Migration Behavior of Life Source Contaminants in a Landfill Site

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Abstract

The author establishes a generalized model of a landfill in China according to the actual sectional view. Such ions as Ca^{2+}, Mg^{2+}, CO_3^{2-}, Na^+ and Cu^{2+} with high concentration of life source contaminants in landfill are used to research their migration in landfill site.

Under the water pressure with 10m, 20m and 30m, such migration characteristics in each year as depth, breadth and concentration when Ca^{2+}, Mg^{2+}, CO_3^{2-}, Na^+ and Cu^{2+} seeping for 20 years in the landfill site are obtained based on the concentration as well as the permeability coefficient of the five ions in the stratum. With the water pressure increasing, the concentration of Ca^{2+}, Mg^{2+}, CO_3^{2-}, Na^+ and Cu^{2+} at the same monitoring site in landfill are rising in varying degrees. Migration rate in descending order is Na^+,Cu^{2+},Mg^{2+},Ca^{2+},CO_3^{2-}. The concentration growth rate of the five ions in descending order is CO_3^{2-},Ca^{2+}, Mg^{2+},Cu^{2+},Na^+. With the compaction degree of clay increasing, the concentration decrease rate in descending rate is CO_3^{2-},Ca^{2+},Mg^{2+},Na^+,Cu^{2+}.

Particularly in terms of Mg^{2+} average concentration variance, it is 70% in the 0-10 years of migration in landfill site, but it reduces to 8% in the 10-20 years of migration. During the 20 years of migration, for 4.5m depth, the concentration of Ca^{2+}, Mg^{2+} and CO_3^{2-} decreases from 186ppm to 0.007ppm, from 414ppm to 3.8ppm, and from 1.241×10^4ppm to 9.89×10^{-9}ppm, respectively. The concentration decreases faster in the 2m clay layer area than that in other landfill sites, especially the concentration of Zn^{2+} and Cu^{2+} can reduce to zero after migration by degrees. Comparative study of the measured data and numerical simulation results are carried out. Furthermore, the proposed compaction degree of clay in the research is not less than 93.00%.

Keywords: life source contaminants; ion migration; landfill; numerical simulation

1. Introduction

The migration of contaminants in soils experiences a long and complex evolution, and its migration law are researched by some scholars. The migration and transformation of contaminants in soils are investigated using centrifuge model tests (Mitchell, 1994a, 1994b; Zhang et al., 2002; Kumar et al., 2012; Yu et al., 2014). The migration of such heavy metal ions as Pb^{2+} and Cd^{2+} in unsaturated soils and clay liners is studied through tests (Zhang et al., 2013; Sui et al., 2013; Chen et al., 2014). The diffusion coefficient of contaminant ions in clay is measured (Xi et al., 2003). Meanwhile, such software as MODFLOW is implied to predict the spatial and temporal distribution of contaminant concentration and seepage parameters (Liu et al., 2008). The migration characteristic on concentration of leachate contamination components in soils are simulated (Di et al., 2008). A coupling model of soil consolidation and contaminant migration is established (Zhang et al., 2009; Hu et al., 2010). Currently, the research results rarely involve in the migration of life source contaminants in clay. However, it is imminent to study the migration of life source contaminants due to the fact that life source contaminants have already become a main pollution source on soil properties.

In this study, the numerical simulation method was adopted to simulate the seepage of life source contaminants in clay liner layers of Yanqun landfill in Xuzhou, in order to calculate and predict the spatial and temporal distribution characteristics of different ion concentrations.

