Experimental study on single phase flow characteristics in tight sandstone oil reservoirs

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Abstract: Tight oil resource is distributed worldwide and has great potential for exploration. As tight sandstone reservoirs have small pores and narrow throats, the liquid boundary layer has great influence on the seepage, inducing starting pressure gradient during fluid seepage. In this paper, flow characters of both single water and single oil phase is investigated. Results show that the curve of flow velocity vs. the pressure difference doesn’t pass through the origin. Extending the trend line will intersect the abscissa pressure difference, indicating it is non-Darcy flow for both single water and oil in tight sandstone cores. The permeability increases slowly with the increase of displacement pressure difference until basically stable.

1. Introduction

Tight oil resource is distributed worldwide and has great potential for exploration [1-2]. The exploration and development of tight oil in China is still in its infancy and the exploitation technology still needs to learn from some foreign experience. The oilfield development shows that the seepage characteristics of tight reservoirs are significantly different from those reservoirs with medium-high permeability and high permeability. The main difference is that there is a starting pressure gradient during seepage [3]. When fluid flows through the solid surface, there will be a thin liquid layer on the rock surface as the interaction among solid and liquid molecules.

The boundary layer is the most important reason for the non-linear seepage and the starting pressure gradient in tight sandstone oil reservoirs [4]. It divides fluid in pores into bulk fluid and boundary fluid. Bulk fluid exists in the middle of the pore and is not affected by the boundary. While the boundary fluid is located at the boundary and affected by the pore surface. As tight sandstone reservoirs have small pores, the liquid boundary layer has great influence on the seepage [4-6]. When the thickness of the boundary layer reaches the middle of the pore, fluid in the pore cannot flow unless the pressure difference at ends of the pore reaches a certain value to overcome the viscous resistance and the adsorption resistance between the solid and liquid interface. This value is usually named starting pressure.

At present, research on low-permeability reservoirs has made progress at home and abroad, but it is still insufficient in the understanding of seepage characters in tight sandstone reservoirs. It is of great significance to carry out research on the seepage mechanism of tight reservoirs for the rational development.
2. Experimental section

2.1. Experimental materials
Kerosene and simulated formation water was used as oil phase with the viscosity of 6 mPa•s and water phase with the viscosity of 0.9 mPa•s, respectively. Samples were taken from the Chang 6 oil reservoir in the Longdong area. The parameters are shown in Table 1.

| Sample | Length(cm) | Diameter(cm) | Pore volume(ml) | Porosity(%) | Permeability(mD) | Note |
|--------|------------|--------------|-----------------|-------------|-----------------|------|
| 1      | 6.23       | 2.51         | 6.00            | 18.3        | 0.0269          | Single water |
| 2      | 6.32       | 2.52         | 5.83            | 18.5        | 0.0208          | Single oil  |

2.2. Experimental instruments
The single-phase seepage experiment was carried out in a conventional core displacement device, shown in Figure 1, including a constant flow pump, a piston container, a core holder, pressure control system, metering device.

![Device for single-phase seepage capacity evaluation.](image)

Figure 1. Device for single-phase seepage capacity evaluation.

2.3. Experimental steps
Sample 1 and sample 2 was separately evacuated and saturated with water or oil, respectively, shown in table1. Then the sample was placed in core holder and displaced by the corresponding single-phase fluid by increasing the displacement pressure difference gradually. The outlet was atmospheric pressure. The flow rate was measured when the displacement pressure was basically stable. Finally, the single-phase permeability was calculated according to the Darcy's formula. Repeat the above steps for samples successively.

3. Results and discussion
Due to the worse property of tight sandstone, the test progress for seepage was very slow and took more than 2~3 weeks when conducted under lower pressure difference. In view of the influence of equipment precision, the minimum displacement pressure difference was taken 1MPa.

Figure 2 shows curves of flow rate vs. pressure difference and water permeability vs. pressure difference for sample1 saturated by water. Figure 2(a) revealed that the curve of flow velocity vs. the pressure difference didn't pass through the origin. Extending the trend line will intersect the abscissa pressure difference, indicating there was non-Darcy flow for single water in tight sandstone core. The water permeability increased slowly with the increase of displacement pressure difference. After the pressure difference exceeded 3 MPa, the permeability was basically stable, shown in Figure 2(b). At the end of the experiment, the final permeability of sample 1 was 0.006 mD.
In short, the tight sandstone reservoir has poor physical properties, reservoir wettability, and formation damage caused by sensitive minerals. The porosity of the target oil reservoir ranges from 7.54% to 18.53%, with an average of 10.68%, mainly distributed between 8% and 14%. The main distribution of permeability ranges from 0.1 to 0.5 mD, which belongs to low permeability and ultra low permeability reservoirs. These reservoirs also develop intergranular pores, dissolved pores, intercrystalline pores and micro cracks.

By the way, studies have shown that the wettability of the target oil layer is mixed with hydrophilic and lipophilic. The clay mineral content is relatively high, mainly with acid sensitive minerals, but the water sensitive mineral content is relatively small. Non-clay sensitive minerals include carbonate minerals, silicate minerals, sulfides and oxide minerals. For silicate and oxide minerals, its ionic and covalent bond structure determines the high surface energy and surface functional groups (surface active sites). Under the weak electric field of the mineral surface, fluid in the porous medium also has different adsorption and wetting properties on the mineral surface.

In short, the tight sandstone reservoir has poor physical properties and complex pore structure. The flow of oil and water in these reservoirs presents non-Darcy flow.
4. Conclusions
This paper investigated the flow characters of both single water and single oil phase in tight sandstone oil reservoirs. Results show that the tight sandstone reservoir has poor physical properties and complex pore structure, which induce non-Darcy flow of oil and water. The curve of flow velocity vs. the pressure difference didn’t pass through the origin. Extending the trend line will intersect the abscissa pressure difference, indicating there was non-Darcy flow for both single water and oil in tight sandstone core. The permeability increased slowly with the increase of displacement pressure difference until basically stable.

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