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APPLICATION OF NANOTECHNOLOGY IN LEACHATE TREATMENT (A CRITICAL REVIEW)

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Abstract: Over the years, new tools and techniques for treating hazardous leachate water. From biological treatment methods to physical/chemical techniques for treating leachate to acceptable standards. The fast and rapid growth of the nanotechnological sector has shown promise in its application for environmental remediation and by extension leachate treatment. Regardless of these met progress in technological approaches to treating leachate, there still remains the need for universal and economically scalable methods for leachate treatment. This paper covers the various leachate treatment methods with emphasis on the application of nanotechnology/nanomaterials in past research in this regard as well as some setbacks the leachate treating method has seen.

Keywords: Nanomaterials, leachate; biological; physical; and chemical treatment

INTRODUCTION

Owing to population growth, lifestyle preferences, consumption and technological advances, the rate of waste generation hascontinued to increase, which has intensified the need to address this environmental concern (Nnamdi I. 2014). As a result of agricultural and industrial revolution, industries are found of producing wastes which may not be recycled again. Nigeria as a case study produces over 32 million tons of solid waste every year, only 20-30% of this stated volume is properly collected. Also, from the United Nations Habitat Watch reports, the populations of African cities will more than triple over the next 40 years, translating in even much higher volume of waste produced. Hence, the need for disposal. This illustrates the vulnerability of the African or Nigerian environment to the toxic hazards that can be caused by improper waste disposal.

Sadly, for many developing countries across the world including Nigeria, waste management remains a major challenge due to lack of standard engineered landfills. Even so, for densely populated countries with high volume of waste produced daily combined with poor waste management infrastructure (Aluko et. al. 2003). Open dumping systems and landfill are the primary means or system of waste disposal in many developing countries around the world including Nigeria since they infer low economical consequences and are capable to storing large volumes of solid waste contrasted with other methods such as incineration. The absence of properly constructed landfills for waste disposal by the governments has led to the rise of even more open dumps that are scattered around the country (Asibor G. & Edjere O., 2016). Over time, these develop into valleys, excavations and mountain heaps of illegal dumping sites without the consideration of the waste synthesis (Ugwoha E. & Emete K.C., 2015).

Open dumps and landfills have been identified as one of the key threats to groundwater sources. Waste disposed of at these sites are often prone to be infiltrated by precipitation. In the Nigerian context where local rivers have also become avenue for dumping refuse and sewage (Sabejeje, *et al*., 2014). As the precipitated water seeps through the waste, it collects various organic and inorganic compounds flowing out of the waste and settles at the bottom of the waste pile. With such contamination of groundwater sources, the quality of life of the local groundwater users can adversely be affected with threats of substantial health risks, including waterborne illnesses such as typhoid, cholera and dysentery, since the contaminated water source ends up createing breeding space for flies, rodents and mosquitoes (Ugwoha E. & Emete K.C., 2015) and in other worst case scenarios, the effects of these contaminated groundwater have been linked with several symptoms and diseases associated with biometal poisoning such as asthma, vomiting and convulsion, anemia, depression, ataxia, diarrhea, cancer, hypertension, pneumonitis. Other biometal poisoning related diseases also include neurological diseases, cardiovascular and renal diseases, skeletal deformities, and gastrointestinal disorders (Boateng et al., 2019).

As these poorly disposed wastes encounter and make interactions with water that percolates the landfill sites, a complex liquid containing disproportionate amounts of biodegradable and nonbiodegradable materials is formed and is known as Leachate (Kamaruddin et al. 2014). This undesirable fluid, which is a source of environmental pollutants is generally heavily contaminated (with high levels of dissolved carbon, inorganic constituents, heavy metals, humic acids, ammonia, salts and other toxic substances) and consists of complex waste water that is very difficult to deal with and would usually contain even more complex contaminants depending on the nature of the age and other factors. The research of Tairu (1998) on the concentrations of pollutants present in leachate, lead to a report of high rate of mortality among domestic animals, low farm produce, production of unpleasant and unwanted gases and contamination of the domestic water sources which were reported and traced to direct discharge of raw leachates into nearby environment at the landfill site

As leachate pollutes the groundwater, its components and constituents are dissolved in it too. For example, cancerous heavy metals seep faster into groundwater. Heavy metals present in leachates from waste disposal sites have been studied to have hazardous effect to public health. Boateng et. al. 2019 multivariate study on the possible sources of heavy metals in the poor condition water media of sites in the Kumasi metropolis of Ghana using the IBM's SPSS was able to reveal that high levels of heavy metal suggests significant contamination of groundwater due to percolated leachate from the landfill site. Also, individually, Lead has been involved in numerous diseases such as anaemia, anorexia, brain damage, mental deficiency, vomiting and even death in human. Cadmium also has been reported to cause agonistic and hostile effects on hormones and enzymes resulting in several malfunctions like kidney failures. These two metals have affinity for sulfhydryl groups in proteins, haemoglobin, enzymes/ hormones. Likewise, Pb and Cd are classified as carcinogens. Other metals examined in the study were Nickel(Ni), Chromium(Cr), Zinc(Zn) and Copper(Cu), each of which were stated to be linked to various health problems due to being non-biodegradable and with the risk of accumulation in the food cycle (Ogundiran O. & Afolabi T., 2008). Hence there is an ever-increasing need for global awareness of the hazardous role these emissions play on human health and also on the environment as well as technological means for the remediation of these damages.

