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Research Article

Complexity Model for Predicting Oil Displacement by Imbibition after Fracturing in Tight-Oil Reservoirs

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With the increasing difficulty of conventional oil and gas exploration and development, oil and gas resources have developed from conventional to unconventional, and the exploration and development of tight-oil reservoirs are highly valued. In view of the complexity of the influencing factors of oil-water spontaneous seepage after fracturing and the instability of reservoir recovery, this paper takes the tight sandstone reservoir of Yanchang Formation in the southern Ordos Basin as the research object. Based on the micro-nano pore throat characteristics of tight sandstone, the seepage experiment is carried out, and the theoretical model of seepage suction is constructed. The mechanism and influencing factors of suction and oil displacement after fracturing in tight reservoirs are analyzed. Based on the analysis of fluid buoyancy and gravity, a mathematical model of the oil-water spontaneous flow after fracturing was established, and its influencing factors were analyzed. The experimental results show that the pore throats of tight sandstone are mainly in micron- and submicron scale, and the reservoir permeability is related to the pore throat structure, oil-water interfacial tension, and wettability. After fracturing, with the increase of the fracture length, the seepage velocity gradually decreases. With the increase of fracture opening, the influence of buoyancy and gravity on seepage velocity increases. With the increase of the fracture number, seepage velocity also increases. The fracture helps to reduce the adsorption of oil droplets on the core surface and improve the efficiency of spontaneous imbibition and oil displacement of the core. The research results provide theoretical data support for enhancing oil recovery and have important application guiding significance for the operational reliability of manufacturing systems with complex topology and the complexity and operability of production operations in manufacturing systems.

1. Introduction

It is important to investigate the operational reliability of manufacturing systems with complex topology structures and complexity and operability of production jobs in manufacturing systems. As a typical application of operational reliability of manufacturing systems with complex topology structures and complexity and operability of production jobs in manufacturing systems, the economy developed rapidly, the external demand for oil is increasing year by year, and the current domestic self-developed oilfield has entered the middle and late stages, and crude oil production is decreasing year by year, which poses a serious threat to China's energy security [1–3]. In the case of energy shortage, it is of great strategic and practical significance to continuously improve the degree of exploitation of petroleum resources, and with the development of the petroleum industry, the exploration and development of traditional conventional oil and gas resources has gradually shifted to unconventional oil and gas exploration and development

[4–7]. In the face of the increasingly severe energy security situation, China has increased its efforts in oil and gas exploration and development, especially unconventional oil and gas. In recent years, with the rapid development of science and technology, unconventional oil and gas has become the main energy source to be developed. With the successful development and commercialization of shale oil and gas in North America, the world has set off a boom in the development of unconventional oil and gas [5, 8–10]. As the most important one of unconventional oil and gas reservoirs, tight-oil reservoirs have a permeability of less than 1 mD in air, a formation overlay permeability of less than 0.1 mD, and a porosity of less than 10% which is a typical low porosity and low permeability. Tight oil is an oil and gas resource existing in tight reservoirs, with broad development prospects, and it is widely distributed in the world. China tight oil is rich in resources, distributed in Songliao Basin, Junggar Basin, Ordos Basin and Sichuan Basin, with an oil-bearing area of about $5 \times 105\ km^2$ and recoverable reserves of about $25 \times 109t$. With the continuous development of tight reservoirs at home and abroad, the problem of productivity decline and production decline is inevitable. Therefore, it is necessary to study the methods of enhancing oil recovery in tight reservoirs. At the same time, due to the particularity of tight reservoirs, it is necessary to adjust and optimize the lifting methods of ordinary reservoirs when they are applied to tight reservoirs, establish an evaluation method for the applicability of the lifting methods of tight reservoirs, and give the restrictions of different lifting methods [11–14].

