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Risk Analysis of Landfill Gas Emissions: A Report on Mid Auchencarroch Project

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Abstract : A risk assessment base of landfill gas migration is presented in order to avoid the associated risks for any receptors next to landfill boundaries. Simulation and quantitative analysis of landfill gas emissions based on the field data of Mid Auchencarroch experimental landfill project are studied in four different cells. The aim of the experimental results presented here is to simulate the effects of landfill management techniques on produced landfill gas emissions, with the objective of minimizing any risks and associated environmental impacts protecting public health. Useful conclusions of the analysis presented are made to minimize the risks associated with landfill emissions and to protect flora, fauna, buildings and the architectural environment.

Key words : Risk analysis, Waste biodegradation, Solid waste management, Landfill gas, Environmental Impact Assessment, Numerical modeling, Spatial analysis, Public health.

Introduction

Waste management is the discipline that is concerned with resources once society no longer requires them. In an effort to meet growing environmental awareness, most industrial companies include in their plan investments that are related to the protection of the environment. Solid waste includes all solid materials useless or unwanted as a result from the human activities and discarded by man. It is necessary to manage the waste in an sustainable way by minimizing the environmental impacts related to waste. Solid waste disposal starts to be problem when the amount and the environmental effects of such disposal arise and become an environmental public health risk. Then the improvement of the management solid waste systems is necessary.

Solid Waste Management (SWM) could be characterized as the most important parameter in life cycle of goods. It is well known that life cycle of particular goods includes: exploitation of raw materials and treatment; trading of goods; production of waste and waste management. The latter is verified due to the fact that on the effectiveness of SWM is dependent a huge amount of energy saving and exploitation, conserving our natural resources (El-Fadel *et al.*, 2000; Koliopoulos, 1999; Koliopoulos *and Fleming*, 2002; Kollias, 2004; Skordilis, 2001; Tchobanoglous *et al.*, 1993).

Nowadays, numerical models provide adequate tools to produce any kind of risk assessment solution, including environmental protection. Risk assessment tools are necessary to protect building properties and

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environmental sustainable projects. Advanced computer programming languages and software tools should be used and associated databases, to solve quickly and efficiently several public health and associated engineering problems (Koliopoulos, 2000; Brimicombe, 2003; Chivers and Sleightholme, 2005).

This paper presents a numerical risk assessment model, which is developed based on Mid Auchencarroch experimental landfill field data. This paper also analyzes a risk assessment base of landfill gas (LFG) migration to environmental resources and anthropogenic properties, like farms, agricultural or veterinary units that are commonly located next to landfill boundaries. The Mid Auchencarroch experimental landfill was a UK Environment Agency (EA) and industry-funded research facility (Wingfield-Hayes, 1997; Koliopoulos, 2000). The rate of landfill heat generation is influenced by several parameters, including waste input characteristics, moisture content and LFG production. The influence of these variables, the enhancement of gas yield, and the temperature control and stabilization processes in a landfill were the main focus of the numerical model presented, in order to minimize these environmental impacts.

The use of controlled anaerobic batch bioreactors keeps waste mass temperature at low levels and so minimizes the risks associated with LFG migration, like gas explosions, fires and others (Derby Evening Telegraph, 1986; DOE, 1989; Koliopoulos, 2000). The use of controlled landfill projects with low temperatures in the waste mass during waste biodegradation is necessary. Many times in arid climates during summer, such as Greece, there are fires next to uncontrolled dumps, provoking environmental impacts to natural landscapes and buildings in the surrounding area (Kathimerini, 2006; To Vima, 2006). Any uncontrolled dumps have to close so as to avoid any threats to the public (Canter, 1996; Davis and Cornwell, 1998; Elliott *et al*., 2001; Friis and Sellers, 2004; Lawrence, 2003).

