LANDFILL BIOREACTOR'S CHEMICAL BALANCE AND ASSESSMENT OF ITS BIODEGRADATION – MID AUCHENCARROCH EXPERIMENTAL PROJECT

Telemachus C. Koliopoulos
Environmental Consultancy, Environmental Management Research,Athens, Greece
Correspondence to author: 1 Melissou Str., 116 35 Athens, Greece.
E-mail: tkol@otenet.gr

ABSTRACT

Nowadays, the global oil crisis and global climate change of the environment obliged the science and technology to the exploitation of renewable energy resources and to the development of hybrid dynamic sustainable ecological designs. Sanitary landfills remain an attractive disposal route for solid wastes, as it is more economical than other alternative solutions. This paper analyzes the waste biodegradation and its emissions, as a result of different disposed waste composition and solid waste management and treatment. Projections are made of several indexes which should be taken into account for the environmental impact assessment of landfill designs and landfill management including probable bioremediation works. An analysis is made of the landfill emissions, which are produced taking into account characteristic field data from Mid Auchencarroch experimental site. In the end are presented several useful conclusions for an efficient solid waste management.

Key words: *Landfill design, biomass, waste biodegradation, biogas, leachates, energy resources, spatial analysis of landfill emissions, environmental impact assessment, solid waste management.*

INTRODUCTION

The progress and the evolution of our civilization increased the waste volume in sanitary landfills, as well the wastewater volume in wastewater treatments. The environmental pollution became hazardous the last years. The technology has been focused on the environmental protection developing methods and systems of effective waste management and energy recovery. The increasing of the SWM recovery rates influences the waste management systems, the waste composition streams, costs and emissions from treatment and disposal activities [3, 9, 5] . Sanitary landfill remains an attractive disposal route for household, commercial and industrial wastes, because, it is more economical than other waste disposal methods [7, 9] . It has gained popularity in the UK compared to mainland Europe, due to clay soils being more common in the UK, particularly Scotland. These enable cost effective engineering to prevent leachates entering the water table from landfill sites. Efficiently managed landfill sites also generate considerable volumes of methane gas (CH_4) which can be recovered producing electricity. The selection of sites for sanitary landfills, and the design, construction and operating practices used at these sites, should:

- be consistent with local land use conditions and zoning codes;
- assure that bird populations do not pose a hazard to aircraft;
- protect flood plains, wetlands, and other ecologically sensitive areas;
- protect archeological, historical, and other culturally sensitive areas;
- protect against problems caused by unstable geological settings;
- provide for best practices in design, construction, operation andclosure; and
- minimize impacts on air or water quality and not to otherwise adversely impact upon public health, safety and welfare.

An integrated waste management policy should be based on five points: waste prevention, recycling and recovery of waste, design optimization of final disposal of waste, control of waste shipment and proper sustainable management-ecological, curative actions. Quality assurance should take place in all stages of an integrated waste management and the use of proper lining methods, where it is necessary, should take place for particular project management within monitoring, maintenance and reclamation, bioremediation or other sustainable technical infrastructure works [4, 5, 8].

Separate collections will influence rates, yields and global amounts of landfill gas, such as the separate collections of organic wastes like garden wastes or of used papers and old used newspapers. The main objective of the above waste policy is to ensure high standards for the disposal of waste, stimulating waste prevention via recycling and recovery. The reduced waste will maintain revenues and operators will need to take into account waste identification, sorting, material separation, and recycling or composting facilities.

EXPERIMENTAL

According to the literature landfill methane emissions are depented on hydrological, geological, geotechnical and topographical factors affecting biogas generation and biomass biodegradation [7, 9] . These factors vary between sites according to microbiological conditions, different waste fractions, different physical and chemical properties of the disposed materials, different waste quantities disposed of to landfill each year and existing facilities for gas collection and flaring or recovery [6, 7, 9] . The principal landfill gases are methane and carbon dioxide with trace concentrations of a wide variety of other gases, depending on the waste mix. The greenhouse gas of most concern in waste management is methane [3, 7] .

This paper presents the landfill biodegradation emissions of four experimental cells at Mid Auchencarroch experimental site in the UK as a case study [7]. The main aim is to evaluate the waste biodegradation of landfill chemical emissions of the four case studies based on the different conditions which exist. The waste fractions which have been disposed into these characteristic landfill sites are different.