As an important unconventional oil reservoir, tight-oil reservoir has complex physical conditions, such as ultralow permeability and ultralow porosity, which makes the output of a single well of tight oil decline too fast and stay in a low efficiency state for a long time. There are two main reasons for the difficulty of tight reservoir development. On the one hand, it is difficult to supplement energy for reservoir development, and it is even more difficult for tight reservoirs to be recovered by supplementing external energy. Therefore, depletion recovery is the main production mode of tight reservoirs. On the other hand, tight reservoirs generally have high water saturation, which makes oil encounter high resistance in the process of percolation; so, it is difficult to produce oil, which also leads to the low recovery factor of tight oil in China. The size, distribution, and distribution type of pore throat are all important factors affecting the imbibition capacity of tight oil, especially tight reservoirs are characterized by poor physical properties, strong heterogeneity, and obvious microscale effect. Therefore, it is more important to correctly understand the micropore structure of tight-oil reservoirs. However, the rapid flowback after high displacement volume fracturing and refracturing can achieve the desired effect of increasing production. The imbibition replacement technology for ultralow permeability tight oil is that fracturing fluid gel breaking fluid or displacement fluid enters capillary channels through capillary force to occupy the capillary space and drives crude oil into larger roaring channels or fractures, thus improving the recovery of tight crude oil. In view of the complex influencing factors of oil-water spontaneous seepage after fracturing and the difficulty in predicting oil recovery, this paper conducts seepage suction experiments on the micro/nano-pore throat characteristics of tight sandstone, analyzes the oil displacement mechanism and influencing factors of tight reservoir after fracturing, analyzes the mechanical characteristics of oil and water phases in fractures, establishes the mathematical model of spontaneous oil and water seepage after fracturing, and analyzes its influencing factors. The research results can be used to improve the recovery of tight crude oil and can provide theoretical support for improving reservoir recovery.

2. Literature Review

Tight-oil reservoirs have the characteristics of low porosity, low permeability, and many micro- and nanopores, and conventional mining methods cannot meet the exploitation of tight-oil reservoirs [15–17]. At present, the exploitation of tight oil is mainly through hydraulic fracturing and other methods to transform the reservoir, open up the internal cracks of the reservoir, and enhance the fluidity of the reservoir fluid to reduce the seepage resistance of the formation fluid to improve the seepage recovery rate. The foreign tight oil and gas production technologies mainly include the following: (1) horizontal well drilling and completion technology: tight reservoir has low production and generally long production cycle, and the application of horizontal drilling technology just solves these problems; so, it is the main method of exploiting tight oil abroad at present. The main completion methods include intelligent completion, perforation completion after casing cementing, open hole perforation completion, and combined bridge plug completion; (2) multistage fracturing technology for horizontal wells: the technology consists of several parts, including horizontal well drilling and completion, staged fracturing, and micro seismic detection technology; and (3) other fracturing technologies including refracturing and synchronous fracturing technology and channel fracturing technology developed in the recent years.

At the present stage, most tight reservoirs are exploited by water drive. Due to the huge difference in the permeability between fractures and matrix, there is still a large amount of remaining oil enriched in matrix rock blocks at the later stage of water injection development. Oilfield development practice has proved that capillary pressure imbibition is the key to improve oil recovery in tight reservoirs. Therefore, it is of great significance to study the capillary imbibition law on the basis of considering the characteristics of tight reservoirs to understand the oil displacement mechanism of tight reservoirs. Some researchers have carried out spontaneous aspiration studies when the dense reservoir contains a large number of natural or artificial cracks under the action of capillary force to wet the phase flow into the matrix. The imbibition displacement of crude oil mainly occurs in the dual medium area. In porous media, the process of replacing the nonwetting phase fluid by the wetting phase fluid relying on the capillary force is called imbibition. When the fluid suction rate in the fracture is slow, the inflow direction of the wetted phase fluid in the reservoir and the outflow direction of the nonwetting phase are the same to achieve codirectional seepage. When the seepage rate of fractured fluid is relatively fast, the reservoir matrix is surrounded by cracks, and the wetting phase fluid flows into the matrix pores from all directions, and the opposite direction of the outflow direction of the nonwetting phase and the inflow direction of the wetting phase is reverse seepage. Some researchers have studied capillary pressure, pore development, phase osmotic curves, matrix, fracture permeability, and in a static and dynamic manner. The influence of matrix oil saturation on reservoir suction velocity is linearly related to capillary pressure, matrix permeability and residual oil saturation, exponential relationship with bound water saturation, and viscosity of crude oil under static conditions power index relationship [18–21]. Some researchers have studied the seepage suction and flooding oil of the core of the fractured reservoir with low permeability under different permeability through spontaneous crack seepage experiments and concluded that the higher the capillary force in the oil reservoir suction system, the higher the suction process. Reverse fracture seepage has a high oil production at the initial stage of oil absorption, and the oil production will decrease obviously after 50 hours until no oil is produced. When the permeability is less than 2 mD, the degree of spontaneous suction and extraction increases with the increase of permeability, and the better the pore and throat structure, the more conducive to spontaneous suction effect. Some researchers have simulated the geological characteristics and fluid properties of tight sandstone reservoirs and carried out dynamic seepage suction experiments, indicating that with the increase of liquid injection pressure, the oil exhalation rate of core seepage and drainage accelerated [22–24]. After the injection rate was accelerated, the suction recovery rate showed a change of first increase and then decreased, and the size of the plug of the infiltration injection section was increased, the holding time was prolonged, and the number of alternate injections was increased. It can effectively improve the seepage recovery of the reservoir. Some researchers have studied the influencing factors of seepage in tight reservoirs and when the sorption method is different, the permeability rate will affect the suction rate. To produce a certain effect, the fracture of the dense reservoir has effectively increased the contact area of the dense matrix, and the suction solution effectively reduced the seepage resistance to improve the seepage recovery rate; when the water injection throughput increases the suction distance, the large-scale volume fracturing changes [25–27]. The wettability of the reservoir and the water injection throughput are conducive to improving the oil recovery of the reservoir. Some researchers have carried out research on the factors affecting the seepage of the core, mainly the influence of the physical properties of the core itself, such as the permeability of the core, the structure of the pore throat and the surface wettability of the core, the influence of fluid properties, including the viscosity of crude oil, the mineralization of the leachate, and the interface tension of oil and water, and the influence of external conditions, including boundary conditions, temperature, and pressure.

