Application research of enhanced in-situ micro-ecological remediation of petroleum contaminated soil

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Abstract: Experimental study of enhanced in-situ micro-ecological remediation of petroleum contaminated loess soil was carried out in Zhongyuan oil production areas, and the enhanced in-situ micro-ecological remediation technique includes optimistic in-situ microbial communities, physical chemistry methods, alfalfa planting and regulation of soil environmental elements. Experiments showed that the oil content in the contaminated soil with oil content about 2898.25 mg/kg can be reduced about 98.61% after in-situ micro-ecological remediation for 99 days, which demonstrated the effectiveness of in-situ micro-ecological remediation methods for petroleum contaminated soil in central plains of China, and explored the practical and feasible application of these methods.

Keywords: Central plains; Oil contamination; Enhanced in-situ; Micro-ecological remediation

Introduction

The long-term and large-scale oil exploitation tends to result in the oil-based contamination of soil vadose zone and the serious environmental problems within the oil production zone. The management and remediation of oil contamination in soil have become the key issues in the environmental protection work. As indicated in Jorgensen's experiment, the oil contents in petroleum contaminated soil can be reduced by 71% (Jørgensen K S et al. 2000) after the biological reasoning is conducted. The main concern of microbial remediation technique is to get oil hydrocarbon directly involved in microbial biochemical reactions, and degrade the soil contaminants through metabolism (DeBont J A M, 1998). The development and research of soil microorganism remediation technique have drawn the widespread attention from international community of environmental science (Mishra S and Jyot J, 2001; Gallego J L et al. 2001; Rabus R et al. 2005; Chaerun S K et al. 2004). It is reported that oil contains over 200 kinds of hydrocarbon-based microbes in over 200 genera, which fall into the category of bacteria, actinomyces, mold fungi, yeast and alga (SHEN Tie-meng et al. 2002; LIN Li et al. 2000; ZHANG Hai-rong et al. 2001; HE Yi et al. 2005). The comprehensive micro-ecological remediation technique, which makes full use of in-situ microflora (native microbes) with the support of physical and chemical methods, and involves growing plants and regulating soil environmental elements, is an in-situ microbial remediation technique to change macro environment through micro-effects. When this technique is used, the key issue is the enhanced combination, interdependence and interaction of in-situ native microbes and soil environment and the regulated environmental elements. The improvement in temperature, water, oxygen, nutrients and soil environment is an elements regulating effort. This technique can apply to in-situ management and protection of oil environment, accelerated conversion of elements, and degradation of toxic and detrimental materials in order to boost the easier
absorption of nutritious substances by living things. The specific remediation methods have such advantages as simple procedure, low cost, effective performance, limited environmental effects, no additional contamination and possible in-situ management. The innovative part of this research is the practical research of comprehensive micro-ecological remediation technique in the petroleum contaminated soil when an effort is made to stimulate the combination of in-situ native microbes and plants. The research results can not merely generate considerable economic, ecological and social benefits, but get widely used in petroleum contaminated areas like oilfield production zones, oil pipeline’s peripheral areas, gas stations and petrochemical plants. They will offer the strong technical supports for petroleum contaminated soil in a practical sense.

1 Overviews of experimental plot

The experimental plot is located in Huzhuang Township, about 309 km in the southeast of Puyang in Zhongyuan Oilfield, Henan Province. This area has the soil seriously contaminated by high-saline reservoir water and crude oil due to the explosion of oil transmission pipeline in 1991, when the leaked crude oil and high-saline reservoir water was about 200 m$^3$–300 m$^3$ and the affected farmland exceeded 0.66 hm$^2$ with the irrigation depth of over 30 cm on average and the fracture of oil pipeline was almost as deep as 2 m. It is a typical area with the serious petroleum contaminated soil problem within Zhongyuan Oilfield. As the site of remediation, it served as a good example.

The basic data are collected for experimental plot before remediation is started. First, we should obtain the topsoil samples of experimental plot. The soil lithology is the khaki silt soil with a small amount of 2–10 mm gravels or ginger stones. Soil bulk density: 1.72 g/cm$^3$, natural water content: 16.3%; pH: 7.4–7.9; salt content: 1 416 mg/kg–18 650 mg/kg; topsoil oil content: 767.7 mg/kg–5 028.8 mg/kg (an average of 2 898.25 mg/kg); soil bottom: 25 cm–50 cm; oil content: 313.6 mg/kg; pH: 8.5; salt content: 203 mg/kg. The test data are described in Table 1 and Table 2.

