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Controlling Landfill Emissions For Environmental Protection : Mid Auchencarroch Experimental Project

Telemachus C. Koliopoulos[1] and D.M. Georgia Koliopoulou[2]

1. Environmental Consultancy,
   Centre for Environmental Management Research,
   University of Strathclyde, Greece.
2. Department of Experimental Physiology,
   Medical School, University of Athens, Greece.

Abstract : This paper assesses the long term behaviour of Mid Auchencarroch experimental landfill site in Scotland, based on characteristic landfill biodegration parameters, making useful conclusions. and analyzes the effects of waste pretreatment and landfill management techniques on landfill emissions and waste biodegradation processes. The biodegradation of Mid Auchencarroch Experimental Landfill Project is studied in four different cells with different waste input materials. The Mid Auchencarroch's experimental design confirm that waste pretreatment and leachate recirculation are sustainable and accelerate the waste biodegradation, protecting public health from associated hazards. The variations of characteristic indexes of landfill emissions are presented and analyzed for different bioreactor's conditions. Landfill emissions' environmental contamination control has to be improved based on the presented evaluations, taking into account different landfill conditions. The experimental results showed that the use of the anaerobic landfill batch bioreactor design is sustainable and it should be used by landfill operators.

Key words : Landfill gas; leachates; landfill design; waste biodegradation; solid waste management; public health.

Introduction :

Nowadays, 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. A successful sustainable development requires a continuous change and harmonization to the life cycle of our society, bearing in mind its current-future necessities (Vlavianos-Arvanitis, 1991; Koliopoulos, 1999). Therefore, the problem is transferred to the dilemma on how can we manage our waste better. Landfills' emissions should be controlled avoiding any environmental impacts to flora and fauna and public health of the surrounding area next to landfill boundaries. Moreover, landfill emissions could be treated and recycled in our society supporting the sustainable development of our planet.

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 (Fleming, 1990; Kollias, 2004; Koliopoulos 2000; Skordilis, 2001; Tchobanoglous *et al.* 1993). The landfill gas and leachate generation are inevitable results of the solid waste biodegradation in landfills and their study is necessary for future efficient designs, controlling air and groundwater pollution

* **Corresponding author :** Telemachus C. Koliopoulos, 1 Melissou Str., 116 35 Athens, Greece, Tel.: +30 210 7012363; E-mail : tkol@otenet.gr

(DOE, 1995; Fleming 1996; Koliopoulos, 2000).

Landfilling technologies have been strongly developed in the last decade. Large sanitary landfills are preferred because these provide better opportunities for potential hazard control and an increasing potential for resources' recovery. Efficiently managed sustainable landfill sites can generate considerable volumes of methane gas (CH_4), which can be exploited by landfill gas recovery installations to produce electricity. Characteristically, 1 m^3 of landfill gas (LFG) is equivalent to 0.6 m^3 natural gas, 0.6 lt oil, 0.8 Kg carbon, 2 Kg wood and 6 KWh (CEC, 1992; Tchobanoglous *et al.* 1993). 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 development public works, minimizing the use of raw resources.

The use of controlled landfill projects is necessary for quick site stabilization of landfill gas and leachate emissions, during waste biodegradation. The use of controlled batch anaerobic bioreactors accelerates waste biodegradation in short periods, minimizing any associated environmental risks due to landfill emissions (Derby Evening Telegraph, 1986; DOE, 1989; Elliott *et al.* 2001; Friis *et al.* 2004; Koliopoulos, 2000). Any uncontrolled dumps have to be closed so as to avoid any threats to the public health and to protect the environment.

Materials and Methods :

This paper assesses the long term behaviour of Mid Auchencarroch experimental landfill site in Scotland, based on characteristic landfill biodegration parameters, making useful conclusions. The experimental landfill Mid Auchencarroch is a field scale facility, constructed in order to assess a number of techniques that promote sustainable landfill Mid Auchencarroch (MACH) experimental landfill, is an Environment Agency, DTI and industry funded research facility. It has been capped since November 1995. The experimental variables are waste pretreatment, leachate recirculation and co-disposal with inert material. In figure 1 is presented a cell plan of MACH experimental batch anaerobic landfill bioreactor. The project consists of four cells each of nominal volume 4,200 m^3. 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%; Miscellanous combust. 3% & 3%; Miscellanous 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% (Koliopoulos 2000; Wingfield-Hayes, 1997).

