Risk assessment for hazardous waste storage site material aging and groundwater contamination

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Abstract—Storage sites are the main sites for solid waste storage and also involve environmental pollution risks, but the aging of geomembrane materials and the evolution of defects in hazardous waste storage yards in service environment, which may lead to long-term increase in leakage and sudden increase in pollution risks, have received less attention from scholars. Taking a hazardous waste storage site in northern China (the main solid waste is cadmium-containing slag) as an example, the geomembrane damage characteristics (vulnerability density) and aging characteristics (aging onset time and half-life) were obtained through on-site dipole testing and laboratory geomembrane performance assessment. On the basis of this, we used a hydrological process assessment model (HELP) to simulate the rainfall-evaporation-runoff-infiltration and leachate generation processes under regional scale conditions, and a landfill groundwater contamination risk simulation model (Landsim) to simulate the lateral discharge-leakage processes inside the storage site and the migration-diffusion behavior in the saturated-unsaturated zone after leakage under the aging and defect evolution of geomembrane materials.

1. Introduction

Hazardous wastes are diverse and complex in nature, and the differences in characteristics and types determine the risk to human health is not the same[1], if the same disposal method is used for hazardous wastes with large differences in hazards, unscientific and bound to increase management costs[2]. Therefore, before disposal, they are usually collected and stored in a unified hazardous waste storage site, and a certain amount of hazardous waste with corrosive, acute toxicity and other dangerous properties, in the storage site, if combined with rainwater will form a toxic and corrosive leachate, and leachate usually contains a variety of heavy metals, inorganic and organic substances and other pollution components[3], once the leakage from the storage site to the seepage zone and aquifers and other environmental For example, cadmium, a heavy metal in leachate, can cause chemical pneumonia and acute respiratory failure when ingested in excess in humans[4].

Domestic and foreign scholars have used various approaches to confirm the importance of risk assessment of storage sites. For example, Gholami, R. et al. assessed the risk of leakage from carbon dioxide storage sites[5]:, Cai, B. et al. studied the composition and pollution characteristics of aluminum ash slag and made suggestions and theoretical references for the environmental risk prevention and control of aluminum ash slag storage[6]. Some countries and regions are also bound in the form of laws and regulations and national standards. For example, China's Hazardous Waste Storage Pollution Control Standard (GB 18597-2001) [7] requires that hazardous waste centralized storage facilities should focus on factors such as leakage of hazardous substances, generation and diffusion of atmospheric pollutants (including malodorous substances), and the risk of accidents that may arise from hazardous waste centralized storage facilities [8].

It is not difficult to find that previous studies have rarely addressed the study of groundwater contamination from hazardous waste storage sites , and even if some studies have addressed the impact on groundwater quality, they have not considered the risk assessment of groundwater contamination from the aging of core impermeable materials in storage sites[9]. However, storage yards, as the main storage unit during waste pre-disposal, may lead to potential risks to the environment that cannot be ignored[10]. In order to remedy the shortcomings of the above studies, this paper uses Landsim and HELP models to establish a risk assessment model for leachate leakage and groundwater contamination under the aging conditions of impermeable materials in hazardous waste storage sites, and analyzes the impact of leachate leakage from storage sites on groundwater quality, and uses a hazardous waste storage site in northern China as a case study to This study provides a theoretical reference for the environmental management of hazardous waste storage sites and the prevention and control of environmental risks in storage.

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2. Models and Methods

In this study, the HELP model was used to simulate the leachate generation characteristics under meteorological rainfall conditions; Landsim was used to simulate the leachate leakage and post-leakage migration transformation behavior in the saturated-unsaturated zone under geomembrane material aging conditions. The aging and defect evolution parameters of geomembrane materials required by Landsim were obtained through field dipole detection and indoor analytical tests, and the specific methods are described as follows.

2.1. Leachate generation prediction method

HELP is a quasi-two-dimensional hydrologic model capable of rapidly evaluating and accounting for precipitation accounting for evapotranspiration, leachate collection and liner leakage. The HELP model is also capable of estimating daily, monthly, and annual scale rainfall, temperature, and solar radiation data for over 3000 locations worldwide. In this study, the HELP model was used to directly generate rainfall and solar radiation data for the study area and calculate runoff, evapotranspiration, leachate collection, and pile infiltration. The infiltration volume of the mound is then used as the design infiltration volume, and the permeability coefficient of the geomembrane in HELP is changed from the value of the design infiltration calculation to 0 or the same value as the underlying soil layer to calculate the aging infiltration volume, which is then input into Landsim.