LEACHATE TREATMENT

Leachate needs to be pre-treated on site in order to meet the standards for its drainage into the sewer or its subsequent discharge into surface water (Abbas A. et. al., 2009). Virtually, various types of treatments methods have been explored for treating leachates for some time now. In fact, traditional treatment methods have proved no longer sufficient anymore to achieve the degree of purification needed to completely mitigate the negative impact of landfill leachates on the ecosystem. Therefore, there exists a need for a universal, adaptable and transferable method of leachate treatment (Aluko O. et. al., 2003). This would owe to the fact that leachates vary greatly in composition/ characteristics from site to site. Some of these factors or differing characteristics that would affect the treatment technique to be used for treating leachate includes COD/TOC and BOD/COD ratios, absolute COD concentration and age of the landfill (Gao et. al., 2014).

Loosely, Leachate treatment techniques can be characterized into two basic types, biological and physical/chemical methods.

- **Biological Treatment:**

These systems are divided into aerobic (with oxygen) and anaerobic (without oxygen) conditions. In particular, the use of microorganisms or bacteria to remove pollutants in the leachate is achieved by an assimilation process. It is widely considered one of the most popular and cost-effective technique of leachate treatment and is best used with other techniques to achieve the best required result. It is energy conservative too. They are best used for younger leachate (1-2 years old).

- **Physical-Chemical treatment techniques:**

These systems utilizes non-biological changes in the leachate whereby only physical or chemical phenomenon are used to improve the quality of the leachate. Examples of physical-chemical treatment methods includes adsorption, coagulation/flocculation and chemical oxidation, activated carbon adsorption, membrane filtration processes (microfiltration, ultrafiltration, nanofiltration and reverse osmosis), ion exchange, electrochemical treatment and flotation. These techniques are, however, disadvantaged due to factors such as membrane fouling, permeation flow, and minimal recovery rate.

- **Recycling:**

On the other hand, involves regulating and enhancing of landfill biological, chemical and physical processes by the addition of leachate into the landfill. This technique, however, would usually lead to an increase in the moisture content in the landfill.

It is worthy to note however that each treatment method has its own advantages and disadvantages and the implementation of a specific method is not always be effective because of the complex characteristics of municipal solid waste leachate and low biological to chemical oxygen demand ratio, resulting in insignificant treatment efficacies (Abbas A. et. al., 2009).

NANOTECHNOLOGY AND ITS RESEARCH APPLICATION TO THE TREATMENT OF LEACHATE

The word "nanotechnology" was first used at the end of the 19th century (1867) when James Clerk Maxwell published his first studies on this technology and proposed possibilities for the manipulation of individual molecules (Zelić E., Vuković Ž., Halkijević I., 2018). In general, nanotechnology would imply the management or manipulation of materials or articles with particle size of 1-100nm. Over the century, however, nanotechnology has shown great potential in advancing environmental remediation. Most of the environmental applications of nanotechnology fall into three categories: (i) environmentally friendly and/or sustainable products (e.g. green chemistry or pollution prevention), (ii) remediation of materials contaminated with hazardous substances, and (iii) sensors for environmental agents (Tratnyek P. & Johnson R., 2006). By extension, nanotechnology has also shown the same magnitude of potential in water and wastewater treatment to enhance treatment efficiency as well as to increase water availability through safe use of unconventional sources of water (Qu et. al., 2013).

Nanomaterials in principle, are materials with dimensions of less than 100 nanometers. Owing to numerous specific unique properties, including high surface to volume ratio and high catalytic activity, nanomaterials finds myriad pharmaceutical, cosmetic, electronic, energy-related and ultimately environmental applications. Currently, the most recent applications of nanomaterial in environmental nanotechnology continues to rapidly gain traction in environmental remediation studies with water purification possibly being among the most advanced environmental applications of nanomaterials. Some of the considered properties that have makes nanomaterials suitable for leachate treatment includes their large surface to volume ratio, behaviour and motion of electrons (quantum effects), their reaction with polluting atoms, faster chemical processes, etc. (Zelić E., Vuković Ž., Halkijević I., 2018). Some of the techniques in which nanomaterials or nanotechnology have been employed in its treatment include the following:

— **Nanofiltration**:

Is a high-pressure membrane filtration-based treatment process which requires a much lower drive pressure (5 to 20 bar), and so allows lower energy consumption. While there exist several controversies regarding the use of the term 'nanofiltration' in connection with nanotechnology, the vast role it plays in leachate treatment and heavy metal removal can be hardly pushed aside.