In the existing literature, the research results of imbibition are mostly aimed at fractured reservoirs or low permeability and ultralow permeability reservoirs, while the research on tight reservoirs is still in its infancy. At home and in abroad, the existing spontaneous imbibition mechanism, influencing factors, models, and production experience are difficult to be transplanted into the production of tight oil, and the micro-nano pore throat characteristics have a great impact on it. Therefore, it is an effective method to build a theoretical model of seepage suction to characterize the irregularity of its microstructure to study the spontaneous imbibition mechanism of tight reservoirs.

3. The Geological Background and Research Methods of the Study Area

3.1. Geological Overview. Ordos Basin is located in the west-central region of China, and the basin is generally rectangular, north and south spread; the north extends Yin Mountain, Daqing Mountain is close to the border, the south is bounded by Qinling Mountains, the east is connected with Lüliang Mountain and Zhongtiao Mountain, and the west extends to Helan Mountain and Liupan Mountain. The research area is a dense sandstone reservoir of the Yanchang Formation in the southern Ordos Basin, with a total area of about 2600 km^2, located in the eastern part of Gansu province, and the surface is characterized by the gully area of the Loess Plateau in the middle reaches of the Yellow River, mostly mountainous. The terrain gradually rises northeast along the river valley, with an altitude of 900–1800 m, with an average altitude of 1400 m. The exploration and development of tight-sandstone reservoirs is mainly 8, 9, and 10 long reservoirs. The first set of oil reservoir systems developed after the formation of large inland depression lake basins in the Ordos Basin is a set of sedimentary systems caused by braided river deltas, meandering river deltas and turbidity fans, and the whole is dominated by medium-fine sandstone and mudstone and its local development of oil shale and coal-bearing sandwich layers. There are 6 reservoir formations in the Yanchang Formation from bottom to top, all of which have reservoir discoveries, of which the Yanchang Formation 8, 9, and 10 are the heyday of lake basin development, and the average permeability of the sandstone of the Reservoir Formation is less than $0.3 \times 10^{-3}\ \mu m^2$, which is the most typical tight-oil reservoir.

3.2. Specimen Preparation and Test Methods. At present, there are two main methods to recognize the pore throat structure of tight sandstone, namely, the image analysis method and the calculation of pore throat size and structural parameters through the change of fluid mass, volume, and pressure. In this paper, the micropore structure of tight-sandstone reservoir is further studied by high-pressure mercury injection and casting thin section experiment. Casting thin section can effectively analyze the reservoir space and the pore type of tight-sandstone reservoir, while the high-pressure mercury injection test is helpful to further determine the pore distribution characteristics of tight-

Table 1: Core parameters before and after fracturing.

