Effect of Oil Pollution on Water Characteristics of Loessial Soil

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Abstract. Northern Shaanxi is the birthplace of the oil industry. In the process of large-scale oil and gas transportation and extraction, oil leakage and inevitability will inevitably result, causing some pollution to soil and groundwater. The purpose of this study is to investigate the impact of oil pollution on soil moisture characteristics. In this study, the loessial soil in northern Shaanxi was used as the research object to determine the wettability, capillary water rise and saturated hydraulic conductivity of soils under five different pollution gradients (0%, 0.5%, 1%, 2% and 4%). The results showed that when the soil was polluted by oil, the wettability of the soil will change, resulting in a certain degree of water repellence. In the same rising period, the uncontaminated soil capillary water rose significantly higher than the oil-contaminated soil, and the higher the degree of pollution, the smaller the capillary water rise. Oil pollution made soil saturated hydraulic conductivity decrease with the increase of pollution concentration, although saturated hydraulic conductivity decreases, but for loessial, it was within an order of magnitude.

1. Introduction

With the rapid development of the world economy, the demand for oil is gradually increasing. In the process of large-scale oil and gas transportation, oil will inevitably cause leakage and spill, thus causing a certain degree of soil and groundwater pollution. The oil in polluted soil will plug the soil pores, affecting the permeability of soil aeration [1], causing changes in soil nutrient status, so that carbon and nitrogen ratio and phosphorus to phosphorus ratio [2], causing changes in soil microbial communities, soil erosion Micro-ecological environment. High levels of oil pollution can also cause oil infiltration, thus polluting the groundwater.

At this stage, the research on oil-contaminated soils mainly focuses on the effects of oil pollution on plant growth [3-4], soil physical and chemical properties [5-6], petroleum pollution ecological risk assessment [7-8] and petroleum pollution bioremediation [9-11]. There are few researches on the influence of oil pollution on soil moisture characteristics. Li carried out a study on the characteristic curves of soil moisture by diesel [12]. Tong carried out studies on the capillary rise in diesel-contaminated soils [13]. Zheng carried out a study on the hydrodynamic characteristics of porous
media contaminated by diesel and oil [14]. Most of these researches have been conducted on petroleum extracts, but less on crude oil's influence on soil moisture characteristics. Soil wettability, water tightness and permeability of capillary water are closely related to soil moisture infiltration, surface runoff generation, soil erosion and so on, and also affect the migration and transformation of pollutants in the soil and the adsorption of pollutants by the soil Wait. Soil wettability, water tightness and permeability of capillary water are of great significance for agricultural management, water recycling and environmental protection. North Shaanxi is rich in oil reserves and is regarded as the birthplace of China's oil industry. Large-scale oil exploration and transportation will inevitably endanger the soil and groundwater. Therefore, in northern Shaanxi carry out oil pollution on the impact of soil moisture characteristics of great significance.

2. Materials and Methods

2.1. Experiment material
The soil samples were taken from Yan'an City, Shaanxi Province. The surface soils of uncontaminated land were collected. The samples were naturally air-dried, cleaned, ground and crushed. The mechanical composition of soil for testing using the MS2000 laser particle size analyzer, the results in Table 1. The test oil was taken from Yan'an Oilfield, the crude oil extracted from the well. The experiment was carried out using artificial homogenized oil-contaminated soil as the research object. Weigh the same quality soil samples and add petroleum oil according to the oil content and mix well. The contaminated levels were 0%, 0.5%, 1%, 2%, and 4% respectively.

| Particle-size distribution (%) | Soil texture |
|-------------------------------|-------------|
| Clay(0~2μm)                   | 5.28        |
| Silt(2~50μm)                  | 71.44       |
| Sand(50~2000μm)               | 23.28       |
|                               | Silty loam  |

2.2. Wettability test
The drip penetration time method (WDPT) [15-16] was used to analyze the wettability of soils with different pollution levels. Placed a dry sample of 80 g in a clean glass petri dish and gently wipe the surface of the soil sample. Distilled water was dropped onto the soil sample surface with a burette to determine the time it took for the water droplets to penetrate into the different treated samples. According to the different time of infiltration of water infiltration to indicate the degree of surface wetting, the longer the more difficult to infiltrate, the more hydrophobic, the wettability will be worse. Each treatment repeated 10 times. The experiment used the Dekker and Jungerius taxonomy [17-18] to divide the surface water repellency into five levels, as shown in Table 2.

| Water infiltration time /s | <5   | 5~60 | 60~600 | 600~3600 | >3600 |
|---------------------------|------|------|--------|----------|-------|
| Level                     | 0    | 1    | 2      | 3        | 4     |
| Water repellency          | No   | Slight | Strong | Serious | Extreme |

2.3. Capillary water rise test
The test soil column is open at the bottom of a transparent soil column of different sizes. Soil column filling capacity was 1.4 g/cm³. Each treatment stratified uniform filling, after filling each surface with fur brush hair, in order to maintain the continuity between the layers. After filling the soil column immersed in a fixed water tank. Wetting front position to determine the capillary water rise height, the observation time based on the capillary water rise speed before dense sparse. After the test, stratified sampling along the soil column height, soil moisture content was measured.
2.4. Saturated hydraulic conductivity test
DIK-4012 four-point soil permeability tester was used to measure the saturated hydraulic conductivity of soils. Before the experiment, the test soil was filled with a ring knife at a preset density (1.40 g/cm³). After fully saturated, the water permeability was measured at intervals, and the saturated hydraulic conductivity of the soil was calculated based on the amount of permeable water.

