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PARAMETRIC SENSITIVITY ANALYSIS OF HUMIC PHASE IN LANDFILL

Dr. Rajeev Kumar Dohare*, Dr. Madhu Agarwal and Dr. Sushant Upadhyaya
Department of Chemical Engineering,
Malaviya National Institute of Technology, Jaipur, India-302017
E-mail: rkdohare.chem@mnit.ac.in (**Corresponding Author*)

Abstract: This paper presents the development of one dimensional mathematical model capable of simulating simultaneous processes of oxygen flow. It is based on some assumptions like the landfill assumed to behave as a bioreactor in which gas phase generation is over i.e. methanogenic is finished and the humic phase is started. This mathematical model actually describes the oxygen concentration in the landfill, leachate migration and capable of simulating simultaneous processes of water transport, leachate migration. The resulting governing equations in the form of partial differential equation (PDE) have been solved by separation of variables (analytical) and backward implicit scheme (BIS). The goal is to study the four transport parameters ($D_{O_2}, \kappa_1, \varepsilon, \text{and } \nu$) on the oxygen concentration which results in degradation of refuse because after a long term processes in landfill, when all the remaining substrate becomes more and more resistant to degradation, microbial activity slows down and the humic phase is reached. During the humic phase, the available degradable organic material is either depleted or either the reactions are too slow to consume oxygen entering the landfill. The main focus is on to study the governing partial differential equations having four transport parameters and their affect on oxygen concentration.
Keywords: Municipal Solid waste (MSW); Modelling and Simulation; Finite difference technique; diffusion; Partial differential equation; backward implicit scheme (BIS).

1. Introduction

During the past decay almost all industrialized nations have become aware of the major consequences of waste generated by its industrial and non industrial activities. Modern society generates a large quantity of waste products that may be solid waste or hazardous waste. The sources of these wastes include agriculture, industry mining, milling, and the household's etc. Hazardous waste may be fatal, toxic, carcinogenic or teratogenic to human and other organisms. So it has to be managed with proper techniques in an effort to reduce their effect on human health and the environment as unlike water born and air dispersed waste, solid waste will not go away as it will be found in the nature where it is thrown [1]. One of the important solutions to this problem is either to produce less waste or government

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should create stronger legislation to reduce production of both solid and hazardous waste. Various waste disposal technologies considered are municipal incineration and different landfill types, including sanitary landfills, hazardous waste incineration, waste deposits in deep salt mines, surface spreading of sludge, municipal wastewater treatment, and building dismantling [2]. Therefore the collection method is used to dispose of waste still land filling is the most common method there. A combined household/industrial landfill in a humid and cold temperate climate is characterized with respect to its chemical composition [3]. In recent times sanitary landfill methods have replaced the one of the oldest methods of dumping waste material to some unwanted lands as open dumps allowed for developing disease. Actually in sanitary landfills the biological decomposition of refusing material takes place. Land filling is the most traditional method of waste disposal as this method is hygienic and relatively inexpensive. Incidents of groundwater contamination by landfill leachate have been widely reported since the early 1970s [4].

Bozkurt et al., 2000 and Tchobanoglous et al.,1993 were investigated that the gas and leachate composition as refusing decomposed [5],[6]. Municipal solid waste (MSW) landfill leachate contains a number of aquatic pollutants [7]. At the initial landfill stage, the leachate exhibited high heavy metals release, high organic matter content (27 000–43 000 g l−1 of TOC) and low pH (5–6) [8] and its quality is regularly maintained by use of pH, alkalinity, oxygen-reduction potential and chemical oxygen demand [2],[3],[9]. But modernized landfill includes methods to contain plastic liners and landfill gas extraction systems. Here the concern about the impact of excessive materials consumption has given rise to efforts to minimize the efforts waste sand to landfill. Degradation processes in the landfills take place over a very long period of time. Through this period an increasing understanding of a complex series of chemical and biological reactions [10] that initiates the burial of refuse in a landfill has been developed. After that transition phase, acid phase, methane fermentation phase and maturation phase take place sequentially as shown in the Figure 1.

During aerobic phase oxygen present in the void spaces of freshly buried refuse is rapidly consumed resulting in production of CO_2. In the second phase the acid concentration as well as BOD COD ratio increases but pH decreases then the decomposition proceeds till methane produced in the fourth phase decreases to zero [11]. When all the development of gas generation is finished then landfill is dead and new phase is generated, i.e. called humic phase. Bozkurt et al., (2000) explained the long term process that may change the leaching behavior of waste during the humic phase.

