Application of permeable reactive barrier in groundwater remediation

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Abstract. As a new in-situ remediation of groundwater, compared with the traditional “pump and treat” technology, the permeable reactive barrier (PRB) has the advantages of low cost, no external power, the small disturbance to groundwater, small secondary pollution and long-term operation, this paper introduces the basic concept of PRB, technical principle, structure type, the principle of active materials selection and mechanisms of remediation, design and installation factors, it provides ideas for further research and application of PRB technology in groundwater remediation projects in China.

1 Foreword

Groundwater resources are important resources affecting the development of national economy. However, with the continuous advancement of industrialization in China, groundwater pollution is becoming more and more serious and the scope of pollution continues to expand. Therefore, in order not to affect the development of national economy, the remediation and treatment of groundwater is imminent. The traditional extraction treatment technology for groundwater remediation not only has high cost, great disturbance to groundwater, but also is easy to form the further diffusion of pollutants [1]. A large number of remediation examples show that the use of extraction treatment technology for groundwater remediation can achieve short-term remediation effect, but it is affected by the type of pollutants and site conditions, and some pollutants in groundwater after remediation are completed. Concentration will rebound and need to be remedied repeatedly to reach the standard. PRB technology, as an in-situ groundwater remediation technology, is widely used in Europe, America and other countries. It has the characteristics of low cost, no external power, little disturbance to groundwater, little secondary pollution and long-term operation. At present, PRB technology gradually replaces the traditional extraction treatment technology abroad.

PRB technology installs the designed permeable reactive barrier downstream in the vertical direction of groundwater flow without external power. Under the action of groundwater hydraulic gradient, pollutants migrate with groundwater runoff, react physically, chemically and biologically with the active materials in the reaction barrier, and remove different types of pollutants in groundwater [2], so as to achieve the purpose of groundwater remediation. European and American countries have carried out a large number of experimental

studies and engineering practices over the past 30 years. At present, there are a large number of applications in groundwater pollution remediation sites. However, PRB technology research in China started relatively late, and there are few engineering applications at present. Therefore, it is of great significance to understand and learn the progress of international advanced PRB technology and engineering experience for the treatment of groundwater pollution in China. The structure of PRB, the mechanism of pollutant removal and the application of active materials are introduced in this paper.

2 Introduction of PRB

2.1 Technical principle of PRB

Permeable reactive barrier (PRB) technology mainly intercepts groundwater pollution plumes by installing reactive barrier filled with permeable active materials downstream of groundwater flow, so that pollutants can adsorb, precipitate, redox and biodegrade with active materials in the reaction barrier, and remove or transform pollutants in groundwater, so as to achieve the purpose of groundwater remediation.

Fig.1. Diagram of permeable reaction barrier

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2.2 Structural types of PRB

As an in-situ remediation technology for groundwater in polluted sites, PRB technology should be selected according to site conditions and hydrogeological conditions. PRB reactive barrier is located downstream of pollution plume of groundwater. The reactive barrier is perpendicular to the direction of groundwater flow. Pollutant concentration can be up the standard of groundwater through the action of reactive barrier and active materials. Therefore, the selection of PRB structure types is one of the important links and key factors for the effect of groundwater remediation. Several factors are mainly considered in the selection of PRB structure types. First, pollutants can be reversed by groundwater. The reactive barrier can fully react with the active materials; the second is that the reactive barrier can not block up during operation and has good permeability; the third is that the reactive barrier can completely intercept groundwater pollution plume and prevent groundwater pollution plume from passing under the reactive barrier. At present, the typical PRB structure types at home and abroad are continuous reactive barrier types, funnel-water gate types and injection types.

1) Continuous reactive barrier

Continuous reactive barrier is to install permeable reactive barrier downstream of groundwater pollution plume. The reactive barrier must include the width and depth of the whole pollution plume, that is to say, to ensure that the whole groundwater pollution plume can pass through, and the thickness of the reactive barrier must ensure that the treated groundwater concentration reaches the standard. Continuous reactive barrier has the advantages of simple design, convenient installation and less interference to ground water. It is suitable for polluted sites with small water level burial depth and small pollution plume. Once the polluted area of the site is large or the ground water is deep, the construction cost of PRB reactive barrier of this structure type is rather high and not economical enough.

Fig.2. Continuous reactive barrier

Fig.3. Funnel-water gate

2) Funnel-water gate types

The funnel-water gate is proposed, which is in order to make up for the deficiency of continuous reactive

barrier in treating groundwater polluted sites with wide pollution range and large depth. The funnel is embedded in the water barrier, and the groundwater is guided into the water diversion gate. After the water is diverted, the active reaction medium in the reactive barrier is used to treat the water so as to prevent pollution. The dyed feathers enter the non-polluted area downstream.

