Research progress of in-situ remediation of polluted soil and groundwater by electrokinetic and permeable reaction barrier

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Abstract. The combination of electrokinetic remediation and permeable reactive barrier (EK-PRB combined remediation technology) is a new green technology for in-situ removal of soil and groundwater pollutants. This technology combines the advantages of electrokinetic remediation and permeable reactive barrier technology, and can deal with different types of organic and inorganic pollutants. It has the characteristics of convenient installation, simple operation, no secondary pollution, etc., and has broad development and application prospect. This paper introduces the technical principle of EK-PRB, summarizes the latest research results on the remediation of heavy metal, organic matter and nitrate contaminated soil and groundwater by the electrokinetic remediation and PRB. Finally,the technical problems of combinated remediation were pointed out, and development and application direction of this technology was noted.

1 Introduction

The pollution of groundwater and soil in China is very serious, the main pollutants are heavy metal ions and toxic and harmful organic compounds. According to the survey, more than 50% of urban groundwater is polluted to varying degrees[1-2]. At present, the remediation technologies for soil and groundwater pollution include soil remediation, solidification stabilization, leaching, chemical oxidation, thermal desorption, plant remediation, electrodynamic remediation and permeable wall remediation [3-8].

Because of the difference of soil composition, pollutant types and properties in polluted sites, especially in the case of compound pollution, single remediation technology is often difficult to achieve the remediation goal, and the combination of electric remediation technology and other remediation technology has been paid more and more attention. Among them, the combination of electrokinetic remediation technology and permeable reaction barrier (EK-PRB) technology is the combination of electric remediation technology and permeable reaction barrier (PRB) technology Combined with the advantages of electric and permeable reaction grid technology, this technology can repair the inorganic and organic contaminated soil in situ at the same time. What's more, this technology not only has a strong ability to repair the poor permeable contaminated soil, which is not affected by the site, temperature and other factors, but also it can effectively prevent the secondary pollution caused by restoration, and the cost of restoration is relatively low. This technology is becoming a research hotspot in the field of soil environmental remediation at home and abroad [9-12]. In this paper, the principle and application of ek-prb technology are reviewed in detail.

2 Technical principle of EK-PRB

2.1 Formatting the title, authors and affiliations

The basic principle of EK-PRB technology is to set the permeable reaction barrier with reducibility in the electric field. The heavy metal ions and macromolecular organic micelles in the polluted soil move to the electrodes at both ends under the driving of electric power. In the process of moving, the pollutants are degraded by the permeable reaction barrier. The technology can effectively reduce the toxicity of pollutants while removing them.(Figure 1 is the basic principle diagram of EK-PRB Technology).

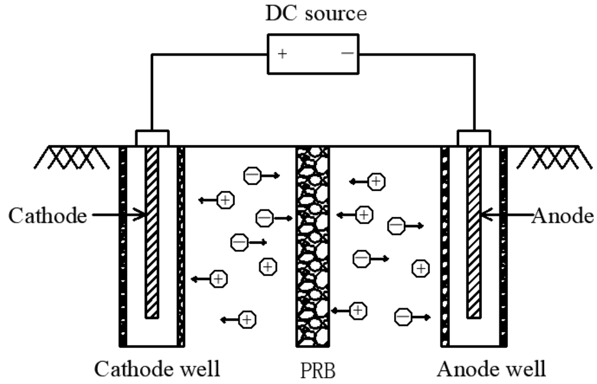

Fig. 1. Basic principle diagram of EK-PRB technology.

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The successful application of this technology is due to two reasons: first, the pollutant moves in a directional direction under the action of external electric field, so that PRB can operate under the action of hydraulic gradient; second, the adsorption of pollutant by PRB reaction medium can effectively reduce or prevent the pollution of external electrode.