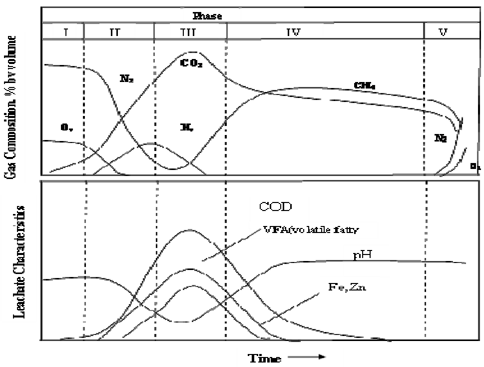

Figure 1: Generalized phases in the generation of landfill gases.

Laner et al., (2011) suggested that MSW are potential long-term sources of emissions, in particular leachate and biogas [12]. The pH and redox conditions are governed by infiltration-oxygenated rainwater, by oxygen and CO_2 that defuse oxygen into the landfills [13]. Then the condition become aerobics and acidic and that might greatly increase the mobility of heavy metals (Cd, Ni, Zn, Ca, Pb and Cr) which are previously been bound in the waste site for hundreds and thousands of years [14]. Aftercare management of closed landfills typically includes monitoring of emissions and receiving systems (e.g. groundwater, surface water, soil, and air) and maintenance of the cover, leachate and gas collection systems, if present in the landfill site [15].

2. Model Development of Landfill: A one-Dimensional model (in Cartesian coordinates) is capable of simulating simultaneous processes of oxygen flow. These models are based on the number of assumptions.

The following assumptions have been made for calculating penetration through sealing layer:

(i) The porous medium through which migration takes place in homogeneous, isotropic, and saturated.

(ii) Porosity of the landfill liner material (ε), bulk density (ρdry), Darcy's velocity (v), and dispersion coefficient (D), do not vary with period of migration and depth along of landfill.

(iii) Reaction in the bed is first order irreversible type.

(iv) Landfill assumed to behave as a bioreactor.

(v) Direction of flow of oxygen in vertical downward.

(vi) Gases can be transported by flow and by molecular diffusion in and out of the landfill.

Final Model Equation with initial and boundary condition

$$D_{O_2}\frac{\partial^2 C_{O_2}}{\partial X^2} - V_{O_2}\frac{\partial C_{O_2}}{\partial X} - \varepsilon\frac{\partial C_{O_2}}{\partial t} - \kappa_1 C_{O_2} = 0 \tag{1}$$

I.C.

$$\text{At} \quad t = 0 \quad C_{O_2} = C_{O_2,atm} \tag{2}$$

B.C.1

$$\text{For} \quad t > 0,\ x = 0 \quad C_{O_2} = C_{O_2,atm} \tag{3}$$

B.C.2

$$\text{At } t > 0 \quad 0 < x \le 10 \text{ m} \quad \frac{\partial C_{O_2}}{\partial x} = 0 \tag{4}$$

Discretization is the best numerical technique to solve any partial differential equation. The developed model has been descritized and then use the back substitution method after change into tri-diagonal matrix form.

3. Result and Discussion

3.1 Effect of Effective diffusivity: Effect of effective diffusivities with respective to time and depth on oxygen concentration in the landfill as shown in the Figure 2.

3.1.1 Increasing Depth and Time: From the simulated results for the particular depth and time, we have found that the oxygen concentration increases with increase in effective diffusivity in both cases as shown in the Figure 2 (a)-(b). Therefore, more and more oxygen diffuses in the landfill with increasing depth and time. Same trend may also be observed at various depths (4m, 8m, 10m) and times (4years, 8years and10years) respectively.