<table>
<thead>
<tr>
<th>Code</th>
<th>Sampling depth (cm)</th>
<th>Water ratio (%)</th>
<th>Wet bulk density (g/cm$^3$)</th>
<th>Dry bulk density (g/cm$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT0906-6</td>
<td>0–25</td>
<td>16.3</td>
<td>1.72</td>
<td>1.48</td>
</tr>
</tbody>
</table>

Table 2 Pre-remediation sampling for the measurement of pH, EC, TDS, salinity and oil content (mg/kg)

<table>
<thead>
<tr>
<th>Code</th>
<th>Sampling depth (cm)</th>
<th>pH</th>
<th>EC (μs/cm)</th>
<th>TDS (mg/l)</th>
<th>Salinity (%)</th>
<th>Oil content (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PT0906-5</td>
<td>0–25</td>
<td>7.4</td>
<td>37 300</td>
<td>18 650</td>
<td>1.86</td>
<td>5 028.8</td>
</tr>
<tr>
<td>PT0906-6</td>
<td>0–25</td>
<td>7.9</td>
<td>2 846</td>
<td>1 416</td>
<td>0.14</td>
<td>767.7</td>
</tr>
<tr>
<td>PT0906-7</td>
<td>25–50</td>
<td>8.5</td>
<td>406</td>
<td>203</td>
<td>0.02</td>
<td>313.6</td>
</tr>
</tbody>
</table>

Leveling and partition of experimental plot: When the experimental plot is selected, the explosion point of oil pipeline should be defined as the center with a peripheral area of over 0.2 hm$^2$. The experimental plot is divided into five remediation sub-zones with different remediation conditions. For No.1 experimental plot, the optimized microbial agents are added for different plants within about one 0.07 hm$^2$. For No.2 experimental plot, the optimized microbial agents are added and alfalfa is plants within about 0.03 hm$^2$. For No.3 experimental plot, the optimized microbial agents are added and ryegrass is planted within about 0.03 hm$^2$. For No.4 experimental plot, nutrients are added and alfalfa is planted within about 0.04 hm$^2$. For No.5 experimental plot, nutrients are added and ryegrass is planted within about 0.04 hm$^2$. The remediation has a designed depth of 0–25 cm, and the final testing is as deep as 50 cm. This paper chooses No.5 experimental plot to introduce and analyze the remediation progress. In this zone, the microbial nutrients are added for the enhanced activity of in-situ native microbes. This study will be very meaningful for the future application on a
large scale. Meanwhile, some intricate procedures like optimized culturing and implementation of microbial agents can be avoided. Ryegrass, which is similar to wheat, provided the scientific basis for growing crops within the experimental plot in the future (some previous papers have been published for other experimental plots).

2 Materials and analysis methods

2.1 Materials

Chemical reagents: MgSO$_4$·7H$_2$O, NH$_4$NO$_3$, CaCl$_2$, FeCl$_3$, KH$_2$PO$_4$, K$_2$HPO$_4$, KCl, HCl, petroleum ether and CHCl$_3$ are all the analytical reagents, which are produced by Beijing Beihua Fine Chemicals Co., Ltd. and Tianjin Sitong Chemical Plant, and are purchased by Beijing Luqiao Technology Co., Ltd.

Additives: Wheat bran or some short wheat straws (mainly local winter wheat).

Main compositions of nutrient solution: MgSO$_4$, NH$_4$NO$_3$, CaCl$_2$, FeCl$_3$, KH$_2$PO$_4$, K$_2$HPO$_4$.

Main instruments: QZD-1 electromagnetic vibrator, KQ218 ultrasonic cleaner, biological shaker incubator, high-speed centrifuge, high-pressure sterilizer, sterile lab, biochemical incubator, shimadzu UV2550 ultraviolet visible spectrophotometer, pHB–3 type pH meter, DDB-303A conductivity meter, electrically heated drying oven and different glass instruments for chemical analysis.

2.2 Analysis and testing methods

The ultraviolet spectrophotometry applies to petroleum and NO$_3^-$, and Na’s reagent colorimetric method applies to NH$_4$+; pH uses pHB-3 type pH meter and TDS uses DDB-303A conductivity meter.