Core numbers	Core lengths (cms)	Core diameters (cms)	Permeability (mD) before fracturing	Permeability (mD) after fracturing	Cracks open degree (μm)	Core crevice types
1	4.894	2.522	0.095	27.290	1.64	Single slit
2	5.477	2.49	0.079	0.137	0.09	Cross-seams
5	5.661	2.512	0.081	15.748	1.43	Cross-seams
7	5.234	2.511	0.041	18.523	1.82	Single slit
10	4.972	2.498	0.082	10.639	0.922	Cross-seams

sandstone reservoir. In order to better understand the micro pore structure of experimental cores, FE-SEM field scanning electron microscopy was used to conduct experimental analysis on several representative compact cores. The FE-SEM field scanning electron microscope further verified that the reservoir is dominated by micropore throat, and the main types are micro- and nanopore throat. For the conventional mining method of micron and nanometer sized pore throat, it is difficult to use, the development effect is not obvious, and the economic benefit is low. How to effectively improve the recovery efficiency of micron and nanometer sized tight reservoirs is the focus of the research.

This time, 10 compact sandstone cores were selected for matrix seepage experiments, with a core length of 5.01–5.71 cm and a diameter of about 2.5 cm. The permeability was 0.01 4–0.185 mD, the porosity is between 3.4% and 12%, and the core appears as weak hydrophilic. In this study, 5 of the tight cores were selected for physical fracturing and fracturing, and a certain amount was applied by bending the fine wire into a U-shaped clamping core pressure fracturing the core so that the core cracks, and then we used glue to paste the fractured core and measured the permeability before and after the cracking and other parameters. Due to the difference in the texture structure of the core, the fractures produced by fracturing may not be single penetration joints, but there are still certain horizontal fractures, which is followed in this article core fracture distribution, dividing the core into single and cross fractures after fracturing. Table 1 and Figure 1 show the comparison of the parameters of the core before and after fracturing, especially with regards to the change in permeability, and the core porosity is between 8% and 13.6%, the permeability range is 0.086 mD–0.105 mD, and the core permeability increases greatly after fracturing, of which the penetration rate of the core increased by 451 times.

Using the collected crude oil and kerosene 1 : 1 configuration simulation oil, the Physica MCR 301 rheometer was used to measure its density and viscosity to obtain a density of 0 8 g/cm^3 with a viscosity of 4.8 MPa·s. The formation water used in the test was 2×104 mg/L of NaCl solution, and the surfactant was dodecylbenzenesulfonate, which was obtained by the volumetric method. The degree of seepage extraction and the rate of seepage suction of the core are carried out by using a 0.01 ml suction flask. The SVT20 interface tensioner is used to perform tension measurements at the oil-water interface of different seeps by filling the sample tube with the seepage and injecting a drop of simulated oil at high centrifugal forces. Under

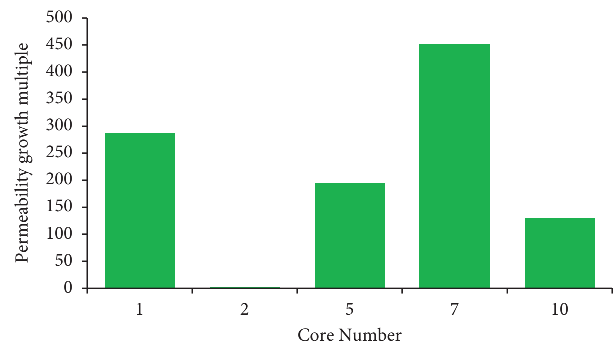

Figure 1: Multiple increase in core permeability before and after fracturing.

the action of a centrifugal velocity of 6000 r/min, the simulated oil is stretched and deformed, and the shooting capture is carried out by a high-precision camera, and its interfacial tension is calculated according to the curvature of the droplets. After that, the core sheet is cut from the core for the wettability test, and the core sheet is first polished and smoothed into the infiltration for 48 hours, and then the contact angle between the oil droplets and the core piece is measured by a high-power microscope. Place the core chip holder in the sample box, add oil droplets under the core slice and pour the seepage solution and observe the contact between the oil droplets and the core piece in the exudation by adjusting the sample box position and using high-power microscope irradiation. The high-powered microscope focal length ensures that the oil droplets and core pieces are in the center of the screen. Take photos and save them using a protractor to measure the angle between the core piece and the oil droplet, which is the wetting angle.