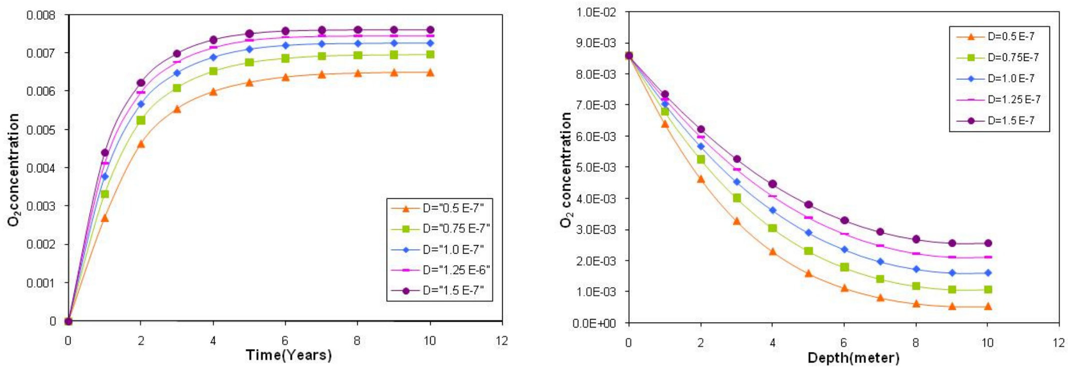

Figure 2: Effect of diffusivity on Oxygen concentration with (a) Depth (meter) and (b) Time(years).

3.2 Effect of rate constant: Effect of rate constant with respect to depth and time on oxygen concentration in the landfill is shown in the Figure 3.

3.2.1 Increasing Depth and Time: As we have observed that the oxygen concentration decreases with increase in rate constant in both cases as shown in the Figure 3 (a)- (b). This is due to the fact that with the increase in rate constant more and more oxygen is consumed in the different type of reactions occurring in the landfill at various phases. Same trend may also be observed at different locations (4m, 8m, and 10m) and times (4years, 8years and10years) respectively in the landfill.

3.3 Effect of Porosity: Figure 4 shows the effect of porosity on oxygen concentration with respect to the depth and time in the landfill.

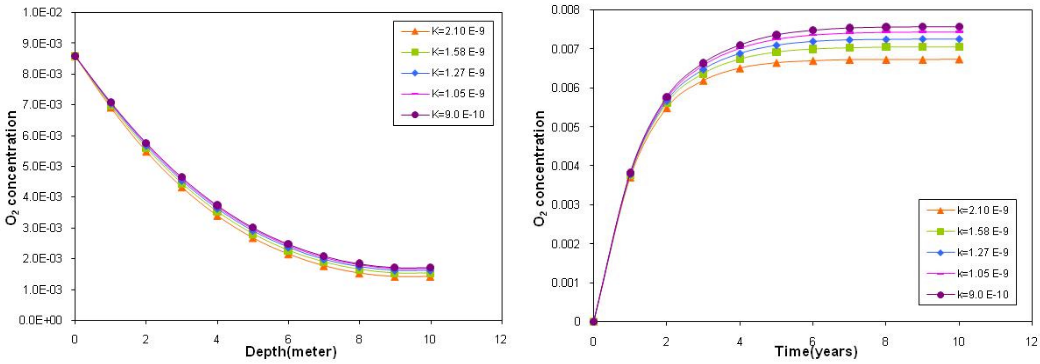

Figure 3: Effect of rate constant on Oxygen concentration with (a) Depth(meter) and (b) Time (years).

3.3.1 Increasing Depth and Time: Result in the Figure 4 (a)-(b) shows that oxygen concentration decreases, as the porosity of the waste materials increases and then become a constant after a particular depth. This is due to the fact that at high porosity more and more oxygen is diffused in the landfill. Same trend is observed at depth 4m, 8m and 10m. With respect to time the oxygen concentration decreases as porosity of the material increases. After 7 years the effect of porosity is negligible and the oxygen concentration behaves like a streamline.

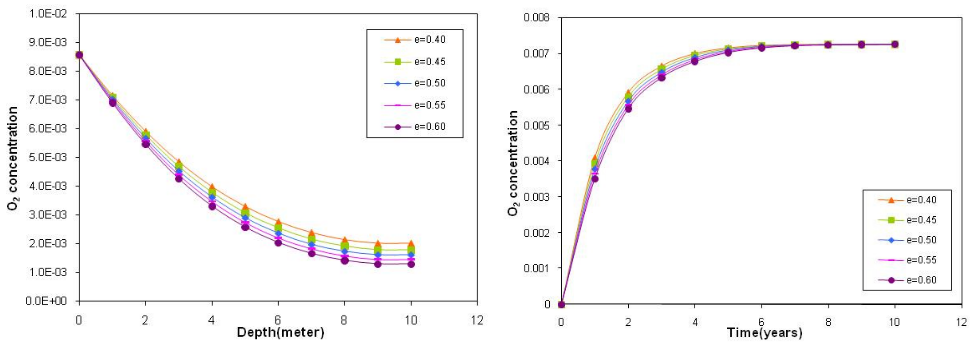

Figure 4: Effect of porosity on Oxygen concentration with (a) Depth (meter) and (b) Time (years)