2.2. Leachate migration transformation prediction method

LandSim was used in a storage site with a similar impermeable structure to a landfill. The process of leachate generation from storage site waste under geomembrane aging is simulated, followed by seepage through geomembrane loopholes and eventually reaching groundwater where it can migrate and disperse. The focus of this study is to simulate the aging process of storage site geomembranes using landsim.HDPE membrane is short for High Density Polyethylene membrane. Although the aging of modern HDPE membrane materials is effectively controlled through reasonable design and the addition of materials such as carbon black, it is difficult to be completely eliminated, and the aging of HDPE membranes leads to a decrease in their permeability performance and an increase in the number and area of holes in the membrane.

The aging of the cover layer is mainly manifested as a decrease in the ability to block leachate seepage, leading to an increase in the infiltration volume of the pile. Landsim assumes that there is a change in the infiltration volume of the aging situation. The four important parameters involved are the design infiltration rate obtained by HELP calculations and the infiltration rate after complete aging; and the method described in section 3.2 is used to determine whether aging occurs and when aging begins and ends.

Landsim assumes that the aging of geomembranes in the liner layer at the bottom of the storage field will inevitably result in defects (e.g., pinholes, holes, etc.) during the design and construction process, mainly in the form of an increase in the number or area of defects over time. It assumes that defects on HDPE membranes increase when they begin to age and that the defect area will periodically double. The holes in the geomemrane are determined according to the test method in section 2.3; the spatial density of defects is determined by the ratio of the number of defects to the area of the bottom of the storage field.

2.3. Aging parameters determination and defect detection methods

In this study, the dipole method (Dipole Method) recommended by the US EPA was used to detect the holes in the membrane. The basic principle is to use the high resistance of HDPE membranes by placing a power supply electrode at the top and bottom of the membrane and connecting it to the two ends of the high voltage signal source to locate the holes accurately based on the collected abnormal potential signals.

Scholars believe that the aging process of geomembranes can be generalized in a 3-stage model, with the three stages being: the antioxidant depletion stage, the oxidation-induced stage of the polymer, and the aging failure stage. When the storage field infiltration (design infiltration) starts to increase gradually, the HDPE membrane performance decreases to 50% of the initial performance, the HDPE membrane starts to age and its life is considered to be terminated. The standard indicators for HDPE films, and their limits, are 14 in total, including: oxidation induction time (standard OIT), tensile yield strength, etc.

3. Case studies

Take a hazardous waste storage site in northern China as an example. The storage site covers an area of 3.8 hm2. During leachate sampling and analysis, the characteristic pollutant cadmium was selected as the target pollutant for risk assessment based on the leachate detection concentration and the groundwater Class III standard.

The parameters required for Landsim simulations are: infiltration parameters, waste characteristics parameters, impermeable system parameters, and porous media water flow and solute transport parameters (shown in Table 1). The infiltration and impermeable system parameters in the table are calculated from the HELP model and tested in the field.

Table 1 Parameter name and value

Project	**Parameter**	**Value***	**Source**
Infiltration	Natural infiltration (*mm*/a)	N(509,56)	2
	Infiltration after closure (*mm*/a)	N(20,3)	2
Storage site and waste characteristic parameters	Waste dry density (kg/l)	U(1.5,1.7)	1
	Waste porosity (%)	0.54	1
	Drainage blanket thickness(m)	0.03	1
Parameters of anti-seepage layer	Defect density (#/ha)	4	1
	Geomembrane permeability coefficient (*m*/s)	3×10^{-7}	3
Water flow and solute transport parameters in porous media	Longitudinal diffusion coefficient of vadose zone (m)	0.002	1
	Aquifer transverse dispersivity(m)	2×10^{-4}	1
	Longitudinal dispersion of the aquifer(m)	0.02	1

Note*: The parameters of code 1 are measured in the field or derived from the design values, code 2 is obtained by calculation, and the parameters of code 3 refer to the default values given by Landsim. n, Lt, Lu, and U stand for normal, logarithmic triangular, logarithmic uniform, and uniform distributions, respectively; the column "Source".

As described in Section 2.1, the HELP model was used to generate the annual rainfall (426-602 mm) for the case area. Of this amount, 357-507 mm is converted into evaporation, a very small amount into surface runoff, and the rest is infiltrated into the waste storage site. The infiltration rate designed by statistical analysis of 10 years of infiltration is normally distributed (20,3) mm/a.

In this study, the average number of holes in both the primary and secondary impermeable layers of the storage yard was determined to be 4/ha using the method in Section 2.3. To test the performance of the HDPE geomembrane, we tested 12 performance indicators (Table 2) of the collected samples. The test results showed that the oxidation induction time (OIT) of the geomembrane for this project was 101.67 min (>100 min), which indicates that the geomembrane of this storage site is still in the depletion stage of antioxidants. Further, the performance residual rate is calculated according to the aging failure criterion. From the table, it can be seen that the performance residual rate of all indicators exceeds 100%. The geomembranes performed well and did not start aging.