3.3. Test Procedure. Due to the difference of fluid properties and reservoir physical properties, tight reservoirs have different percolation laws and mechanisms from conventional high permeability reservoirs, usually showing low-speed nonlinear percolation characteristics. The narrow pore throat and complex environment in the tight reservoir make the oil-water channel fine and have great seepage resistance and liquid-solid interface interaction, and the reservoir permeability is low. The overlying effective stress has a great influence on the physical parameters of low permeability porous media, affects the seepage law, deviates from Darcy's law, and presents the phenomenon of low-speed nonlinear seepage.

The opening of the crack directly affects the seepage process of the crack, and the suction rate is faster when the crack is opened. As the surrounding pressure of the core increases, the cracks in the core begin to close under the action of pressure and the opening of the fractures gradually decreases. The core liquid permeability measurement step is to dry the core at 100°C for more than 12 h and measure the dry weight of the core. After the weight of the core is stabilized, the core is evacuated for 12 h; saturation of the core using stratigraphic water; place the core into the gripper, adjust the equipment, set the confining pressure, pump the formation water in through the constant-flux pump, and record at the same time the pressure and flow rate of the inlet and outlet of the lower gripper, and the permeability of the core is calculated after the flow is stabilized; by increasing the confining pressure, the permeability of the core under different confining pressures is calculated. Figure 2 shows the permeability of the core sample 5 at different confining pressures. The permeability of the core gradually increases with the increase of the confining pressure, and the two are essentially linear, which is consistent with Darcy's law; that is, the core permeability is proportional to the fracture opening, and the greater the core permeability, the greater the crack opening.

By performing a seepage test on the core after fracturing, Figure 3 shows the process of the seepage test of the core after fracturing, through a 35°C incubator. Simulate the reservoir temperature, take the time when the solution touches the bottom of the core as the starting point of the seepage time, record the seepage of the core at different times, and take pictures to record the changes of oil droplets on the surface of the core.

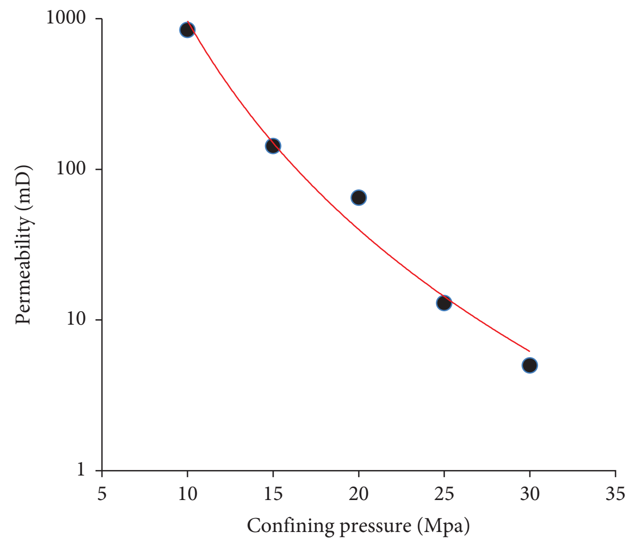

Figure 2: Permeability of the core sample 5 under different confining pressures.

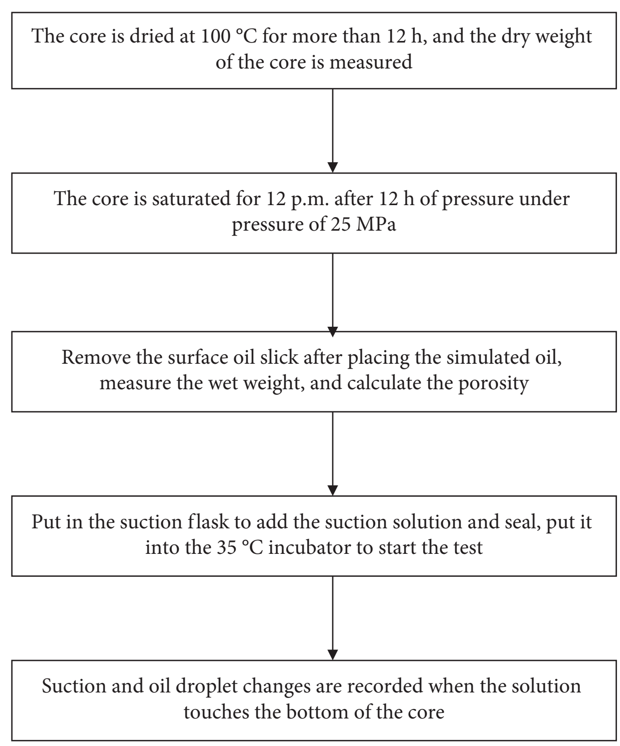

Figure 3: Core seepage test process after fracturing.

