ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 3, Issue 5, September 2014

Modelling of Contaminant Transport from Landfills

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Abstract: Amongst all hydrological and environmental problems the most typical one is ground water contamination. Waste material is to be placed in engineered landfill as ground water contamination can take place due to landfill leachate. In order to design engineered landfill mathematical models proposed for the landfill. The general model of the ground water layer include various hydro geological process as contaminant transport, mechanical dispersion, molecular diffusion, sorption, chemical reactions, etc. the time behaviour of a contaminated ground water layer is to be predicted for practical situation. Realistic data for mathematical model is to be analysed using realistic results. Various soil parameters porosity, dispersivities, sorption, coefficients etc. are to be used in the model. The objective of this study is to develop and validate mathematical model that would address the problem of migration of contaminants from the bottom of landfill. This concentration was found to be in a consonance with the simulated concentration with chloride and sodium in ground water considering one dimensional transport model. Governing equation of contaminant transport involving advection-diffusion using explicit finite difference method with upwind correction.

***Keywords*- Groundwater, Sodium, Chloride, Solid Waste.**

I. INTRODUCTION

Human activities create waste, and the disposal of these wastes has been an important issue for human society. The methods of handling, storing, collecting and disposing of these wastes can pose risk to the environment and to public health [1]. A landfill site is defined as a tip, dump, rubbish or dumping ground and it is a site for the disposal of waste material by burial. It is one of the oldest methods to treat waste. Landfills are an essential part of everyday living but they may contaminate groundwater as well as surface water. In the United States, plastic liners were used to protect groundwater quality. The design and operation of landfill facilities are essential with respect to aesthetic, safety, and health problems [2]. To minimize the environmental impacts the design, construction and operation of the Modern landfill sites or engineered landfill sites are necessary. Production of leachate from landfill sites cause groundwater and surface water pollution. Also the generation of the landfill gas cause adverse health effects, explosive conditions, and global warming [3][4].

II. MECHANISMS OF CONTAMINANT TRANSPORT

When the leachate drifts over the top of liner, the leachate from landfill tends to migrate to the bottom of the aquifer carrying away with contaminant leached [5]. There is various mechanisms which account for the migration of leachate contaminant from landfill into barrier. The first mechanism consider in the groundwater system is due to advection transport which associated with mean flow or currents, such as rivers, streams, or tidal motion [6]. The second mechanism is diffusive transport of contaminant due to concentration gradient. Third mechanism is dispersion which involves the mixing of contaminant at relatively high flow[7]. Fourth mechanism is sorption which indicates a physical and chemical process by which one substance becomes attached to another [8].

Now considering the conservation of mass it is deduced that the increase in contaminant concentration within smaller region can be calculated from addition of increase in mass due to advective diffusion and decrease in mass due to sorption, which is given by equation (1)[9]. Where, f is the total mass flux represent by equation (2) which is the summation of flux due to advection, diffusion and dispersion, But in mathematical modelling diffusion and dispersion processes are lumped together to form a composite parameter, which is denoted by D_h called hydrodynamic dispersion coefficient. Which is given by summing these two coefficient i.e. $D_h = D_e + D_{md}$. (Hydrodynamic dispersion coefficient = effective molecular diffusion + mechanical dispersion)[10]. In clayey soil diffusion will usually control parameter than dispersion or diffusion can be important in vapour transport in unsaturated zone. In aquifer or saturated ground water flow dispersion is an important factor which dominant diffusion. So the governing equation of contaminant transport is expressed by equation (3). Where, R_f is

Retardation coefficient for freundlich isotherm, $R_f = 1 + \frac{\rho_d K_f C^{b-1} b}{n}$ where, b and K_f are the material constants for the soil- solute system and ρ_d is dry density[11][12][13].

