Natural Degradation Simulation and Phytoremediation of Oil-Contaminated Soil

Yijie Dong, Zhiyang Zheng, Lei liao, Jiaqing Yan, Shaoqiao Deng*
(NO.290 Research Institute of Nuclear Industry, Shaoguan 512029, China)

Corresponding authors at: E-mail addresses: 151452313@qq.com, hgy290yys@cnnmail.cn

Abstract: In order to remediate the soils contaminated by oil and solve the disruption of ecological balance caused thereby, appropriate measures shall be taken to improve the oil degradation effect of the soil. This paper is based on study of current available soil remediation techniques of the oil-contaminated soil, focuses on the simulation of microbial degradation and phytoremediation techniques so as to conclude the corresponding degradation schemes with the optimal type of plants, which is aimed at providing the theoretical guidance for the actual remediation effect of oil contaminated soil.

1. Introduction
The economic development of the nation is inseparable from the consumption of oil. According to statistics, in 2020, China's oil consumption relying on foreign imports accounts for 50% of the annual consumption. Since the production of the domestic large oilfields, such as the Daqing and Shengli Oilfields, has come into a later stage, it is urgent to find new energy to replace the oil. Over years of application of oil, the exploration, exploitation, storage, processing and use of it had caused a large amount of non-renewable energy consumption, besides, the application of oil causes great environmental pollution. As the material foundation on which the human survival relies, soil is not only the base for plant production, but also the basics for animal and human production. Due to the fact that production, storage and processing of oil will cause loss of certain number of resources, the loss of oil not only causes soil pollution, but also disrupts the balance of local ecological environment in the long run, and even damages the ecological environment of a whole region [2]. Therefore, it is necessary to strengthen the knowledge of the laws of oil migration and transformation in soil, in order to lay a theoretical foundation for controlling the oil pollution in soil to finally ensure the ecological balance and the sustainable development of a whole region.

This paper focuses on the natural degradation simulation and phytoremediation of the oil-contaminated soil, and is detailed as bellow:

2. Remediation Techniques of the Oil-Contaminated Soil
It is researched that oil contamination of soil mainly concentrates at 0-30cm of the soil surface, and the available remediation techniques include the bioremediation technique, the physical remediation technique and the chemical remediation technique. This part shall study the above three soil remediation techniques.

2.1. Bioremediation technique
The bioremediation technique for remediating the soil contamination by oil originated in the 1990s,
which is considered to be the most viable and cleanest remediation technique. Bioremediation technique mainly consists of the microbial remediation technique and the phytoremediation technique [3].

The microbial remediation technique refers to the oil-degraded microorganisms that derives from the long-term oil contaminated soil, which will degrade the oil in the soil, accelerate the decomposition rate of the oil in the contaminated soil, so as to realize the remediation of the oil-contaminated soil, improve and optimize the conditions of the soil environment.

The phytoremediation technique refers to the absorption, transformation and migration of oil in the soil by plants over their growth process, so as to achieve the remediation of the oil-contaminated soil. Such remediation is mainly based on the facts that the roots of the plants can effectively improve the soil microenvironment; the plants can absorb and degrade the oil components in the soil; and the plants can promote the soil humification and enhance the inertness of oil with the action of the humification, thus slowing down the soil contamination by oil of a region [4].

2.2. Physical remediation technique
Physical remediation technique refers to using certain physical means to reduce the oil concentration of the soil or fundamentally eliminate the content of oil. Common physical remediation techniques include soil replacement, oil vapor extraction and thermal remediation, among which the thermal remediation technique can reduce the oil content of soil by more than 90% and is hence widely used.

In terms of the thermal remediation technique, the new microwave thermal remediation technique is mainly used in recent years. The main principles of the microwave remediation technique are as follows: the soil and the oil in it are heated by the microwave technique, and the volatile or semi-volatile oil in the oil is eliminated by volatilization after heating; the non-volatile components of oil can be decomposed under the action of high temperature; in addition, the soil can be vitrified under the action of high temperature and wrap the extremely non-volatile components of oil to avoid its diffusion and migration in a sudden [5].

2.3. Chemical remediation technique
The Chemical remediation technique refers to adding a certain amount of chemical remediation agent to the oil-contaminated soil, so the oil in the soil reacts with the chemical remediation reagent and decomposes. Chemical remediation technique consists of the chemical leaching, chemical oxidation, extraction, etc.

Where, the extraction method is the most widely used, which is mainly based on the theory that similar substance is more likely to be dissolved by each other. The organic solvent reacts with the pollutants in the soil, and then the reaction products are separated, that is, the pollutants are extracted from the reaction products, so as to recover the oil pollutants in the soil and achieve reuse of resources.

This part will focus on the study of the natural degradation of pollutants by microorganisms as the bioremediation technique, as well as the phytoremediation technique.