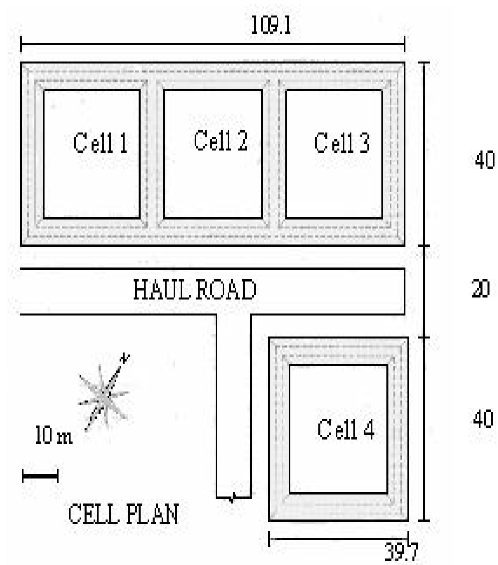


Fig. 1 : Plan of MACH experimental site.

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. This project attempts to develop and assesses 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 and leachate data, which were used for the present paper, cover simultaneously the 22-month period of waste biodegradation at MACH site (Koliopoulos, 2000; Wingfield-Hayes, 1997).

Experimental Results - Potential Landfill Emissions : Evaluating and analyzing the MACH landfill gas emissions, it is clear that methanogenesis was achieved after 1996 as the carbon dioxide emissions reduced and the methane emissions increased. Landfill gas peak production, and peak temperature reached in the first 105 days of waste disposed at MACH site. In Table 1 are presented the landfill gas production characteristics for MACH cells (Koliopoulos, 2000; Koliopoulos *et al*. 2002). The best biodegradation exists at cell 3 as the pretreatment by wet pulverisation since the recirculation of leachate expedite the biodegradation and methanogenesis (Koliopoulos, 2000). In Table 2 the mid-depth peak temperatures of MACH site and its experimental technical characteristics are presented.

On the other hand, the estimations of the main leachate concentration parameters change with landfill age for the particular sites in time and they can be defined as presented below in table 3 (Tchobanoglous *et al.*, 1993; Koliopoulos, 2000).

Table 1 : Landfill gas characteristics of Mid Auchencarroch cells.

Landfill site Case Study	Landfill gas Methane yield (lt gas/kg/MSW)	Landfill gas yield (m^3/hr)	Leachate Recirculation
MACH Cell 1	21.53	8.2	Yes
MACH Cell 2	22.67	9	Yes
MACH Cell 3	21.3	7.8	Yes
MACH Cell 4	21.65	7.4	No

Table 2 : Biomass peak temperature & technical characteristics of Mid Auchencarroch experimental cells.

Landfill site Case Study	Pretreatment of waste by wet pulverisation	Specific Heat J/(kg ^oC)	Measured biomass peak temperature (^oC)
MACH Cell 1	Yes	1171.8	31
MACH Cell 2	No	1329.6	39
MACH Cell 3	Yes	1264.8	39
MACH Cell 4	No	1329.6	36

Table 3 : Landfill leachate characteristics in time.

Parameter	0-5 yr	5-10 yr	10-20 yr	<20 yr
BOD (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