3.4 Effect of Velocity: Effect of velocities as shown in the Figure 5 are negligible with respect to depth and time, because in landfill the flow is through porous media and the Reynolds number is less than one. Nominal operating parameters for the oxygen depletion is given in Table 1.

Table: 1 Nominal Operating Parameters for finding the oxygen concentration in the landfill at different conditions

Type of case		Effective Diffusivity (D)	Rate Constant (κ)	Porosity (ε)	Velocity (υ)
Without cover		$D = 1.0\times 10^{-7}$ m²/s	$\kappa = 1.27\times 10^{-9}$ s⁻¹	ε =0.5	$\upsilon = 1.0\times 10^{-13}$ m/s
With cover	Length of the cover1= 0.1 m	$D_1 = 1.0\times 10^{-7}$ m²/s	$\kappa_1 = 30$ year⁻¹	$\varepsilon_1 = 0.45$	$\upsilon_1 = 1.0\times 10^{-13}$ m/s
	Length of the cover2= 0.9 m	$D_2 = 1.0\times 10^{-6}$ m²/s	$\kappa_2 = 20$ year⁻¹	$\varepsilon_2 = 0.40$	$\upsilon_2 = 1.0\times 10^{-13}$ m/s
	Length of the cover3= 1.0 m	$D_3 = 1.0\times 10^{-5}$ m²/s	$\kappa_3 = 10$ year⁻¹	$\varepsilon_3 = 0.35$	$\upsilon_3 = 1.0\times 10^{-13}$ m/s
	Length of the landfill=10m	$D_4 = 2.0\times 10^{-6}$ m²/s	$\kappa_4 = 25$ year⁻¹	$\varepsilon_4 = 0.50$	$\upsilon_4 = 1.0\times 10^{-13}$ m/s

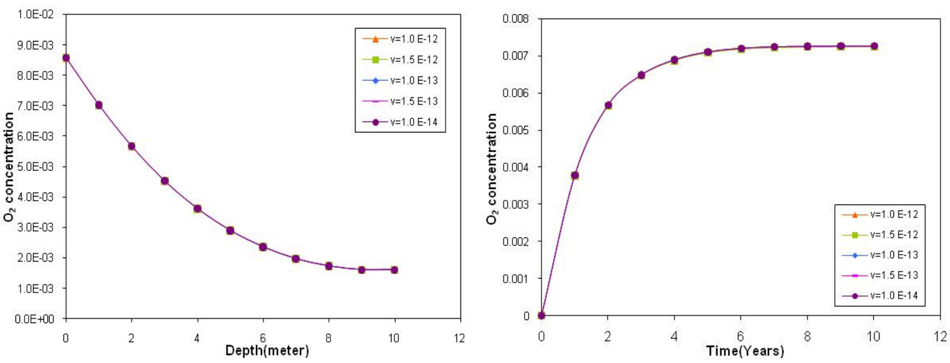

Figure 5: Effect of velocity on Oxygen concentration with (7a) Depth (meter) and (7b) Time (years)

4. Conclusions: After solving the model and analyzing the results following conclusions are be made. Oxygen concentration decreases with the increase in reaction rate constant (κ1) with times and depths in the landfill. Oxygen concentration in the landfill increases with decrease in porosity (ε) at a particular time at all depths. Oxygen concentration increases with increase in effective diffusivity D_{O_2} with time and depths. No effect is seen on oxygen concentration with the increase or decrease in velocity (ν), because in porous media Reynolds number is very less, due to that flow occurs in the Darcy's region.

Nomenclature

ε = porosity

C_{O2} = oxygen concentration (which varies with time t and depth x) (kmol/m³)

t= time(s)

V = velocity of the oxygen (m/s)

x = distance in the direction of transfer (m)

D_{AB} = effective diffusion coefficient (m^2/s)

x = Depth, m

R = Rate of reaction

κ_1 = First order rate constant

D = diffusion coefficient ,cm^2 / s

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