$$n\frac{\partial c}{\partial t} = -\frac{\partial f}{\partial x} - \rho_d \frac{\partial s}{\partial t} \qquad (1)$$

$$f = n\, v_a\, c - n\, D_h \frac{\partial c}{\partial x} \qquad (2)$$

$$\frac{\partial c}{\partial t} = \frac{D_h}{R_f}\frac{\partial^2 c}{\partial x} - \frac{v_a}{R_f}\frac{\partial c}{\partial x} \qquad (3)$$

This is the equation of advection diffusion which represents mathematical model of contaminant transport from landfill. Both boundary condition and initial conditions are needed to obtain solutions to any differential equation, and the advection Diffusion equation is one of them. Boundary conditions apply to specific locations in the modelled physical domain, and are usually specified in one of three ways[14].

Specify concentration (e.g. $C = C_0$ at $x = 0$), possibly time dependent. In combination with velocity, this gives advective flux.
Specify gradient (also possibly time-dependent), which in combination with the diffusivity, gives diffusive flux.
Specify total flux, as a (linear) combination of both diffusive and advective fluxes.

Boundary condition play a very important role in determining the behaviour of a particular solution, and care should be taken in specifying the correct condition for any given problem.

Initial condition $C\ (x \geq 0, t = 0) = 0$

Boundary condition $C\ (x = 0,\ t \geq 0) = C_0$

Boundary condition $C\ (x = \infty,\ t \geq 0) = 0$

III. NUMERICAL SOLUTION TO THE ADVECTION DIFFUSION EQUATION

The solution to the contaminant transport model represent by equation (3) subjected to boundary conditions and was implemented using the numerical method, explicit finite difference method with upwind correction describing the contaminant transport model for landfill include terms representing derivatives of continuous variable[15]. Finite difference method is based on the approximation of these derivatives by discrete linear changes over small discrete intervals of space and time.

General finite difference formulation for the solution to the one dimensional advection-diffusion equation assuming a conservative substance (no reactions) and constant v_a and D_h using a forward difference for the time derivative is given by equation (4). Where, ω is weighting factor that allows different weighting for implicit and explicit terms, with ω = 1 method is fully explicit Where α is the weighting factor for first spatial derivative α = 0, for backward difference, $\alpha = \frac{1}{2}$, for central difference put, $\alpha = \frac{1}{2}$ in equation (4) and resulting equation is given by equation (5) and References[16][17].

$$\frac{C_i^{m+1} + C_i^m}{\Delta t} = \frac{D_h}{R_f \Delta x^2}\{(1-\omega)\times(C_{i+1}^{m+1} - 2C_i^{m+1} + C_{i+1}^{m+1}) + \omega\times(C_{i+1}^m - 2C_i^m + C_{i-1}^m)\} - \frac{v_a}{R_f \Delta x}\{(1-\omega)$$

$$[\alpha\,(C_{i+1}^{m+1} - C_i^{m+1}) + (1-\alpha)(C_i^{m+1} - C_{i-1}^{m+1})] + \omega\,[\alpha(C_{i+1}^m - C_i^m)] + (1-\alpha)(C_i^m - C_{i-1}^m)\} \qquad (4)$$

$$C_i^{m+1} = C_i^m - \frac{v_a \Delta t}{R_f \Delta x} \times \frac{1}{2}(C_i^m - C_{i-1}^m) + \frac{D_h \Delta t}{R_f \Delta x^2}(C_{i+1}^m - 2C_i^m + C_{i-1}^m) \qquad (5)$$

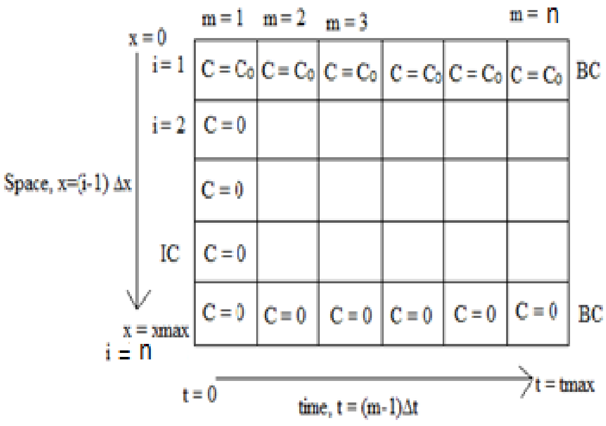

Fig 1: Schematic diagram of Finite Difference Method

The above equation can be arranged by keeping$K_1 = \frac{1}{2}\times\frac{v_a\Delta t}{R_f\Delta x}$, $K_2 = \frac{D_h\Delta t}{R_f\Delta x^2}$