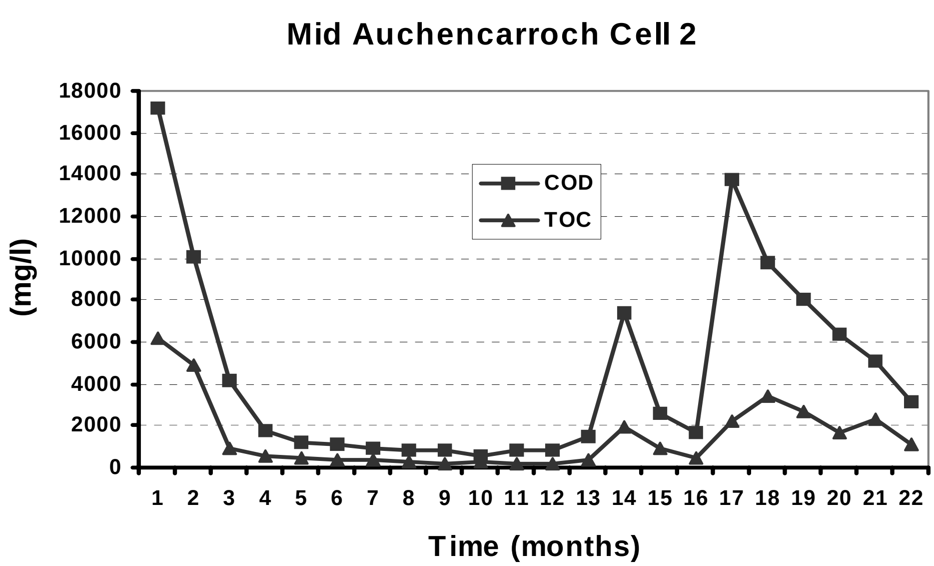
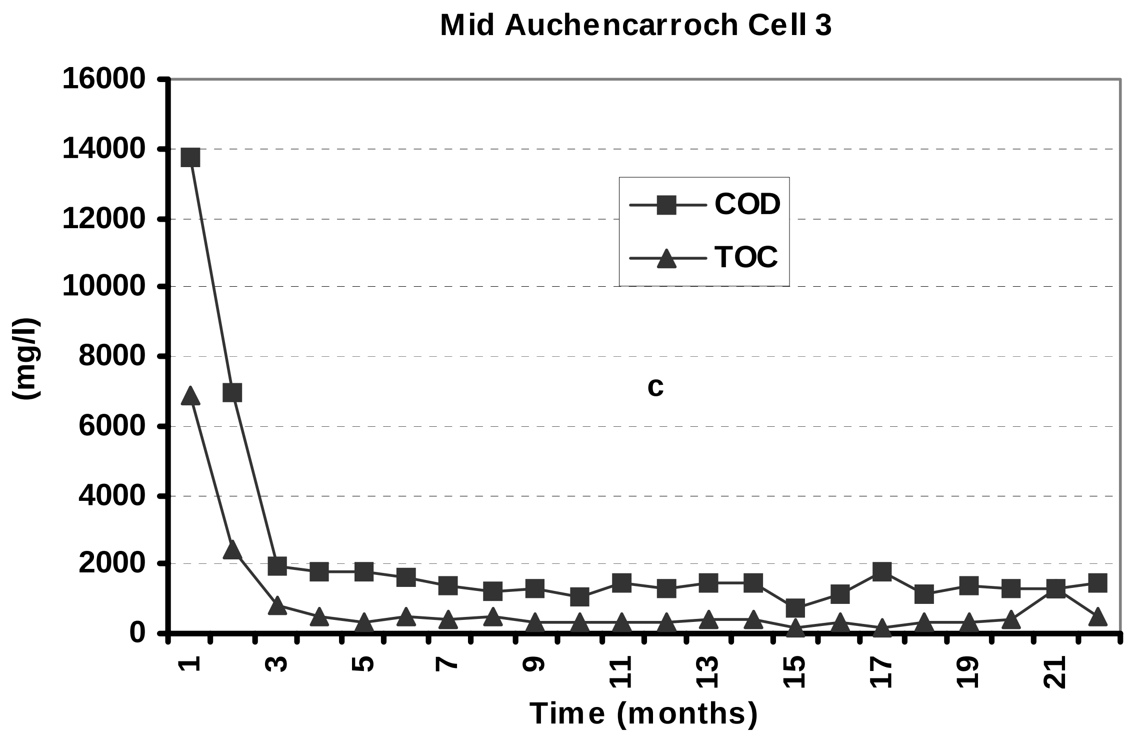


Fig. 2, 3 : Mid Auchencarroch COD, TOC concentrations vs time for Cell 1 and 2.