The waste biodegradation could be described using stoichiometric calculations for different waste fractions giving indicative results of landfill emissions. The general anaerobic transformation of solid waste can be described by means of the following chemical reaction and respective equation constraints for the examining chemical mass balances

$$C_aH_bO_cN_d + \left(\frac{4a-b-2c+3d}{4}\right) H_2O \rightarrow \left(\frac{4a+b-2c-3d}{8}\right) CH_4 + \left(\frac{4a-b+2c+3d}{8}\right) CO_2 + dNH_3$$

or

$$C_aH_bO_cN_d + (2t-c)H_2O \rightarrow (a-t)CH_4 + tCO_2 + dNH_3 \qquad \ldots(1)$$

where,

$$t = \frac{4a-b+2c+3d}{8} \qquad \wedge \qquad A = \{\, a, b, c, d \,\} \subset R^+$$

Therefore, from the above equation, there are the following constraints, which should be followed in the stoichiometric calculations

$$\frac{c}{2} < t < a \quad \text{or} \quad t \in (\frac{c}{2}, a), \quad (c < 2a) \qquad \ldots(2)$$

The term $C_aH_bO_cN_d$ is used to represent, on a molar basis, the composition of the organic material. Dynamic numerical simulation models based on field data should be used for better accuracy of chemical landfill emissions' magnitudes and their respective spatial analysis in time. Moreover, dynamic lining methods should take place based on the numerical simulation results and monitoring data so as to be taken the right maintenance and probable reclamation works in time on given landfill topographical characteristics. The produced landfill emissions, gases and leachates, are as a result from the waste biodegradation of the organic material which has been disposed into the landfill mass [6, 7].

In this paper are presented landfill gas emissions from the Mid Auchencarroch (MACH) experimental landfill is a UK Environment Agency and industry funded research facility [7]. It has been capped since 1995. The experimental variables are waste pretreatment, leachate recirculation and co-disposal with inert material. 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. The disposed waste synthesis for the untreated, pulverised waste input is: Paper-Card: 27%,34%; Plastic film 6%,7%; Dense plastic 5%,8%; Textiles 3%; Misc.combust. 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%. The project consists of four cells each of nominal plan dimensions 28m x 30m and 5m deep, Fig. 1, giving a nominal volume of 4200 m^3 [7, 10].

However, the biodegradation stages which exist within landfill life cycle and its respective biogas and leachate stabilized chemical emissions are presented below in Tables-1 and 2 [7].

In Table- 2, are presented common leachate emissions in big scale landfills that there are not any waste treatment in landfill mass. During the hydrolysis and acetogenesis stages the COD values have big magnitudes within a period of five years (0-5 years) and they are decreasing in time. Also, during the methanogenesis stage pH equals to 7, neutral environment.

According to the experimental field data which were collected and measued from the leachates samples at MACH's cells, the COD and BOD magnitudes found that they were below 2000 (mg/l) for cell 1 in fifteen months, for cell 2 in twenty three months, for cell 3 in three months, for cell 4 in ten months, since the MACH site was capped [7]. The measured landfill gas yield was found between 7 and 9 m^3/hr for both MACH's cells in less than two-year period since the site was capped [6, 7]. The latter measured field data and the measured methane and carbon dioxide emissions (vol%) (figure 2, 3) in short time verify the quick MACH site stabilization in time, avoiding any long term environmental impacts to the environment and to the public health.

In figures 2 and 3, are presented for first time in the literature the measured carbon dioxide and methane emissions at MACH experimental site, per volume % composition, as a result of landfill biomass biodegradation for the four MACH cells, in the total two-year time series of biogas emissions since MACH site was capped. Also in figures 2 and 3 are presented the respespective least-square fitting curves as trend lines of carbon dioxide and methane emissions at MACH experimental site. The increase of methane and the decrease of carbon dioxide in the trends of the respective fitting curves (figures 2, 3) verify that methanogenesis stage and MACH's site stabilization were achieved both in short time period. The methane and carbon dioxide chemical emissions are the most important for the identification of the life cycle analysis of the biodegradation stages of a landfill site. According to figures 2 and 3 is clear that methanogenesis biodegradation stage was achieved in short term time period, avoiding any long term landfill chemical emissions to the environment.

