2

Leachates' treatment of toxic hazardous chemicals for public health protection

Tilemachos K. Koliopoulos [1], Sanjay K. Sharma [2], Elias T. Nerantzis [3]

[1] Telegeco, Collaborator University of West Attica, Department of Public Health and Community Health, Egaleo, Athens, Greece
[2] Professor & Head, Department of Chemistry, JECRC University, Engineering Chemistry & Environmental Chemistry, Jaipur, India
[3] Professor Emeritus, Department of Enology and Brewing, University of West Attica, Egaleo, Athens, Greece

Abstract

Landfilling of municipal waste is a selected economic waste disposal method of the waste management system in most of the countries in the world. The generated leachate must be appropriately treated before being discharged into the environment for public health protection and sustainable development. The main technologies meant for leachate treatment can be classified as follows (i) biological methods, (ii) chemical and physical methods. This is a review presenting the main processes currently used for the landfill leachates treatments as well as future design parameters that should be taken into account the climate change. Water quantities should be saved from landfill leachates waste water treatments supporting sustainability.

Keywords: Landfill leachate; biological process; advanced oxidation processes; leachate recirculation; landfill bioreactors; sanitary engineering; public health; constructions for sustainability.

Contact Author: Tilemachos Koliopoulos, Managing Director Telegeco, Collaborator Department of Public Health and Community Health, University of West Attica, Egaleo, Athens, Greece, Telephone number: +30 - 2107561914, e-mail: t.kol@otenet.gr.

1. INTRODUCTION

Sanitary landfill remains an attractive disposal route for municipal solid waste, because it is more economical than alternative solutions. It is accepted that the landfill biodegradation processes are complex, including many factors that control the progression of the waste mass to final stage quality [4,15,31,33,35,36,37,59]. The landfill gas and leachate generation is an inevitable result of the solid waste biodegradation in landfills and their study is necessary for efficient designs, environmental management schemes, monitoring, protecting land uses from air, soil and water pollution [1,5,8,9,11,17,20,21,23,24,30,32,38, 54,55,64].

A successful sustainable development requires a continuous change and harmonization to the life cycle of our society, bearing in mind its current-future necessities; utilizing properly efficient green chemistry's applications and associated engineering technologies [16,17,42,48,50,51,59,63]. A plethoric flow and use of resources characterize our society in an unsustainable way. Waste management is the discipline that is concerned with resources once society no longer requires them. Therefore, the problem is transferred to the dilemma on how can we manage our waste better. Sanitary landfill has been shown to have lower environmental costs. Selection of the right landfill and operational procedure are of the upmost importance if small urban areas are to be served effectively. Clay soils enable cost effective engineering to prevent leachates entering the water table from landfill sites.

During biomass's fermentation there are five phases of waste biodegradation in a landfill bioreactor. Phase I is the initial adjustment phase. In Phase I, biological decomposition occurs under aerobic conditions, because a certain amount of air is trapped within the landfill. In Phase II, identified as the transition phase oxygen is depleted and anaerobic conditions begin to develop. As the landfill becomes anaerobic, nitrate and sulphate, which can serve as electron acceptors in biological conversion reactions, are often reduced to nitrogen gas and sulfide.

In Phase III, the acid phase, the microbial activity initiated in Phase II accelerates with the production of significant amounts of organic acids, increased concentrations of COD (chemical oxygen demand) and lesser amounts of hydrogen gas. In Phase IV, the methane fermentation phase, a second group of

Any uncontrolled dumps have to close so as to avoid any threats to the public health and to protect the environment. The use of controlled batch anaerobic bioreactors accelerates waste biodegradation in short periods, minimizing any associated environmental risks, public health's hazards due to landfill emissions [11,16,22,23,28]. The use of controlled landfill projects is necessary for quick site stabilization of landfill gas and leachate emissions, during waste biodegradation.

Landfill leachate is a dark coloured liquid, having a smell. Landfill leachate presents a high organic and inorganic load. It is an aqueous solution in which four groups of pollutant are present: dissolved organic matter (volatile fatty acid and more refractory organic matter such as humic substances), macro inorganic compounds (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, NH_4^{+}, Fe^{2+}, Mn^{2+}, HCO_3), heavy metals (Cd^{2+}, Cr^{3+}, Cu^{2+}, Pb^{2+}, Ni^{2+}, Zn^{2+}), and xenobiotic organic compounds originating from chemical and domestic residue present at low concentrations (aromatic hydrocarbons, phenols, pesticides, etc.) [13], and microorganisms that indicate, predominantly total and thermotolerant coliform [45].

Table 1.1. Landfill leachate characteristics in time. Parameter 0-5 yr, 5-10 yr, 10-20 yr

microorganisms, which convert the acetic acid and hydrogen gas formed by the acid formers in the acid phase to CH_4 and CO_2, becomes predominant. In phase IV leachates have neutral pH. Phase V, is the maturation phase.

The last phase of biodegradation occurs after the readily available biodegradable organic material has been converted to CH_4 and CO_2 in Phase IV. In this phase COD, BOD (biochemical oxygen demand) and TOC (total organic carbon) concentrations have been reduced. Also, the rate of landfill gas generation diminishes significantly in Phase V, because most of the available nutrients have been removed with the leachate during the previous phases [3,12,23,26,27,28,50].

Parameter	0-5 yr	5-10 yr	10-20 yr	<20 yr
BOD_5 (mg/l)	4,000-30,000	1,000-4,000	50-1,000	<50
COD (mg/l)	10,000-60,000	10,000-20,000	1,000-5,000	<100
Ammonia (mg/l)	100-1,500	300-500	50-200	<30
pH	3-6	6-7	7-7.5	6.5-7.5
Chloride (mg/l)	500-3,000	500-2,000	100-500	<100
Sulphate (mg/l)	50-2,000	200-1,000	50-200	<50

Source: [30]

2. EXPERIMENTAL SETUPS AND REVIEW OF LANDFILL LEACHATE TREATMENTS

Nowadays, complicated socio-economic, environmental systems begin to cause problems when their environmental effects become an environmental public health risk.

Environmental management is the discipline that is concerned with resources once society requires them. It is necessary to manage environmental resources in a sustainable way by minimizing the environmental impacts related to the operation of environmental systems. In an effort to meet growing environmental awareness, most companies include investments in their plans that are related to the production of eco-designs and the sustainable development, protection of the environment.

Thus, improved monitoring and proper quality management of environmental systems are necessary. Several useful applications of numerical analysis should be applied for the proper management of environmental systems;

manufacturing; public health protection; and sustainable economic development of resources [31,33,34,36,50].

Young acidogenic landfill leachate is commonly characterized by high biochemical oxygen demand (BOD) (4000–13,000 mg/L) and chemical oxygen demand (COD) (30,000–60,000 mg/L) concentrations, moderately high strength of ammonium nitrogen (500–2000 mg/L), high ratio of BOD/COD ranging from 0.4 to 0.7 and a pH value as low as 4 [44,68] with biodegradable volatile fatty acids (VFAs) appear to be its major constituents [3]. Table 1 represents classification of landfill leachate according to the composition changes in time.