Table 2 Geomembrane performance discount rate and residual performance percentage

Indicator		Unit	Standard value	The current test	
				Current Value	Residual properties
Tensile Yield Strength	Vertical	N/mm	29	39.8	137%
Tensile breaking strength		N/mm	53	63.05	119%
Tensile elongation at yield		%	12	13	108%
Tensile elongation at break		%	700	826.5	118%
Tensile Yield Strength	Horizontal	N/mm	29	38.45	133%
Tensile breaking strength		N/mm	53	58.85	111%
Tensile elongation at yield		%	12	14	117%
Tensile elongation at break		%	700	832	119%
Longitudinal right angle tear strength		N	242	381.5	158%
Transverse right angle tear strength		N	242	401.5	166%
Puncture strength		N	640	807.5	126%
OIT		Min	100	101.67	102%

4. Results and Discussion

Using the HELP-Landsim coupled model, exposure points at 50m, 400m, 800m were selected for risk analysis, and short-term (3 years, 5 years), medium-term (10 years, 30 years) and long-term (100 years) leachate seepage and groundwater contamination were simulated as follows.

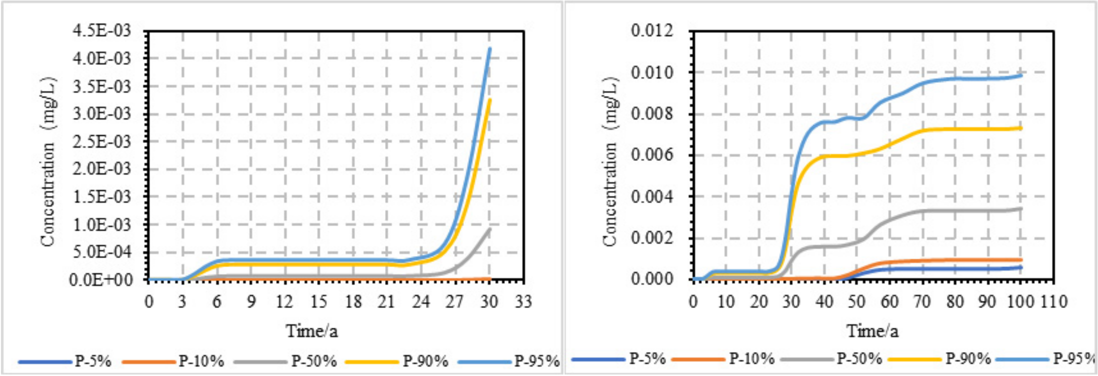
4.1. The variation pattern of leakage volume with time

The site design parameters and meteorological parameters of the Chifeng storage site were brought into the HELP model, and the amount of leachate generated in the storage site during the predicted period (10 years) was 1290-2550 m^3/year, most of which was collected centrally through the drainage system, and a very small amount (0.012-0.04 m^3/year) would leak through the holes in the HDPE membrane of the impermeable layer. The leakage volume at the initial moment is close to 0, which is because the storage site is equipped with multi-layer clay liner, whose permeability coefficient is very small, and the seepage liquid needs to experience a long time to pass through the clay liner. However, as the infiltration time increases, the volume of leachate in the pile gradually increases, the saturation water level on the impermeable membrane rises, and the intensity of leakage gradually increases.

