Relationship Between Throats Characteristics and Permeability in Tight Sandstone Based on Rate-controlled Mercury Injection

——Example of Fuyu oil layer in Da'an area of Songliao Basin

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Abstract. There are a large number of throats in tight sandstone reservoir, the throat morphology is various and the distribution of throat radius is wide. These characteristics have great influence on the permeability of the tight sandstone reservoir. However, it has not been well studied. In this paper, we address this issue using a case study in the Da'an area of Songliao Basin, northeast China (Fuyu oil layer age, 2000-2500 m). Pores and throats dominate the properties of the reservoir. However, only the pores were the focus of previous studies. Thus, here we investigate the throats and its impacts on permeability, providing a complementary understanding of the microscopic characteristics in the tight sandstone reservoir. Using Rate-controlled Mercury Injection data of core samples, it was discovered that the throat radius of tight sandstone varies widely from 200 nm to 1100 nm, with an average of 580 nm. The rate-controlled mercury injection test results showed that the throat radius of the samples with different permeability was different. The size and number of the effective throat are the main controlling factors to increase the permeability of the reservoir.

Introduction

As the exploration of oil and gas becomes more and more difficult worldwide, extending the exploration from the conventional reservoir to unconventional tight reservoir has become a prominent trend [1, 2]. Previous studies have shown that tight sandstone reservoir was considered to be the most potential unconventional reservoir [3, 4]. Thus, it is not surprising that tight sandstone reservoir and its microscopic characteristics have attracted substantial and persistent interest in the field of petroleum and reservoir geology. Tight sandstone reservoirs are sandstone reservoirs with absolute permeability of less than 1×10^{-3} μm^2 (or in-situ matrix permeability of less than 0.1×10^{-3} μm^2) [5]. With oil and gas saturation of generally less than 60%, these reservoirs have no oil natural industrial capacity, but can reach industrial oil and gas productivity with the help of some stimulation techniques. Many petroliferous basins in China have favorable geological conditions for the formation of tight sandstone oil and gas reservoirs. For example, the Triassic Yanchang Formation in Ordos Basin, the Triassic Xujiahe Formation in Sichuan Basin and the Cretaceous Quantou Formation in Songliao Basin. The Songliao Basin is an important area for petroleum exploration and production in northeast China, with a commercial production of oil and gas at approximately 4.6×10^7 ton by 2015. The unconventional reservoir has attracted increasing exploration and research attention recently along with the deepening of the exploration [6]. The tight sandstone reservoir of Fuyu oil layer in southern central depression is one of the key targets, which currently contains many oil fields (i.e., The Da'an field and the Changlin field).

Previous studies have shown that the There are a large number of throats in tight sandstone reservoir [7]. But, the throat radius is wide. These characteristics have great influence on the permeability of the tight sandstone reservoir. And the permeability is the key parameters affecting the productivity of tight sandstone oil. Thus, a study of the throats characteristics in tight sandstone and its impact on the permeability is of significance theoretically and locally to regional exploration. However, it has not been well investigated previously worldwide. Thus, here, to expand on the previous studies and present a systematic and comprehensive picture of the tight sandstone and its microscopic characteristics, we focused on the throats characteristics.

Geological backgrounds

Songliao Basin is located in the northeast of China. The Greater Khingan Mountains are to the west, the Zhangguangcai Mountains are to the southeast and the Lesser Khingan Mountains are to the northeast, resulting in an irregular diamond-shaped basin with a north-south length of 750 km, an east-west width of 350 km and a total area of 26×10^4 km^2. The Songliao basin is divided into the north plunge, central depression, northeast uplift, southeast uplift, southwest uplift and west slope. Da'an area is located in southern central depression. And it is one of the most important tight oil sandstone reservoirs in Songliao Basin.

Songliao Basin is a Mesozoic and Cenozoic continental basin. The sedimentary sequence developed from the bottom upwards: the Cretaceous Huoshiling Formation, Shahezi Formation, Yingcheng Formation, Denglouku Formation, Quantou Formation, Qingshankou Formation, Yaojia Formation, Nenjiang Formation, Sifangtai Formation, Mingshui Formation, Paleogene, Neogene and Quaternary. Fuyu oil layer belong to the lower Cretaceous Quantou Sec.4 (here in after referred to as K_1q_4), which is one of the most important oil-bearing strata in the southern Songliao Basin. The sedimentary facies include alluvial fan-fluvial facies, delta facies and shore shallow lacustrine facies in Fuyu oil layer. In this period, the meandering river delta is developed extensively in the Da'an area. A large area of fluvial facies sandstone is formed.

