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Control Mechanism and Parameter Simulation of Oil-Water Properties on Spontaneous Imbibition Efficiency of Tight Sandstone Reservoir

*Dazhong Ren[1]**, Litao Ma[2], Dengke Liu[3], Jing Tao[4], Xueqing Liu[2] and Rongjun Zhang[1]*

[1]College of Petroleum Engineering, Xi'an Shiyou University, Xi'an, China, [2]CNOOC EnerTech-Drilling & Production Co., Tianjin, China, [3]School of Human Settlement and Civil Engineering, Xi'an Jiaotong University, Xi'an, China, [4]Oil Production Plant 6 of Petrochina Changqing Oilfield Company, Xi'an, China

Spontaneous imbibition is an effective method of tight sandstone reservoirs development. However, their underlying mechanisms are still unclear due to the representative issue caused by strong heterogeneity and complex oil-brine properties. In this research, physical properties and thin-section images were systematically analyzed, and the spontaneous imbibition efficiency was examined from core tests. The results show that quartz and feldspar predominantly contribute to mineralogy. Low brine salinity, high oil viscosity, and high interfacial tension corresponded to strong spontaneous imbibition ability and fast process. High interfacial tension is the dominant controlling factor in this field. Furthermore, the parameter simulation model established by the dimension reduction method could catalyze the prediction of spontaneous imbibition efficiency, which is confirmed by higher reliability.

Keywords: physical properties, mineralogy, oil-water properties, spontaneous imbibition efficiency, tight sandstone reservoir

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****Correspondence:***
Dazhong Ren
dzren@xsyu.edu.cn

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INTRODUCTION

With the advancement of petroleum development, tight oil, an unconventional oil resource, has become a research hot spot that has received increasing attention [1]. As one of the typical tight sandstones, tight lacustrine sandstones are widely developed in China [2, 3]. Although this type of reservoir has excellent potential, the limitations of current techniques for its extraction mean that a large amount of oil remains in the strata [4]. Spontaneous imbibition is a state-of-art and efficiency developing method that is widely used in oil fields in China [3, 5, 6]. There is so much literature that focuses on using this method to extract tight oil and enhance oil recovery. However, the spontaneous imbibition efficiency is not very high [7]. In addition, understanding of the spontaneous imbibition mechanism cannot catch up with the development of tight sandstones oil. Previous studies have focused on how minerals and the related parameters of pore structures impact the spontaneous imbibition behaviors and their efficiency; however, the relationships between oil-water properties and spontaneous imbibition behaviors are still not well understood [3, 5, 8]. With the development of chemical flooding, the importance of fluids, especially injected fluids, is becoming increasingly apparent [9, 10]. Therefore, to catalyze the comprehension of the mechanism of spontaneous imbibition and facilitate the fieldwork of the technique, the control mechanism and parameter simulation of oil-water properties on the spontaneous imbibition efficiency of tight sandstone reservoirs were analyzed.

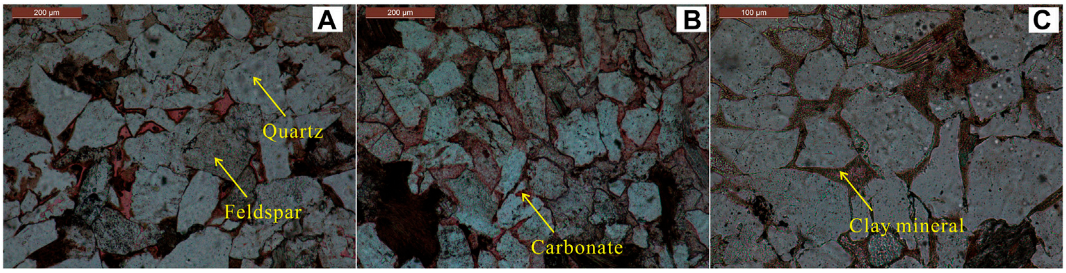

FIGURE 1 | SEM images of the study area.

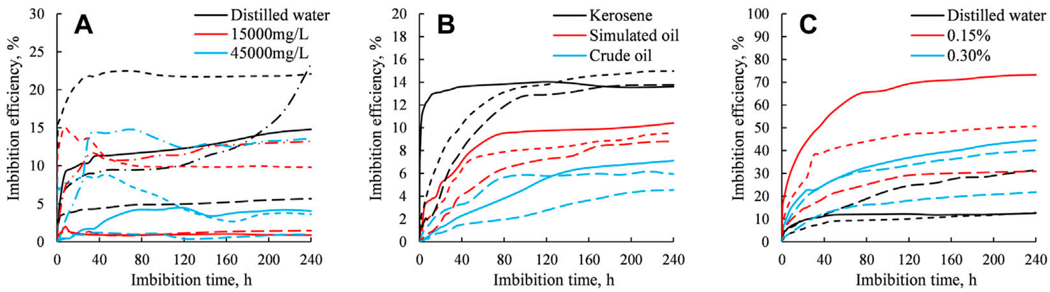

FIGURE 2 | Spontaneous imbibition efficiency versus time with different **(A)** brine salinity, **(B)** oil viscosity, and **(C)** interfacial tension.

