater treatment, political planning and framework is essential. Governments must implement and enforce policy guides in order to set the legal rules that will ensure hazardous waste is properly treated. Further studies may include the investigation of sustainable technologies for waste treatment with low environmental impact and promotion general sustainability.

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