Due to strong compaction and cementation, the sandstone of Fuyu oil layer is tight. The porosity range is from 1.1% to 13.5%, with an average porosity value of 7.27%. The porosity mainly distribute between 4% and 10%. The permeability varies from $0.01\times10^{-3}\mu m^2$ to$16.00\times10^{-3}\mu m^2$, and averaged at $0.25\times10^{-3}\mu m^2$. The permeability mainly distribute between $0.01\times10^{-3}\mu m^2$ and $0.3\times10^{-3}\mu m^2$. According to the standard of reservoir rocks classification in China Petroleum industry (SY/T6285-1997), the sandstone reservoir of Fuyu oil layer is ultra-low porosity and ultra-low permeability or tight sandstone reservoir rocks.

Samples and analysis methods

All of the investigated samples are collected from the moderately to deeply buried Fuyu oil layer (2000-2500 m) in the Da'an area. The absolute permeability of investigated samples is less than $1\times10^{-3}\mu m^2$. All of the investigated samples meet the criterion for tight sandstone. After a close core examination, the samples were subject to Rate-controlled Mercury Injection (6 samples) to determine the throat radius. The test was carried out at the laboratory of exploration and development research institute of Petrochina Huabei Oilfield Company. During the test, the rate-controlled injection speed is 0.00005ml/min, the maximum injection pressure is 900psi, corresponding to the minimum throat radius is about 120 nm.

Results and discussions

(1)Size and distribution of the throat radius

The rate-controlled mercury injection test with a low injection velocity (usually 0.00005ml/min) will be mercury injected into the rock pores and the throats. By detecting the pressure fluctuations in the mercury injection process, the pores and throats of the rock will be separated. Thus, compared with the conventional mercury injection test results, the rate-controlled mercury injection test results can determine the number and size of the pore, the number and size of the throat, ratio of pore and throat radius etc. Therefore, its measurement accuracy is higher than that of the conventional mercury injection test results. Compared with conventional reservoir, the throat radius of tight sandstone reservoir is relatively small, and ratio of pore and throat radius is relatively large. The rate-controlled mercury injection test results of 6 samples are listed in Table 1. The results show that the throat radius of tight sandstone varies widely from 200 nm to 1100 nm, with an average of 580 nm (Fig. 1). The rate-controlled mercury injection test results showed that the throat radius of the samples with different permeability was different.

Table 1 Summary of the rate-controlled mercury injection test results

Sample	Depth(m)	Porosity (%)	Absolute permeability ($10^{-3}\mu m^2$)	Mercury injection saturation of throat (%)	Effective throat volume (cm^3)	Effective throat radius (nm)	Effective throat number
S9	2131.13	9.60	0.293	9.55	0.009	160	183
S58	2153.71	12.0	0.912	20.68	0.025	620	2907
S83	2180.02	13.4	1.000	24.58	0.033	690	3352
S114	2201.48	11.2	0.395	19.25	0.021	390	2381
S136	2205.25	8.40	0.307	19.7	0.016	400	1467
S157	2220.39	12.5	0.734	22.8	0.029	630	2935

Fig. 2 shows that the distribution of throat radius varies greatly between sample S9 and sample S83, according to the rate-controlled mercury injection test results. The absolute permeability of sample S9 is $0.293\times10^{-3}\mu m^2$, and the absolute permeability of sample S83 is $1.000\times10^{-3}\mu m^2$. The throat radius of sample S9 range is from 100 nm to 200 nm. And only a small amount of the throat can be detected in the rate-controlled mercury injection test. The throat radius of sample S83 varies from 100 nm to 1100 nm, and the throat radius mainly distribute between 500 nm and 900 nm. A large number of throats can be detected in the rate-controlled mercury injection test.