$$C_i^{m+1} = C_i^{m} \times (1-2K_1-2K_2) + C_{i+1}^{m} \times K_2 + C_{i-1}^{m} \times (2K_1+K_2) \qquad (6)$$

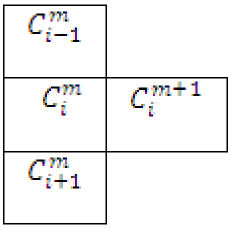

Fig 2: Finite Difference Method Node

Under condition of space Δx and time step Δt is the explicit 1-D finite method stable. The accuracy of explicit formulation is 0, (Δt, Δx^2) and for 1-D method it is numerically stable (stable means that the solution remain bonded) so long as the following stability criterion is met $\frac{D_h\Delta t}{R_f\Delta x^2} + \frac{1}{2}\times\frac{v_a\Delta t}{R_f\Delta x} \leq \frac{1}{2}$. Thus entire domain divided into m_n= T/Δt, and i_n = Z/Δx. Initial and boundary conditions are considered by keeping C_i^m at beginning of solution zero everywhere at the entire depth of the domain [18].

IV. VALIDATION OF MODEL

Model developed in this study was tested for two parameters of field data for an uncontrolled landfill at Huainan, China [19].Field data from this site was adopted to use to validate the numerical model. The field profile of chloride in the media was compared with the numerical model developed in the study. The results obtained by the mathematical model assuming pure diffusion. The effective diffusion coefficient of sodium for the soils was assumed to be 0.025 m^2/yr on the basis of the published data [20]. The retardation factor of the soils was assumed to be 1.5. This value is in the range of the published data (i.e., 1–5) provided by Rowe et al. (2004). The predicted migration depth of sodium assuming pure diffusion was about 2m. This value also underestimate the observed migration depth (i.e., about 4 m). The observed data fall into the range of the predicted curves using the advection–dispersion model. However, it is also difficult to obtain a well-fitted curve using the advection–dispersion model. The source concentrations of sodium, i.e., 5500 mg/L were used in the simulations. The data used for simulation of sodium and chloride are given below.

Table 1: Model parameters for Chloride (T.L.T. Zhan et al. 2014)

S.No.	Model Parameter	Unit	Value
1	Depth	m	7
2	Effective molecular diffusion coefficient	m^2/yr	0.023
3	Porosity		0.40
4	Retardation Factor		1.0
5	Advective Velocity	m/yr	0.04
6	Dispersivity	m	0.05

Table 2: Model parameters for Sodium (T.L.T. Zhan et al. 2014)

S.No.	Model Parameter	Unit	Value
1	Depth	m	4
2	Effective molecular diffusion coefficient	m^2/yr	0.025
3	Porosity		0.40
4	Retardation Factor		1.5
5	Advective Velocity	m/yr	0.275
6	Dispersivity	m	0.14

V. RESULTS AND DISCUSSION

The result of simulations was obtained for these cases are compared with the observed field data. The possible uncertainties in the chloride source function, comparison of the field data and numerical results were considered to be good if the model simulation fit the declining concentrations in the top 2-3 m of the profile. For greater depths, their model results did not agree with the observed data and the sharp localized concentration changes identified beyond 3 m were attributed to the variations in the source concentration within the landfill and due to unidentified changes in local geochemistry. In case of sodium simulated results match well with the observed values. The uncertainties in the sodium source function, is quite less as compared to chloride at the depths up to 9m. The simulated concentration of chloride and sodium with respect to depth is given in tables 3 and 4.