The analysis method for bacteria content and degrading oil bacteria content: Research Methodology of Soil Microbes (Microbe Research Office of Nanjing Soil Research Institute of Chinese Academy of Sciences, 1995), and the methods as introduced in References (LIN Li et al. 2000; ZHANG Hai-rong et al. 2001; YAO Zhi-hua et al. 2006).

3 Remediation procedures

Step 1: The site for remediation is leveled up and divided into several testing zones. As far as additives are concerned, wheat bran is evenly scattered at the quantity of about 10 500 kg each hm$^2$ within each experimental plot. After multiple plowing and rotary tillage are completed by tractors, the additives can be evenly involved in the remediation layer.

Step 2: Use a sprayer to spray the prepared nutritional supplements of 750 L each hm$^2$.

Step 3: Spray 1 500 kg of fertilizer and urea and phosphorus-potassium nitrate fertilizer each hm$^2$.

Step 4: Use tractor to mix the newly added fertilizer and liquid nutrients into remediation layer after rotary tillage for several times.

Step 5: Plant ryegrass within experimental plot as required.

Step 6: Irrigation, because considerable water content in soil following over 30 mm of rainfall; the absence of irrigation wells around experimental plot renders watering attempts impossible.

The water content in experimental plot remains at its natural level. Sampling is conducted within a given interval. The sampling method is to get the soil samples of the same depth (0–25 cm) from five different points and perform the coning and quartering method following the sufficient mixture. The tested compositions include oil quantity, pH, soluble salt in soil, water content, NH$_4$+ and NO$_3^-$. Furthermore, the temperature of topsoil and test soil is monitored. When the test period ends, sampling is performed within the strata under test layers.

4 Remediation results and discussions

4.1 Remediation results

The remediation results are shown in Table 3. Based on the whole remediation process and methods, we can draw conclusions as follows:

For the soil seriously contaminated by high-saline reservoir water and crude oil due to the explosion of oil transmission pipeline, The
comprehensive micro-ecological remediation technique, which uses nutritional agents to stimulate in-situ native microflora and plant the ryegrass, is used together with physical and chemical methods and regulation of soil environment. The regulation and remediation results of nutritional and environmental elements in soils within experimental plot show that the pre-remediation oil content in soil averages 2,898.25 mg/kg, and the post-remediation oil content in soil drops to 40.35 mg/kg following the strong in-situ microbial remediation for 99 days, implying the degradation of 98.61%. Since there is no water source available near the experimental plot, the high salt content in soil is not well utilized at the beginning of remediation period for cleansing and discharging, the coupling by precipitation and evaporation results in unsteady salt content in soil. So some negative effects are imposed on the growth of ryegrass. This phenomenon can be changed for better in the future remediation. Yet, the remediation process has produced some obvious results as a whole, and the seriously petroleum contaminated soil has resumed its ecological functions. This test has proved the practical value of comprehensive micro-ecological remediation technique for remedying the petroleum contaminated soil in Zhongyuan Oilfield.

Table 3 Test results of oil content varying with time in the soil of experimental plot (mg/kg) and removal rate (%)

<table>
<thead>
<tr>
<th>Sampling date (M/D)</th>
<th>Pre-remediation content</th>
<th>7/7</th>
<th>7/15</th>
<th>7/23</th>
<th>8/3</th>
<th>8/11</th>
<th>8/19</th>
<th>9/2</th>
<th>9/22</th>
<th>10/15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of test days (d)</td>
<td></td>
<td>3</td>
<td>10</td>
<td>18</td>
<td>28</td>
<td>36</td>
<td>44</td>
<td>56</td>
<td>76</td>
<td>99</td>
</tr>
<tr>
<td>Content mg/kg</td>
<td>2,898.25</td>
<td>572.6</td>
<td>133.3</td>
<td>34.62</td>
<td>10.9</td>
<td>23.51</td>
<td>36.99</td>
<td>-</td>
<td>60.51</td>
<td>40.35</td>
</tr>
<tr>
<td>Removal rate %</td>
<td>0</td>
<td>80.24</td>
<td>95.4</td>
<td>98.81</td>
<td>99.62</td>
<td>99.19</td>
<td>98.72</td>
<td>-</td>
<td>97.91</td>
<td>98.61</td>
</tr>
</tbody>
</table>

