Application Status of Vertical Barrier Technology in Site Contamination Remediation

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Abstract. The development of industry has brought serious heavy metal pollution in the soil. There are various kinds of site contamination remediation technologies. The slurry wall barriers technology has many advantages, such as low permeability, good chemical compatibility, and low cost, so it was widely used in groundwater and soil pollution control projects. In this paper, the application status of vertical barrier technology in contaminated sites is reviewed. Currently, those research progress at home and abroad payed more attention on barrier materials, barrier mechanisms, and site types.

1. Introduction

In recent years, with the development of industry and the acceleration of urbanization, a series of problems have arisen such as soil heavy metal pollution and groundwater pollution. This has caused many countries and regions to face water shortages. Therefore, the protection and restoration of contaminated sites has become one of the most important tasks currently underway. Since the 1970s, foreign countries have successively conducted a lot of research on the control and repair technology of contaminated sites. The control and remediation technologies are mainly divided into the following three stages: First, pollution source control; second, pollution diffusion control; and third, contaminated site restoration. Source control is the key. Its main methods are: controlling the emission of pollutants, interception of pollutants, and treatment of pollutants. Diffusion control is mainly the interception control[1], and the use of technologies such as the construction of water-retaining systems and low-permeability walls. The main purpose of these methods is to delay and prevent the movement of pollutants so as not to pollute clean soil, remediation technologies are mainly used in situ repair and ectopic repair techniques[2]. Repair technology can effectively and completely remove pollutants, but due to the complexity of site conditions and surrounding environmental conditions, the repair cost is high and the repair time is quite long, and the effect is not ideal[3].

The barrier technology is used to separate the contaminated site from the surrounding environment, so that the contaminants are sealed in situ, blocking the migration of pollutants, cutting off the route of exposure, and protecting the safety of the groundwater body. The barrier technology has the advantages of mature technology, low cost, short construction period, and good barrier effect for different types of pollution, and is widely used in risk control of contaminated sites[4]. The barrier technologies are divided into three categories: cover barrier technology, vertical barrier technology,
and horizontal barrier technology. In this paper, the application status of vertical barrier technology was introduced from three aspects: barrier material, barrier mechanism, and site type.

2. Barrier materials

The vertical barrier technology is mainly divided into mud wall, grouting wall, sheet-pile wall, deep soil mixing, geomembrane and lining technology[5]. In order to prevent the migration of pollutants, the permeability coefficient of the barrier wall material is usually required to be very low and often required less than $10^{-7}\text{cm/s}$[6] in practical applications. At present, the main barrier materials are divided into two categories: one is chemical slurry, and the chemical slurry can be injected well into fine pores and crevices in the soil layer. However, the wall formed by the chemical slurry has low strength, poor durability, secondary pollution, and high price, so it is not widely used. The second category is cement, clay, bentonite and other inorganic materials. This type of inorganic material is widely used because it has very low permeability, good consolidation performance, low price, and wide source. Here we focus on inorganic materials.

Opdyke et al.[7] adopted three kinds of materials: slag, cement and bentonite, and used different formulations to block the wall and tested the hydraulic conductivity and compressive strength of the wall material. The slag content was the main research object, when its content within 60%, the permeability of the material is not affected; when the content exceeds 70%, the permeability increases sharply, but its compressive strength increases by 10~20%. Kashir M[8] et al conducted a study on the chemical compatibility of backfill materials and acidic mine wastewater. The barrier wall was prepared using with 6% content of bentonite and backfill soil of carbon-rich/carbon-depleted organic matter. By soaking, experiments found that carbon-rich backfill has a good retention effect on heavy metals, and can neutralize the pH value of acidic wastewater, and carbon-poor backfill soils have poor barrier effect on heavy metals and neutralization of wastewater pH. The addition of some inorganic dispersants can change the physical properties of the barrier wall, and a small amount of sodium hexametaphosphate dispersant is added to the soil-bentonite barrier wall, resulting in a drastic drop in the liquid limit, sediment volume, and apparent viscosity of the material. However, the high-dose dispersant has little change in the above physical properties[9]. Some scholars modified the soil-calcium bentonite materials by adding zeolites with different contents and different particle sizes. The operability, compressibility, and hydraulic conductivity of the mixed materials were determined by the slump and consolidation experiments. The results show that fine particles Zeolite has little effect on compressibility and hydraulic conductivity[10]. Abbaslou H studied the compatibility of sepiolite on bentonite barrier wall, the results show that the addition of a certain amount of sepiolite can increase the permeability of the wall, the adsorption of heavy metals, reduce cracks and increase the service life[11]. Industrial solid waste cement ash mixed with soil-bentonite were used to prepare a low permeability barrier wall and showed that cement ash can well replace ordinary silicate cement. What’s more, it have many advantages as low permeability and high strength.