Gases found in landfills include methane (CH_4), carbon dioxide (CO_2), carbon monoxide (CO), hydrogen (H_2), hydrogen sulfide (H_2S), nitrogen (N_2), oxygen (O_2) and trace gases. The anaerobic phase is the main phase, occupying the greater part of the life of the landfill. This phase is more significant in terms of methane gas formation. Many researchers have pointed out that temperature is an important factor of chemical, physical and biological phenomena in a sanitary landfill (Tabasaran, 1982; El Fadel, 1991; Yoshida *et al*., 1999; Bockreis and Steinberg, 2005; Koliopoulos and Kolipoulou, 2007). Methane production in landfills can be optimized by temperature control. The optimum temperature for methane production has been reported as 41-42°C during anaerobic digestion of waste (Pfeffer, 1974; El Fadel, 1991; Tchobanoglous *et al*., 1993). Yoshida and colleagues indicated that the maximum temperature in a landfill can reach about 65°C with aerobic-anaerobic conditions and around 35-39°C under anaerobic conditions (Yoshida *et al*., 1999; Koliopoulos, 2000; Koliopoulos and Koliopoulou, 2007).

Materials and Methods

This paper analyzes the modeling of landfill temperature control based on field data of Mid Auchencarroch (MACH) experimental landfill project, which is located next to Alexandria area, between the Loch Lomond and Kilpatrick hills outside from Glasgow city, in Scotland. It has been constructed in order to assess a number of techniques that promote sustainable landfill design. MACH experimental landfill, is an Environment Agency, DTI and industry funded research facility. MACH experimental batch anaerobic landfill bioreactor has been capped since November 1995. The experimental variables are waste pretreatment, wet biomass pulverization, leachate recirculation and co-disposal with inert material. The experimental landfill Mid Auchencarroch is a field scale facility which is consisted of four cells each of nominal volume 4,200 m^3. The total MACH waste mass depth is 5 meters, without the topsoiled surface cap depth. In cells 1 and 3 there is pretreatment by wet pulverization 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 20% by volume (Koliopoulos, 2000; Koliopoulos and Kolipoulou *et al.*, 2006, 2007).

MACH experimental project examines techniques so as to enhance the waste degradation, pollutant removal processes and control of landfill emissions. The MACH experimental landfill project has presented a number of waste management techniques that accelerate waste biodegradation and heat generation, minimizing the associated environmental impacts of landfill emissions (Koliopoulos and Koliopoulou *et al.* 2006, 2007). The wet-flushing sequential batch bioreactor landfill model is seen as the method of achieving the goal of sustainable development. The examining experimental and computational data, which are presented below, cover the time period of the first two-year of waste biodegration at MACH site.

Experimental results - Potential landfill gas risk

According to MACH landfill emissions, evaluating and analyzing them, it is clear that methanogenesis was achieved in short time period. The most crucial period at MACH for landfill gas peak production and peak temperature reached in the first 105 days of biomass biodegradation since MACH site was capped. Moreover leachate emissions and their respective pH values stabilized in the first 22-month period of biomass biodegradation since MACH site was capped (Koliopoulos and Koliopoulou, 2006, 2007). For MACH the higher temperature in the waste mass is taken at the landfill mid-depth.

However, there have been found the following useful heat generation heat generation source terms at MACH site mid-depth, in order to evaluate biomass biodegradation parameters under different solid waste management techniques, which are presented below. The heat generation source terms for the three different examining waste types in MACH cells, after calibration, are the followings (Koliopoulos and Koliopoulou, 2007) :

$$\alpha_{wt1} = 1.18\ D_{waste}\ Gt\ 0.41\ e\text{-}^{l\ t} \qquad (1)$$

$$\alpha_{wt2} = 1.18\ D_{waste}\ Gt\ 0.68\ e^{-l\ t} \qquad (2)$$

$$\alpha_{wt3} = 1.18\ D_{waste}\ Gt\ 0.89\ e^{-l\ t} \qquad (3)$$

where

α_{wt1} : heat generation source term at landfill mid-depth for waste type of co-disposal of pulverized waste with inert material (Kcal/m^3 day)