Moreover, the rate of leachates biodegradation and landfill gas generation is influenced by several parameters [37,59] including waste characteristics, moisture content, temperature, pH, the availability of nutrients and microbes, and the presence of inhibitors such as oxygen, metals and sulphates. The production will not ensue if any of the values of these is within a range of threshold values. The influence of these variables, the enhancement of gas yield, and stabilization leachate biodegradation processes in landfills have been the focus of numerous studies [13,17,23,29,37,38,44,55,59,77]. It was found [37,59] that gas production in sanitary landfills increases with increased moisture content up to saturation.

2.1. Biological treatment

Due to its simplicity, reliability, and high cost-effectiveness, biological treatment (suspended/attached growth) is commonly used for the removal of the bulk of leachate containing high concentrations of BOD.

Biodegradation is carried out by microorganisms, which can degrade organic compounds to carbon dioxide and sludge under aerobic conditions and to biogas.

Biogas is a mixture comprising chiefly CH4 and CO2 under anaerobic conditions and waste pre-treatment with pulverized waste and inert material that is presented by collected field data, like Mid Auchencarroch sequential batch bioreactor experimental landfill site protecting public health

Leachate biodegradation trends can be combined with landfill gas emissions so as to evaluate monitoring schemes and reclamation shemes for public health protection to nearby receptors from landfill boundaries.

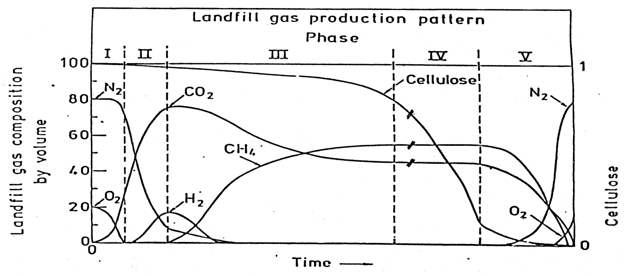

Fig. 2.1. Various stages of landfill gas production. Source: [59]

and associated risks to environmental resources receptors from long term chemical hazardous toxic concentrations [23,25,49,59].

Biological processes have been shown to be very effective in removing nitrogenous and organic matter from immature leachates when the BOD / COD ratio has a high value (>0.5). With time, the major presence of refractory compounds (mainly fulvic and humic acids) tends to limit process's effectiveness [21,62]. Waste biodegradation and leachate treatment are a complex system [59,78]. Figure 1 presents the various stages of landfill gas production as an index for waste biodegradation.

Wang et al. [65] applied a two stage up-flow sludge blanket (UASB) and sequencing batch reactor (SBR) system to treat municipal landfill leachate and took high efficiency in the removal of nitrogen. The results demonstrated that COD removal is highly effective by anaerobic biodegradation. The effluent NHþ 4 –N removal efficiency was maintained around 99%. Total nitrogen (TN) removal efficiency could reach 85% with the effluent TN lower than 15 mg/L. Sun et al. [57] investigated treatment of real leachate from municipal landfill with high ammonia nitrogen content by using lab-scale anoxic/anaerobic UASB-A/O process. On the basis of achieving simultaneous COD and nitrogen removal, how to achieve and stabilize partial nitrification in the A/O reactor was studied. Denitrification and methanogenesis were conducted in UASB reactor, and the average removal rate of organics and NOx–N was 5.3 and 1.1 kg/(m3 d), respectively. Partial nitrification was achieved (nitrite accumulation ratio was above 50%) after 54 days of operation, and after 70 days, nitrite accumulation ratio in A/O reactor reached above 90% at ambient temperature of 12–30.6 C.

Trabelsi et al. [60] studied anoxic digestion based on the endogenous biomass activities in batch reactor (V = 150 L) for the treatment of landfill leachate of Jebel Chekir landfill (Tunisia). With a retention time of 90 days, the anoxic digestion reactor has shown reductions in BOD5, COD, TOC, NH4–N and TKN respectively by 91%, 46%, 65%, 45% and 63%. Later, the effluent was further treated in down flow cascade in three aerated submerged biological reactors, with 7 days of total retention time. Yahmed et al. [76] carried out Jebel Chekir landfill leachate (Tunisia) treatment using an aerobic pilot unit with three immersed and fixed biofilms reactors. A preliminary analysis indicates a high biodegradable fraction in the leachate (BOD5/COD = 0.4), which implies that biological treatment process can be applied. Performance results obtained during this study indicate a significant organic matter reduction; between 60% and 90% of TOC reduction was obtained. However, a consortium containing a mixture of the bacterial isolates inoculated in the raw leachate, reaches TOC yield of about 84%.

Sun et al. [56] investigated the nitrite accumulation in the denitrification process with sequencing batch reactor (SBR) treating pre-treated landfill leachate in anoxic/anaerobic up-flow anaerobic sludge bed (UASB). Nitrite accumulates obviously at different initial nitrate concentrations (64.9, 54.8, 49.3 and 29.5 mg / L) and low temperatures, and the two break points on the oxidation–reduction potential (ORP) profile indicate the completion of nitrate and nitrite reduction. Usually, the nitrate reduction rate is used as the sole parameter to characterize the denitrification rate, and nitrite is not even measured. For accuracy, the total oxidized nitrogen (nitrate + nitrite) is used as a measure, though details characterizing the process may be overlooked. Additionally, batch tests are conducted to investigate the effects of C/N ratios and types of carbon sources on the nitrite accumulation during the denitrification. It is observed that carbon source is sufficient for the reduction of nitrate to nitrite, but for further reduction of nitrite to nitrogen gas, is deficient when C/N is below the theoretical critical level of 3.75 based on the stoichiometry of denitrification. Five carbon sources used in this work, except for glucose, may cause the nitrite accumulation. From experimental results and the cited literature, it is concluded that Alcaligene species may be contained in the SBR activated sludge system.

Sun et al. [57] investigated treatment of real leachate from municipal landfill with high ammonia nitrogen content by using lab-scale anoxic/anaerobic UASB-A/O process. On the basis of achieving simultaneous COD and nitrogen removal, how to achieve and stabilize partial nitrification in the A/O reactor was studied. Denitrification and methanogenesis were conducted in UASB reactor, and the average removal rate of organics and NOx–N was 5.3 and 1.1 kg/(m3 d), respectively. Partial nitrification was achieved (nitrite accumulation ratio was above 50%) after 54 days of operation, and after 70 days, nitrite accumulation ratio in A/O reactor reached above 90% at ambient temperature of 12–30.6 degrees Celsius.