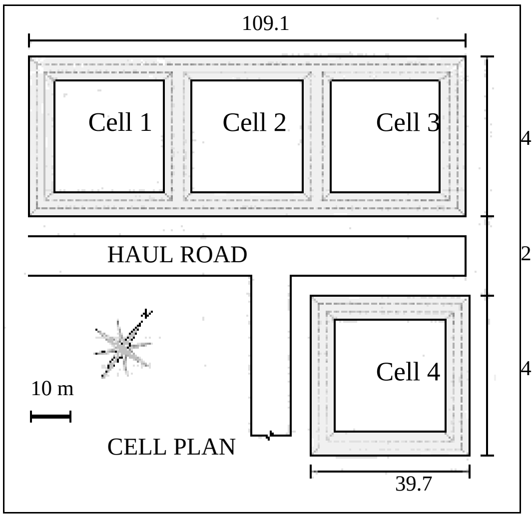

Fig. 1 Mid Auchencarroch experimental site cell plan

Table-1:Landfill biodegradation stages

Degradation stages of $C_aH_bO_cN_d$ chemical organic substrates with big molecular weights, like fats, hydrocarbons and proteins.

Stage I : **Hydrolyisis,** production of fatty acids with long molecular chains, polyalcohols, sugars and degradation of aminoacids.
There is acid environment.

Stage II : **Acidogenesis,** production of hydrogen, carbon dioxide and organic acids, like propionate and butyrate acids.
There is acid environment ($3 \le pH \le 6$).

Stage III : **Acetogenesis,** production hydrogen, carbon dioxide and the acetic acid, organic acid. There is acid environment within biomass ($pH<7$).

Stage IV : **Methanogenesis,** biogas generation and production of several landfill gases is taken place in this stage, according to the waste input materials, which have been disposed into a landfill mass. There is neutral environment within landfill mass ($pH \simeq 7$). For an anaerobic bioreactor could be found the next biogas compositions: Methane (45-80 vol%), carbon dioxide (30-60 vol%), sulfureous (0.1-5 vol%), volatile gases (0.01-0.6 vol%), oxygen (0.1-1 vol%), carbon monoxide (0-0.2 vol%), hydrogen (0-0.2 vol%).

Stage V: **Mature,** final fate of landfill mass behaviour, almost there is not more gas and leachate biodegradation in this stage ($6.5 \le pH \le 7.5$). There are several hydro-geotechnical properties, in this stage, which interact with the chemical elements which have not been degradaded yet within landfill mass. Monitoring, maintenance, lining of reclamation or bioremediation works, quality assurance and probable investigation of landfill emissions migration and bioremediation works should take place in all stages.

Table -2: Leachate emissions during landfill biodegradation in time

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

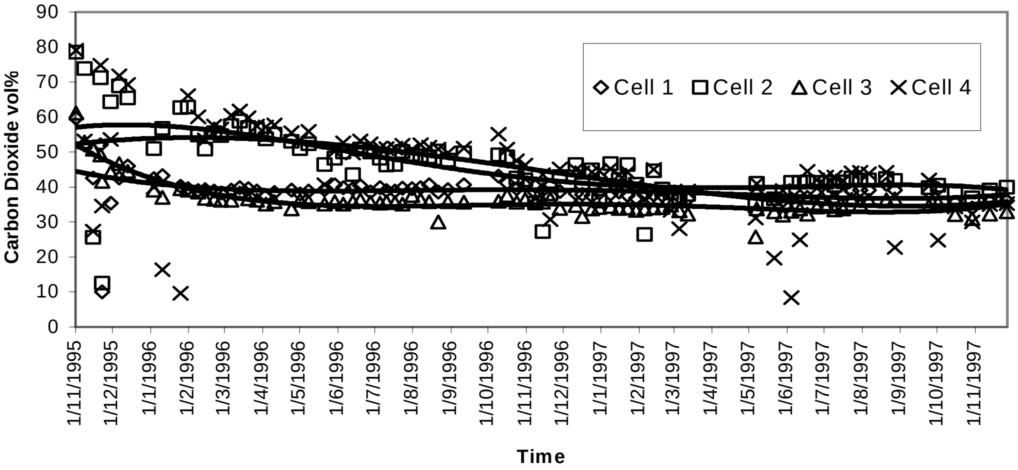

Fig. 2 Carbon Dioxide Emissions in Gas Vents at Mid Auchencarroch site

MACH case study clearly identifies the importance of site design and management in order to achieve optimal gas generation and rapid stabilisation of the site. The use of dynamic numerical simulation models is necessary for the proper monitoring and project management of landfills' chemical emissions [1, 2, 5, 6, 7] .