3. Simulation of Natural Degradation of Oil-Contaminated Soil
The key of microbial remediation technique is the activity of microorganisms in the soil, and the respiratory intensity of soil is the key indicator of microbial activity. When the soil is polluted by oil, its respiration intensity will be affected. Therefore, monitoring the respiration rate of the oil-contaminated soil can reflect the condition of oil degradation in a region. In other words, for a sudden change of specific oil concentration, the soil respiration rate can be increased by controlling the N content and water content in the soil to enhance the activity of the microorganisms in soil, and further enhance the natural degradation efficiency of soil [6].

3.1. Design of simulation experiment
The main factors affecting soil respiration rate and microbial activity include the oil concentration in soil, the N content and the water content. Therefore, in this part, the orthogonal test of the above three factors will be carried out to study the sequence of the factors affecting soil respiration rate. In the test,
the oil concentration in the soil is chosen at 0g/kg, 5g/kg, 10g/kg, 15g/kg, 20g/kg, 40g/kg and 80g/kg respectively. According to the experimental requirements, a group of matrix blank is designed, the corresponding oil concentration is 2000ml/kg; the ratio of C content to N content is 6:1, 25:1; the water content of soil is 20% and 5% respectively.

In order to fully understand the influence of different factors on soil respiration intensity, the soil respiration rate is measured at the 16th, 32th, 48th and 60th days, and the oil degradation rate in the soil is measured at the 60th day.

3.2. Analysis of experimental results
SPSS17.0 software is used to analyze and process the experimental data, and the influence of environmental conditions on soil respiration intensity and oil degradation effect is analyzed according to the experimental data [7].

3.2.1. Effect of environmental conditions on soil respiration intensity

3.2.1.1 Effect of the ratio of C content to N content on soil respiration intensity
The experimental results of the ratio of C content to N content on respiration intensity of oil-contaminated soil are as shown in Figure 1.

![Figure 1. Effect of the ratio of C content to N content on soil respiration intensity](image1)

As shown in Fig. 1, the respiration of oil-contaminated soil is the strongest when the ratio of C content to N content is 6:1; the respiration of soil is inhibited when the ratio of C content to N content is 25:1. Further analysis shows that when the ratio of C content to N content is 6:1, the respiratory rate increased gradually in 4 hours of test and reaches the peak value in 62 hours.

3.2.1.2 Effect of water content on soil respiration
The experimental results of water content ratio on respiration intensity of oil-contaminated soil are as shown in Figure. 2

![Figure 2](image2)

(a) The ratio of C and N content is 6:1, and the water content is 50%
Comprehensive analysis of Fig. 2 shows that water content has a significant effect on soil respiration intensity, but its influence mechanism is also affected by the ratio of C content to N content, which is specific when the ratio of C and N content is 6:1 and the moisture content of soil is 20%, the time to reach equilibrium of respiration intensity is earlier than that when the water content is 50%. That is to say, when the water content is 20%, the soil respiration is stronger [8].

3.2.1.3 Effect of oil concentration on soil respiration
Similarly, it can be seen from Fig. 2 that with the increase of oil concentration in the soil, the soil respiration intensity shows an increasing trend. Specific analysis shows that when the oil concentration in the soil is less than 20g/kg, the respiration intensity of the soil is less than that of the blank group, and the difference is not significant. When the oil concentration in the soil is more than 20g/kg, the respiration intensity of the soil is significantly enhanced compared with the blank group. The results show that when the oil concentration in the soil is low, the microorganisms in the soil have a certain resistance to oil and their activity is low.

3.2.2. Influence of environmental conditions on degradation rate of petroleum pollutants
By analyzing the data of degradation rate in different groups of soil in 60 days, the following conclusions can be drawn:

(1) When the soil moisture content is 50%, the degradation rate of oil is higher than that of water content of 20%;
(2) When the ratio of C to N content is 6:1, the degradation rate is higher than that when the ratio of C to N content is 25:1.

Moreover, the variance values of different influencing factors are obtained by using SPSS17.0 software analysis, which are as shown in Table 1:

| Influence factors | Oil concentration value | Ratio of C content to N content | Water content |
|-------------------|-------------------------|---------------------------------|--------------|
| Variance value    | P<0.01                  | P<0.05                          | P>0.05       |

Theoretically, the smaller the variance value, the greater the impact on the results; and when the variance value is greater than 0.05, it means that the influence factor on the results is not obvious or zero. According to table 1, the oil concentration in the soil, the ratio of C content to N content, and water content in the soil are the significant factors affecting the oil degradation rate, followed by the ratio of C content to N content, and finally the water content in the soil. Therefore, for the soil with specific oil concentration, the ratio of C content to N content can be adjusted so as to improve the degradation efficiency of oil pollutants by the microorganisms in the soil.
4. Phyto Remediation of Oil-Contaminated Soil

The phytoremediation of oil-contaminated soil refers to the remediation technology that relies on the plants above the contaminated soil and the microorganisms contained therein to remove the oil pollutants [9]. At present, the plants that can be applied to soil remediation of oil pollutants include algae, gymnosperms and vegetation plants. This section will focus on the experimental study on the remediation effect of corn, bermudagrass and seepweed on oil-contaminated soil.