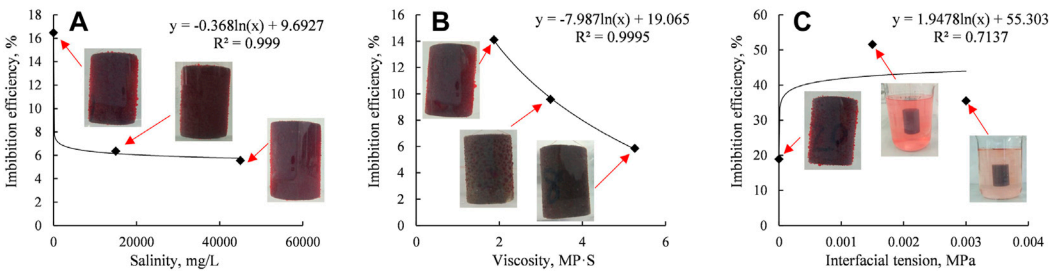

FIGURE 3 | Final spontaneous imbibition efficiency evolution with different **(A)** brine salinity, **(B)** oil viscosity, and **(C)** interfacial tension.

Focusing on the lacustrine Lower Triassic Yanchang Formation tight sandstones in the Southwestern Ordos Basin, this study investigated surfactant, salinity, temperature, oil viscosity, and spontaneous imbibition efficiency. A new parameter simulation is investigated to acquire the spontaneous imbibition efficiency judgment. Finally, the main controlling factors of spontaneous imbibition efficiency of tight sandstones were discussed to solve the problem of reservoir spontaneous imbibition efficiency distribution and evaluation.

METHODS

Physical Property

The helium porosity and nitrogen permeability were used to judge the physical property in the room temperature and atmospheric pressure.

Casting Thin Section and XRD

After being polished by sandpapers, the rocks were glued by T-1502 and sealed by two glass slices. XRD method was used for mineral content determination quantitatively.

Surface Tension

Aviation kerosene served as a low-density phase, while a surfactant with different dilatability served as a high-density phase. We use a video rotation measuring instrument to measure the surface tension.

Brine Salinity, Crude Oil Viscosity, and Their Interfacial Tension

The brine salinity was configured by NaCl and distilled water, and the viscosity was determined by the viscometer. The interfacial tension was calculated by the instrument Dataphysics Kruss K20.

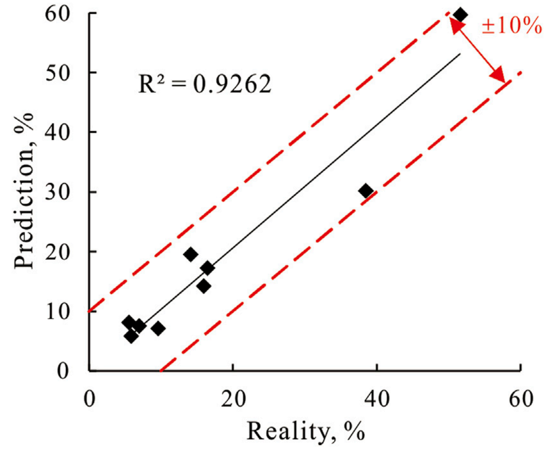

FIGURE 4 | Prediction model validation.

Spontaneous Imbibition Tests

The experimental device of the mass method is composed of one end of the balance connected to the computer and the other end connected to the core. The connected core is immersed in a beaker containing an osmotic solution. The high-precision electronic balance can record the core weight in real-time. The computer data acquisition system is connected to the balance to collect the core weight at different times. When imbibition occurs, the wetted phase displaces the non-wetted phase in the rock core, and there is a replacement between them. The principle of this method is that the wetted phase and the non-wetted phase are replaced, and the different densities of the wetted phase and the non-wetted phase will lead to the weight change of the core. Therefore, the imbibition of the core can be obtained by recording the weight change of the core at different times.

RESULTS

Physical Property

Physical properties, especially porosity, were strongly heterogeneously distributed (**Supplementary Table S1**). The porosity ranged from 2.00% to 10.28%, with an average of 6.15%, while permeability was distributed between 0.028 and 0.287 mD, with an average of 0.106 mD. The physical property results demonstrated that the selected samples were typical tight sandstones [3].