α_{wt2} : heat generation source term at landfill mid-depth for waste type of pulverized waste (Kcal/m^3 day)

α_{wt3} : heat generation source term at landfill mid-depth for waste type of untreated waste (Kcal/m^3 day)

D_{waste} : waste density (kg/m^3)

Gt : LFG production in time (m^3 LFG/1,000 kg waste day)
l : biodegradation rate (day^{-1})
t : (day)

During the decreasing period of biogas production l depends on the k kinetic parameter of landfill gas production. Substituting equation (1) or (2) or (3) to (4) yields the governing equation for the landfill mid-depth temperature and heat transfer in one dimension, in a homogenous landfill like MACH one.

$$\frac{\partial U(y,t)}{\partial t} - \beta \frac{\partial^2 U(y,t)}{\partial y^2} = \alpha \qquad (4)$$

where

$\beta = k/\rho Cu$

k : thermal conductivity (kcal/ day m ^oC)
ρ : density (kg/m^3)
Cu : heat capacity (kcal/kg ^oC)
U : temperature in vertical location in Y axis (^oC)
t : time (day)
y : vertical distance in landfill depth (m)
α : heat generation source term ($kcal/m^3$ day)

A numerical module was presented solving the coupling of equations (1), (2), (3), (4) and the results were compared with the experimental MACH field data. Based on the field data and the numerical results, it was clear that the particular numerical modules operate efficiently, giving satisfactory results (Koliopoulos *et al.*, 2007). The output results could be saved in data files, which can be easily manipulated by the user, applying them in several types of digital spatial databases, worksheets packets or Geographical Information Systems databases for further spatial analysis and probable reclamation works based on any particular landfill topography characteristics (Koliopoulos, 2000; Brimicombe, 2003). The experimental field data from Mid Auchencarroch batch experimental bioreactor show that waste biodegradation has been achieved in a short time, minimizing any hazards of landfill emissions to natural resources or anthropogenic properties over the longer term (Koliopoulos and Koliopoulou, 2007). Uncontrolled dumps or landfills with high putrescible waste fractions should close to prevent plant asphyxiation, landscape degradation, flora and fauna degradation, gas explosions and landfill fires next to buildings. Efficient anaerobic landfill sequential batch bioreactors, such as MACH, should be used to minimize any risks from landfill emissions.

Based on the biomass's peak temperature and waste input, certain physical properties can be calculated. These include the LFG migration (by advection) velocity, which is analyzed below. Inside the waste mass, before biogas generation starts, a pressure of 1 atmosphere exists, as existed during waste disposal. The gas pressure change due to gas generation in the waste mass, in time, provokes a gas velocity Ug, which follows Darcy's law, as presented below.

$$Ug = -\frac{k}{\mu}\frac{\Delta Pg}{\Delta h} \qquad (5)$$

where

Ug : advection velocity (m/sec)
μ : gas viscosity (N-s / m^2)
k : intrinsic permeability (m^2)

P : pressure (N/m^2)
h : vertical distance (m)

If we will take into account that for a given Δh', inside the landfill in vertical direction there is gas change pressure ΔP'g, then for a specific area S, into which gas enters, we will have, from equation (5).

$$SU'g = \frac{k}{\mu}\frac{\Delta P'g}{\Delta h'}S \qquad (6)$$

The term S U'g defines a volumetric flow (m^3/s) over time, which equals to the volume production rate of the generated gas in the waste mass. Also valid is that G't = Gt/d (m^3gas/m^3 waste), where Gt is calculated LFG production quantities, and d is the waste density (t/m^3), with conversion to the relative units. For a given area S and change of height h', the produced volume of gas, will be G't S Δh. The intrinsic permeability for the waste porous medium is taken as the value of 1 Darcy or 10^{-12} m^2 (Tchobanoglous *et al.* 1993; Koliopoulos, 2000). Hence, we will have the following.

