AN EFFICIENT METHANE GREENHOUSE EMISSIONS' FLUSHING OUT AT MID AUCHENCARROCH EXPERIMENTAL LANDFILL SITE AND PROPOSED EFFECTIVE LININGS OF BIOGAS COLLECTION-MONITORING NETWORKS

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ABSTRACT

The modern environmental problems obliged the science and technology to the exploitation of renewable energy resources and to the development of efficient 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 biological waste biodegradation into landfill bioreactors in terms of landfill gas, methane production, biomass temperature regime and cumulative landfill gas, methane production which are produced by experimental waste cells with different disposed waste composition and dynamic solid waste management and treatment biotechnology techniques. Projections are made of the cumulative methane which is produced, avoiding the associated environmental impact assessments. In the end are proposed efficient lining monitoring solutions for landfill operation and management of landfill gas collection next to landfill boundaries, utilizing proper spatial numerical models and developing associated informatics applications. This paper examines landfill gas emissions based on characteristic field data from Mid Auchencarroch experimental site. Useful conclusions are presented for efficient solid waste management units so as to avoid risks to any surrounded infrastructure works or to other land uses next to landfill boundaries.

Key words: *Landfill chemical emissions, landfill design biotechnology, landfill biology and waste biodegradation, waste management.*

INTRODUCTION

Nowadays, the necessities of our life are getting increased in time due to the nature of our civilization the associated environmental management problems are becoming more complex. There are several modern environmentl problems on planet Earth, like the continuously increasing energy consumption, environmental pollution, global climatic change of the environment, forest fires, ecoterrorism, industrial accidents, toxic emissions, oil crisis and others, which are related to the waste production by several anthropogenic activities. The progress and the evolution of our civilization increased the waste volume in sanitary landfills, as well the landfill leachate and wastewater volume in wastewater treatment units. Efficient sustainable solutions to the current environmental problems of our planet should be given as soon as possible so as to save the global environment.

The technology should be focused on the environmental and public health protection, developing proper methods and techniques for effective solid waste management (SWM) and energy recovery systems. The increasing of the SWM recovery rates influences the waste management systems, the waste composition streams, costs and emissions from treatment and disposal activities. Sanitary landfill remains an attractive disposal route for household, commercial and industrial wastes, because, it is more economical than other waste disposal methods [4,10,11,12,17]. 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 or upgraded natural gas biofuels [13,17].

The selection of proper sites for sanitary landfills, and the design, construction and operating practices used at these sites, should take into account the environmental impacts to neighboring land uses next to landfill boundaries, hydrological maps, geological maps and landfill topography's characteristis related to any associated reclamation and monitoring works of landfill emissions. Moreover, quality assurance, landfill bioreactor life cycle analysis, risk assessment and application of efficient lining methods to any associated landfill technical construction, reclamation or bioremediation works should take place in all stages of an integrated waste management and the use of efficient lining methods to any construction or other work, should take place properly for particular economic project management within monitoring, maintenance or other dynamic sustainable associated technical infrastructure works, avoiding any hazardous chemical treahts to the environment [1,2,,5,6,7,8,9,13,15,16].

EXPERIMENTAL

According to the literature variations on landfill methane emissions arise from factors affecting methane generation. These factors vary between sites according to different disposed waste fractions, microbiological conditions, 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. 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 gases in waste management are methane as well as carbon dioxide [13,17].

In this paper are presented landfill emissions from the Mid Auchencarroch (MACH) experimental landfill is a UK Environment Agency and industry funded research facility. 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 waste fractions which have been disposed into these characteristic landfill sites are different provoking several different chemical emissions to the environment [6,10,11,12,13]. 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 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. Dynamic numerical simulation models based on field data should be used for better simulation and evaluation of chemical landfill emissions' quantitative trends and their respective spatial analysis on given topographies in time. Moreover, efficient dynamic lining methods should take place based on the results of dynamic robust numerical simulation spatial models, monitoring data and any other available digital spatial data (i.e. 3D digital spatial databases, signal processed aerial photographs, G.P.S. data, G.I.S thematic maps, simgasrisk numerical spatial model utilization etc.) so as to be taken the right maintenance and probable reclamation works in time at particular landfill topographies, protecting public health and any nearby landuses next to landfill boundaries [3,7,,8,9,10,11,12,13,14,18].