Yabroudi et al. [75] studied the landfill leachate biological treatment by nitritation/in an activated sludge sequencing batch reactor. The removal efficiencies of N–NO2-at the end of the anoxic phase (1 h) ranged between 8% and 31% indicating low availability of easily biodegradable organic matter in the leachate. No imbalance was observed over the nitritation process at the end of the aerobic phase (48 h) of treatment cycles and the specific rates ranged from 0.043 to 0.154 kg. N-NH3/kg.SSV day, demonstrating the applicability of the simplified nitritation/denitritation in the treatment of effluents with low C/N. Zhu et al. [80] introduced a system which combined ASBR with pulsed SBR (PSBR) to enhance COD and nitrogen removal from the real landfill leachate. The results obtained from the joint operation period (157 days) show that the COD removal rate of ASBR was 83–88% under the specific loading rate of 0.43–0.62 gCOD gVSS / day. PSBR's operation can be divided into four phases according to the different influent NHþ 4 –N which increased to 800– 1000 mg L1 finally, and total nitrogen (TN) removal rate of more than 90% with the effluent TN of less than 40 mg L1 was obtained. Consequently, the system achieved COD and TN removal rate of 89.61–96.73% and 97.03–98.87%, respectively.

Xu et al. [73] developed a Tabiological treatment with the integration of partial nitrification, anaerobic ammonium oxidation (Anammox) and heterotrophic denitrification in a SBR with periodical air supply to treat landfill leachate. An operating temperature of 30 ± 1 C and a dissolved oxygen concentration within 1.0–1.5 mg/L were maintained in the SBR.

In general, biological are not costlier treatments, than chemical, electrochemical, and physical treatments. Hence, the case of sequential batch landfill bioreactors can be applied for developing countries. Waste pretreatment and co-disposal of inert material with pulverized waste showed that are sustainable [23,24,26,27,28].

The Mid Auchencarroch (MACH) experimental landfill is a UK Environment Agency (EA) and industry funded research facility [23,67,68]. It has been capped since 1995. The experimental variables are waste pretreatment, leachate recirculation and co-disposal with inert material. The project consists of four cells each of nominal plan dimensions 28m x 30m and 5m deep, giving a nominal volume of 4200 m^3 [23,24,25,67]. The experimental landfill Mid Auchencarroch (MACH) is a field scale facility, constructed in order to assess a number of techniques that promote sustainable landfill.

In cells 1 and 3 there is pretreatment by wet pulverisation and in cells 2 and 4 the disposed waste is untreated. In cells 1,2 and 3 there is recirculation of leachate and in cell 1 there is addition of inert material around 20% by volume [23,24,25,67]. The disposed waste synthesis for the untreated and pulverised waste input is respectively: Paper-Card: 27%&34%; Plastic film 6%&7%; Dense plastic 5%&8%; Textiles 3%&3%; Misc.combust. 3%&3%; Misc. non-combust.0.5%&2%; Glass 5.5%&7%; Putrescibles 38%&24%; Ferrous metal 6.5%&8%; Non-ferrous metal 1.5%&2%; Fines 4%,2% [23,24,25,67].

This project attempts to develop and assess techniques to enhance the degradation, and pollutant removal processes for Municipal Solid Waste (MSW) landfill. The wet-flushing bioreactor landfill model is seen as the method of achieving the goal of sustainability. The MACH landfill gas data, which were used for the present study, cover simultaneously the 22-month period [23,24,25,67].

Methanogenesis biodegradation stage exists in landfill waste material mass due to the methanogens bacteria, which are the most obligate anaerobic biological organisms known; they are inhibided or killed by trace amounts of oxygen. The methanogens could be divided in two types: Acetophilic and hydrogenophilic. Methanogens can only utilise a number of substrates, which are respectively; acetate and, hydrogen + carbon dioxide. These bacteria work in harmony with the acetogenic bacteria, maintaining a suitable environment in which the acetogens may continue to produce substrate for them. The products of methanogens are carbon dioxide and methane [23,25,59]. The two reactions can be shown below:

Acetate dismutation by Acetophilic Methanogens

$$CH_3 - COO^- + H_2O \rightarrow CH_4 + HCO_3^-$$

and the reduction of carbon dioxide by hydrogen & by Hydrogenophilic Methanogens

$$4\ H_2 + CO_2 \rightarrow CH_4 + 2\ H_2O$$

The methanogeneseis stage has been achieved succesfully in short time at both MACH cells avoiding any assosiative long term chemical risks. Higher cumulative methane production rate exists in cell 2 than in the rest cells due to its different waste input and its waste materials conditions in comparison to the rest cells (ie different biodegradable waste fractions and leachate recirculation in landfill mass).

Moreover, according to the experimental results and the measured field data the landfill gas production has been found between 7 and 9 m^3/hr for both MACH's cells in less than two-year period since the site was capped. The latter field data in comparison with the methane and carbon dioxide emissions (vol%) satisfactory trends in short time as well as for the leachate emissions verify the quick MACH site stabilization, avoiding any long term environmental impacts and associated risks to the environment and to the public health [23,24,25,26,27,28].

MACH's experimental bioreactor design principles could be applied to any relative big scale bioreactors or to any proper shallow sequential batch bioreactor biotechnologies. It could be applied as an economic solution for sanitary landfill and solid waste treatment in developing countries. Particular landfill topographic constraints should be taken into account carefully in order to collect properly big quantities of produced biogas to renewable energy resources' production units.

In the case study of Mid Auchencarroch experimental batch landfill bioreactor showed that landfill stabilization achieved in short time based on the chemical concentrations of butyric acid, acetic Acid, COD, and TOC, pH. The next figures verify that well designed landfill batch bioreactors can be used as an economic solution for solid waste mass treatment especially for developing countries.

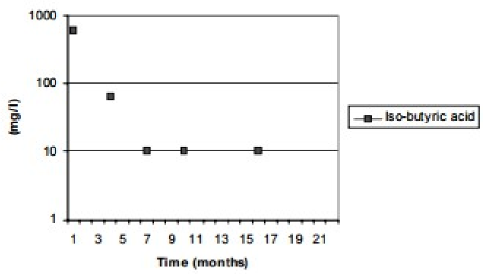

Fig. 2.2. Iso-butyric acid concentrations in time for landfill leachates for MACH cell 1.

Source: [27]

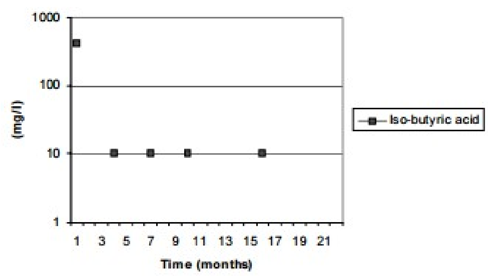

Fig. 2.3. Iso-butyric acid concentrations in time for landfill leachates for MACH cell 2.

Source: [27]

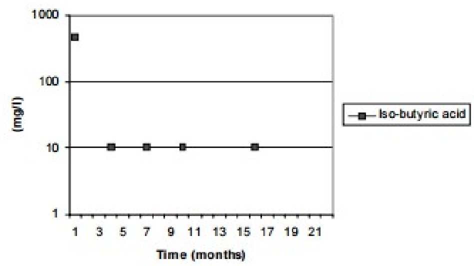

Fig. 2.4. Iso-butyric acid concentrations in time for landfill leachates for MACH cell 3.