$$G'_t S\Delta h' = \frac{k}{\mu}\frac{\Delta P'g}{\Delta h'}S \qquad (7)$$

or

$$\Delta P'g = G'_t \Delta h'^2 \frac{\mu}{k} \qquad (8)$$

where

G't : gas generation (m^3gas/s m^3 waste)
P'g : gas pressure in the waste mass (N/m^2)
μ : gas viscosity (N^{-s} / m^2)
k : intrinsic permeability (m^2)

P : pressure (N/m^2)
h : vertical distance (m)

Equation (8) calculates the gas pressure over atmospheric pressure in the waste mass. However, as the volume G't is calculated at standard temperature and pressure conditions, conversion of this volume to landfill mid-depth temperature, using the state equation, gives an increase in its value (taking for a given gas that the ratio of temperatures is analogous to the ratio of volumes under constant pressure conditions). Viscosity also changes due to temperature and for a given average biogas synthesis with 60% methane by volume and 40% carbon dioxide by volume is calculated by the following equation (Tchobanoglous *et al.*, 1993).

$$\mu_{lfg} = 0.6\ \mu_{methane} + 0.4\ \mu_{carbon\ dioxide} \qquad (9)$$

where

μ : gas viscosity (N-s / m^2)
$\mu_{methane}$: $(1.935 + 0.0305\ T)\ 10^{-6}$
$\mu_{carbon\ dioxide}$: $(-30.212 + 0.256\ T - 0.00035\ T^2)$
T : temperature in Kelvin

Based on the above could be developed a simulation of gas risk (SIMGASRISK) assessment numerical model, combining all the associated presented computational modules, in order to quantify and examine the peak biogas and heat emissions for different waste types in anaerobic batch landfill bioreactors for MACH landfill conditions, with discussion of associated risks and environmental impacts.

A numerical modeling solution of heat transfer could be realized solving the lateral temperature regime in one meter clay width next to landfill boundaries. The governing equation of this phenomenon in four dimensions, 3-D in space and 1-D in time, is given below:

$$\frac{\partial U(x,y,z,t)}{\partial t} - \beta\frac{\partial^2 U(x,y,z,t)}{\partial x^2} - ,$$
$$\beta\frac{\partial^2 U(x,y,z,t)}{\partial y^2} - \beta\frac{\partial^2 U(x,y,z,t)}{\partial z^2} = \alpha \tag{10}$$

where

$\beta = k/\rho Cu$

k : thermal conductivity (kcal/day m ^{o}C)

ρ : density (kg/m^3)

Cu : heat capacity (kcal/kg ^{o}C)

U : temperature in vertical location in Y axis (^{o}C)

t : time (day)

x, y, z : spatial location in x, y, z axis (m)

α : heat generation source term from landfill mass material (kcal/m^3 day)

Due to the fact that the examining one meter in width clay barrier next to landfill boundaries is assumed that has a homogenous material the same results approximately will give the selection of the numerical solution of the 2-D in space heat transfer equation problem. The latter selection could make not only quicker numerical solutions than the computation of 3-D in space problem for long time-series but also the numerical results could be manipulated easy in any spatial digital databases and associated risk assessments. The numerical solution of the above governing equation gives higher temperature inclination in the middle of the examining clay barrier as it is shown in figure 1, taking into account the temperature boundaries conditions next to the landfill mass in one meter width of a homogenous clay barrier and as height the landfill depth (Koliopoulos, 2000). The numerical solution (3-D) finite difference approximation scheme of the differential equation (10) at a grid point (x,y,z) applying the simple explicit method and using forward time central space discretization, can give the following direct finite difference form:

$$\frac{U_{I,J,K,L+1} - U_{I,J,K,L}}{\Delta t}.DCY =$$
$$= KC\frac{U_{I+1,J,K,L} - 2U_{I,J,K,L} + U_{I-1,J,K,L}}{(\Delta x)^2} +$$
$$+ KC\frac{U_{I,J+1,K,L} - 2U_{I,J,K,L} + U_{I,J-1,K,L}}{(\Delta y)^2} +$$
$$+ KC\frac{U_{I,J,K+1,L} - 2U_{I,J,K,L} + U_{I,J,K-1,L}}{(\Delta z)^2} + \alpha \tag{11}$$

where

D : density of the porous medium (kg/m^3)