During each biodegradation stage there are several different bacterial colonies, which exist under particular favourable physical, biological and chemical conditions for them during the life cycle of a labdfill bioreactor. During the methanogenesis stage pH equals to 7, neutral environment. On the other hand, during the hydrolysis and acetogenesis stages the pH has low values indicating an acid environment and the COD values have big magnitudes during an initial time since the waste was disposed and later they are decreasing in time. Inestigating the landfill bology, the biodegradation stages, which exist within landfill life cycle and its respective biogas and leachate stabilized chemical emissions, include the hydrolysis, acidogenesis, acetogenesis, methanogenesis and mature stage [6,13,17].

Efficient landfill designs, managements and proper biotechnologies should be developed and used in landfill manufactures taking into account different waste syntheses, physical, biological, chemical properties and landfill topographical characteristics, spatial landfill emissions behaviour. A robust simulation landfill gas risk numerical modelling (simgasrisk) has been carried out for MACH experimental field data and its results are shown below in the next figures [12,13]. Below in figures 1, 2, 3 and 4 is presented the simulated biogas production versus simulated biomass temperature and field data pH variation of each MACH cell respectively. Moreover, in figures 5, 6, 7, and 8 is presented the cumulative methane emissions flushing out in time versus hourly methane production and daily methane production of each MACH cell respectively.

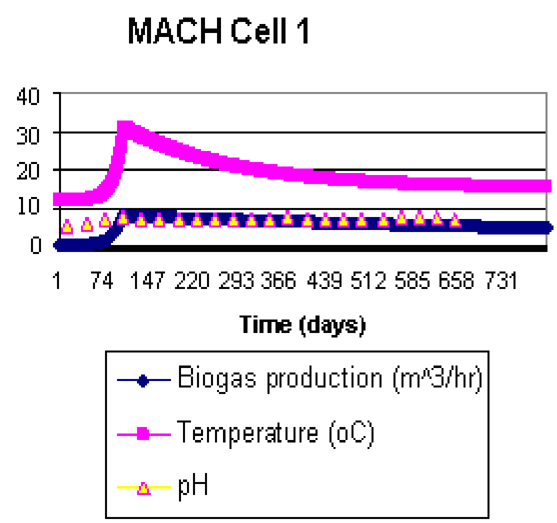

Fig. 1: Biogas production (in m^3/hr) vs Biomass temperature (in ^{o}Celsius degrees) and pH variation at Mid Auchencarroch experimental cell 1 site

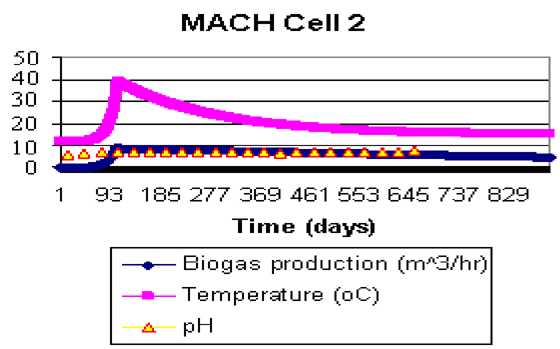

Fig. 2: Biogas production (in m^3/hr) vs Biomass temperature (in ^{o}Celsius degrees) and pH variation at Mid Auchencarroch experimental cell 2 site

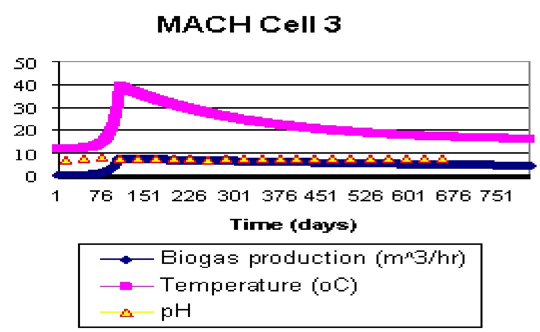

Fig. 3: Biogas production (in m^3/hr) vs Biomass temperature (in ^{o}Celsius degrees) and pH variation at Mid Auchencarroch experimental cell 3 site

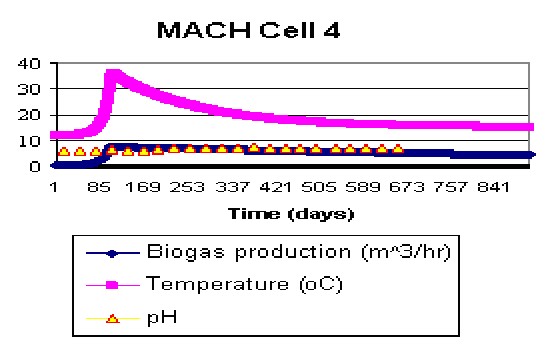

Fig. 4: Biogas production (in m^3/hr) vs Biomass temperature (in ^{o}Celsius degrees) and pH variation at Mid Auchencarroch experimental cell 4 site