Source: [27]

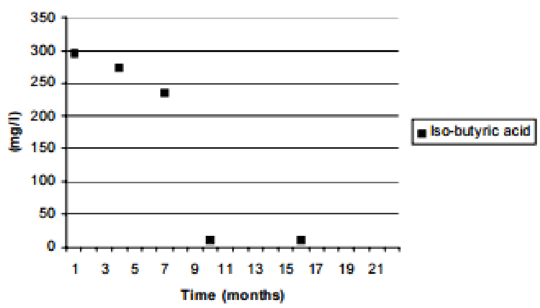

Fig. 2.5. Iso-butyric acid concentrations in time for landfill leachates for MACH cell 4.

Source: [27]

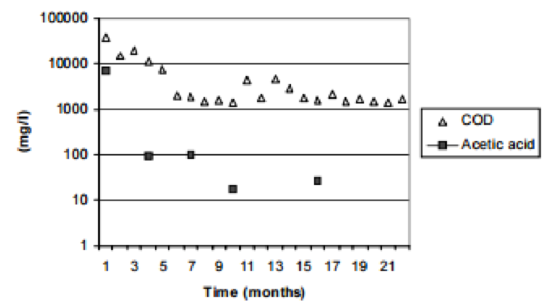

Fig. 2.6. Acetic acid and COD concentrations in time for landfill leachates for MACH cell 1.

Source: [27]

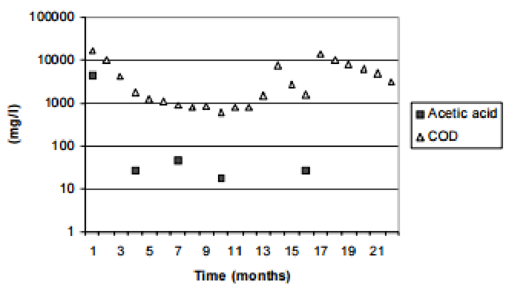

Fig. 2.7. Acetic acid and COD concentrations in time for landfill leachates for MACH cell 2.
Source: [27]

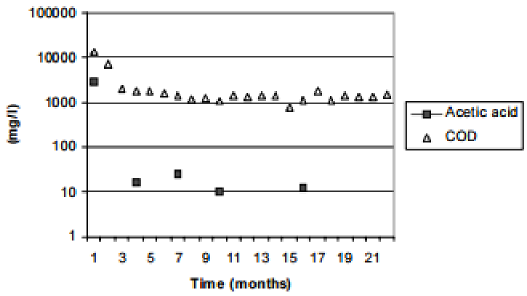

Fig. 2.8. Acetic acid and COD concentrations in time for landfill leachates for MACH cell 3.
Source: [27]

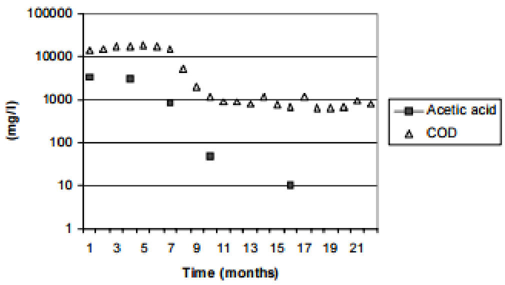

Fig. 2.9. Acetic acid and COD concentrations in time for landfill leachates for MACH cell 4.
Source: [27]

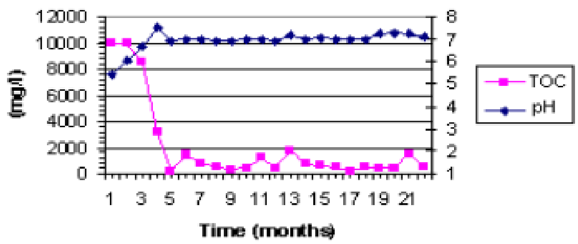

Fig. 2.10. pH and TOC concentrations in time for landfill leachates for MACH cell 1.
Source: [26]

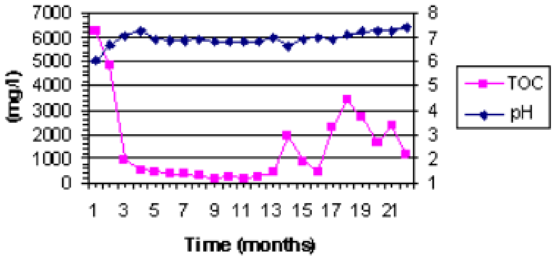

Fig. 2.11. pH and TOC concentrations in time for landfill leachates for MACH cell 3.
Source: [26]

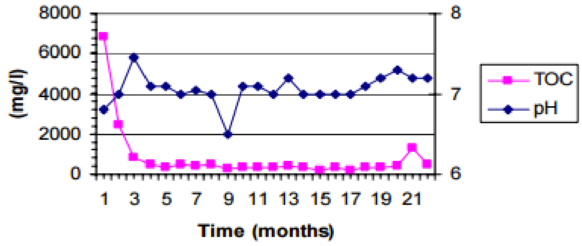

Fig. 2.12. pH and TOC concentrations in time for landfill leachates for MACH cell 3.
Source: [26]

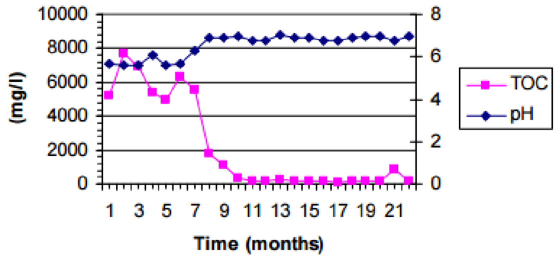

Fig. 2.13. pH and TOC concentrations in time for landfill leachates for MACH cell 4.
Source: [26]

The above results from the experimental batch landfill bioreactor for Mid Auchencarroch site show that sequential landfill waste mass bioreactors can be used properly for the treatment of chemical hazards and the protection of public health. It can be used as economic solution for leachates treatment combined with waste water treatment techniques for young age leachate concentrations. Treated landfill leachate produced quantities could be used in irrigation designs for annual agricultural cultivations like olive oil, wine production etc.

Landfill gas produced quantities could be exploited also for electricity production supporting agricultural activities as well as the necessities of sanitary facilities for units in live stocks or other associated anthropogenic activities in electricity consumption for food production; green chemistry's measurements; air conditioning; indoors quality; monitoring schemes for environmental resources and associated construction designs; innovative development of sustainable design projects; shipment of goods; minimisation of green house emissions - environmental costs; new jobs for unemployed people; sustainability and public health protection.

2.2 Physical and Chemical methods

Microfiltration (MF) remains interesting each time that an effective method is required to eliminate colloids and the suspended matter like, where the lab control system includes 1; control system, 2; influent pump, 3; effluent pump, 4; pH controller, 5; stirrer, 6; probes (pH, DO, T), 7; jacketed SBR, 8; air compressor, 9; thermostatic pump, 10; thermostatic tank, 11; heater. Piatkiewicz et al. (2001), in a polish study, reported the use of MF as prefiltration stage. No significant retention rate (COD reduction between 25% and 35%) was achieved.