KC : thermal conductivity (kcal/day m ^{o}C)

CY : heat capacity of the medium (kcal/kg ^{o}C)

$\Delta x, \Delta y, \Delta z$: discretization parameters in X,Y, Z axes

Δt : discretization parameter in time

U : temperature on the particular node of the grid in particular x,y,z location and in time t

α : source term (kcal/m3 day)

The stability conditions of the above governing equation are given below (Koliopoulos, 2000).

$$\frac{\beta\Delta t}{(\Delta x)^2}+\frac{\beta\Delta t}{(\Delta y)^2}+\frac{\beta\Delta t}{(\Delta z)^2}\le\frac{1}{2} \qquad (12)$$

According to the above, the calculation of the advection velocity of biogas migration near to the landfill is calculated below. In Fig. 1, is presented the landfill gas mid-depth pressure P_1 and the soil pressure P_2 in 1 m of clay soil material next to the landfill boundary. Soil pressure equals 1 bar and soil temperature equals 12 °C at boundaries (Tchobanoglous *et al.* 1993; Koliopoulos, 2000).

From the equation of state, we have (the subscripts 1 and 2 of each variable are referred to points 1 and 2 respectively, which are presented in Fig. 1, T_2 = 12 °C).

$$\rho_2=\rho_1(P_2/P_1)(T_1/T_2) \qquad (13)$$

where

r : gas density (g/lt)

P : gas pressure (atm)

T : temperature in degrees Kelvin

The advection velocity q in the x horizontal direction is given by the following equation.

$$q=-\frac{k}{\mu}\frac{dP}{dx} \qquad (14)$$

The law of conservation of mass states that the difference in the mass of gas entering a control volume and that of gas exiting the control volume is equal to the change of mass with time in the control volume. Taking a steady state $\frac{dM}{dt}=0$ change of mass with time in a homogenous and isotropic medium, we have the following.

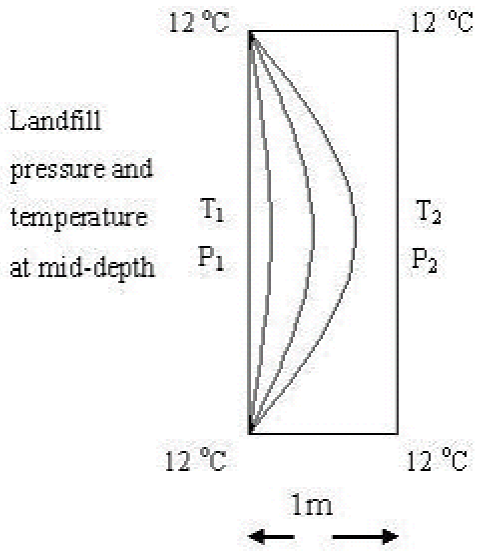

Figure 1 : Landfill temperature and pressure at mid-depth and at boundaries at 1m width next to landfill boundary.

$$-\frac{d}{dx}(\rho q)=0 \qquad (15)$$

Substituting (8) and (9) into (10) yields:

$$\frac{d^2P^2}{dx^2}=0 \qquad (16)$$

The solution of equation (16) is subject to boundary conditions P = P_1 at x = 0 and P = P_2 at x = L.

$$P^2=P_1^2+\frac{P_2^2-P_1^2}{L}x \qquad (17)$$

Differentiating equation (17) yields

$$2PdP=\frac{P_2^2-P_1^2}{L}dx \Rightarrow \frac{dP}{dx}=\frac{P_2^2-P_1^2}{2PL} \qquad (18)$$