3. Results and discussion

3.1. Influence of Oil Pollution on Soil Wettability
Clean soil usually has some degree of hydrophilicity, but when the soil is contaminated with oil organic matter, the surface wettability may change from hydrophilic to hydrophobic surface, resulting in different degrees of water repellency, resulting in Soil water capacity reduction. When the oil polluted the soil, the residual oil in the soil contains a large amount of polar molecules. When the soil is relatively dry or the moisture content is very low, the surface of the oil will have the characteristic of oil wettability, resulting in the occurrence of soil hydrodynamic characteristics big changes, thus seriously affecting the oil-contaminated soil in situ treatment technology.

Table 3 shows the wettability test results of soils with different levels of oil pollution. By comparing the results of drip infiltration test on soils contaminated with different petroleum concentrations, it can be seen that the infiltration rate can be quickly infiltrated at 0% and 0.5% oil infiltration rate, the infiltration time was less than 5s and the wetting level was 0, and no water repellency was found. The water repellency of loessial soil increased from 2% oil content, while the soil with 2% and 4% oil content showed slight water repellency and strong water repellency, respectively.

Table 3. Wettability test results.

| Oil polluted level | Water infiltration time/s | Level | Water repellency |
|--------------------|----------------------------|-------|------------------|
| 0%                 | <5                         | 0     | No               |
| 0.5%               | <5                         | 0     | No               |
| 1%                 | <5                         | 0     | No               |
| 2%                 | 5-60                       | 1     | Slight           |
| 4%                 | 60-600                     | 2     | Strong           |

3.2. Oil pollution on the capillary water rise characteristics
The variation of capillary rise height in petroleum-contaminated soils over time was shown in Fig.1. The figure showed that the height of soil capillary water increased with time, but the increase decreased with time. In the same rising period, the undiluted soil capillary water rose significantly higher than the oil-contaminated soil, and the more serious pollution, the smaller the capillary water rise. When the capillary water increased 10 cm, the loessial soil with 0%, 0.5%, 1%, 2% and 4% contamination gradient took 55, 71, 85, 169 min and 678 min, respectively. The 4% oil consumption time was 12.3 times, 9.6 times, 8.0 times and 4.0 times of the other four treatments respectively.
Figure 1. Capillary water rise height with time.

The vertical distribution of capillary water under different oil content was shown in Fig. 2. In capillary water rise, the bottom of soil column is capillary saturated zone, while the capillary zone above capillary zone. With the increase of soil column height, soil water content decreases rapidly [4]. As can be seen in Figure 2, capillary volume of loessial soil decreases with increasing capillary height, and decreases with the increase of soil oil content. According to the vertical distribution of capillary water, the influence of petroleum pollution on soil water storage at 0~20 cm depth was analyzed. The results are shown in Fig. 3. It can be seen that with the pollution degree aggravating, the soil water storage capacity decreases in turn, but for the loessial soil, the water storage capacity had smaller amplitude.

Figure 2. Distribution of capillary water in oil contaminated soil.
3.3. Influence of oil pollution on soil saturated hydraulic conductivity

Soil saturated hydraulic conductivity is one of the important physical properties of soil. The soil saturated hydraulic conductivity under different pollution directly characterizes the influence of petroleum pollution on soil water infiltration capacity. The trend of saturated hydraulic conductivity with the oil change was shown in Figure 3. The figure shows that petroleum pollution has a significant impact on the saturated hydraulic conductivity. Saturated hydraulic conductivity showed a downward trend with the increase of pollution degree. Although the saturated hydraulic conductivity decreased, it was within an order of magnitude and no magnitude jump occurred. The saturated hydraulic conductivity of loessial soil was in the order of $10^{-5}$. The effect of pollution concentration on saturated hydraulic conductivity of soil was more obvious when the oil content was lower. With the increase of oil content, the decreasing trend of saturated hydraulic conductivity became slower.

![Figure 3. Effect of oil pollution on water storage in 0~20 cm soil.](image)

![Figure 4. Soil saturated hydraulic conductivity of the tested soils under different pollution degree.](image)
Soil moisture transport and material transport, surface water supply to groundwater, pollutant migration and soil permeability are closely related [17]. Petroleum contaminated soil bound to the soil permeability will inevitably have a certain degree of impact, thus affecting the soil moisture and material exchange. Mashalah et al. [18] also showed that soil saturated hydraulic conductivity is proportional to soil particle size and inversely proportional to oil content. On one hand, oil which contaminated soil will clog soil moisture transport channel, on the other hand it will make the surface of the soil produce certain hydrophobicity to reduce the resistance to water transport, both of which will cause the soil permeability to change.

4. Conclusion
Oil pollution can significantly change the water characteristics of loessial soils. Soil surface wettability decreased, resulting in a certain degree of water repellency. In the same time period, the capillary water rise height decreased with the increase of the pollution level, and the higher the pollution degree, the smaller the capillary water rise height. Saturated hydraulic conductivity of soil showed a downward trend with the increase of pollution degree, although the saturated hydraulic conductivity decreased, all within an order of magnitude.

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