4.2 Discussion

4.2.1 Removal rate of oil in soil

As shown in Table 3, different nutritional elements and additives are provided and some ryegrass is planted within the experimental plot when the above-stated remediation is conducted on site. The oil residuals in soil has a removal rate of over 95%, but nutrients cannot produce the instant stimulation of native microflora at the beginning of remediation period, and their activity will gradually increase to a small extent. In summer when topsoil has high temperature (about 25 °C–30 °C), microbial activity will start the logarithmic period after the stimulation of liquid nutrient for one to five days, and will get much stronger. When remediation continues for 99 days, removal rate will become 98.61%. Statistically, the remediation results are satisfactory enough. But the data are somewhat unsteady. This means that the oil contamination in soil is uneven and complicated. In particular, some small lumps generated by the contamination of crude oil can affect the measurement results. What’s more, some changes to each sampling location are also one of the contributors. Also, the analysis of errors can exert some effects as well. The ryegrass sowing time should range from the early September to the early November. The growth of ryegrass will be affected as well in July. However, in general, the degradation and remediation effects of oil residuals in soil are significant by stimulating the activity of native microflora in soil and planting the ryegrass. In other words, the degradation and remediation effects of oil residuals in soil are feasible after nutrients, additives and fertilizers are applied and the ryegrass is planted.

4.2.2 Analysis of soil pH, soluble salt (TDS), $\text{NH}_4^+$, $\text{NO}_3^-$, degrading bacteria and total bacteria contents

According to the monitoring results of pH value in Table 4, the liquid nutrients have the high phosphate content, so some amounts of phosphate buffering agents in soil can make sure pH value remains within the scope of 7.0–8.0, mostly around 7.5. For most oil degrading bacteria, an ideal environment is the neutral-alkaline soil. The ryegrass can grow in different terrains and soils.
But the most preferential condition is the soil with soft texture and pH value of 6–7. Therefore, pH value scope within the experimental plot has a limited effect on this comprehensive micro-

Table 4 Test results of pH, TDS, NH$_4^+$, NO$_3^-$, degrading bacteria and total bacteria content varying with time in the soil of experimental plot

<table>
<thead>
<tr>
<th>Sampling date (M/D)</th>
<th>Background value</th>
<th>7/7</th>
<th>7/15</th>
<th>7/23</th>
<th>8/3</th>
<th>8/11</th>
<th>8/19</th>
<th>9/2</th>
<th>9/22</th>
<th>10/15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of test days (d)</td>
<td>3</td>
<td>10</td>
<td>18</td>
<td>28</td>
<td>36</td>
<td>44</td>
<td>56</td>
<td>76</td>
<td>99</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>7.4</td>
<td>7.7</td>
<td>8.0</td>
<td>7.6</td>
<td>7.0</td>
<td>7.6</td>
<td>7.2</td>
<td>7.1</td>
<td>7.1</td>
<td>7.4</td>
</tr>
<tr>
<td>Soluble salt (mg/kg)</td>
<td>18.650</td>
<td>1.640</td>
<td>249</td>
<td>780</td>
<td>1.882</td>
<td>831</td>
<td>890</td>
<td>849</td>
<td>769</td>
<td>1.569</td>
</tr>
<tr>
<td>NH$_4^+$ (mg/kg)</td>
<td>56.74</td>
<td>336.88</td>
<td>56.74</td>
<td>87.47</td>
<td>184.02</td>
<td>178.51</td>
<td>55.51</td>
<td>31.97</td>
<td>80.6</td>
<td>20.18</td>
</tr>
<tr>
<td>NO$_3^-$ (mg/kg)</td>
<td>28.14</td>
<td>22.69</td>
<td>4.9</td>
<td>-</td>
<td>90.69</td>
<td>236.7</td>
<td>34.43</td>
<td>94.16</td>
<td>88.73</td>
<td>263.93</td>
</tr>
<tr>
<td>Degrading bacteria (cfu/g)</td>
<td>2.5×10$^3$</td>
<td>2.0×10$^6$</td>
<td>8.1×10$^7$</td>
<td>2.4×10$^8$</td>
<td>7.0×10$^9$</td>
<td>2.0×10$^{10}$</td>
<td>1.0×10$^{11}$</td>
<td>5.0×10$^{12}$</td>
<td>4.0×10$^{13}$</td>
<td>3.0×10$^{14}$</td>
</tr>
<tr>
<td>Total bacteria content (cfu/g)</td>
<td>1.5×10$^6$</td>
<td>1.2×10$^7$</td>
<td>6.2×10$^8$</td>
<td>2.4×10$^9$</td>
<td>1.9×10$^{10}$</td>
<td>3.2×10$^{11}$</td>
<td>2.5×10$^{12}$</td>
<td>5.2×10$^{13}$</td>
<td>2.5×10$^{14}$</td>
<td>5×10$^{15}$</td>
</tr>
</tbody>
</table>