4. Results

4.1. Test Results. Hagen–Poiseuille's law (H-P law) describes the steady laminar flow of incompressible fluid in a horizontal pipe. In 1927, Kozeny J applied the H–P law to the capillary flow and established an ideal capillary bundle model for the reservoir flow, that is, the flow path of fluid in the pores was equivalent to a group of parallel capillary bundles with different radii. When there is a crack in the core, the crack will seep due to capillary force. When the crack is completely immersed in water, the crack is mainly affected by gravity, viscosity, capillary force, buoyancy force, crack end pressure, crack seepage and crack opening, length, and inclination. The oil-water interface tension is related to the wetting angle. In order to analyze the influence of different factors on crack seepage, this paper simulates using MATLAB based on the control variable method, and Table 2 gives the parameters required for crack seepage simulation.

(1) *Effect of Fracture Length on Crack Seepage.* Set the opening degree and the inclination angle of the fracture according to Table 2, and select the core of different fracture length to carry out the infiltration test. The test shows that the seepage rate of the core is gradually increased with the suctioning test, but the oil and water suction rate decrease with the increase of the fracture length. In the process of seepage and suction, due to the constant crack opening, the capillary force of the crack remains unchanged, and the pressure difference between the two ends of the crack is the main driving force for the suction of the crack. As the infiltration continues, the oil in the crack is driven out by water, the height of the oil-water interface increases, and the internal flow weight of the fracture increases, resulting in a decrease in the buoyancy and viscosity of the fluid. At the same time, the combined force of the fluid in the

Table 2: Parameters required for fracture seepage simulation.

Names	Numeric values
Crack length (cm)	12
Crack width (cm)	2.525
Crack opening (μm)	1.2
Crack inclination (°)	62
Oil phase viscosity (MPa·s)	5
Aquatic phase viscosity (MPa·s)	1.1
Oil-water interface tension (mN/m)	14.19
Contact angle (°)	48

crack increases, and the seepage rate of the fracture increases. Therefore, when the crack opening degree is fixed, the viscosity is the main factor affecting the seepage rate.

(2) *Effect of Crack Opening on Crack Seepage*. Crack opening is an important parameter to describe the characteristics of cracks, and different crack opening degrees are set, which are 100 μm, 10 μm, 1 μm, 0.1 μm, 0.01 μm, etc., to simulate crack penetration. The test shows that with the increase of crack opening, the crack seepage rate continues to increase, and when the crack opening degree is 100 μm, the crack seepage rate decreases with the increase of the height of the oil-water interface, and when the crack opening is ≤10 μm, the crack seepage rate increases with the increase of the height of the oil-water interface. At the same time, as the crack opening increases, the capillary force gradually decreases, but the gravity, buoyancy, and viscosity of the fluid are subjected as the pressure increases at both ends of the crack. Therefore, when the crack opening degree is certain, the viscosity is the main factor affecting the fracture seepage, and increasing the crack opening can effectively improve the crack penetration rate.

(3) *Effect of Crack Inclination on Crack Seepage*. Different crack inclination angles are set, which are 0°, 45°, 60°, 75°, and 90°, to simulate the fracture suction process. When the crack opening is small (crack opening is 1 μm), the fracture penetration rate does not change significantly with the increase of the crack inclination. With the increase of crack opening, the gravity and buoyancy of the fluid in the crack also increase, the capillary force of the crack decreases the seepage suction, and the seepage rate increases with the increase of the crack inclination, and at the same time, with the increase of the inclination angle of the crack, the fluid viscosity of the crack increases slightly, which is mainly due to the increase of the inclination angle of the crack, resulting in the increase of pressure difference, buoyancy, and gravity components at both ends of the crack so that the fluid viscosity in the crack increases.