Table 3: Simulated and observed Chloride Concentration (17 years)

Depth (m)	Observed Chloride Concentration (mg/l)	Simulated Chloride Concentration (mg/l)
0.5	2528	2358
1.0	2253	1817
2.0	1209	1365
3.0	659	1146
4.0	604	1010
5.0	549	914
6.0	425	843
7.0	502	786

Table 4: Simulated and observed Sodium Concentration (17 years)

Depth (m)	Observed Sodium Concentration (mg/l)	Simulated Sodium Concentration (mg/l)
0.5	2803	2915
1.0	2441	2265
2.0	2441	1726
3.0	1265	1446
4.0	1305	1304
5.0	1185	1191
6.0	1157	1106
7.0	1129	1038

8.0	457	738
9.0	412	697

8.0	1156	981
9.0	1074	931

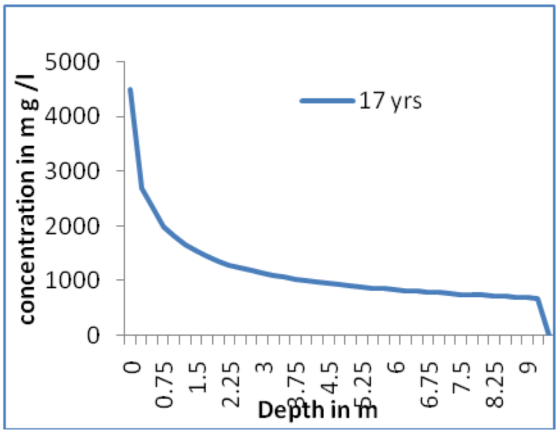

Fig 3: Results of chloride Concentration using Numerical Model of diffusion and advection

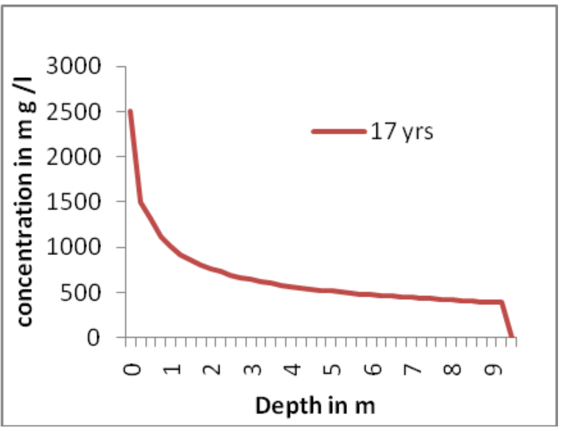

Fig 4: Results of sodiumConcentration using Numerical Model of diffusion and advection

VI. CONCLUSION

Mass transport of chloride and sodium from landfill leachate was modelled was taking into account the mechanism of contaminant transport advection and diffusion-dispersion and using the finite difference method with upwind correction. The model was solved and validated with the field data of solute transport (T.L.T. Zhan et al. 2014). Simulation of the validate model rum for two parameters. The possible uncertainties in the chloride source function, comparison of the field data and numerical results were considered to be good if the model simulation fit the declining concentrations in the top 2-3 m of the profile. For greater depths, their model results did not agree with the observed data and the sharp localized concentration changes identified beyond 3 m were attributed to the variations in the source concentration within the landfill and due to unidentified changes in local geochemistry.

The severity of the groundwater contamination is significant on account of associated complexity in pollution source identification, limited feasible options for treatment of groundwater all being cost prohibitive, complicated process in fixing geophysical boundaries, difficulty in prediction of movement, insufficient dilution, slow movement, lack of any natural cleansing capability. As a sizeable population in India is dependent on groundwater as the only source particularly densely populated, urgent attention to activities of solid waste disposal by land filling is highly needed.

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