Mineralogy

The mineral compositions analyzed by XRD are presented in **Supplementary Table S1**. Quartz, feldspar, and clay minerals were the predominant minerals in the research area (**Figure 1**). The average quartz content is higher than the average content of feldspar and clay minerals.

Spontaneous Imbibition Efficiency With Different Brine Salinity

To study the influence of salinity on spontaneous imbibition efficiency, we selected four cores for repeated oil washing and saturation for the imbibition experiment. Each core was subjected to imbibition experiments of distilled water, salt solution with a salinity of 15,000 mg/L, and salt solution with a salinity of 45,000 mg/L. The results show that the replacement rate of core imbibition in distilled water is the largest, while the other two depend on the core's properties (**Figure 2A**).

Spontaneous Imbibition Efficiency With Different Oil Viscosity

Three cores were selected to study the effect of viscosity on the Imbibition effect:

1. The core was saturated with kerosene, and the degree was 1.87 MPa s at room temperature.
2. The simulated oil was prepared for testing by mixing the core saturated crude oil and kerosene. The viscosity of the simulated oil prepared at room temperature was 3.23 MPa s.
3. The core was tested with crude oil.

The viscosity of crude oil at room temperature is 5.26 MPa s. The results show that the replacement rate of core saturated kerosene was the highest, followed by the simulated oil prepared by the mixture of saturated kerosene and crude oil. The replacement rate of core saturated crude oil is the lowest (**Figure 2B**).

Spontaneous Imbibition Efficiency With Different Interfacial Tension

When studying the influence of interfacial tension on the Imbibition effect, we selected three cores for repeated oil washing and saturation for imbibition experimental research. The core has the highest replacement rate in the surfactant solution with a concentration of 0.15%, followed by the surfactant solution, with a concentration of 0.3%, the mixed solution with salt with a salinity of 10,000 mg/L, then the surfactant solution with the concentration of 0.15%, and finally distilled water (**Figure 2C**).

DISCUSSION

Main Controlling Factors of Oil-Water Properties on Spontaneous Imbibition Efficiency

The results revealed that many factors affect the imbibition of tight sandstone, such as interfacial tension, crude oil viscosity, and brine salinity. These factors have varying degrees of influence on the imbibition rate and the final recovery of imbibition. We use the relative size of range value to evaluate the relative contribution—the greater the range, the stronger the control effect. As shown in **Figure 3**, within the scope of the experiment, the influence degree of each influencing factor on the displacement rate was interfacial tension, salinity, viscosity, and interfacial tension, which mainly affected the imbibition displacement rate.

Parameter Simulation of Spontaneous Imbibition Efficiency

Many factors affect reservoir imbibition efficiency, and they also belong to multi-dimensional spatial distribution. To more conveniently establish the evaluation chart of reservoir imbibition efficiency, the dimension reduction method is adopted to synthesize a variety of influencing factors into a comprehensive influence factor Y and draw the charts of reservoir imbibition efficiency and its influencing parameters with different Y values, to solve the problem of reservoir imbibition efficiency distribution and evaluation (**Figure 3**). The core properties were also described by porosity, permeability, and mainstream pore radius—those parameters including the macroscopic and microscopic features of the cores. According to the fitting formula, simulate the comprehensive impact factor, and the formula is as follows:

$$f = -1.214S - 26.21V + 117.24IF - 6.69\o + 2.96 \times 10^{2}K - 2.44e^{5.42R_m}$$

where S, V, and IF represent salinity, viscosity, and interfacial tension, respectively.

To verify the accuracy of the established recovery method of reservoir imbibition efficiency value, the measured reservoir imbibition efficiency value established by seven nonparticipating reservoir imbibition efficiency recovery charts was compared with the simulated reservoir imbibition efficiency value (**Figure 4**). The recovery value obtained from the reservoir imbibition efficiency value recovery chart agrees with the measured value and has high reliability.

CONCLUSION

(1) According to the statistics of physical properties results, the samples were typical tight sandstones. Quartz and feldspar were the predominant minerals.
(2) Within the scope of the experiment, the influence degree of each influencing factor on the displacement rate was interfacial tension, salinity, viscosity, and interfacial tension, which mainly affected the imbibition displacement rate.
(3) The prediction model derived from parameter simulation had high reliability. The prediction data could be used for spontaneous imbibition efficiency prediction directly.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

Conception: DR; figure drawing: DL; Funding acquisitor: DR, LM, and DL; writing-first version: JT and XL; Supervision: RZ; writing-revision: RZ and DL.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fphy.2022.829763/full#supplementary-material

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Conflict of Interest: Author LM and XL were employed by CNOOC EnerTech-Drilling & Production Co. Author JT is employed by Oil Production Plant 6 of Petrochina Changqing Oilfield Company.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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