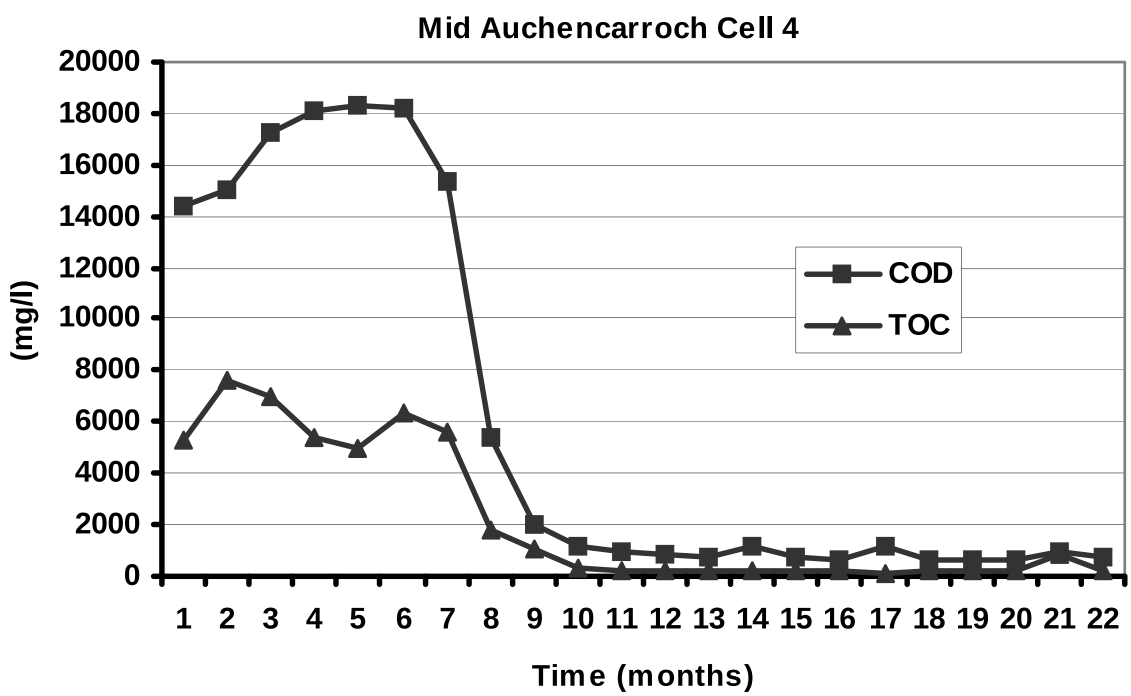


Fig. 4, 5 : Mid Auchencarroch COD, TOC concentrations vs time for Cell 3 and 4.