3 Research progress of EK-PRB

3.1 Remediation of heavy metal pollution

At present, the remediation of heavy metal and metalloid contaminated soil by EK-PRB technology mainly involves arsenic, cadmium, chromium, nickel and arsenic. The United States, the United Kingdom and other countries have carried out large-scale test and field research on the electrokinetic remediation and PRB joint repair technology, and achieved some results. Nader Shariatmadari et al.[13] used the electrokinetic remediation and PRB combined remediation technology to treat chromium contaminated soil, and compared with the single EK technology, when the voltage gradient was 2V / cm and the PRB material was zero valent iron for 24 hours, when the PRB was set, the removal rate of total chromium was 17-19%, and the removal rate of hexavalent chromium was 75-90%. Compared with the single EK, the removal rate of hexavalent chromium was increased by about 60%, and the removal rate of total chromium was increased by 5% %. When PRB is placed 2cm away from anode and the pH of cathode electrolyte is controlled around 6, the removal rate of total chromium can reach 42% [13].Chung and Lee [14] reported the satisfactory results of EK-PRB in remediation of cadmium contaminated soil on the basis of laboratory experiments. Their removal rate of cadmium and trichloroethylene by using atomized slag as PRB reached 90%. Saeedi et al. [15] studied the removal of Ni from kaolin by the combination of active carbon permeable reaction wall and EK. The removal efficiency of Ni in kaolin with high pH reached 50%. Weng et al. [16] studied the application of EK-ZVI to remove chromium (VI) from clay on the basis of laboratory. They used a constant voltage gradient of 2V / cm to repair 144h, and obtained the removal rate of chromium of 60-70% and 100% reduction efficiency. In this process, the energy consumption is also quite high. When they reduced the voltage gradient to 1V / cm, the removal efficiency of chromium increased from 68.2% to 85.0% .

The research on EK-PRB combined repair is relatively late in China. In 2006, Weng et al.[16] From Shouyi University in Taiwan reported for the first time that Cr^{6+} in soil was restored by the combination of electrokinetic remediation and PRB. When the ratio of zero valent iron and quartz sand was 1:2, the removal rates of Cr^{6+} and total chromium were 100% and 71%, respectively, when the voltage gradient was 1 ~ 2V / cm. The removal mechanism of Cr (VI) was also discussed: the oxidation-reduction reaction of Cr (VI) with Fe^0, Fe^{2+} and the precipitation of Cr (III) and Cr (VI) in PRB. Hu Hongtao et al.[17] removed cadmium from water and soil by electric PRB simulation test. When zero valent iron and activated carbon were used as media, the removal rate was about 73% . Yuan and Chiang [18-19] used EK-PRB system to treat arsenic contaminated soil. In the experiment, the removal rate of as (Ⅵ) in the control group with reaction wall increased 51% ~ 60% after 5 days of power on, which was 1.6 ~ 2.2 times of that in the control group without permeable reaction barrier.

3.2 Remediation of organic pollution

At present, there are many researches on the remediation of soil polluted by chloro organic substances, such as tetrachloroethylene (PCE), trichloroethylene (TCE), etc. Wan et al. [20] used micro Pd/Fe powder to permeate the wall and surfactant TX-100 (octylphenol ethoxylate) to repair the yellow brown soil polluted by hexachlorobenzene (HCB). It was found that the removal rate of HCB increased by 40% - 50% compared with the single electric remediation. Yang Jinzhong et al. [21] used EK-PRB (Fe^0) system to treat pentachlorophenol and 1,1,2,2-tetrachloroethane. The results showed that when the amount of iron powder material was larger, the removal rate of pollutants was higher; the amount of iron powder and the treatment time were the key factors to remove 1,1,2,2-tetrachloroethane, and their contribution rates were 11.0% and 70.87% respectively; when the particle size of iron powder was 165-245 μm, the mass fraction of iron powder was at 0.2%, 1,1,2,2-tetrachloroethane was the best, 69.56%. Mena et al.[22] used bioreactor membrane as PRB medium to treat clay polluted by diesel oil. The degradation rate of diesel oil was 39% when sodium dodecyl sulfonate was added to the cathode as cosolvent for 336h. The main reason is that the cosolvent makes the diesel oil emulsification flow with electroosmosis.