2. Engineering Geological general situation of Yanqun Landfill Site and Generalized Model

2.1 Geological general situaionzai of landfill site

Yanqun landfill site is located in Dapeng Town, Tongshan District, Xuzhou City, and the first phase

of the project covers an area of about 802.64mu, with

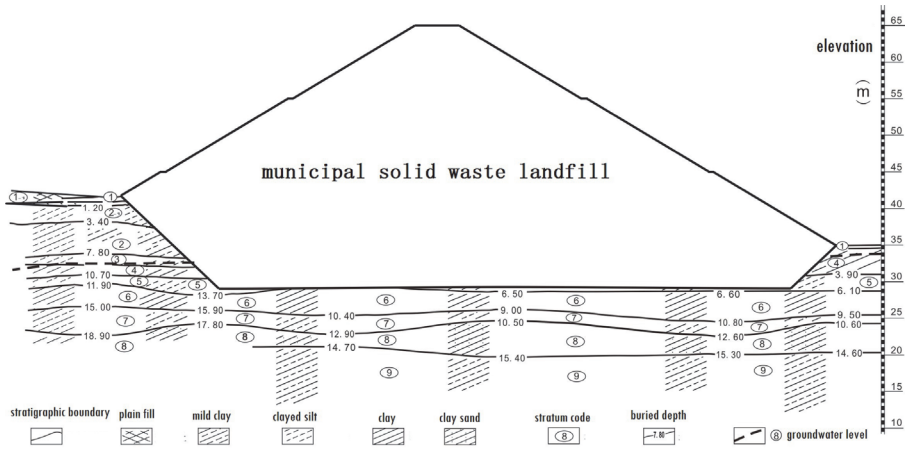


Fig. 1 Soil layer distribution of Yanqun landfill

National Road 310 on the north and 720m away from the site. The elevation of the northeast site is higher ranging from 41.00m to 43.50m than that of the southwest site ranging from 34.00m to 35.50m, with the total area about 50,000m^2 and the depth 5-8m. The geomorphic unit of the site is fluvial facies. In the first phase of the project, the total landfill storage capacity is 3,500,000m^3, with the design total landfill amount 3,100kt, the design maximum height of the waste body 36m, as well as the maximum and mean excavation depth 13.25m and 6m. The soil layers under the landfill site can be divided into 11 layers from top to bottom: cultivation soil, mild clay, clayey silt, sandy loam, clay, mild clay, sandy clay, mild clay, as shown in Figure 1.

2.2 Generalized model of Yanqun landfill site

A two-dimensional generalized model of Yanqun landfill site is established, with the unit of vertical and horizontal coordinate m and the model scale 1:100. The upper part represents waste layer, and the middle 2m part compacted clay liner layer, the lower 5-8m part simplified clayey silt layer. The generalized model is divided into grids, most of which are triangular and quadrilateral elements, as shown in Figure 2.

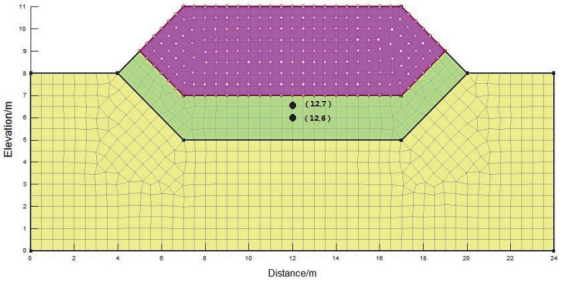


Fig. 2 Grid division for generalized model of Yanqun landfill site

2.3 Major ions of contaminants and the parameters of the numerical simulation

According to the water quality test results of life source contaminants, CO_3^{2-}, Ca^{2+}, Mg^{2+}, Cu^{2+} and Na^+ with higher concentration are selected as the main migration ions. The initial concentration and permeability coefficient of the five ions in clayey silt and clay are determined as illustrated in table 1.

Table 1 Migration model parameters of five ions of leachate

ion species	initial concentration (ppm)	permeability coefficient of clayey silt (m/d)	permeability coefficient of clay (m/d)	boundary conditions
Ca^{2-}	186	0.00010	0.0000010	Total water head of
Mg^{2+}	414	0.00030	0.0000030	the top of waste layer: 64m;
CO_3^{2-}	12410	0.00001	0.0000001	the top of clay layer:
Na^+	3319	0.00100	0.0000100	29m, 39m, 49m, 59m;
Cu^{2+}	0. 02	0.00100	0.0000100	the bottom of sandy loam layer: 0m