Syzdek and Ahlert [54] suggested that Ultrafiltration (UF) might prove to be effective as a pre-treatment process for reverse osmosis (RO). UF is effective to eliminate the particles, and the macromolecules but it is strongly dependant on the type of material constituting the membrane. UF can be used to remove the larger molecular weight components of leachate that tend to foul reverse osmosis membranes.

Chen and Yang [14] investigated the best running condition and the effluent quality of membrane system for the treatment of SBR leachate drainage by submerged ultrafiltration membrane process in pilot equipment. In the condition of EFM cleaning of hydrochaloric acid and the best running existing, the operation of membrane system was stable. The trans-membrane pressure (TMP) was less than 0.025 MPa. Membrane system for COD and NH3–N removal was effective. And SDI was less than 1. All of that made the pollution of the next process reduced.

Moreover, Vogel et al. [61] carried out bench-scale filtration experiments to study the fouling behaviour during the NF of a synthetic landfill leachate. The results indicate that calcium in combination with organic matter could play a major role in governing the fouling process.

Furthermore, Reverse Osmosis (RO) seems to be one of the most efficient and promising methods among the new processes for landfill leachate treatment. In the past, several studies performed both at lab and industrial scale, have already demonstrated RO performances on the separation of pollutants from landfill leachate. Values of the rejection coefficient referred to COD parameter and heavy metal concentrations higher than 98% and 99%, respectively, were reported.

Moreover, the leachate ultraviolet (UV) quenching substances (UVQS) must be reduced or removed to a level that UV disinfection is not strongly affected. UVQS consist of three major humic acids, fractions, hydrophilics, and fulvic acids each of which has distinct behaviors and characteristics during treatment. In general, chemical, electrochemical, and physical treatments are more effective than biological treatments, but also costlier. Integration of multiple treatment methods to target the removal of different fractions of UVQS can aid in optimizing treatment. The importance of UVQS effects on wastewater treatment should be better recognized [18,20,45,70]..

Chemical treatment of leachate UVQS can be conducted by chemical oxidation (e.g., Fenton, Ozone, Percarbonate) and/or coagulation-flocculation. On average, chemical treatments have demonstrated the UV absorbance decrease of 46% and UVQS removal of 51% in term of TOC. Chemical treatments such as Fenton's oxidation are very effective and could achieve an average removal of 84.5% UV absorbance and 67.4% UVQS (in term of TOC) from leachate [18,20,45,70]. While treatments such as Ozone can achieve a 65% UV absorbance decrease, only 5.6-30% of UVQS removal in term of TOC was achieved, mainly because of its selective reaction with hydrophobic compounds, which subsequently transform to hydrophilic smaller molecular weight fraction after ozone treatment [20,66,69]. For example, 100%

decrease of HA, 16.2% decrease of FA, and 78% increase of HPI fraction was observed after ozone treatment [66]. Likewise, as demonstrated in Fig. 5, the UV absorbance of the HPI fraction after ozone treatment did not change, possibly because of the recalcitrance of the HPI to ozone or interconversion of the hydrophobic fractions to the hydrophilic fraction. Due to this, the contribution of the HPI to the total UV absorbance increased from 41% to 93% after ozone treatment. Also, the polydispersity index increased from 2.9 to 15.6 after ozonation of leachate, indicating a broader molecular weight distribution of leachate organics with ozonation [66]. To improve the performance of ozone treatment, combination of ozonation with other treatments (e.g., ozone/UV, ozone/H2O2, ozone/persulfate) has been investigated and exhibited improved UVQS removals, for instance, from 8 to 23% with ozone/UV treatment [53,65,67]. Chemical oxidation mainly works on the principle of interconversion of leachate UVQS during treatment. For example, Fenton removes most of the hydrophobic HA and FA by converting them into the HPI fraction [20, 74, 79]. The possible pathway of such conversions is via the nonselective reaction of OH radicals with both hydrophobic and hydrophilic compounds [10,20] The total TOC removal after Fenton treatment was reported to be less than the COD and humic substances removal, indicating that some of the organics were converted into intermediates after Fenton treatment [70,71]. These smaller sized intermediates with fewer carboxylic groups than initial humic substances are more susceptible to oxidation than original molecules and exert less COD after treatment [66]. A broad range of intermediates during the degradation of HA and FA can be utilized as a carbon source for bacteria, as a result of increased biodegradability of leachates by Fenton treatment [65]. To improve the performance, different types of Fenton processes such as solar photo-Fenton and iron oxide coated GAC assisted Fenton (FeGAC/H2O2) have been investigated for removing leachate UVQS and were able to achieve the removal of 80e85% humic substances [14,52]. Fenton was also coupled with SBR for leachate treatment, and in this system Fenton removed high molecular weight aromatic rings and conjugated moieties, while the SBR removed low molecular weight fractions, carboxylic acids, and proteins [41]. Fenton treatment, though a strong and effective chemical oxidation process for UVQS removal, has issues such as high reagent cost, sludge production, and foaming during the initial pH adjustment.

Figure 2.14 presents a flow diagram, sanitary drawing for locations (red bullets) that should be installed monitoring schemes, HACCP systems at leachates treatment collection systems. In this way associated risk assessment, sustainable designs and reclamation works could take place for public health protection from environmental chemical accidents, toxic, hazardous, risks in nearby outdoors spaces and indoors spaces from landfill boundaries i.e. community health centers, agricultural facilities etc.

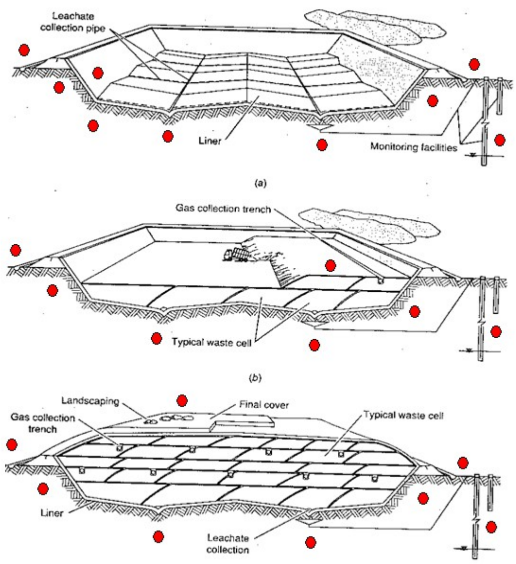

Fig. 2.14. Flow diagram, sanitary drawing for monitoring schemes of landfill emissions, HACCP systems.

In this way are protected food, water, air, soil and associated environmental receptors [1,5,7,8]. In the case that waste disposal does not follow proper sanitary landfill design guidelines then risks of bad odours from leachates and landfill gases can be produced to the nearby indoors and outdoors spaces from landfill boundaries. Moreover, uncontrolled dumps can provoke residues of Polycyclic Aromatic Hydrocarbons (PAHs) and Persistent Organic Pollutants (POPs) as toxic, mutagenic, teratogenic and carcinogenic chemicals that could exist in ambient air of landfill site where EPA toxicity assessment and risk characterization could take place [7,21].