(4) *Influence of Interface Tension on Crack Seepage*. The fracture length, crack opening, and crack inclination angle are set according to Table 2 and passed. The fracture infiltration was simulated by changing the oil-water interface tension, and the oil-water interface was set to 14.91 mN/m, 10.62 mN/m, 7.23 mN/m, 4.67 mN/m, and 3.63 mN/m, respectively. Since each group of samples is taken from the same full diameter core, the basic physical properties, pore structure, and wettability are roughly the same. The role of interfacial tension in fracture seepage can be simply investigated without the influence of other factors. When the oil-water interface tension is greater, the greater the seepage rate of the crack. This is due to the increase of the oil-water interface tension, in which the capillary force of the crack also increases, and at the same time, under the action of crack seepage, the viscosity of the water is less than the oil viscosity in the crack. The combined force of the fluid increases so that the fracture seepage rate increases. Due to the small crack opening of the setting, the influence of gravity and buoyancy on the fracture seepage is small, and with the increase of the height of the oil-water interface, the viscous resistance of the fluid gradually decreases, which accelerates the fracture suction rate.

(5) *The Influence of the Wetting Angle on Crack Seepage*. At present, researchers at home and abroad have proposed a variety of methods to analyze the wettability. The Amott self-priming oil drainage method has the advantages of a large test range, clear numerical definition, and small impact on oil and gas exploration and development and is widely used in the quantitative evaluation of core wettability. The wetting angle of the crack surface is set to 0°, 30°, 50°, 70°, 80°, and 89°, respectively. The test shows that with the increase of the wetting angle of the crack, the seepage rate of the crack is significantly reduced, and in the process of suction and suction, when the length, opening, inclination angle, and oil-water interface tension of the crack remain unchanged, the gravity of the fluid in the crack, both buoyancy and pressure difference, remain constant, and the viscosity of the fluid in the crack decreases as the rate of seepage decreases. This is due to the fact that the hydrophilicity of the fracture surface decreases with the increase of the wetting angle and the capillary force of the fracture decreases, resulting in a decrease in the seepage rate of the fracture. The relative wettability index has a positive correlation with the imbibition recovery. The imbibition process is a process in which the wetting phase spontaneously inhales into the porous medium by capillary pressure to displace the nonwetting phase. For water wet reservoirs, water is the wetting phase and capillary pressure is the imbibition power. Therefore, the higher the degree of water wetness is, the stronger the role of capillary pressure is. The higher the proportion of pores that water can enter in the total pores, the more the oil expelled, and therefore, the higher the imbibition recovery factor.

Table 3: Summary of core aspiration results.

Core numbers	Degrees of extraction	Core numbers after fracturing	Degrees of extraction
1	0.184	2	0.254
3	0.201	5	0.266
14	0.154	11	0.215
19	0.104	16	0.184
20	0.112	19	0.177

4.2. Comparison of Oil Drainage before and after Fracturing. In order to study the effect of fractures on core aspiration, a comparative analysis of seepage suction tests of fractured cores and matrix cores was carried out, as shown in Table 3 and Figure 4. The seepage results of each core are given, and the degree of core extraction and the seepage rate are analyzed.

First, dry and weigh the core, vacuumize, saturate the test water, and weigh the wet weight; then, oil displacement is carried out at room temperature to saturate the core with experimental oil; finally, without external pressure, the core is completely immersed in the experimental water. At this time, the core will self-absorb water and drain oil under the action of capillary force. In the process of absorbing water and draining oil, the core quality will continue to increase due to the poor density of oil and water. Use the electronic balance to continuously weigh the core and record the change of core quality.

It can be seen from Figure 4 that after core fracturing, due to the development of fractures, the degree of core extraction and the seepage rate are significantly improved, and the degree of core extraction after fracturing increases at least 10%; this is due to the presence of cracks to increase the contact area between the suction and the core, providing an infiltration channel for the flow of fluid inside the core.

The degree of crack opening obtained from the seepage specimen has a certain influence on the seepage of the crack, and with the increase of the crack opening, the fracture seepage rate also increases. In this experiment, the fractures of core 11 and core 16 are the same, but the fracture opening of the two is very different, and the seepage rate of core 16 is much higher than that of core 11, which is consistent with the model results.