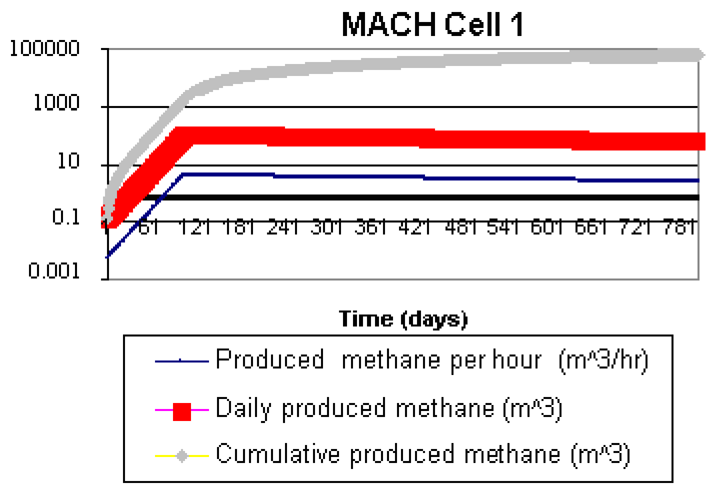

Fig. 5:Cumulative flushing out methane in time vs daily produced methane at Mid Auchencarroch experimental cell 1 site, y axis in logarithmic scale

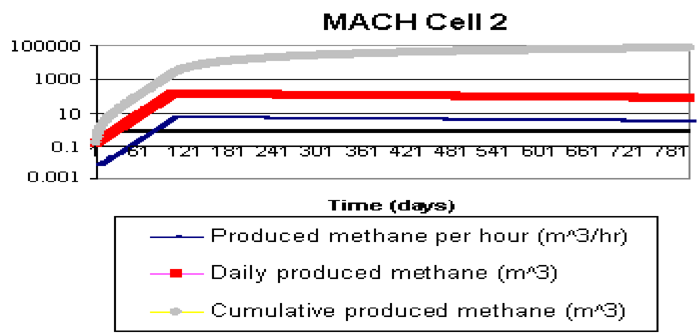

Fig. 6:Cumulative flushing out methane in time vs daily produced methane at Mid Auchencarroch experimental cell 2 site, y axis in logarithmic scale

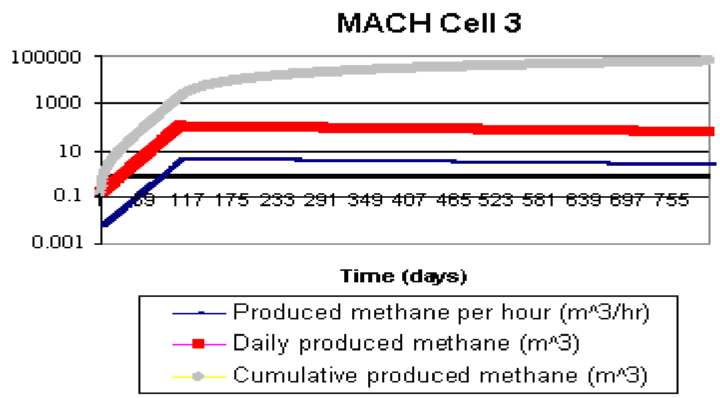

Fig. 7:Cumulative flushing out methane in time vs daily produced methane at Mid Auchencarroch experimental cell 3 site, y axis in logarithmic scale