3. Ion migration in landfill compacted clay layer

3.1 Variation of pollution plume with migration time

The pollution plumes of the five ions after 20 years of migration under 20m water pressure are shown from Figure 3 to Figure 7. The Na^+ pollution plumes pass through the clayey silt layer. Meanwhile, concentration increases caused by boundary effect, and symmetric pollution plumes gradually form. Moreover, the formation speed of Na^+ pollution plume is equal to the migration velocity of Na^+. Furthermore, the five ions in descending order of migration velocity are Na^+, Cu^{2+}, Mg^{2+}, Ca^{2+}, CO_3^{2-}. Additionally, it is worth emphasizing that the pollution plumes of Na^+, Cu^{2+}, Mg^{2+} and Ca^{2+} pass through the slope clay layer preferentially.

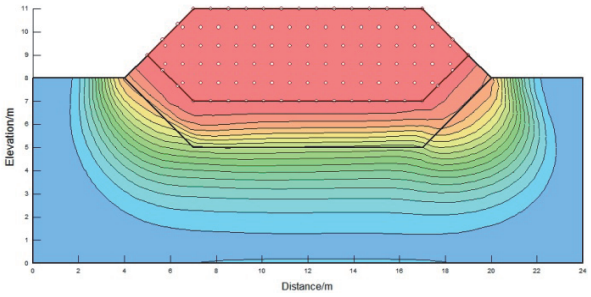


Fig. 3 Pollution plumes of Na^+ after 20 years of migration under 20m water pressure

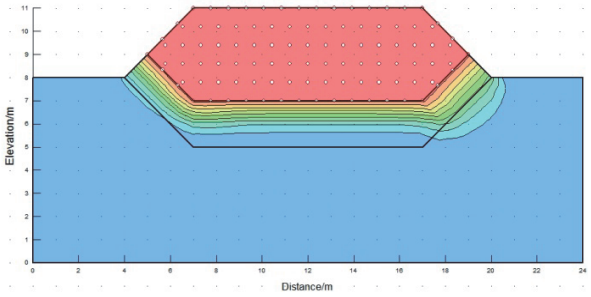


Fig. 4 Pollution plumes of Ca^{2+} after 20 years of migration under 20m water pressure

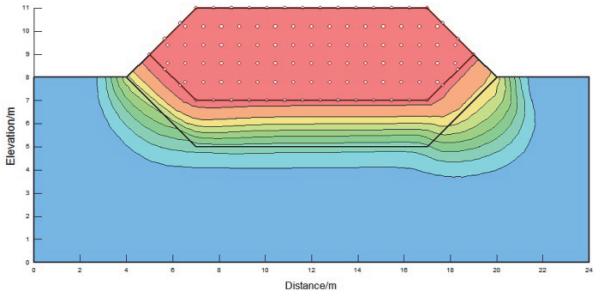


Fig. 5 Pollution plumes of Mg^{2+}after 20 years of migration under 20m water pressure

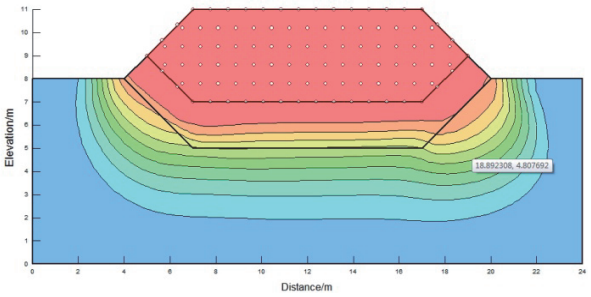


Fig. 6 Pollution plumes of Cu^{2+} after 20 years of migration under 20m water pressure

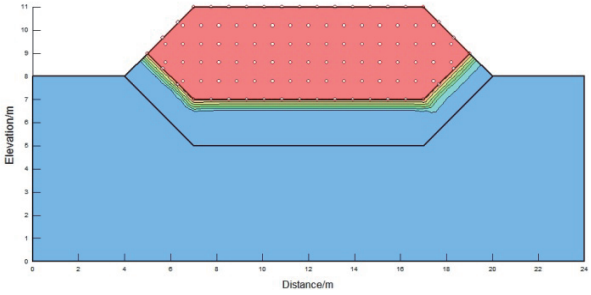


Fig. 7 Pollution plumes of CO_3^{2-} after 20 years of migration under 20m water pressure

3.2 Variation of ion concentration with migration time

The point with the coordinates (12, 6) on the soil layer of the landfill model (as shown in Figure 2) is selected to extract the concentrations of Na^+ at different migration time, as shown in Figure 8.