Based on equations (16), (17) and (14) the advection velocity is given below in terms of the distance x.

$$q = -\frac{k}{2\mu L}\frac{P_2^{\,2} - P_1^{\,2}}{\sqrt{P_1^{\,2} + \frac{P_2^{\,2} - P_1^{\,2}}{L}x}} \qquad (19)$$

Equation (19) can be used for calculation of the advection velocity of migrated landfill gas next to landfill site boundaries. In Table 1, are presented the calculated numerical results of LFG emissions, applying all the above formulae to conditions in MACH cells 1, 2, 3 and 4, for the crucial period where landfill gas peak production and peak temperature reached in the first 105 days of biomass biodegradation since MACH site was capped.

Therefore, based on the above results in terms of LFG production and gas migration, respectively, a higher risk exists in cells 2 and 4 than in cells 1 and 3 for gas explosions and damage to properties under unfavourable conditions. Monitoring boreholes should be located next to landfill boundaries to allow measurement of landfill emissions and proper remedial action. In this way, buildings and surrounding landscapes will be protected. After the above analysis of quantified risk assessment elements, an additional risk assessment planning base is presented in Table 2. It should be followed during any examination of landfill study.

Table 1. Numerical results of landfill gas emissions.

Landfill site Case Study	Pressure of landfill gas (N/m^2)	Landfill gas migration advection velocity (m/sec)	Landfill production rate (m^3 gas/t waste)
MACH CELL 1	1250	1 E-7	33.1
MACH CELL 2	2361	1.89 E-7	37.8
MACH CELL 3	1506	1.23 E-7	32.8
MACH CELL 4	2340	1.78 E-7	36.1

The above presented risk assessment planning base should take place when LFG risks are quantified by numerical models such as the above presented one.

Discussion

The MACH waste management techniques have to be taken into account for efficient designs of future sequential batch bioreactors. Shallow landfill concept can be used as an efficient economic sustainable sequential batch bioreactor. The concept of an efficient anaerobic batch landfill bioreactor design of municipal solid waste is feasible in terms of establishing and maintaining a suitable environment for biomass degradation to occur at significant rates. It is possible to enhance and control landfill emissions, heat generation and flush potential pollutants from the biomass, by manipulating the whole process of landfill.

However, risk assessment is an analysis of the potential for adverse health effects. Risk assessment estimations of environmental impact controls are usually site specific, with no single preferred method available. Risk-based approaches to landfill temperature control, allowing us to take the right

Table 2. Steps of risk assessment base for additional activities.

Steps	**Activities**	**Steps (continued)**	**Activities (continued)**
1	Installation of monitoring boreholes – data collection & analysis*	5	Planning of alternatives
2	Development of goals and objectives	6	Recommendation of actions and evaluation
3	Clarification and diagnosis	7	Development of an implementation program
4	Indentification of alternative solutions	8	Monitoring and surveillance in time

emergency measures, are necessary for the environmental protection of building properties or architectural landscapes next to landfill boundaries. In table 3 are presented the associated adverse impact issues of waste management units on users or owners of nearby building properties or architectural landscapes.

- Migration of Methane, Carbon Dioxide and VOC's - *Public Health, Explosions, Toxicity to Plants, Landscape degradation, Loss of Building Properties;*
- Illegal Roadside Dumping and Litter near Landfill - *Aesthetics, Landscape degradation, Public Health, Economics;*
- Truck Traffic near Landfill - *Congestion, Air Pollution, Aesthetics,*

Table 3. Adverse Impact Issues of Waste Management Units on Receptors of Nearby Properties.