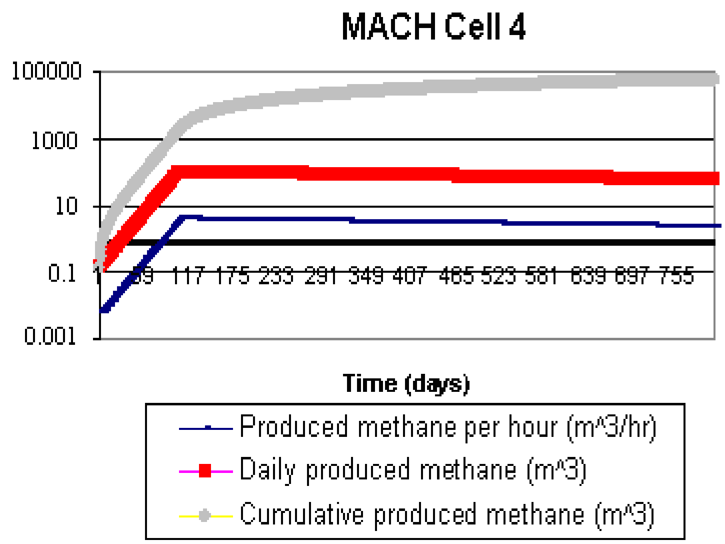

Fig. 8:Cumulative flushing out methane in time vs daily produced methane at Mid Auchencarroch experimental cell 4 site, y axis in logarithmic scale

According to the above presented results, tremendous flushing out methane emissions could be collected and be treated properly by the application of efficient sustainable landfill design biotechnologies like MACH one. 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 (Koliopoulos, 2000; Tchobanoglous *et al.* 1993). 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

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

According to the above presented numerical modeling simulation biogas results which can be used for spatial simulation gas risk assessments (simgasrisk), is clear that 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 biodegrable waste fractions and leachate recirculation in landfill mass).
Moreover, according to the above 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 verify the quick MACH site stabilization,

avoiding any long term environmental impacts and associated risks to the environment and to the public health [6,13]. MACH's experimental bioreactor design principles could be applied to any relative big scale bioreactors or to any proper shallow sequential batch bioreactor biotechnologies. 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.

A proposed lined landfill gas collection pipe network system for the production of renewable energy resources is presented in figure 9, for a proper selected radius of influence on landfill topography. The produced landfill gas could be exploited for energy recovery, for greenhouse heating, for biofuel use and for energy supply at several anthropogenic activities of land uses. Also leachate treatment units should be used for water supply in irrigations networks and associated regional renewable resources public works, minimizing the use of raw resources. In figure 10 is presented the energy equivalence of the produced methane, either from landfill mass biodegradation or from other biomass digesters, where 1 m^3 of methane is approximately equivalent to 1.66 m^3 landfill gas, 1.15 oil, 1.7 l alcohol, 1.3 Kg coal, 1 lt crude oil, 0.94 m^3 liquefied petroleum gas (GLP), 2 Kg wood and 10 KWh [13,17].

Quick and accurate lining methods should be used for the right construction, operation, maintenance and emergency support of the latter biogas exploitation sustainable environmental system taking into account particular spatial characteristics of landfill topographies.
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 avoiding any long term associative risks and hazards to the environment. A proper biogas monitoring system should be lined next to landfill boundaries. The lining of a dense monitoring system in space and frequent samples of landfill emissions in time should take place next to landfill boundaries. An initial investigation grid of boreholes should be installed at 5-10 m along adjacent to landfill boundary and on the latter location should be installed monitoring gas probes at 10-20 m across distance.

The latter monitoring spatial network could be made denser properly taking into account different landfill topographical spatial data, particular landfill gas produced quantities, landfill physical and chemical properties and high permeable geological stratas. A biogas suction pumping network, operationally supported by renewable resources, should operate for safety reasons in order to adverse gas migration. The use of dynamic numerical simulation spatial models are necessary linking them properly with efficient informatincs spatial applications for the right monitoring, proper lining of any probable emergency confrontation works, public health and environmental protection, quality assurance, diagnosis and economic project management of landfills' chemical emissions treatment [1,3,7,8,9,11,13,14,15,16,18].

RESULTS AND DISCUSSION

According to the MACH's experimental field data is clear that anaerobic design under favourable landfill's physical, biological and chemical conditions assists the methanogenesis stage to be achieved in short time period, where at MACH site there was a two-year rapid waste biodegradation. Moreover, based on the above presented results is clear that the co-disposal with inert material is sustainable as well as the pretreatment by wet pulverisation since the recirculation of leachate expedite the biomass biodegradation and methanogenesis stage. From the above presented results was clear that at landfill sites that there is big fraction of the disposed putrescible material into the biomass it influences the produced biogas quantity in time, which should be taken into account for any assosiative renewable resources energy exploitation systems. However, leachate recirculation for anaerobic bioreactor designs could increase the moisture content and the rate of biodegradation, influencing landfill's biological conditions and developing favourable conditions for biogas recovery and reduction of landfill greenhouse methane emissions to the environment in short term, avoiding any associated long term environmental impacts.