3. Theory

The migration mechanisms of pollutants in soil are mainly divided into convection migration, mechanical dispersion, molecular diffusion and adsorption[12]. The main pollutant migration mechanism formulas are shown in Table 1.

Lv Shuqing[13] discussed the blocking mechanism of the soil-bentonite barrier wall using the one-dimensional solute transport equation model. When the wall thickness is large, the one-dimensional convection dispersion model can be used for the solute transport process; when the wall thickness is small, the convection model is mainly used. Xie Haijian[14] studied the transport behavior of pollutants in stratified soils and deduced the analytical solution of the one-dimensional convection dispersion equation to predict the migration of inorganic and organic materials in soil, geomembrane and soil-bentonite materials. In the situation, the simulation results are in good agreement with the experimental cases. Pan Qian[15] established the stress calculation model of the barrier wall under the surrounding environment, and revealed the force mechanism of the
soil-bentonite barrier wall and the influence law on the wall permeability coefficient. Li Zhenze[16] systematically analyzed the adsorption and desorption characteristics and mechanism of four common heavy metal ions (Cd, Cu, Pb, Zn) in two typical soils under the influence of various factors. He proposed a new method for inversion of transport parameters based on mass concentration and newly defined the desorption partition coefficient based on the desorption process, accordingly proposed an analytical method for the desorption isotherm, developed a test method that can simulate the remediation process of contaminated soils, and obtained a series of meaningful conclusions. Chen Yonggui[17] established a mathematical model for the migration of pollutants in a clay-solidified grouting curtain and performed simulation calculations. The basic equations for the transport of leachate and pollutants in the curtain (soil) and groundwater were summarized, detailed derivation of the continuity equation of groundwater seepage, first derived the leachate flow differential equation based on the time-dependent permeability coefficient, and discussed its definite solution conditions and numerical solutions. Carreto[18] proposed a mechanism to explain the slurry walls for contaminant migration barrier by the microstructure model. The chemical reaction between the pollutant and the wall resulted in the change of the pore structure and further affected the permeability of the wall. Anderson[19] calculated the performance of a barrier cutoff wall under different recharge and water head conditions by analytical solution and numerical solution analysis, and deduced the overall performance model formula for evaluating the barrier wall.

Table 1 Contaminant transport mechanism

| Type               | Formula                        | Instructions                                                                 |
|--------------------|--------------------------------|-----------------------------------------------------------------------------|
| Convection         | $v_a = -k_z \frac{\partial h}{\partial z}$ | $v_a$: Darcy speed. $k_z$: Permeability coefficient. $h$: Total head. $z$: Flow direction. |
|                    | $J_{d1} = v_a C_i$              | $J_{d1}$: Convective flux. $C_i$: Concentration. When pollutants flow in the pores of the wall material under the action of the driving force of the hydraulic gradient, pollutants are carried in the pores at the speed of the water body. |
| Mechanical dispersion | $D_{md} = \alpha v_s$ | $D_{md}$: Diffusion coefficient [L^2T^{-1}]. $\alpha$: Dispersion degree [L]. $v_s$: Percolation velocity [LT^{-1}]. |
| Molecular diffusion | $J_{d2} = -D_i \frac{\partial C_i}{\partial z}$ | $J_{d2}$: Molecular diffusion flux [ML^2T^{-1}]. $D_i$: Effective diffusion Coefficient [L^2T^{-1}]. |
| Adsorption         | $S = k_d C_i$                  | $S$: Adsorption capacity [\text{unit}]. $k_d$: Linear adsorption distribution coefficient [M^2L^3]. |