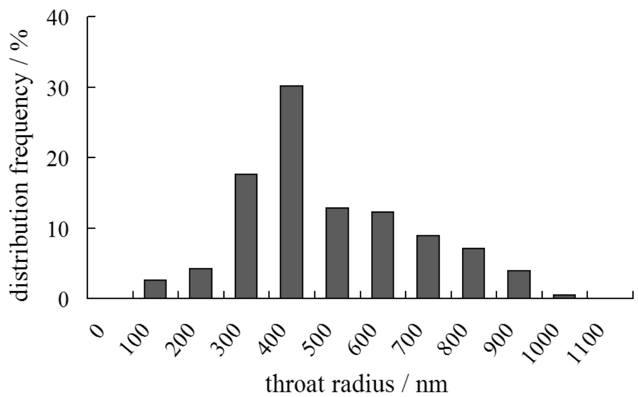

Fig.1 Distribution of throat radius of tight sandstone under rate-controlled mercury injection test

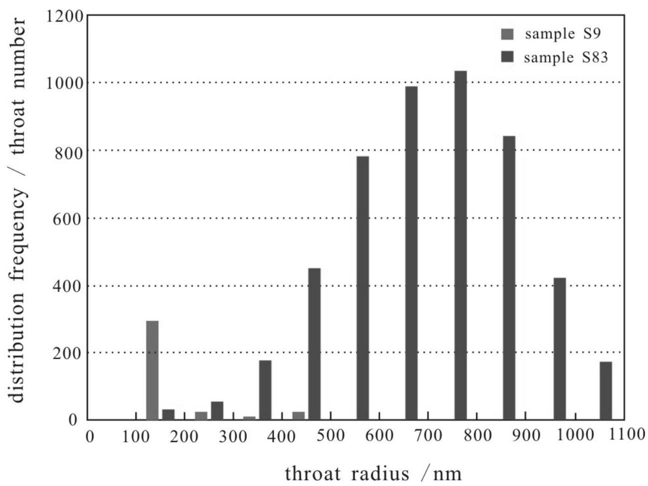

Fig.2 Distribution of throat radius of sample s9 and sample S83

(2)Discussion on the relationship between the throat and permeability

The rate-controlled mercury injection test results of 8 samples (including 2 samples with permeability greater than 1) show that the number of the nano throat is more; the permeability is smaller in tight sandstone reservoir. When the permeability is less than $1\times10^{-3}\mu m^2$, the throats of the sample are mainly nano scale. That is, the throats radius of contribution to permeability is are mainly nano scale. When the permeability is greater than $1\times10^{-3}\mu m^2$, the distribution frequency of the nano throat decreases with the increase of permeability. The test results also show that the size and number of the effective throat are the main controlling factors to increase the permeability of the reservoir (Fig. 3).

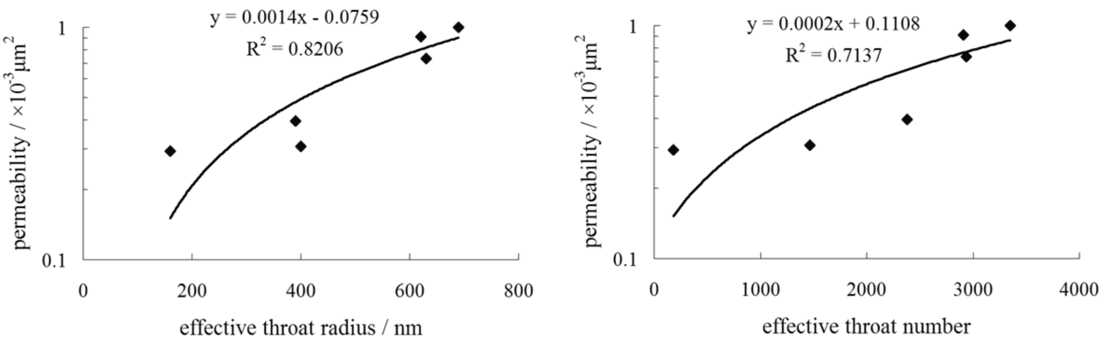

Fig.3 Relationship between the nano throat and permeability according to rate-controlled mercury injection test results

Conclusions

The throat radius of tight sandstone varies widely from 200 nm to 1100 nm, with an average of 580 nm. The throat radius of the samples with different permeability was different. The size and number of the effective throat are the main controlling factors to increase the permeability of the reservoir. When the permeability is less than $1\times10^{-3}\mu m^2$, the throats of the sample are mainly nano scale. That is, the throats radius of contribution to permeability is are mainly nano scale. When the permeability is greater than $1\times10^{-3}\mu m^2$, the distribution frequency of the nano throats decreases with the increase of permeability.

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