The funnel-gate PRB is mainly composed of a water-proof funnel, a water-proof gate and active materials. The water-proof funnel is embedded in the water-proof layer to prevent the polluted plume from seeping into the downstream non-polluted area. The water-proof funnel consists of a water-proof curtain or a cut-off barrier, which guides the groundwater flow into the water gate and then treats it through the permeable reaction medium. In view of some specific pollution characteristic sites, funnel-gate PRB can provide one or more dense treatment areas to maximize the capture of groundwater pollution plumes; funnel-gate PRB has a smaller reaction area and is easy to replace and remove when the reactive barrier is blocked by reactive sediments and fine soil particles. Material, so funnel-gate PRB field adaptability is better. In addition, according to different site conditions, multiple funnel-gate PRB systems can be set up simultaneously in series or in parallel.

3) Injection PRB

When groundwater is polluted deeply, the excavation cost of PRB reactive barrier with the above two types of structure is often high and its operability is affected. Therefore, the treatment zone can be formed by injecting remediation agent directly into groundwater (i.e. injected PRB). The treatment areas of injection wells overlap with each other, so as to make the treatment zones of injection wells overlap with each other. After the pollutants in groundwater react fully with remediation agents, the purpose of removing pollutants is achieved.

Injected PRB has the advantages of relatively simple structure and low cost, but it requires high permeability of site stratum. Theory and engineering practice prove that this type of structure is often not suitable for aquifers with poor permeability. At the same time, the remediation agent reacts with adsorption, blockage and agglomeration in porous soil media, and the remediation agent is repaired. Complex influence radius is limited [1].

Fig.4. Injection PRB

3 Active materials and its remediation mechanism

3.1 Selection principle of active materials

Regardless of the type of PRB reactive barrier, it is necessary to add some active materials in the barrier or reactor to remove the contaminated components in the polluted groundwater. The key to the success of PRB technology is to select the appropriate active filling in the reactive barrier. The suitable active filling should be selected according to the type, composition, concentration, range and different hydrogeological conditions of groundwater pollutants, taking into account the physical and chemical properties, cost and other factors of the active filling. Generally speaking, the selection of active materials should consider the following five factors:

1) Activity of the reactants. Active materials should have the activity matching with pollutant composition and concentration, and have enough degradation ability to remove pollutants thoroughly during the residence time in the reaction zone.

2) Permeability of reactive barrier. The permeability coefficient of the reactive barrier is generally more than twice that of the aquifer. The larger the particle size of the active materials, the better the permeability of the reactive barrier, the easier the pollution plume to pass through, the shorter the reaction time, and the insufficient reaction results in the increase of the cost. On the contrary, the smaller the particle size of the active materials, the larger the specific surface area and the higher the material activity, but its permeability is poor, and the pollution plume is increased. The longer the residence time is, the longer the treatment time is. Therefore, the weight of activity and permeability should be fully considered when selecting active materials.

3) Stability of active materials. In groundwater polluted environment, the acidity and alkalinity of groundwater affect the formation of precipitation. Therefore, by adjusting the acidity and alkalinity of groundwater in the reaction area, the influence of precipitation on the permeability of reactive materials can be reduced and the long-term operation of the system can be ensured.

4) Cost and availability of active materials. On the premise of guaranteeing its activity, active materials should select materials with low price and easy access, so as to achieve the best economic performance of PRB.

5) Prevention of secondary pollution. Active materials should be selected as materials that do not produce secondary pollution or minimal pollution in the inter-mediate products during the reaction.

3.2. Remediation mechanism of active materials

3.2.1 Common active materials

The types of pollutants are also the key factors to select the active materials expect the above principles. The removal mechanism of pollutants is generally adsorption, precipitation and degradation according to the different types of pollutants. At present, the main active materials are zero-valent iron, iron oxide, activated carbon, clay minerals and zeolite. Phosphates, etc.

3.2.2 Mechanisms of remediation

The remediation mechanism of PRB can be divided into biochemical degradation and physical adsorption exchange process. The remediation mechanism of active materials in removing pollutants is different, mainly depending on the physical and chemical properties of groundwater, pollutant composition and concentration, hydrogeochemical conditions.

1) Biochemical degradation can be divided into redox reaction and microbial degradation. Through chemical and biological action, the target pollutants can be converted into non-toxic or less toxic substances. Redox reaction is a chemical reaction between the target pollutant and the active materials. The pollutant is precipitated or the harmless substance is left in the PRB reactive barrier. It can also pass through the PRB reactive barrier. At present, the most commonly used redox active materials at home and abroad is zero-valent iron, which releases electrons in groundwater when dealing with chlorinated organic pollutants in groundwater. As an electron acceptor, chlorinated hydrocarbons react with it to dechlorinate or dehydrogenate chlorinated hydrocarbons, thus removing chlorinated hydrocarbons pollution. The mechanism of biodegradation is favorable. The purpose of removing pollutants from groundwater is to use the growth and metabolism of microorganisms in groundwater to consume organic matter.

2) Physical adsorption and exchange is to adsorb pollutants on the surface of active materials or form precipitation to fix pollutants in PRB reaction area through adsorption, precipitation and ion exchange, so as to reduce the concentration of target pollutants in groundwater. Adsorption is to make full use of the characteristics of large specific surface area of active materials. Pollutants are adsorbed on the surface of active materials particles. The adsorption mechanism of different active materials are also different. For example, activated carbon can remove organic pollution, zeolite can remove heavy metal ion pollution in groundwater, and cationic surfactant can be used. In order to increase the adsorption capacity of porous media to organic matters, the mechanism of precipitation reaction is that low-soluble pollutants are precipitated and precipitated, so as to purify groundwater.