4. Site types
At present, major pollution sites at home and abroad are divided into: sanitary waste landfills, mine waste dumps, tailings ponds, waste chemical production sites, nuclear waste landfills, and seawater intrusion.

Sun Xiaodong[20] compared rigid vertical barriers through a hazardous waste emergency control project in Jingjiang City, Jiangsu Province, and adopted flexible vertical barriers to better block the hydraulic links between landfilled pollutants in the site and the surrounding soil and groundwater. The flexible vertical barrier has the characteristics of good anti-seepage performance, strong anti-deformation ability and long service life. Chen Suyun[21] took a chemical plant relocation site risk control as an example, and conducted applied research of barrier technology from the aspects of feasibility, cost, time, and effectiveness of risk control to provide basis for the implementation of engineering control technology at home.

Luca[22] and others used the numerical simulation software MODFLOW to analyze and calculate...
the barrier wall in a lake basin in Italy and studied the effect of the barrier wall on the groundwater body. The results showed that the barrier wall effectively blocked the migration of pollutants and protected the groundwater body. Carreto[23] studied the wall left behind in the history of the monastery of Santa Clara Vila, and the barrier wall can well blocked the migration of pollutants and protected the groundwater body.

The problem of underground environmental pollution caused by seepage of leachate in simple landfills has received increasing attention and attention from the society. The treatment of such simple landfills is usually a comprehensive remediation measure, among vertical anti-seepage curtains are the most important pollution control measures and have been widely used. Liu Wei[24] based on the investigation results of the landfill site in Huainan City, Anhui Province, conducted an analysis of the migration law and influencing factors of pollutants in the subsoil of a simple landfill site, then forecasted and assessed the pollution development trend of the landfill site. Zhang Wenjie[25] proposed that under the condition of high head water, the blocking mechanism of the barrier wall in landfills was analyzed from the aspects of convection, diffusion and adsorption.

The problem of seawater intrusion has been plaguing coastal cities and threatens groundwater resources and soil resources. Jr R L[26] studied the discharge of residual salt water from barrier walls through laboratory experiments and numerical simulations. The results showed that when the slurry wall was shallow, the residual salt water could be returned in a very short time, gave the minimum wall depth at the same time, and provided some theoretical guidance on the management of seawater intrusion. Kaleris[27] used numerical analysis to evaluate the influence of barrier walls on seawater intrusion and groundwater exploitation, and deduced a dimensionless variable equation. Abdoulhalik[28-29] proposed a barrier wall with an impervious wall combined with a semi-permeable surface dam to prevent seawater intrusion. Using a combination of digital imaging system laboratory experiments and numerical simulation software, the results showed that this new type of barrier wall could effectively prevent the intrusion of seawater and could drain residual salt water through the action of reflux.

5. Conclusions
(1) At present, the barrier wall materials at home and abroad are soil-bentonite, cement-clay-bentonite, etc. These materials have the characteristics of low permeability (<10⁻⁷ cm/s), strong adsorption, and low cost, and were widely used in engineering control repair system.
(2) The blocking mechanism is mainly based on the solute transport equation, which considers the convection, dispersion, adsorption and other factors under different conditions.
(3) The contaminated sites can be classified into solid waste landfills, mine waste dumps, tailings dumps, nuclear waste disposal sites, and seawater intrusions due to different uses and modes of action. And research on pollution at different sites has been conducted at home and abroad.

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