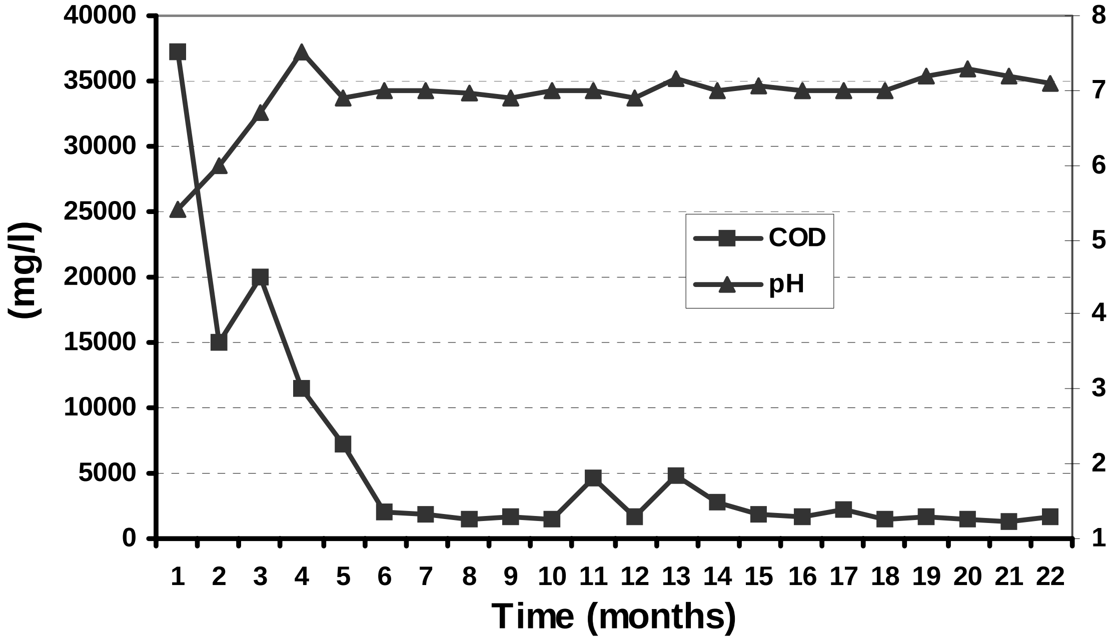


Fig. 6 : Mid Auchencarroch COD concentrations and pH values vs time for Cell 1.

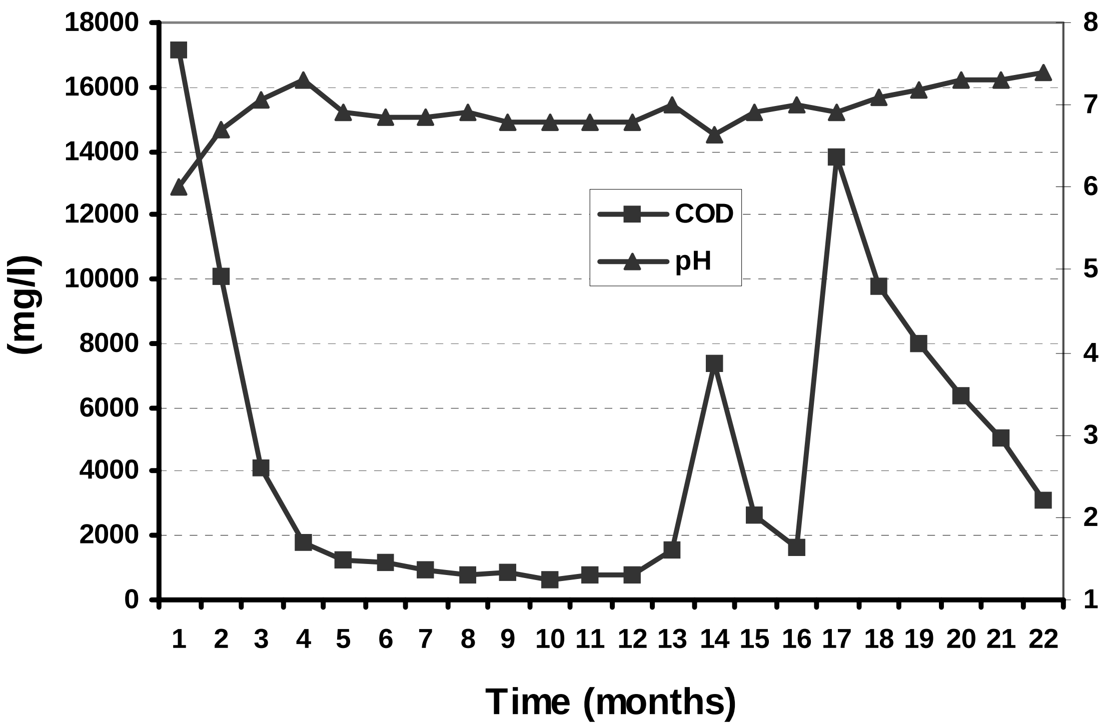


Fig. 7 : Mid Auchencarroch COD, BOD concentrations vs time for Cell 2.