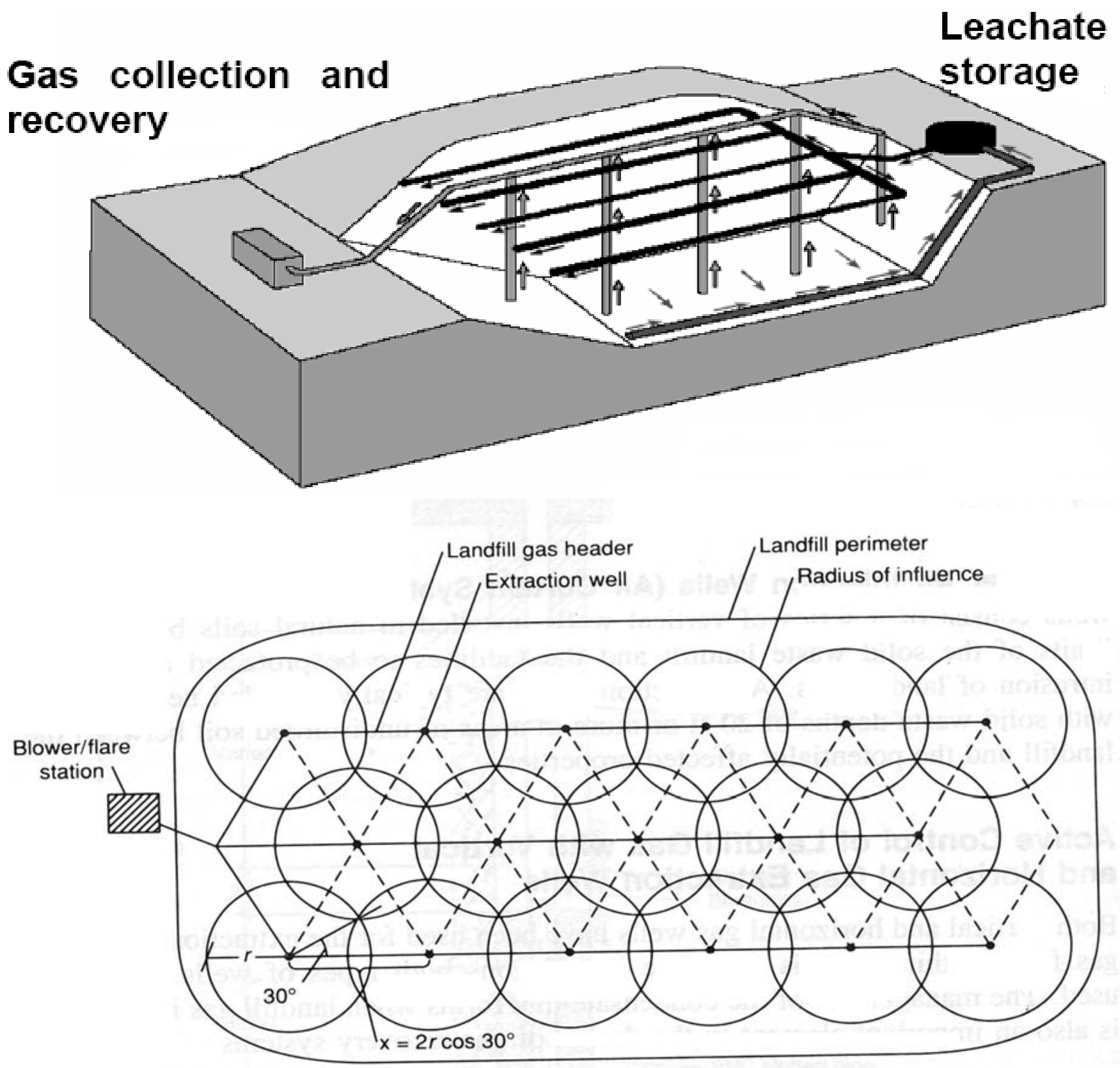

Fig. 9: Spatial characteristics of a landfill gas collection, recovery and leachate recirculation, drainage pipe networks' integrated systems on a given landfill topography

Fig. 10:Energy equivalence of produced methane by biomass biodegradation to other energy resources