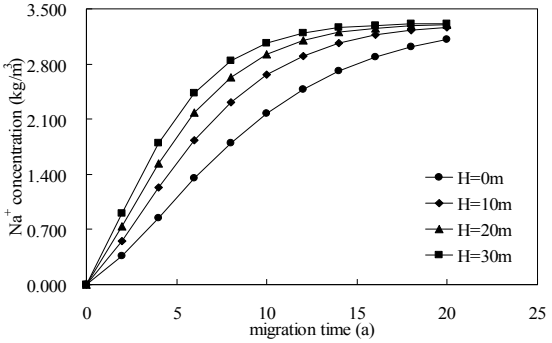


Fig. 8 Variation of Na^+ concentration with migration time

The results show that with the migration time increasing, the concentration of Na^+ gradually increases at the point (12, 6) by a decreasing speed. During the 20 years of migration, for 4.5m depth, Ca^{2+} concentration decreases from 186ppm to 0.007ppm, Mg^{2+} concentration from 414ppm to 3.8ppm and CO_3^{2-} concentration from 1.241×10^4ppm to 9.89×10^{-9}ppm. Meanwhile, the concentration change rate of Mg^{2+} gradually declines. Specifically, the change rate of Mg^{2+} concentration is 70% in the former decade but 8% in the latter decade. Moreover,

the decrease of Mg^{2+} concentration is slower than that of Ca^{2+} concentration in the migration process, due to the fact that the exchange adsorption capacity of Mg^{2+} is smaller than that of Ca^{2+}. Similarly, the decrease of CO_3^{2-} concentration is faster than that of Mg^{2+} and Ca^{2+} concentration because the exchange adsorption capacity of CO_3^{2-} is larger than that of Mg^{2+} and Ca^{2+}.

The migration velocities of the five ions in descending order is Na^+, Cu^{2+}, Mg^{2+}, Ca^{2+} and CO_3^{2-}, which is consistent with the migration velocities determined indirectly by pollution plumes. The concentrations of Na^+ and Cu^{2+} vary from fast to slow with migration time, and that of Mg^{2+}, Ca^{2+} and CO_3^{2-} vary from slow to fast. The reason is that the small migration velocities of Mg^{2+}, Ca^{2+} and CO_3^{2-} in clay layers are greatly affected by clay saturation; Furthermore, the saturation and unsaturated hydraulic conductivity of the clay gradually increase with the increasing migration time, resulting in the increase of the migration velocities of Mg^{2+}, Ca^{2+} and CO_3^{2-}.

3.3 Variation of ion concentration with migration depth

The point with the coordinates (12,7) on the soil layer of the landfill model (as shown in Figure 2) is selected as the initial depth in order to extract the variation of Na^+ concentration after 20 years of migration, as shown in Figure 9. With increasing migration depth, Na^+ concentration remains constant at the beginning, but then gradually decreases. The descending order of the five ions in vertical migration capability is Na^+, Cu^{2+}, Mg^{2+}, Ca^{2+} and CO_3^{2-}. Furthermore, the ions whose concentrations drastically reduced with increasing depth have weaker migration capacity, such as CO_3^{2-}, while Na^+ has stronger migration capacity conversely, which proves that clay has different barrier capability as to different ions. The variation rates of the concentrations of different ions with increasing depths are different. Specifically, the concentrations of Na^+ and Cu^{2+} vary from slow to fast, while Mg^{2+}, Ca^{2+} and CO_3^{2-} varying from fast to slow, which is just contrary to the ion migration characteristics with time, but both based on the same reason.