Steps	**Activities**	**Steps (continued)**	**Activities (continued)**
1	Installation of monitoring boreholes – data collection & analysis*	5	Planning of alternatives
2	Development of goals and objectives	6	Recommendation of actions and evaluation
3	Clarification and diagnosis	7	Development of an implementation program
4	Indentification of alternative solutions	8	Monitoring and surveillance in time

Public Health of Buildings' Residents;

- Odors - Dumping & Landfill Gas - *Aesthetics, Public Health;*
- Dust and Wind-Blown Litter - *Aesthetics, Public Health;*
- Landfill Fires - Gas Explosions - *Aesthetics, Public Health.*

The principal hazard of concern with LFG emissions is the potential for explosion of methane. The lower explosive limit for methane is about 5%; methane in concentrations above about 5% in air is explosive. There have been numerous case studies reported of explosions next to landfill boundaries and loss of anthropogenic properties. There have also been numerous examples of underground migration of LFG to nearby properties and sufficient accumulation of LFG in buildings to become an explosive mixture, which could be set off by a spark (Derby Evening Telegraph, 1986; DOE, 1989, 1995).

Moreover, LFG 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 that includes the development of vegetation (usually grasses) to reduce erosion of the cover. The emission of LFG can exclude oxygen from the root zone of vegetation and thus lead to vegetation death. Many landfill covers which have inadequate LFG collection systems and have large, non-vegetated areas due to LFG emissions through the cover and the surrounding areas, downgrading the landscape. Special study should be taken so as use specific trees and plants, resistant to LFG emissions on landfill covers and special care should be taken on slope stability design in flood areas (DOE, 1995; Koliopoulos, 2000).

The problems of explosive conditions developing from methane emissions from waste disposal sites have stimulated regulatory agencies to require that the landfill owner or operator construct LFG collection systems. These are envisioned, in concept, to collect sufficient LFG so it is not transported below the ground surface to cause explosive conditions in nearby anthropogenic structures. Any uncontrolled dumps should be closed, minimizing the threat to any architectural and building receptors next to landfill boundaries. Any bioremediation lining of technical works should be made for a given topography of contaminated site in order to protect natural resources and public health. Based on the above presented numerical results, the cell 1 at MACH site presents safer design than the rest cells in terms of pressure and produced LFG advection velocity.

Conclusions

This MACH experimental study showed that landfill gas peak production and methanogenesis can be achieved in a short time, thereby avoiding long term threats of loss of anthropogenic property or natural resource degradation. The investigation of landfill field data and results from the presented comprehensive integrated numerical model allows better control of landfill risks and protects the health and safety of properties, humans, animals and flora and fauna next to landfill boundaries. MACH field data and the presented numerical model can be used as a guide and tool, respectively, for temperature control in landfills and the protection, safety of anthropogenic properties.

At MACH, in cell 1, the co-disposal of inert material with waste showed that it is sustainable. The lower heat generation of biomass in cell 1 resulted in lower temperatures, LFG pressures and gas migration advection velocities than in the rest of the MACH cells. MACH's cell 1 provides safer conditions in relation to probable landfill fire under favourable circumstances. Dynamic numerical spatial models are necessary not only to evaluate landfill temperatures and associated risks but also to demonstrate efficient sustainable designs that minimize any environmental impacts to receptors located next to landfill boundaries. Landfill gas and biomass temperature field data are of great importance, not only for making estimations, comparisons and predictions, but also for calibrating field data in mathematical models in order to develop useful risk assessments and take the right measures for a given landfill topography in time.

However, control of LFG emissions has to be improved, based on the present study, taking into account different field data for different waste inputs and landfill conditions. The MACH project attempts to develop and assess techniques to enhance the degradation and pollutant removal processes for Municipal Solid Waste (MSW) landfills, so that the associated environmental impacts can be minimized. The MACH wet-flushing bioreactor landfill project is seen as the method of achieving the goal of sustainability, minimizing the risks of landfill fires and associated environmental impacts, such as loss of flora-fauna resources, buildings, architectural values or other anthropogenic properties.

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