4.1. Experimental design of phytoremediation effect

In this experiment, the remediation effects of different types of plants on soil with oil concentration of 0g/kg, 1g/kg, 2g/kg, 5g/kg, 8g/kg and 10g/kg are compared. Corn, bermudagrass and seepweed are planted in pots with the same size (the width of pot mouth is 17cm, the depth is 10cm, and the width of pot bottom is 13cm). Among them, the number of seeds in corn pot is 10, of that in bermudagrass pot is 80, and in seepweed pot is 100. Corn, bermudagrass and seepweed are planted in the soil with different oil concentrations, and they are produced under the same temperature and sunshine environment. The potted plants are watered regularly to ensure that the water content is about 80%. The experimental data are analyzed at the 90th day.

4.2. Analysis of experimental results

In the same way, SPSS17.0 software is used for statistical analysis of the experimental data, focusing on the statistical analysis of the data of oil pollutant degradation by different plants in the soil, and the following experimental results are obtained, as shown in Figure 3:

By analyzing the degradation effect of different plants in Figure 3, the following conclusions can be drawn:

1. For corn plants, with the increase of oil concentration in the soil, the degradation effect of corn on oil shows a trend of increasing at first and then decreasing; moreover, when the oil concentration in the soil is at 2g/kg, the corresponding oil degradation rate is the highest, and the degradation rate reaches 65%. At the 90th day, the degradation rate of oil in the pot without planting any plants is 7.62%. In other words, corn can significantly enhance the oil degradation rate in the soil, but the specific degradation effect is related to the oil concentration in the soil. When the oil concentration is more than 5g/kg, the degradation rate of corn in the oil shows a downward trend. The main reason is that with the increase of oil concentration, the corresponding toxicity is greater, which is not conducive to the growth of corn.

2. For seepweed plants, with the increase of oil concentration in soil, the degradation rate of the oil by seepweed shows a trend of decreasing at first and then increasing. That is to say, when the oil concentration is at 5g/kg, the degradation rate of oil by seepweed is the lowest, only at 40.66%; when the oil concentration is at 8g/kg and 10g/kg, the corresponding oil degradation rate is similar and at the
maximum, which can reach 63.87%.

3) For bermudagrass, with the increase of oil concentration, the oil degradation effect by bermudagrass changes little, that is, the oil degradation effect of bermudagrass is relatively stable. Moreover, in this experiment, when the oil concentration is at 10g/kg, bermudagrass has the best degradation effect on oil in the soil with a degradation rate of 72.71%; when the oil concentration is at 8g/kg, the oil degradation effect of bermudagrass is the worst at a degradation rate of 63.97%. Therefore, the oil degradation of the soil by bermudagrass has little relationship with its own oil concentration.

In conclusion, for corn, seepweed and bermudagrass, the oil degradation effect of corn and seepweed is greatly affected by the oil concentration in the soil while the oil degradation effect of bermudagrass has nothing to do with the oil concentration. Moreover, the oil degradation rate of bermudagrass is significantly higher than that of corn and seepweed. Therefore, bermudagrass can be used to degrade the oil pollutants.

5. Summary
As an essential resource for social production and living, oil will inevitably cause soil pollution in the process of exploitation, exploration, storage and use. In addition, the migration mechanism of oil in the soil will continue to spread, which will not only pollute the groundwater, but also destroy the ecological balance of a region [10]. In order to improve the treatment effect of oil pollutants in soil, the effects of soil microorganisms and plants on oil degradation are compared and analyzed in this paper, and summarized as follows:

1) Soil respiration intensity is the main factor affecting the activity of microorganisms, which further affects the oil degradation by microorganisms. The results show that the oil concentration is the main factor affecting the respiration intensity, followed by the C content and N content in the soil, whereas the water content in the soil has the weakest effect on the respiration intensity. Therefore, for the soil with certain oil concentration, the ratio of C content to N content can be appropriately adjusted and controlled at 6:1 to ensure the soil respiration intensity, so as to enhance the soil microorganisms and enhance the oil degradation effect by the microorganisms.

2) The research shows that the oil degradation effect by corn and seepweed is greatly affected by the oil concentration in the soil, and the oil degradation effect by bermudagrass is not related to the oil concentration of soil. Moreover, the oil degradation rate by bermudagrass is significantly higher than that by corn and seepweed. Therefore, bermudagrass can be used to degrade the oil pollutants.

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