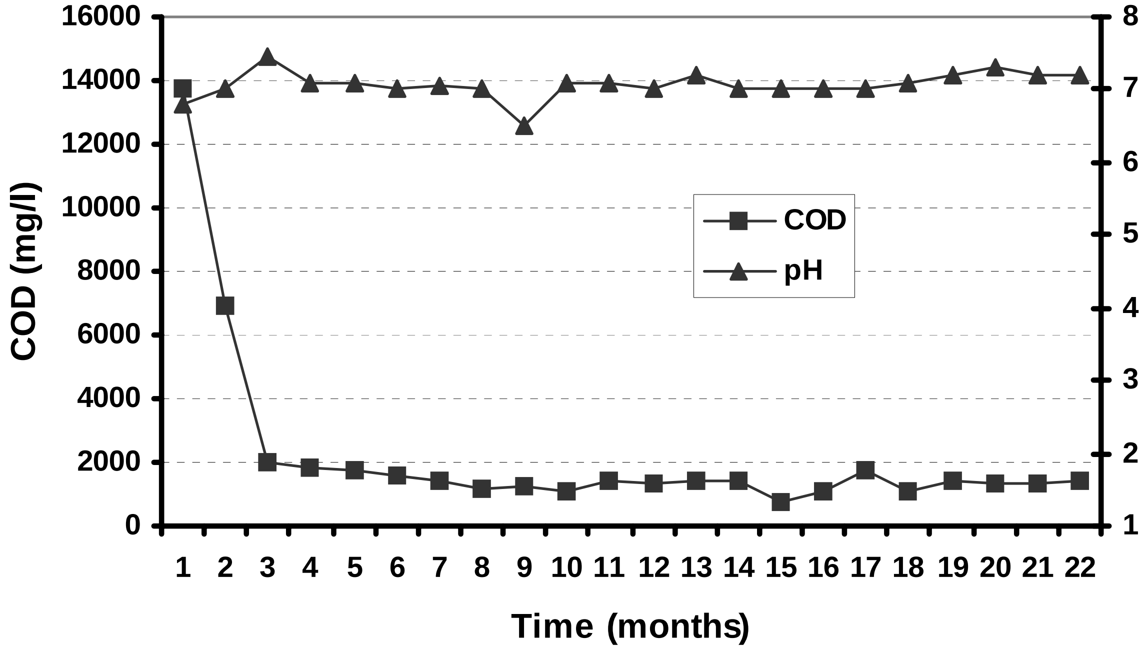


Fig. 8 : Mid Auchencarroch COD, BOD concentrations vs time for Cell 3.