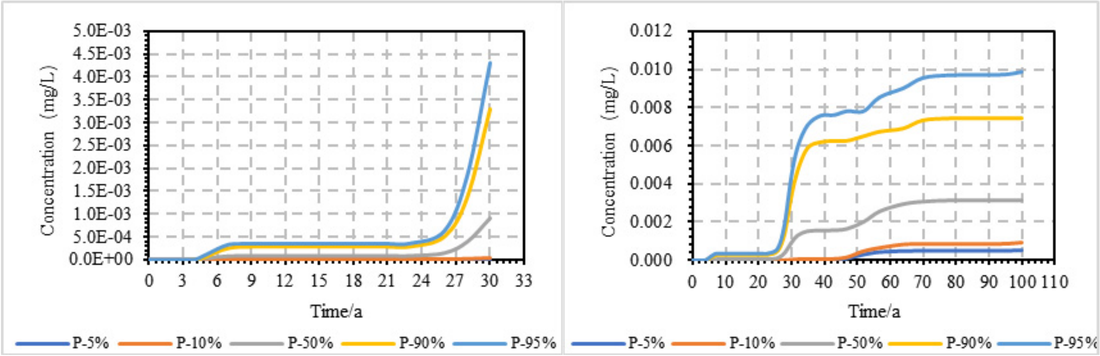
4.2. Risk of groundwater contamination

According to the storage records and testing data, the main solid waste of the storage site is cadmium-containing sludge, so the analysis focused on the impact of cadmium concentration on groundwater. Figure 2-5 shows the variation of cadmium concentration with time at different exposure points. 50% quantile value is the predicted value of contaminant concentration at average risk level, which is chosen for analysis to reflect the impact of storage leakage on groundwater under general conditions. The Chinese groundwater III water quality standard (GB/T14848-93) stipulates that the concentration of cadmium in groundwater should be less than or equal to 0.005 mg/L. It can be seen from the figure that the peak concentrations at 800m, 400m and 50m exposure points in the short term (0~5a) are also 0 in 0~3a, and the peak concentration at 50m in 3~5a is 0.00024mg/L, which is much lower than the groundwater quality standard of Class III, and the environmental risk is acceptable. Further considering the long-term risk of the main storage unit, it can be seen from Figure 1(e) and (f) that the cadmium concentration in groundwater at the exposure point at 800m under the 50% quantile value is 3.9×10-4mg/L and 3.4×10-3mg/L at the monitoring time of 30 and 100 years, respectively, which do not exceed the groundwater Class III water quality standard and the environmental risk is acceptable. This is mainly because the geomembrane of the case storage site has no aging reaction, so it has strong pollution interception ability.

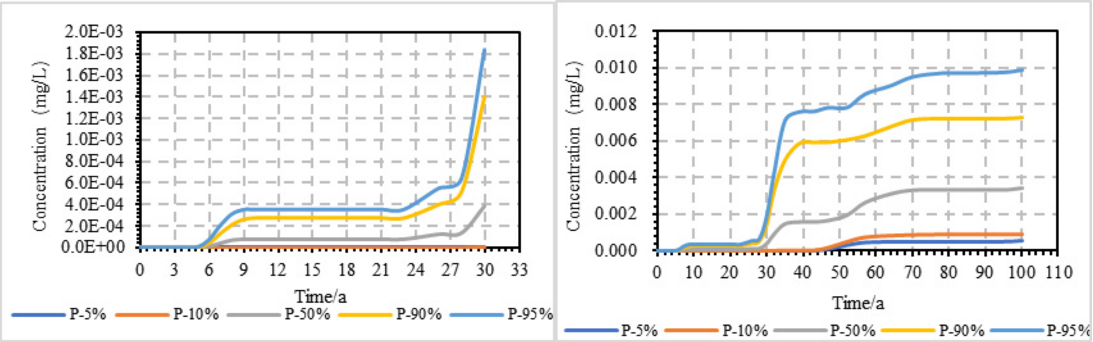
Therefore, we recommend that more attention be paid to the aging process and service life of HDPE GM in the actual service environment. In addition, it is recommended to locate and repair the defects of HDPE GM by geoelectric testing before storage site operation, thus reducing the possibility of leakage, and more attention should also be paid to long-term monitoring and risk assessment of storage site.



(a) Exposure point:50m Time:30a (b) Exposure point:50m Time:100a



(c) Exposure point:400m Time: 30a (d) Exposure point:400m Time: 100a



(e) Exposure point:800m Time: 30a (f) Exposure point:800m Time:100a

Figure 1 Decay of cadmium concentration at different distances with time

5. Conclusion

(1) Using the HELP-LandSim coupled model and combined with the field test data, a risk assessment model of aging of engineering materials and leachate leakage of hazardous waste storage sites was established and applied to specific cases. The study showed that the residual rate of all index properties of the case site exceeded 100%. The oxidation induction time of geomembrane is 101.67min ＞ 100min, so the case storage site is still in the consumption stage of antioxidant, no aging reaction has occurred, and the influence of material aging on risk assessment is small.

(2) The concentration of pollutants at the same exposure point increases with the growth of leachate leakage time. For example, at the 50m exposure point of the case site, the concentration result under the 50% quantile is 0.0034mg/L in the 100th year, which is obviously larger than the concentration diffusion result in the 30th year (0.0009mg/L), but it is smaller than the limit concentration of cadmium (0.005 mg/L), so the risk of pollution is small.

(3) The concentration of pollutants in the same period becomes smaller with the increase of monitoring distance. For example, the case site in the monitoring time of 100 years, take the concentration results under the 50% quantile value, the concentration diffusion results of the 400m (0.0031mg/L) is significantly smaller than the concentration results of the 50m (0.0034mg/L).

(4) According to the current performance assessment of the material, decreasing with distance in the long term, the concentration of pollutant cadmium at 800m of the exposure point is still lower than the groundwater class III standard at the 100th year, and the probability of exceeding the standard is 0, which is sufficient to prove that the geomembrane of the storage site has good impermeability and has not been aged. This practical study also brings some guidance for the safe water supply for the residents around the local storage site.

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