According to the seepage of each core, the relationship between the degree of extraction and the seepage rate of each core and the number of fractures in the core is compared. Core 5 is a single fracture, and its recovery degree and seepage rate are high; Core 16 is a cross fracture, although the number of fractures is large, but the degree of extraction is between core 20 and core 5, and the seepage rate is much higher than that of the other two tight cores. The seepage rate is about 2 times that of core 5. Therefore, it can be concluded that the number of core fractures has a certain influence on the seepage rate of the core and the greater the core seepage rate is with the increase of the number of fractures. At the same time, by comparing the seepage rate curve of the three cores, it can be found that each core has a high seepage rate in the early stage of seepage, but the seepage rate decreases rapidly, and with the increase of the number of core fractures, the seepage rate decreases significantly.

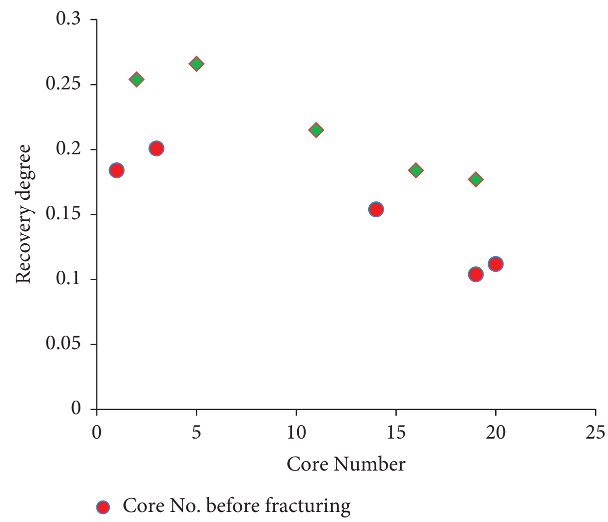

Figure 4: Different degrees of core extraction.

By observing the oil droplets on the surface of the core during the seepage process, it can be found from Figure 4 that when the infiltration begins, oil droplets appear at the fractures of the core, but with the growth of time, the oil droplets will gradually become larger and eventually leave the core. Core 5 and 16 seepages are the same, but from the distribution of oil droplets on the core surface, the number of oil droplets adsorbed on the surface of the core 16 is small. This is mainly due to the different distribution of fractures in the core 5 and 16; the core 16 is a cross-fractured core and the number of fractures is more. In the process of seepage suction, the oil produced by the seepage of the matrix is discharged through the fracture of the core Therefore, there are fewer oil droplets on the surface of the core. The radius of the oil droplets adsorbed on the surface of the core 5 is very large, which is due to the large interfacial tension between the formation water and the simulated oil, resulting in small oil droplets on the surface of the core that cannot be separated from the core; so, with the increase of the infiltration time, the oil droplets on the surface of the core accumulate to form large oil droplets. The core 16 oil droplets are mainly concentrated and produced at the cracks, and more cracks in the core make the oil droplets in the core more likely to gather, which is also the main reason for the rapid output and the large seepage rate at the beginning of the core 16 seepage.

5. Conclusion

This paper takes the tight sandstone reservoir of Yanchang Formation in the south of Ordos Basin as the research object, conducts core seepage pumping experiments before and after fracturing, builds a seepage theoretical model, analyzes the seepage drainage mechanism of tight reservoirs after fracturing and its influencing factors, and establishes a mathematical model of oil and water spontaneous seepage after fracturing and analyzes its influencing factors, which provides theoretical data support for improving oil recovery. (1) The porous throat of tight sandstone is mainly at the micron- and submicron scales, and the infiltration rate of the reservoir is related to the pore throat structure, oil-water interface tension, and wettability. The oil-water infiltration rate decreased with the increase of fracture length. With the increase of crack opening, the suction rate of crack seepage increases; with the increase of crack inclination, the seepage rate of the crack increases; with the greater the tension at the oil-water interface, the greater the seepage rate of the crack; with the increase of the wetting angle of the crack, the suction rate of the crack is significantly reduced. (2) The crack is the main seepage channel of the fractured core, which can effectively reduce the adsorption of oil droplets on the outer surface of the core. At the beginning of the seepage, the oil droplets first appear at the fractures of the core, and as time increases, the oil droplets gradually become larger and eventually leave the core. With the increase of cracks in the core, the number of adsorbed oil droplets on the core surface decreases and the radius of adsorbed oil droplets decreases. This work serves as an important reference to operational reliability of manufacturing systems with complex topology structures and complexity and operability of production jobs in manufacturing systems.

Data Availability

Data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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