The mechanism of PRB technology for removing groundwater pollutants is complex and varied. The influence mechanism of acidity and alkalinity, redox potential and dissolved oxygen in groundwater on active materials are not very clear. Therefore, more mature and clear reaction medium should be selected as active materials in practical engineering application.

4 Design and installation

In order to enable PRB to operate long-term, efficiently and steadily, the site characteristics should be analyzed at the beginning of design, including groundwater pollution characteristics, pollutant types and concentrations, topography, hydrogeological conditions, geochemistry and other factors. Firstly, the site pollutant migration

model and groundwater hydrodynamic model should be established, and the appropriate active materials should be preliminarily selected. After that, the half-life of pollutants, hydrogeological parameters and geochemical parameters are determined through laboratory or field tests, and the installation location, direction, structure type and size of PRB are designed by constantly adjusting and adjusting parameters combined with hydrogeological numerical simulation. Finally, the installation of PRB reaction unit and cutoff barrier is guided by reasonable construction scheme, and the appropriate PRB is selected on this basis. Monitoring and maintenance program. In general, the following factors should be considered in the design and installation of PRB:

1) Permeability of reactive barrier [3]. The permeability of the barrier is usually required to be twice that of the aquifer, but to achieve the best results, the permeability of the barrier must be more than 10 times that of the aquifer. Because there are many restrictive factors, the permeability of the system decreases with time. For example, the inflow and deposition of fine soil particles will reduce the pore volume of the barrier and reduce its permeability; the precipitation and precipitation of carbonate (calcium carbonate and magnesium carbonate), the precipitation and precipitation of such compounds as iron oxide, iron hydroxide, ferrous carbonate and other metals; the growth of uncontrollable microorganisms will form the so-called biological plugging phenomenon, and other factors that may reduce the permeability of the system. Therefore, in order to ensure its permeability, barrier s are often designed to consist of filter, screen and reaction materials. At the same time, changes in groundwater physical and chemical characteristics (temperature, pressure, oxygen content, pH, nutrient composition) should be avoided. It should be known that if these changes are beneficial to pollution control, they should be utilized without doubt.

2) Filling and thickness of reactive barrier. Usually according to the different types of pollutants, degradation rate and groundwater flow rate and other factors. For example, when the groundwater flow rate is relatively fast, the barrier must be very thick in order to ensure full contact between the reaction medium and pollutants, but at the same time, the construction cost is increased.

3) Replacement of active materials. The design of reactive barrier should consider the renewal of active materials after several years or decades of operation of the system.

4) A pipeline system should be designed in the barrier to inject water or air for flushing to remove sediment or sediment, or to mix materials.

5) Openings should be designed to monitor and inspect the reactive barrier system and update the reaction materials.

The main barrier factors mentioned above include geology and hydrogeology (topography, groundwater depth, aquifer thickness, groundwater flow direction, aquifer permeability, hydrogeochemistry, etc.), concent-

ration and scope of pollutants, site human activities, costs, etc. [6].

5 Expectation and discussion

5.1 Expectation

As a new remediation technology of in-situ groundwater pollution, PRB compared with others, not only does not need to extract groundwater from the ground for treatment, disturb the flow of groundwater, but also does not need continuous external power in the operation process. Not only the PRB can remedy various types of sites, but also the cost is more lower. Although PRB technology has better development prospects and many advantages mentioned above, the following problems need to be solved and perfected urgently if it is to be applied more widely in the future.

5.2 Discussion

1) PRB technology can not guarantee the treatment effect of each pollutant, and has a certain randomness. Therefore, the selection of active materials, the types and components of pollutants should be considered comprehensively in future research and engineering application.

2) With the accumulation of groundwater pollutants on the surface of the reactive barrier, the blockage of the reactive materials cause it to lose its activity gradually. Therefore, the periodicity of the replacement of the reactive materials should be considered comprehensively in the design of PRB to ensure its treatment efficiency.

3) It is difficult to ensure the effective time for the immobilization of heavy metals by active materials when heavy metal is remedied by PRB, and to determine which environmental conditions may lead to the reactivation of heavy metal contaminants. Therefore, the effective period of immobilization and which environmental condition may lead to the reactivation of heavy metals be considered comprehensively in depth research;

4) The reaction between reactive materials and some substances in groundwater may produce toxic intermediate products, which may cause secondary pollution. Therefore, the mechanism of remediation should be fully considered to avoid secondary pollution when selecting reaction materials.

5) The design process of PRB is greatly influenced by the characteristics of pollutants and the hydrogeological parameters on site. It is necessary to establish pollutant migration model and groundwater dynamic model, to accurately understand the hydrodynamic characteristics of groundwater, the migration and transformation of pollutants before the design of PRB. Therefore, the collection of preliminary data and experimental work are needed in the preliminary stage.

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