The necessary water content should be guaranteed within experimental plot. After all, water is an integral substance for the survival of cell and an important medium and oxygen source in the oil contaminants degrading process by microbes and plants. The water content should remain at a level of about 20% within experimental plot. The selected remediation period should fall within the local rainy season (June to September). According to the local precipitation data, the annual precipitation is 564.2 mm, including 375.4 mm during the rainy season, and the rainfall frequency is about 5–10 days. So the soil water can get recharged and the water content in soil can be ensured within the experimental plot, thus promoting the oil degradation by microbes and ryegrass.

In general, salt content in soil have limited effects on microbial growth, but substantial effects on the growth of ordinary plants. The excessive salt content may disable or kill plants to some degree. TDS content is a key indicator of salt content in soil. Table 4 shows that the pre-remediation salt content within the experimental plot is extremely high, but the salt content falls noticeably after such measures as addition of wheat bran and plowing are taken, but remain unsteady since they may rise or fall under the influence of precipitation and evaporation. So it’s necessary to make further improvements at the moment of remediation. The top task is to cleanse and degrade salt in soil.

In Table 4, the content of NH$_4^+$ and NO$_3^-$ within the experimental plot will change in the experimental process. When various nutritional elements were added to the experimental plot on July 5, the enhanced activity of microbial activity and growth of ryegrass in the remediation process will result in the use, degradation and conversion of oil and different elements. As indicated in the table, the activity intensity (quantity) of microflora will increase as more nutrients are added, but will decrease as time continues and pollutants are degraded and different nutritional elements get consumed. The bacteria content decrease in this situation as well. Due to the presence of microbes, NH$_4^+$ will be partly converted into NO$_3^-$. What’s more, after microbes get decomposed, the organic nitrogen in wheat bran as additive can release NO$_3^-$, so NO$_3^-$ tends to increase. This process has proved that the nutritional elements regulated and added in this test are quite moderate, but the oil degradation has significant effects.

4.2.3 Analysis of contributing elements in in-situ remediation

The comprehensive in-situ microbial remediation process needs adding various nutrients, like oxygen, nitrogen, phosphorus, potassium, iron, trace element, biotin and vitamin are the key elements to manage the microbial activity. The addition of some nutrients proves more important than the inoculation of special microbes. Some data show that the degrading role of native microbes in oil can be effectively promoted by regulating the ratio of C:N:P in petroleum...
contaminated soil. It takes 3.4 mg of oxygen to oxidize 1 mg of hydrocarbon and 0.056 mg of nitrogen to oxidize 1 mg of oil. Theoretically, we can estimate the required amount of nitrogen and phosphorus, but there are many unforeseeable elements. So there’s a big gap between theoretical estimation and actual value. For instance, for the microbial remediation of petroleum contaminated soil, different researchers can obtain different ratios of C:N:P, specifically 800:60:1, 100:10:1 and 70:50:1 separately. Some ratios even differ in one order of magnitude. Thus, the quantity of additives and nutrients should be determined after the actual condition of experimental plot is examined and tested. The necessary considerations include the content and type of oil contaminants in soil, time and depth of pollution, soil lithology, physical and chemical property, nutrient content, water content, nature of additives and nutritional salt, long-effect, safety, and demand, growth period and season of different plants. It is required to have sufficient analysis and consider necessary maintenance.