Leachates should be collected properly and treated according to the methods that presented above avoiding hazards and risks for groundwater, water resources pollution and public health. Monitoring schemes and Hazardous Control Check Point systems should be applied at particular locations at leachate collection systems, (see figure 13, red bullets).

3. CONCLUSIONS

The main factors that influence on leachate emissions are type of composition of the waste, waste deposited, site hydrogeology, seasonal weather variations, age of the landfill, dilution with rainfall and degree of decomposition within landfill.

Waste matrix degradation occurs by various biological and chemical processes following four pathways; initial transition phase, acidogenic phase, methanogenic phase and a final maturation phase.

Monitoring schemes are necessary during the biomass degradation at leachate collection systems.

Chemical emissions should be investigated with Hydrological balance for particular extreme weather scenarios in order to estimate leachate risks and flowrates in terms of landfill safety designs in emergencies for public health protection.

Mass balances for both waste gasification and anaerobic digestion plus biogas production in scenarios I and II and estimation of flue gas flowrates and composition; 4. Data acquisition from the numerical weather prediction model COSMO LAMI and simulations by taking into account real meteorological conditions; 5. Evaluation of pollutants concentration in air, groundwater, soil, river, sea, vegetables, fish, milk, meat; 6. Calculation of Hazard Index and Cancer Risk for each pollutant and pathway; 7. Health Risk Assessment [7].

Risk assessment, sanitary drawings and monitoring frameworks are necessary to be applied properly for public health protection from hazardous toxic chemicals from landfill emissions based on particular landfill sites' characteristics [1,5,7,8,9,59]. Reclamation works and sanitary, construction designs are necessary to be realised in time for the protection of water resources supporting sustainable development.

ACKNOWLEDGMENTS

The authors acknowledge the UK Energy Technology Support Unit (ETSU, UK), Department of Trade and Industry (DTI) and UK Environmental Agency (EA) for their support of the Mid Auchencarroch experiment project. The conclusions expressed herein represent the findings of the authors and are based on their expertise and experience in this area and their findings in their professional literature. It does not necessarily represent the views of EA or other stakeholders.

REFERENCES

[1] Aldrich, T., Griffith, J. (1993) Environmental Epidemiology and Risk Assessment, (Ed. Cooke, C.), Van Nostrand Reinhold, New York, U.S.A.,

[2] Alvarez-Vazquez, H., Jefferson, B. and Judd, S.J. (2004) Membrane Bioreactors vs Conventional Biological Treatment of Landfill Leachate: A Brief Review. Journal of Chemical Technology and Biotechnology, 79, 1043-1049.

[3] Aziz, H.A., Alias, S., Adlan, M.N., Faridah Asaari, A.H., Zahari, M.S. (2007) Colour removal from landfill leachate by coagulation and flocculation processes, Bioresour. Technol. 98, p. 218–220.

[4] Augenstein, D., Pacey, J. (1991) Modelling landfill methane generation, In: Proceedings Sardinia, Third International Landfill Symposium, pp. 115-148, Ed. T.Christensen, R.Cossu, R.Stegmann, Sardinia, Italy.

[5] Best, G. (1999) Environmental Pollution Studies, Liverpool University Press.

[6] Bohdziewicz J., Bodzek M. and Gorska J. (2001) Application of pressure-driven membrane techniques to biological treatment of landfill leachate. Process Biochem, vol. 36, (7), p. 641-646.

[7] Butt, T.E., Lockeley, E., Oduyemi, K.O., 2008. Risk assessment of landfill disposal sites state of the art. Waste Manage. 28 (6), 952–964.

[8] Blackman, C., Paige, C., Cuffaro, N., Sears, L. (2013) Industrial Design, Rockport, USA.

[9] Blackman, W. (2001) Basic Hazardous Waste Management, Lewis Publishing.

[10] Cataldo, F., Angelini, G., (2012) Radiolysis and ozonolysis of a landfill leachate. J. Radioanal. Nucl. Chem. 293 (1), p.141-148.

[11] Cheremisinoff, N.P., Cheremisinoff, P.N. (1995), Hazardous Materials and Waste Management, Noyes publications.

[12] Chian, E.S.K., De Walle, F.B. (1976) Sanitary landfill leachates and their treatment, J. Environ. Eng. Div. Proc. Amer. Soc. Civ. Eng., vol.102, p. 411-431.

[13] Christensen, T.H., Kjeldsen, P., (1991) Basic biochemical processes in landfills, Editors: Christensen, TH., Stegmann, R., Cossu, R., Sanitary Landfilling: Process, Technology and Environmental Impact, Academic Press, London, p. 251–256.

[14] Chen, Q., Yang, F., (2012) Pilot studies on treating leachate by submerged ultrafiltration membrane, J. Membrane Science and Technology, vol. 32, p. 83– 86.

[15] DOE (1995) Making Waste Work, White Paper, HMSO, London.

[16] Ejder-Korucu, M., Gurses, A., Dogar, C., Sharma, S.K., Akyildiz, M. (2015) Removal of Organic Dyes from Industrial Effluents: An Overview of Physical and Biotechnological Applications, In: Green Chemistry for Dyes Removal from Waste Water, Research Trends and Applications, Ed. Sharma, S.K., p. 1-34, Wiley publications.

[17] El-Fadel, M., Bou-Zeid, E., Chahine, W., Alayli, B. (2002) J. Waste Manage. 22, p.269–282.

[18] Eldyasti, A., Andalib, M., Hafez, H., Nakhla, G., Zhu, J. (2011) Comparative modeling of biological nutrient removal from landfill leachate using a circulating fluidized bed bioreactor (CFBBR), J. Hazard. Mater., v.187, p.140–149.

[19] Elliott, P., Briggs, D., Morris, S., Hoogh, C., Hurt, C., Jensen, T.K., Maitland, I., Richardson, S., Wakefield, J., Jarup, L. (2001) Risk of adverse birth outcomes in populations living near landfill sites, BMJ, 323: p. 363-368.

[20] EMCON (1980) Methane generation and recovery from landfills, EMCON Associates, San Jose, California, Ann Arbor Science Publishers, Ann Arbor, MI, pp. 44-51.

[21] EPA. (1996) Risk Assessment Guidance for Superfund (RAGS) Part A: Chapter 7 (Toxicity Assessment) and 8 (Risk Characterization).

[22] Fan, H.J., Chen, I.W., Lee, M.H., Chiu, T., (2007) Using FeGAC/H2O2 process for landfill leachate treatment. Chemosphere 67 (8), p.1647-1652.

[23] Fleming, G. (1996) Hydrogeochemical Engineering in Landfills. In: Geotechnical Approaches to Environmental Engineering of Metals, Rudolf, R. (ed.), Springer, pp. 183-212.

[24] Friis, R.H., Sellers, T.A. (2004) Epidemiology for Public Health Practice, Jones and Bartlett Publishers.