RESULTS AND DISCUSSION

Based on the experimental results we can see that the co-disposal with inert material is sustainable as well as the pretreatment by wet pulverisation since the recirculation of leachate expedite the biodegradation and methanogenesis. Pretreatment of waste should become obligatory in future landfill management, influencing waste biodegradation, methane, carbon dioxide and leachate emissions. According to the experimental results, we can see that the best waste biodegradation exists in cell 3 which has both waste pretreatment and leachate recirculation.

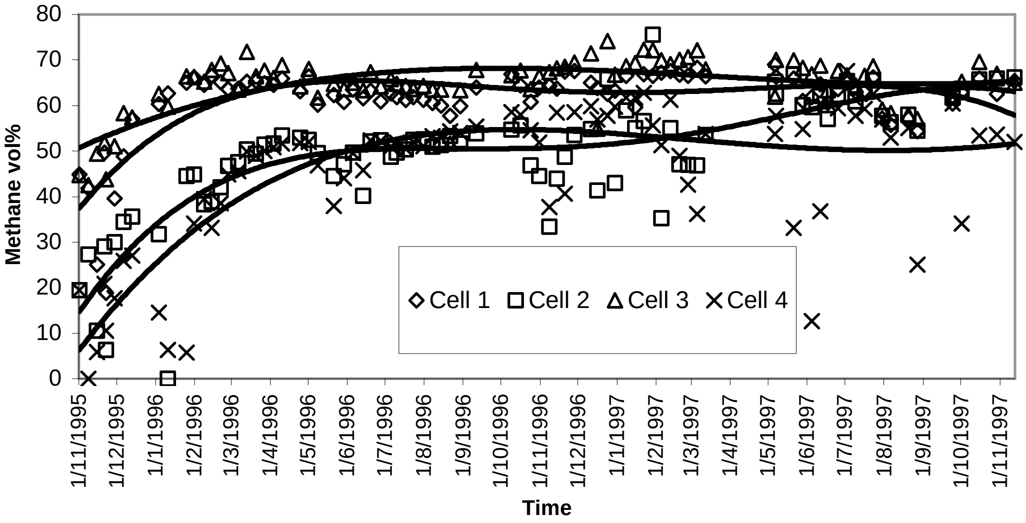

Fig. 3 Methane Emissions in Gas Vents at Mid Auchencarroch site

According to the experimental results is clear that anaerobic design under favourable landfill's physical and chemical conditions assists the methane and carbon dioxide production in short time period, two-year rapid waste biodegradation at MACH site. The monitoring results of biogas emissions could be used as an indication of the total biodegradation stage of biomass taking into accound and the magnitudes of produced leachates emissions from an examining landfill site. If both biogas and leachate emissions' magnitudes are not within the same biodegradation stage according to the bibliography then the suspition of landfill emissions' migration should be made taking into account the geological and topographical data next to landfill boundaries. Then the use of proper lining methods is necessary in order to take place in space and time the right bioremediation and rehabilitation technical works on given brownfield sites.

However, at landfill sites that there is big fraction of the disposed putrescible material into the biomass it influences the biogas production in terms of m^3 biogas / kg waste, giving a high magnitude, which should be taken into account for landfill gas exploitation as renewable resource of energy. However, leachate recirculation for anaerobic designs could increase the moisture content and the rate of biodegradation, developing biogas recovery and reducing landfill emissions' magnitudes in short term.

On the other hand, the operation of an aerobic landfill biotechnology would increase the waste temperature in higher mangnitudes than the anaerobic one. When an aerobic landfill design is sealed then the ingress of oxygen is limited, the biomass temperature is increased and the methanogenesis partly is achieved [7] . Future research and relative numerical simulation models should be focused on hybrid landfill designs, taking into account the principles of the aerobic and anaerobic landfill biotechnologies and the physical and chemical properties of the disposed waste materials.