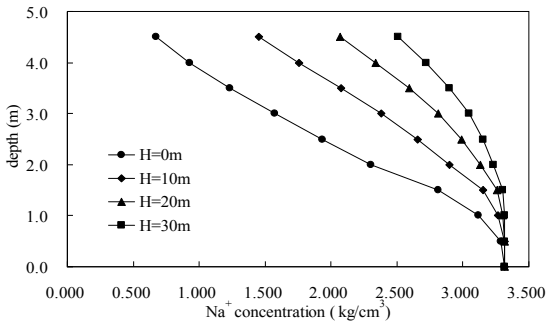
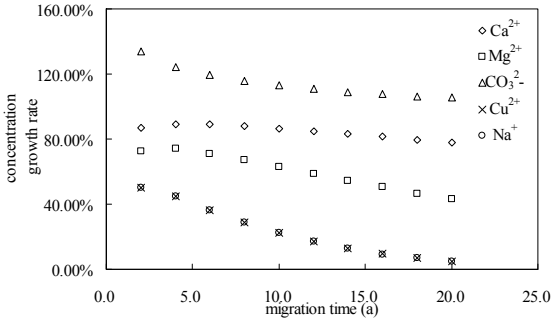


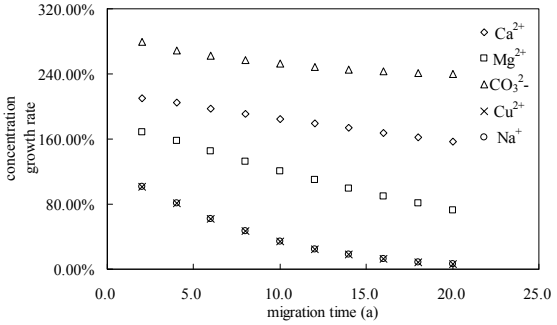
Fig. 9 Variation of Na^+ concentration with migration depth

3.4 Influence of water pressure on ion migration

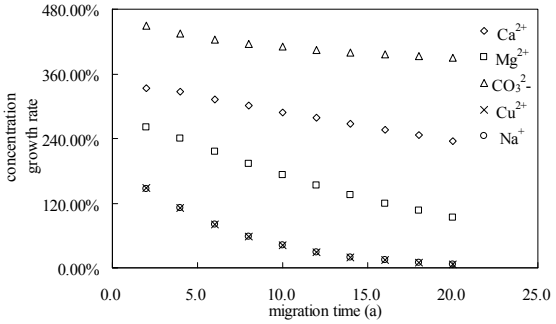
Compared with the concentration variation of Ca^{2+}, Mg^{2+}, Cu^{2+}, Na^+ and CO_3^{2-} under the water pressures with 0m,10m, 20m and 30m expressed as H_0, H_1, H_2 and H_3, the concentration growth rates of the five ions are calculated respectively under the water pressure difference with $\Delta H_1=H_1-H_0=10.0$m, $\Delta H_2=H_2-H_0=20.0$m, $\Delta H_3=H_3-H_0=30.0$m, as shown in Figure 10.



(a) ΔH_1=10.0m



(b) ΔH_2=20.0m



(c) ΔH_3=30.0m

Fig. 10 Influence of water pressure on growth rate of ion concentration

[1] With the migration time increasing, the growth rates of the ion concentrations gradually decrease under the different water pressure.

[2] Under the same migration time and different water pressure, the descending order of the five ions in concentration growth rate is: CO_3^{2-}, Ca^{2+}, Mg^{2+}, Cu^{2+},Na^+; In other words, the five ions in descending order of migration velocity sensitivity to the variation of water pressure are CO_3^{2-}, Ca^{2+}, Mg^{2+}, Cu^{2+} and

Na^+.

[3] Under the water pressure with 10m, 20m, 30m, the concentration growth rates of CO_3^{2-} are 105.56%-133.75%, 239.59%-279.17% and 390.51%-450.00% respectively, which indicates that the promotion of each additional 10m water pressure to CO_3^{2-} migration become increasingly obvious.