When used for treating wastewater, nanofiltration produces water that meets very strict criteria for the reuse of water. Currently, the advancement of nano-filtration technologies has been adopted into many processes i.e., demineralization in the dairy industry, pulp-bleaching of textile industry effluents, virus removal and metal recovery from wastewater, and extraction of biopharmaceuticals from fermentation broths. Nano-filtration shows notable promise as a technique for the treatment of inorganic pollutants and natural organic matter in leachates (M. Rafique et al., 2019).

— **Nanomaterials for catalysis and Photocatalysis:**

Nanocatalysts have seen wide applications in the oxidation of organic and inorganic pollutants in leachates in advanced oxidation processes as it increases the catalytic activity at the surface due its high surface area with shape dependent properties (Deepa Madathil et al, 2013.). Researches has shown that iron nanoparticles can act as effective catalysts in detoxifying a large variety environmental contaminant, such as agricultural pesticides, trinitrotoluene (TNT), heavy metals, nitrates, polychlorinated biphenyls (Kashitarash Z. et al, 2012.).

Photocatalysis is known to be a more effective method for detoxifying waste water, which also affects our environmental pollution and suppresses energy crises (M. Rafique et al., 2019). In this treatment, the nanocatalyst is illuminated by activated visible light resulting in the formation of highly reactive hydroxyl radical which can then react easily with pollutant molecules and degrade it (Zelić E., Vuković Ž., Halkijević I., 2018).

Metal nanoparticles and metal oxides have shown promise for environmental pollution remediation as regards their use as nanocatalysts and in photocatalysis. Titanium nanomaterials, for example, are at large considered efficient and favourable nanocatalysts and photocatalysts for use in research due to their relatively low cost, stability and environmental friendliness. Results obtained from the use of these nanomaterials can further be tuned by doping them with metallic ions to affect their surface and structural morphology (M. Rafique et al., 2019).

Many studies have shown that doping TiO_2 NPs with metal ions (with transition and earth metals seeing more applications in this case) is one of the most effective methods used to enhance the photoelectrochemical properties of TiO_2 under ultraviolet radiation and sunlight. Heterogeneous photocatalysis with TiO_2 nanomaterials have been established to adsorb heavy metals such as Pb, Cd, Cu, Zn, and Ni at pH of 8 (Ghasemzadeh G. et al, 2014). A study by Azadi et al. (2017) on the efficiency of the photocatalytic treatment process of landfill using TiO_2 and W-doped TiO_2 showed that using W-doped TiO_2 as a photocatalyst is more efficient than using a TiO_2 catalyst and that a 46% rate of Chemical Oxygen Demand (COD) removal was achieved under optimal operating conditions. Elleuch et al. (2020) also found in his research that the removal efficiencies of TiO_2 doped with silver (Ag) were found to be 90, 100, 96, and 75%, for TOC, Cd, Ni, and COD

— **NanoZerovalent Iron Injections:**

Zerovalent metals are typically prepared through the borohydride reduction of metal salts. Due to their large surface area, reactivity and environmental reactivity, zerovalent metals are considered ideal compounds for effectively detoxifying organic and inorganic contaminants in aqueous solutions. Nanoscale zero-valent iron has found different applications in wastewater remediation, sediments or soils for nitrates reduction and removal (Ghasemzadeh G. et al, 2014). It also has been shown to be effective for removing chemical pollutants such as heavy transition metals including chromium, cobalt, copper, lead, silver, nickel; post-transition metals, actinides, azo dyes etc.

Kashitarash Z. et al. (2012) investigated the effect of Nanosized Zero Valent Iron (NZVI) for treatment of Hamadan landfill leachate. It was observed that this procedure attained a fast removal efficiency of 47.94% for COD in 10 min at optimal conditions of pH value of about 6.5, temperature of 18 ± 1°C and 2500 mg/L concentration of iron nanoparticles. It is to be noted that the optimal condition will differ for different leachate samples due to differing properties and characteristics of the leachate earlier mentioned in this paper.

CONCLUSIONS

With the volume of waste produced being on a rise and some country looking to run out of landfill space over time, there arises the need for better waste management systems and also for providing universal, cost-effective and sustainable method for treating the resulting leachate produced thereof. Over the past years, however, different techniques for treating landfill leachate has been developed and tested in a bid to find economically scalable and transferrable method. Nanotechnology has shown rapid growth in its application in leachate and wastewater treatment. While, some of the techniques have been argued to be more cost-effective, durable and eco-friendly, more research still needs to be done to be able to provide a commercial based system of application of nanotechnology to the treatment of leachate and wastewater and to provide a sound basis on which the adverse effects of these advanced treatment techniques might have on the environment and human health can be determined.

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ISSN: 2067-3809

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