[25] Christensen, T. H, Kjeldsen, P. (2009) Basic biochemical processe in landfills. In: Christensen, T. H., Cossu, R. and Stegmann, R. (eds), Sanitary Lanfilling: Process, Technology and Environmental Impact. Academic Press, p.29-49.

[26] Gupta, A., Zhao, R.Z., Novak, J.T., Goldsmith, C.D. (2014) Application of Fenton's reagent as a polishing step for removal of UV quenching organic constituents in biologically treated landfill leachates. Chemosphere 105, p. 82-86.

[27] Gupta, A., Zhao, R.Z., Novak, J.T., Goldsmith, C.D. (2014) Variation in organic matter characteristics of landfill leachates in different stabilisation stages. J. Waste Manag. Res. 32 (12), p. 1192-1199.

[28] Jung, C., Deng, Y., Zhao, R., Torrens, K., (2017) Chemical oxidation for mitigation of UV-quenching substances (UVQS) from municipal landfill leachate: Fenton process versus ozonation. Water Res. 108, p. 260-270.

[29] Kargi, F., Pamukoglu, M.Y., (2003) Aerobic biological treatment of pre-treated landfill leachate by fed-batch operation, J Enzyme and Microbial Technology, vol. 33, issue 5, p. 588– 595.

[30] Koliopoulos, T., Kollias, V., Kollias, P. (2002) Modelling the risk assessment of groundwater pollution by leachates and landfill gases, Wessex Institute of Technology Transactions, Water Pollution, vol. 7, Modelling, Measuring and Prediction, W.I.T Press, Editors Brebbia C., Almorza, D., Sales, D., p. 159-169.

[31] Koliopoulos, T., Koliopoulou, G. (2007) Evaluation of optimum landfill design: Mid Auchencarroch experimental landfill emissions, Wessex Institute of Technology Transactions, Computer Aided Optimum Design in Engineering (OPTI), vol. 10, W.I.T. Press Publications, U.K., p. 231-239.

[32] Koliopoulos, T., Koliopoulou, G. (2007) Evaluating Landfill Chemical Emissions - Mid Auchencarroch Experimental Design, Asian Journal of Chemistry, Vol. 19, No.5, p. 3911-3917.

[33] Koliopoulos, T. (2008) An Efficient Methane Greenhouse Emissions' Flushing Out at Mid Auchencarroch Experimental Landfill Site and Proposed Effective Linings of Biogas Collection Monitoring Networks, Rasayan Journal of Chemistry, Vol. 1, No. 3, p. 437-446.

[34] Koliopoulos, T. (2008) Leachate Emissions at Mid Auchencarroch Experimental Site and Environmental Impact Assessment – Efficient Spatial Analysis Utilizing Remote Sensing and Digital Image Processing Software for Leachate Monitoring, Rasayan Journal of Chemistry, Vol. 1, No. 4, p. 788-794.

[35] Koliopoulos, T., Koliopoulou G. (2008) Evaluation of Iso-Butyric Acid and Acetic Acid in Landfill Leachate Emissions – Mid Auchencarroch Experimental Design, Asian Journal of Chemistry, vol. 20, (2), p. 1153-1162.

[36] Koliopoulos T., Koliopoulou, G. (2009) The Biodegradation of Iso - Valeric Acid in Relation to Other Chemical Indexes and Spatial Liner Risk Assessment at Landfill Topographies – Mid Auchencarroch Experimental Site, Asian Journal of Chemistry, Vol. 21(4), p. 2989 - 3000.

[37] Kollias, P. (1993) Solid Wastes, Athens, Greece.

[38] Kjeldsen, P., Barlaz, M.A., Rooker, A.P., Baun, A., Ledin, A., Christensen, T.H. (2002) Present and long-term composition of MSW landfill leachate: A review, Environmental Science and Technology, vol. 32, issue 4, p. 297-336.

[39] Li, F.Y., Wichmann, K., Heine, W. (2009) Treatment of the methanogenic landfill leachate with thin open channel reverse osmosis membrane modules , J. Waste Management, vo. 29, issue 2, p. 960– 964.

[40] Linde, K., Jonsson, A. (1995) Nanofiltration of salt solutions and landfill leachate, J. Desalination 103, p. 223–232.

[41] Liu, Z.P., Wu, W.H., Shi, P., Guo, J.S., Cheng, J., (2015) Characterization of dissolved organic matter in landfill leachate during the combined treatment process of air stripping, Fenton, SBR and coagulation. J. Waste Management, vol. 41, p.111-118.

[42] Metcalf and Eddy, Inc. (1991) Wastewater engineering: Treatment, disposal, and reuse. McGraw-Hill, New York, NY, ISBN 0-07-100824-1

[43] Mohammad, A.W., Hilal, N., Pei, L.Y. (2004) Treatment of landfill leachate wastewater by nanofiltration membrane, Int. J. Green Energy, vol. 1, issue 2, p. 251–263.

[44] Monje-Ramirez*, I., Orta de Velasquez, M.T. (2004) Removal and transformation of recalcitrant organic matter from stabilized saline landfill leachates by coagulation–ozonation coupling processes, J. Water Research, v. 38, p. 2359–2367.

[45] Moravia, W.G., Amaral, M.C.S., Lange, L.C. (2013) Evaluation of landfill leachate treatment by advanced oxidative process by Fenton's reagent combined with membrane separation system, J. Waste Management, vol. 33, issue 1, p. 89–101.

[46] Pirbazari, M., Ravindran, V., Badriyha, B.N., Kim, S. (1996) Hybrid membrane filtration process for leachate treatment, Water Research, Volume 30, Issue 11, p. 2691–2706.

[47] Piatkiewicz, W., Biemacka, E., Suchecka, T. (2001) A Polish study: Treating landfill leachate with membranes, Filtration and Separation, vol. 38, issue 6, p. 22– 26.

[48] Polirakis, J. (2003) Environmental Agriculture, Psichallou publications, Greece.

[49] Renou, S., Givaudan, J.G., Poulain, S., Dirassouyan, F., Moulin, P. (2008) Landfill leachate treatment: Review and opportunity, Journal of Hazardous Materials, vol. 150, issue 3, p. 468–493.

[50] Shamai U.M. (2005) GIS Applications for Water, Wastewater and Stormwater Systems,

CRC Press.

[51] Sharma,S., Mudhoo, A., Zhang, W. (2010) Green Chemistry and Engineering, A Versatile Perspective, In: Green Chemistry for Environmental Sustainability, Ed. Sharma, S., Mudhoo, A. , CRC Press, p. 1-52.

[52] Silva, T., Silva, M.E.F., Cunha-Queda, A.C., Fonseca, A., Saraiva, I., Sousa, M.A., Goncalves, C., Alpendurada, M.F., Boaventura, R.A.R., Vilar, V.J.P. (2013) Multistage treatment system for raw leachate from sanitary landfill combining biological nitrification denitrification/solar photo-Fenton/biological processes, at a scale close to industrial Biodegradability enhancement and evolution profile of trace pollutants. Water Res. 47 (16), p.6167-6186.