Liao Xuanfei et al. [23] used ekrprb (Fe^0) to repair TCE contaminated soil. It was found that there was no significant difference in the removal rate of TCE by using graphite, copper, zinc and other electrodes of different materials, but it was positively related to the voltage gradient. With the increase of applied voltage gradient, the removal rate of TCE could be increased from 32% to 76%. When it was increased to 2V / cm, the removal rate of TCE could reach 100%. Liu Youchang et al[24] used this technology to treat the soil polluted by trichloroethylene and 4-chlorophenol, and added iron powder as PRB medium, the removal rate of trichloroethylene was 88.9%, and the removal rate of 4-chlorophenol was 49.84%. Yuan Jing, Zhang Rixing and other researchers [25] studied the best position of PRB, using graphite as electrode and zero valent iron as PRB material. Yuan Zhu and other researchers found that when the position of reaction wall moved from anode to cathode, the removal rate of tetrachloroethylene increased from 44% to 66%. The main reason is that the reaction time between pRB and pollutant is sufficient when PRB is at the cathode. However, Zhang rihang et al.[26] came to the opposite conclusion: when PRB was placed on the anode, the highest removal rate of tetrachloroethylene was 78%, because the H^+ produced by anode electrolysis kept the zero valent iron active, and it was conducive to the release of electrons from the zero valent iron wall for reductive dechlorination [26].

3.3. Remediation of nitrate pollution

The combined remediation technology of electrokinetic remediation and permeable reaction barrier has a high removal efficiency of nitrate in contaminated soil, which can achieve satisfactory remediation effect. Under laboratory conditions, chew et al. [27] first tried to combine electric remediation technology with zero valent iron PRB for remediation of nitrate contaminated soil. It was found that the addition of PRB greatly improved the remediation efficiency of nitrate. Suzuki et al. [28] under the laboratory conditions, the nitrate nitrogen conversion rate was 25% - 37% when the nitrate polluted soil was repaired by electric motor alone, while the conversion rate was 54% - 87% when ekr-prb (Fe0) was repaired, the conversion rate was doubled, and the main conversion products were ammonia nitrogen and nitrogen gas. Li Xiaolan [29] treated the soil polluted by nitrate with nano zero valent iron powder wall and electric remediation method. The removal rate of nano iron powder (50-80nm) with mass fraction of 0.28% could reach 98.06%. Setting a permeable reaction wall in the electric field can greatly improve the removal efficiency of nitrate, but the particle size of reductant added in the reaction wall is an important parameter affecting the removal efficiency. At present, PRB technology is mostly used in remediation of nitrate contaminated soil [30], while the research on the application of EK-PRB in remediation of nitrate contaminated soil and groundwater is still relatively small.

4 Conclusions

EK-PRB combined remediation technology combines the advantages of EK and PRB. It has a wide range of applications, high economic benefits and less secondary pollution. It will have a broad application prospect in the field of in-situ remediation of contaminated soil and groundwater, but there are still some problems to be further studied. EK-PRB technology is mainly based on laboratory research. Most of the experimental soil is simulated contaminated soil, and the pollutants in the actual contaminated site are more complex, so the current laboratory research cannot be well used to repair the actual contaminated site. In addition, PRB media material cost is high, the actual repair site consumption is large, resulting in waste of resources. The optimal position of reaction barrier is still controversial. When there are multiple reaction walls, the relative position between the walls and the optimal distance between the walls and the anode and the cathode are still uncertain. In the process of repair operation, there is the phenomenon of electric field polarization. Besides, under the action of electric field, harmful by-products such as chlorine, trichloromethane and acetone may be produced, which need to be further solved.

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