Nutritional elements are the active components to make up microbial cells and enzymes, the material transportation system and the energy provider of physiological activity. The main elements of microbial cells include C, H, O, N and P. Specifically, C and H come from organic substances like oil contaminants. Oxygen comes from water, air and other regulated source. Nitrogen and phosphorus, as well as trace elements like S, K, Ca, Mg and Fe need supplementing and regulating as nutrients. So we supplement and regulate such elements as N, P, S, K, Ca, Mg and Fe in soil within experimental plot. Besides, the local wheat bran is used as additives to supplement other biotins and nutritional salt. The decomposition of such additives, as an extended process, plays a role of sustained release. Wheat bran improves soil to make soil fluffy and ventilating, and large quantity of salt substances can be absorbed so as to reduce the effects of high salinity on growth of plants (ZHANG Sheng et al. 2008; ZHANG Sheng et al. 2009; ZHANG Sheng et al. 2010; ZHANG Sheng et al. 2011; ZHANG Sheng et al. 2013).

## 5 Effects of remediation process on deep soil

Table 5 shows the test results of oil, pH, TDS, NH$_4^+$, NO$_3^-$, degrading bacteria and total bacteria content at the depth of 50 cm within the experimental plot after the remediation period. According to the test results, the oil content in deep soil of remediation layer has decreased to a large extent by over 97% when compared to the oil residual content of 313.6 mg/kg in oil with the same original depth. This means that oil in soil has been degraded and experiences nothing like downward diffusion. The changes in TDS, NH$_4^+$, NO$_3^-$, degrading bacteria and total bacteria contents, which see a limited rise, mean that those soluble nutrients like nitrogen and phosphorus can slightly flow into the deep soil, so the degradation of oil in deep soil quickened. The test results offer a good insight into the requirements of this remediation work for nutrition.

<table>
<thead>
<tr>
<th>Deep part of experimental plot</th>
<th>Oil (mg/kg)</th>
<th>pH</th>
<th>TDS (mg/kg)</th>
<th>NH$_4^+$ (mg/kg)</th>
<th>NO$_3^-$ (mg/kg)</th>
<th>Degrading bacterial content (cfu/g)</th>
<th>Total bacteria content (cfu/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth 50 cm</td>
<td>7.37</td>
<td>7.8</td>
<td>996</td>
<td>3.68</td>
<td>67.34</td>
<td>4.0×10$^3$</td>
<td>1.5×10$^3$</td>
</tr>
</tbody>
</table>

## 6 Conclusions

From the whole remediation process and method, we can draw main conclusions as follows. For the soil seriously contaminated by high-saline reservoir water and crude oil due to the explosion of oil transmission pipeline within the oil exploitation zone, the comprehensive micro-ecological remediation technique, which uses nutritional agents to stimulate in-situ native microflora and plant the ryegrass, is used together
with physical and chemical methods and regulation of soil environment.

The regulation and remediation results of nutritional and environmental elements in soils within experimental plot show that the pre-remediation oil content in soil averages 2,898.25 mg/kg, and the post-remediation oil content in soil drops to 40.35 mg/kg following the in-situ microbial remediation for 99 days, implying the degradation of 98.61%. Since there’s no water source available near the experimental plot, the high salt content in soil is not well cleansed and discharged at the beginning of remediation period, so resulting in the unsteady salt content in soil. So some negative effects are imposed on the growth of ryegrass. This phenomenon can be changed for better in the future remediation. Yet, the remediation process has produced some obvious results as a whole, and the seriously petroleum contaminated soil has resumed its ecological functions. This test has proved the validity, feasibility and practicality of comprehensive micro-ecological remediation technology for remediating the petroleum contaminated soil in Zhongyuan Oilfield. What’s more, this method has such advantages as simple procedure, effective performance, limited environmental effects, no additional contamination and possible in-situ management. But it’s an in-house research; the large-scale remediation outdoors needs improvement. We can achieve this goal through our constant efforts. This method can complete in-situ oil remediation, treat oil-based contamination of soil vadose zone, and prevent oil from contaminating groundwater. When the soil fertility and environment are improved, there are no negative effects. This method is very meaningful for remediating petroleum contaminated soil and increasing cropland yield, so it’s one of the workable methods to remedy and manage the large-scale petroleum contaminated soil. In this sense, it deserves our popularization and application in the future. The enhanced in-situ microbial remediation technique is a highly potential and efficient environmental remediation technique with limited investment. This technique, which is being used within Zhongyuan Oilfield, has produced some satisfactory ecological and economic benefits. It can offer the technical support for remediating the contaminated soil of the same nature in China and an important insight into the remediation and management of the petroleum contaminated by other organic substances.

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