[4] The promotions of water pressure to the migration of Ca^{2+}, Mg^{2+} and CO_3^{2-} have the similar effects with that of CO_3^{2-}, but converse effects with that of Cu^{2+} and Na^+, that is to say, the promotion of each additional 10m water pressure to the migration of Cu^{2+} and Na^+ become increasingly weak. In summary, under the same water pressure difference, the higher the absolute water pressure is, the stronger the promotion to the migration ability of Ca^{2+}, Mg^{2+} and CO_3^{2-} becomes, instead of that of Cu^{2+} and Na^+.

[5] The measured data in Yanqun landfill shows the similar regulation with that of numerical simulation results.

3.5 Clay compaction degree influence on ion migration

The effects of clay compaction degree on ion migration are shown as follows.

[1] At the same migration time, when the clay compaction degree increases from 78.55% to 89.83%, the descending order of the five ions in concentration decrease rate is CO_3^{2-}, Ca^{2+}, Mg^{2+}, Na^+ and Cu^{2+}.

[2] Compared with the promotion of water pressure to ion migration, the inhibition of clay compaction degree to ion migration is more obvious, which proves that the higher the clay compaction degree is, the stronger the interception capacity becomes.

Combined with the regulations about the compaction degree of clay layer in the bottom of reservoir area in the *Technical code for sanitary landfill of municipal domestic refuse*, the compaction degree of the clay liner layer of Yanqun landfill is suggested as not less than 93.00%.

4. Mechanisms of Migration of Life Source Contaminant in Compacted Clay Layer

With the migration of life source contaminants in soil layer, the exchange of such ions as Na^+, Ca^{2+} and CO_3^{2-} with the ions adsorbed on the surface of clay particles reduces the thickness of the electrical double layer, leading to the cohesion for the gravitation enhancement among the particles, thus causing the increase of pore size and then promoting the migration of contaminants in clay layer. Such metal ions as Cu^{2+} in contaminants react with $NH_3 \cdot H_2O$ can produce the precipitation $Cu(OH)_2$. Subsequently, $[Cu(NH_3)_4]^{2+}$ can be produced through complex reaction, which can increase the ion concentration of life source contaminants and clay porosity, thus promoting the migration of contaminants. Meanwhile, the carbonate precipitation can be created by the chemical reaction between CO_3^{2-} in life source contaminants and ions on the surface of clay particles, which can reduce clay porosity and inhibit the migration of contaminants. Additionally, a large amount of organic matters with macro molecular and their intermediate metabolites existing in the degradation process can produce CH_3COOH and release H_2O and CO_2 finally. The gas produced can reduce the soil saturation degree, thus inhibiting the migration of contaminants. However, CO_2 dissolved in H_2O can produce H_2CO_3, declining the solution pH, which increases the solubility of the insoluble salts and chemical reaction rate. Consequently, the migration of life source contaminants can be promoted.

5. Conclusions

Based on the generalized model of Yanqun landfill site, the migration of Na^+, Cu^{2+}, Mg^{2+}, Ca^{2+}, and CO_3^{2-} in clay liner layer is simulated under different clay compaction degrees and water pressures. Furthermore, the variation of the pollution plume and concentration with migration time and depth are predicted. The results show as follows.

[1] The descending order of the five ions in migration velocity is Na^+, Cu^{2+}, Mg^{2+}, Ca^{2+}, and CO_3^{2-}.

[2] The descending order of the five ions in concentration growth rate is CO_3^{2-}, Ca^{2+}, Mg^{2+}, Cu^{2+} and Na^+ with the increase of water pressure, which can greatly promote the migrations of such ions as Ca^{2+}, Mg^{2+} and CO_3^{2-} with slow initial velocity.

[3] The descending order of the five ions in concentration decrease rate is CO_3^{2-}, Ca^{2+}, Mg^{2+}, Na^+ and Cu^{2+} with the increase of clay compaction degree, which can greatly inhibit the migrations of such ions as Ca^{2+}, Mg^{2+} and CO_3^{2-} with slow initial velocity.

[4] The migration mechanisms of contaminants in clay layer are revealed from such perspectives as ion exchange, complex reaction, biochemical reaction and inorganic sediment. Finally, the proposed clay compaction degree is not less than 93.00% according to the technical code for sanitary landfill.

Acknowledgements

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