[53] Soubh, A., Mokhtarani, N. (2016) The post treatment of composting leachate with a combination of ozone and persulfate oxidation processes. RSC Adv. 6 (80), p.76113-76122.

[54] Syzdek, A.C., Ahlert, R.C., (1984) Separation of landfill leachate with polymeric ultrafiltration membranes, Journal of Hazardous Materials, vol. 9, issue 2, p. 209-220.

[55] Tchobanoglous, G., Burton, F.L. (1991). Wastewater engineering treatment, disposal and re-use, McGrawHill publications.

[56] Sun, H.W., Peng, Y.Z., Shi, X.N., Zhang, S.J., Yang, Q., Hou, H.X., (2009) Achieving nitrogen removal from landfill leachate via UASB-A/O process , J. China Environmental Science, vol. 29, issue 10, p. 1059-1064.

[57] Schnepp, R. Gantt, P. (1999) Hazardous Materials, Regulations, Response & Site Operations, Kentucky, Delmar publisher.

[58] Sır, M., Podhola, M., Patocka, T., Honzajkova, Z., Kocurek, P., Kubal, M., Kurasˇ, M., (2012) J Hazard Mater 207–208, p. 86–90.

[59] Tchobanoglous, G., Theisen, H., Vigil, S. (1993) Integrated Solid Waste Management, Engineering Principles and Management Issues, Mc Graw-Hill International Editions.

[60] Trabelsi, I., Sellami, I., Dhifallah, T., Medhioub, K., Bousselmi, L., Ghrabi, A., (2009) Coupling of anoxic and aerobic biological treatment of landfill leachate, J. Desalination, vol. 246, p. 506–513.

[61] Vogel, D., Bilitewski, B., Nghiem, L.D. (2007) Membrane fouling in the nanofiltration of landfill leachate and its impact on trace contaminant removal, International Journal of Environment and Waste Management, vol. 1, No. 4, p. 338–350.

[62] Vilar, V.J.P., Rocha, E.M.R., Mota, F.S., Fonseca, A., Saraiva, I., Boaventura, R.A.R., (2011) Treatment of a sanitary landfill leachate using combined solar photo-Fenton and biological immobilized biomass reactor at a pilot scale, J. Water Research, vol. 45, issue 8, p. 2647–2658.

[63] Vlavianos-Arvanitis, 1991, Biopolitics, BIO, Athens, Greece.

[64] Rothery, B. (1995) ISO 14000 and ISO 9000 Series of Quality Standards, Gower publications.

[65] Wang, H.W., Li, X.Y., Hao, Z.P., Sun, Y.J., Wang, Y.N., Li, W.H., Tsang, Y.F., (2017) Transformation of dissolved organic matter in concentrated leachate from nanofiltration during ozone-based oxidation processes (O-3, O-3/H2O2 and O-3/UV). J. Environ. Manag. 191, p. 244-251.

[66] Wang, H.W., Wang, Y.N., Li, X.Y., Sun, Y.J., Wu, H., Chen, D.L., (2016) Removal of humic substances from reverse osmosis (RO) and nanofiltration (NF) concentrated leachate using continudusly ozone generation-reaction treatment equipment, j. Waste Management, vol. 56, p.271-279.

[67] Wingfield-Hayes, C. (1997) The Enhanced Landfill Bioreactor: A Sustainable Waste Management Option for the 21st Century? The Mid Auchencarroch Experiments. PhD Thesis. Dept. of Civil Engineering, University of Strathclyde, Glasgow, U.K.

[68] Wu JJ, Wu CC, Ma HW, Chang CC, Masten SJ. (2001Treatment of landfill leachate by ozone-based advanced oxidation processes. In: Proceeding of the 15th IOA world congress, London, p. 339–349.

[69] Wu, J.J., Wu, C.C., Ma, H.W., Chang, C.C. (2004) Treatment of landfill leachate by ozone-based advanced oxidation processes. Chemosphere 54 (7), p.997-1003.

[70] Wu, Y.Y., Zhou, S.Q., Qin, F.H., Peng, H.P., Lai, Y.L., Lin, L.M. (2010) Removal of humic substances from landfill leachate by Fenton oxidation and coagulation. Process Saf. Environ., vol. 88, issue 4, p. 276-284.

[71] Wu, Y.Y., Zhou, S.Q., Qin, F.H., Ye, X.Y., Zheng, K. (2010) Modeling physical and oxidative removal properties of Fenton process for treatment of landfill leachate using response surface methodology (RSM). J. Hazard Mater., vol. 180, p.456-465.

[72] Wu, Y.Y., Zhou, S.Q., Ye, X.Y., Chen, D.Y., Zheng, K., Qin, F.H. (2011) Transformation of pollutants in landfill leachate treated by a combined sequence batch reactor, coagulation, Fenton oxidation and biological aerated filter technology. Process Saf. Environ., vol. 89, issue 2, p.112-120.

[73] Xu, Z.Y., Zeng, G.M., Yang, Z.H., Xiao, Y., Cao, M., Sun, H.S., Ji, L.L., Chen, Y. (2010) Perspectives on technology for landfill leachate treatment, Bioresour Technol, S2573, vol. 101, p.79–86.

[74] Xu, J., Long, Y.Y., Shen, D.S., Feng, H.J., Chen, T., (2017) Optimization of Fenton treatment process for degradation of refractory organics in pre-coagulated leachate membrane concentrates. J. Hazardous Materials, vol. 323, p.674-680.

[75] Yabroudi, S.C., Morita, D.M., Alem, P. (2013) Landfill Leachate Treatment Over Nitritation/Denitritation in an Activated Sludge Sequencing Batch Reactor?, APCBEE Procedia, vol. 5, p.163–168.

[76] Yahmed, A.B., Saidi, N., Trabelsi, I., Murano, F., Dhaifallah, T., Bousselmi, L., Ghrabi, A., (2009) Microbial characterization during aerobic biological treatment of landfill leachate, Desalination, vol. 246, issues 1–3, p.378–388.

[77] Schroeder, P. R., et al. (1984) The Hydrologic Evaluation of Landfill Performance (HELP) Model, Documentation for Version I, EPA/530/SW-84-010, 2, U.S. EPA Office of Solid Waste and Emergency Response, Washington, DC.

[78] Tchobanoglous, G., F. L. Burton, and H. D. Stensel (2003) Wastewater Engineering: Treatment and Reuse, McGraw-Hill, publications.

[79] Zhao, X., Wei, X.Y., Xia, P.F., Liu, H.J., Qu, J.H., (2013) Removal and transformation characterization of refractory components from biologically treated landfill leachate by Fe2þ/NaClO and Fenton oxidation. J. Separ. Purif. Technol., vol. 116, p. 107-113.

[80] Zhu, R.L., Wang, S.Y., Li, J., Wang, K., Miao, L., Ma, B., Yongzhen Peng, Y.Z., (2013) Biological nitrogen removal from landfill leachate using anaerobic–aerobic process: Denitritation via organics in raw leachate and intracellular storage polymers of microorganism, J. Biores Technol, vol. 128, p.401–408.