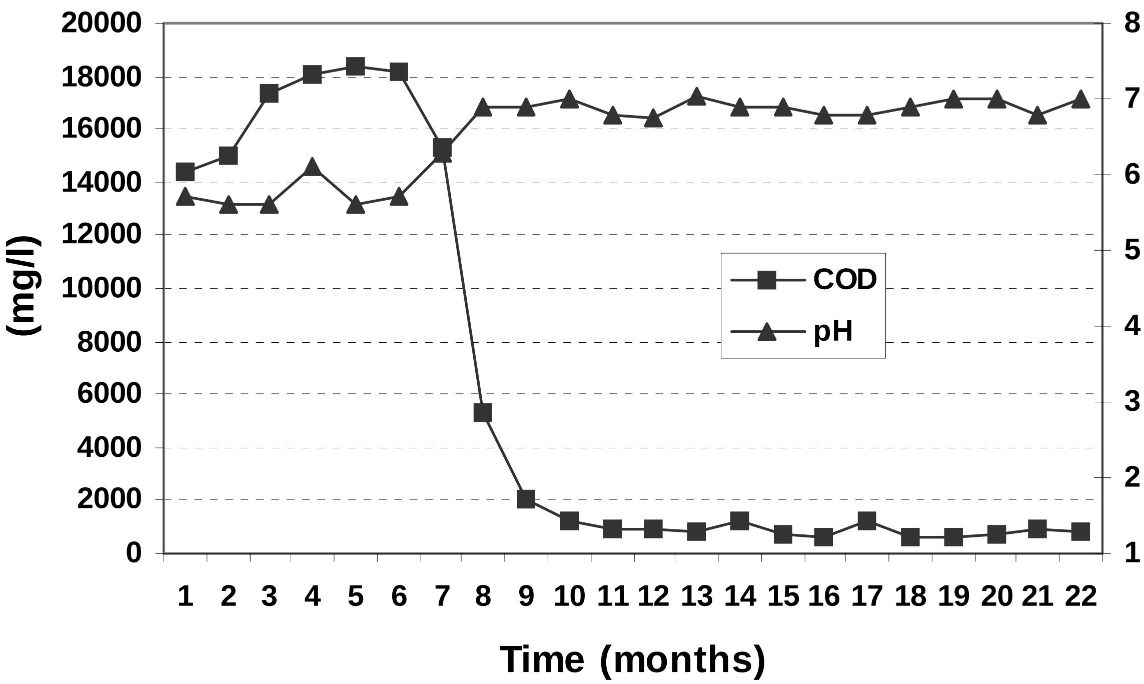


Fig. 9 : Mid Auchencarroch COD, BOD concentrations vs time for Cell 4.

For the MACH the biodegradation rate could be evaluated according to the most indicative characteristic biodegradation indexes of the produced leachate emissions. In figures 2, 3, 4 and 5, the Chemical Oxygen Demand (COD) and Total Organic Carbon (TOC) concentration trends in time for the four MACH cells are presented. COD could be characterized as the most hazardous leachate characteristic in relation to groundwater and site contamination (Koliopoulos, 2000; Tchobanoglous *et al.* 1993).

Moreover, below in figures 6, 7, 8 and 9, the biodegradation rate of COD concentrations and pH values in time during waste biodegradation for leachate emissions of MACH cells are presented.

Evaluating the above results it is clear that there was the greatest depletion of carbon and COD pollutants at cell 1. Moreover, cell 4 presents higher COD concentrations due to the fact that there has been disposed higher waste fraction of biodegradable carbon content in it than at cell 3 and 2. Cell 2 presents temporarily high risk between the 15^{th} and 21^{st} month. The latter can be explained due to the fact that leachate recirculation began in November 1996. After that period chloride was rising sharply, indicating flushing out of soluble salts, which had already occurred in the pulverized cells and they exhibited a greater electrical conductivity affecting further chemical reactions. In the end, all the TOC and COD concentrations present great reduction after 1996. The latter fact certifies the quick Mid Auchencarroch site stabilization.

Discussion :

Risk is a combination of the probability, or frequency, of occurrence of a defined hazard and the magnitude of the consequences of the occurrence. Hazard is a property or situation that in particular circumstances could lead to harm (human, ecological, physical, financial, psychological and social). Risk assessment is an analysis of the potential for adverse health effects (DOE, 1995; Koliopoulos, 2000). Risk assessment estimations to several environmental pollution subjects, most are site specific, with no single preferred method available. A risk assessment analysis of particular characteristic biodegradation parameters for MACH emissions is analyzed below.

In Table 4, the potential problems associated with landfill emissions are presented. Any uncontrolled dumps should be closed minimising any environmental impact threat to anthropogenic activities next to landfill boundaries. Also leachates should be collected and treated avoiding any environmental impacts of groundwater pollution and threats to public health. Controlled landfill bioreactors should replace any uncontrolled dumps protecting the environment and public health.

Table 4 : Potential Problems Associated with Landfill Emissions.

- Vegetation Distress – CO_2
- Explosions – CH_4
- Property Value Reduction
- Physical Disruption of Cover
- Landscape impacts
- Toxic Gases - VOC's,
- Groundwater Pollution
- Environmental impacts to flora and fauna
- Public health hazards

Moreover, landfill gas can also have adverse impacts on vegetation that is developed on the landfill cover or next to the boundaries of a landfill. Typically, when a waste disposal unit stops receiving wastes, i.e., when it is closed, a cover is installed over the landfill and includes the development of vegetation (grasses) to reduce erosion of the cover. The emission of landfill gas can exclude oxygen from the root zone of vegetation, and thus lead to the death of the surrounded vegetation. Many landfill covers that have inadequate landfill gas collection systems have large, non-vegetated areas due to landfill gas emissions through the cover and the surrounded areas (Koliopoulos, 2000; Tchobanoglous *et al.* 1993).