The monitoring measurements of both biogas and leachate emissions should be taken frequently and the collected field data should be evaluated in time, investigating the life cycle of landfill bioreactor. In the case of particular diagnosed landfill emissions' migration an advanced risk assessment and spatial analysis on a given topography should be made, taking into account any assosiative data from relative hydrological, geological, water resources and topographical maps next to landfill boundaries. The use of efficient dynamic lining methods is necessary to take place in space and time for any associative construction, maintenance, rehabilitation and bioremediation technical works in time on a given landfill topography. The development of dynamic spatial models, linking them properly with any available spatial databases and developing efficient informatics applications, is necessary not only to evaluate existing sites but also to diagnose landfill life cycle and to propose relative confrontation designs and relative emergency measures in case that there have been found any associated risks or hazards by the landfill emissions. Long-term liability can be minimized if waste is quickly treated to a point that will not be occured further emissions. In this way will be protected not only the public health but also any surrounded infrastructure works or other anthropogenic activities and land uses next to landfill boundaries, avoiding any long term hazardous explosive biogas emissions and other associated risks.

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REFERENCES

1. C.I. Efraimidis, Project Management, Symmetria Pubs, Athens, Greece, p.273 (2001).
2. G. Fleming, Hydrogeochemical Engineering in Landfills. In: Geotechnical Approaches to Environmental Engineering of Metals, Rudolf, R. (ed.), Springer, 183-212 (1996).

3. G.M. Foody, P.M.Atkinson, Uncertainty in Remote Sensing and GIS, John Wiley and Sons Publications, 307 (2002).
4. Greek Ministry for the Environment, Physical Planning and Public Works (MEPPPW) National Allocation Plan for the period 2005 – 2007, Hellenic Republic, Athens, Greece, 60 (2005).
5. S. Kaparis, Special Subjects of Topography, Ministry of Education Pubs, Athens, Greece, p.208 (1993).
6. T.C. Koliopoulos, Landfill Bioreactor's Chemical Balance and Assessment of its Biodegradation – Mid Auchencarroch Experimental Project, *RASAYAN Journal of Chemistry*, **1(1),** 171-178 (2008).
7. T.C., Koliopoulos, G. Koliopoulou, C.Axinte, The use of efficient lining methods combined with numerical models for optimum project management of manufactures, *M.O.C.M Journal*, **Number 13, Volume II**, 379-384 (2007).
8. T.C., Koliopoulos, G. Koliopoulou, C.Axinte, Optimized management in curved manufactures' design using efficient lining methods, *M.O.C.M Journal*, **Number 13, Volume II**, 385-390, (2007).
9. T.C., Koliopoulos, G. Koliopoulou, C.Axinte, An efficient Iterative Angle Trisection lining method for the management of curved manufactures in technical designs, *M.O.C.M Journal*, **Number 13, Volume II**, 391-396 (2007).
10. T.C., Koliopoulos, G. Koliopoulou, Evaluation of Leachate Emissions – Mid Auchencarroch Experimental Project, *e-Journal of Science and Technology*, **2(1)**, 1-8 (2007).
11. T.C., Koliopoulos, G. Koliopoulou, A diagnostic model for M.S.W landfill's operation and the Protection of Ecosystems with a Spatial Multiple Criteria Analysis – Zakynthos Island Greece, Wessex Institute of Technology Transactions on Ecosystem and Sustainable Development (ECOSUD), W.I.T. Press Publications, U.K., 449-462 (2007).
12. T.C., Koliopoulos, G. Koliopoulou, Evaluation of optimum landfill design: Mid Auchencarroch experimental landfill emissions, Wessex Institute of Technology Transactions on Computer Aided Optimum Design in Engineering (OPTI), W.I.T. Press Publications, U.K., 231-239 (2007).
13. T.C., Koliopoulos, Numerical Modelling of Landfill Gas and Associated Risk Assessment, PhD Dissertation, Dept. of Civil Engineering, University of Strathclyde, Glasgow, U.K., 200 (2000).
14. D.A. Landgrebe, Signal Theory Methods in Multispectral Remote Sensing, John Wiley and Sons Publications, 508 (2003).
15. P. M. Padouvakis, Construction Management, N.T.U.A. Academic Notes, Athens, Greece, 367 (2002).
16. B. Rothery, ISO 14000 and ISO 9000 series of quality standards, Gower Pubs, U.K., p. 321 (1995).
17. G. Tchobanoglous, H. Theisen, S. Vigil, Integrated Solid Waste Management, McGraw-Hill Book Company, New York, USA, 978 (1993).
18. B. Tso, P.M. Mather, Classification Methods for Remotely Sensed Data, Taylor and Francis Publications, 331 (2001).

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