As well as the fact that the future within the waste policy is likely to concentrate on waste minimisation policies this will encourage the recycling of used materials and therefore will reduce the waste quantity which is disposed into landfill or to be incinerated. Due to the new global reduction targets opportunities may arise for supplying know-how design and proper technology use based on experimental field data for the waste identification and separation; economic units of the leachates' treatment; landfill gas collection design; gas utilisation management; bioclimatic ecological designs and composting facilities and composting utilisation management.

Long-term liability can be minimized if waste is quickly treated to a point that will not occur further degradation, protecting the environment from long biogas and leachate emissions. The recycling, waste pretreatment, and leachate recircurlation will play an important-catalytic role in the reduction of the biogas and leachate emissions and the acceleration of the waste biodegradation in short time periods, avoiding any long term chemical threat of pollutants migration to the environment.

Direct field measurements, laboratory experiments and improved statistics on waste arisings and composition to reduce uncertainties will improve the data input to existing chemical biodegradation prediction models. Moreover, the development of dynamic models is necessary not only to evaluate existing sites but also to propose efficient sustainable landfill designs. The four case studies showed the effects of biodegradable material, the co-disposal with inert material, the waste pretreatment and the leachate recirculation on the waste biodegradation and the biogas emissions. Leachate recirculation could be used in landfills that it does not exist in order to achieve optimum results in landfill biodegradation.

ACKNOWLEDGEMENTS

The author would like to thank University of Strathclyde and the Centre for Environmental Management Research for the opportunity given to him to collaborate with their praiseworthy academic staff and other colleagues from the industry so as to work within Mid Auchencarroch experimental project. Also the author would like to thank several colleagues within the educational institutes, research centres and particular departments, which have been collaborated with him and gave a moral support to his scientific work.

REFERENCES

1. G. Courter, A.Marquis, Mastering Microsoft Project 2000, Sybex Pubs., Alemeda, U.S.A. p.822 (2006).
2. C.I. Efraimidis, Project Management, Symmetria Pubs, Athens, Greece, p.273 (2001).
3. Greek Ministry for the Environment, Physical Planning and Public Works (MEPPPW) National Allocation Plan for the period 2005 – 2007, Hellenic Republic, Athens, Greece, p.60 (2005).
4. S.Kaparis, Special Subjects of Topography, Ministry of Education Pubs, Athens, Greece, p.208 (1993).
5. T.C. Koliopoulos, G. Koliopoulou, *Wessex Institute of Technology Transactions on Ecodynamics and Sustainable Development (ECOSUD)*, A diagnostic model for M.S.W landfill’s operation and the Protection of Ecosystems with a Spatial Multiple Criteria Analysis – Zakynthos Island Greece, W.I.T. Press, Southampton, U.K., **6,** pp. 449-462, (2007).
6. T.C. Koliopoulos, G. Koliopoulou, *Wessex Institute of Technology Transactions on Computer Aided Optimum Design in Engineering (OPTI),* Evaluation of optimum landfill design: Mid Auchencarroch experimental landfill emissions, W.I.T. Press, Southampton, U.K., **10,** pp. 231-239, (2007).
7. T.C. Koliopoulos, Numerical Modelling of Landfill Gas and Associated Risk Assessment, PhD Dissertation, Dept. of Civil Engineering, University of Strathclyde, Glasgow,U.K., p. 200 (2000).
8. B. Rothery, ISO 14000 and ISO 9000 series of quality standards, Gower Pubs, U.K. p. 321 (1995).
9. G.Tchobanoglous, H. Theisen, S. Vigil, Integrated Solid Waste Management, McGraw-Hill Book Company, New York, USA, p. 978 (1993).

10. C.Wingfield-Hayes, The Enhanced Landfill Bioreactor: A Sustainable Waste Management Option for the 21st Century? The Mid Auchencarroch Experiments, PhD Dissertation, Dept. of Civil Engineering, University of Strathclyde, Glasgow,U.K., p. 344 (1997).

(Received: 3 October 2007 Accepted: 13January 2008 RJC-124)