However, based on the presented data of Table 1, it is clear that high risk of environmental contamination by LFG emissions is presented in MACH cells where in high fermentable waste fractions have been disposed into the landfill. Landfill specific heat in cell 1 due to the co-disposal of waste with inert material kept mid-depth landfill peak temperature at low levels, minimizing thereby any associated risks of landfill gas migration, gas explosions and other environmental impacts to the surrounded area next to landfill boundaries. The use of controlled anaerobic landfills keeps waste mass temperature at low levels in order to minimizing the associated risks due to landfill gas migration, like gas explosions, fires and others (DOE, 1989; Koliopoulos, 2000).

On the other hand, evaluating and analyzing MACH leachate emissions, it is clear that higher short-term risk of environmental contamination by leachates present cell 1 and 4 than 2, 3 ones. Cell 1 presents the highest short-term risk, as greater carbon and COD depletion rate exists in it than at the rest of the cells. However, Cell 4 presents higher short-term risk than at the rest of the cells from the point of view that it presents high constant COD values without any decrease in the first seven months of waste biodegradation since landfill was capped. The latter exists due to the fact that not only there is no leachate recirculation at cell 4 for quick carbon depletion but also there is the high disposed putrescible waste fraction into it. According to the above presented results, it is clear that thermophilic methanogenic bacteria have been grown up and site has been stabilized in short time since MACH was capped. However, pH values show that organic acid genesis was in the first days of waste biodegradation and neutral one during MACH's methanogenesis and site stabilization was achived in short time

Conclusions :

At Mid Auchencarroch experimental site, it was 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 waste biodegradation. According to the TOC and COD experimental field data, the best waste biodegradation existed in cell 3, as well good organic depletion presented cell 1, minimizing both their emissions and associated environmental risks in short time. According to pH values for the MACH cells, it is concluded that quick landfill stabilization has been achieved in time avoiding long term landfill emissions and associated environmental impacts.

Monitoring networks, dynamic numerical models and geographical information systems or other digital spatial databases should be used so as to keep records and control of landfill emissions in time. Long-term liability can be minimized when waste is quickly treated to a point where no further degradation occurs, protecting the environment from long-term biogas and leachate emissions.

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References :

CEC. (1992) : Landfill Gas from Environment to Energy, Brussels, Belgium.

Derby Evening Telegraph (1986) : Destroyed Bungalow at Loscoe, Derbyshire, UK Newspaper.

DOE. (1989) : Waste Management Paper No 27, Landfill Gas, HMSO, London.

DOE. (1995) : Making Waste Work, White Paper, HMSO, London.

DOE. (1995) : A guide to risk assessment and risk management for environmental protection, HMSO.

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

Fleming G. (1990) : Monitoring the Methane Gas Generation from Different Classifications of Waste Using the Clay-Waste Sandwich Method of Landfill, CEMS.

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

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

Koliopoulos T. (1999) : Sustainable Solutions for the Most Pressing Problem within Solid Waste Management, *International Solid Waste Association Times Journal*, **3,** 21-24, Copenhagen, Denmark.

Koliopoulos T. (2000) : Numerical Modelling of Landfill Gas and Associated Risk Assessment, Ph.D. Thesis, Dept. of Civil Engineering, Univ. of Strathclyde, Glasgow, U.K.

Koliopoulos T., Fleming G. (2002) : Modelling of Landfill Gas Production of Treated and Untreated Waste - Mid Auchencarroch, In Proceedings of I.S.W.A Congress, 1019-1028, (Ed. G.Kocasoy, T.Atabarut, I. Nuhoglu), Istanbul, Turkey.

Kollias P. (2004) : Solid Wastes, Lichnos Publications, Athens, Greece.

Skordilis A. (2001) : Waste Disposal Technologies for Non-Hazardous wastes, ION publications, Athens, Greece.

Tchobanoglous G., Theisen H. and Vigil S. (1993) : Integrated Solid Waste Management, McGraw-Hill Book Company, New York.

Vlavianos-Arvanitis A. (1991) : Biopolitics the Bio-Environment, B.I.O. Publications.

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, Univ. of Strathclyde, Glasgow.