Stress-dependant Permeability Variation of Tight Sandstone

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Summary

As one of the key factors in enhanced oil recovery, permeability can be affected by many factors including effective stress. Compared with conventional reservoir, the stress sensitivity is severer for unconventional reservoirs including tight sandstone[1-4]. In this work, permeability variation with increasing effective stress is the main factor to discuss, and the objective here are to (1) quantitatively characterize the permeability sensitivity of heterogeneous tight sandstone and (2) select a stress-dependent permeability calculation model for tight sandstone. In this work, such a model has been utilized and is then verified by experimental data. The results show that this model can quantitatively predict the permeability stress sensitivity of heterogeneous tight sandstone fairly accurately with relative errors within a reasonable range. It also suggests that the permeability decreasing rate has a positive relation with initial permeability of core.

Introduction

Tight sandstone reservoirs are important target areas for oil exploration and their parameters change along with the variation of effective stress have been extensively studied to understand real-time production performance of such reservoir[5-8]. Exsiting works are mainly conducted by experimental study, due to the discrepancy of experimental methods and rock properties, mass inconformity lies in those experiments, the work can not directly get precise result on stress sensitivity of heterogeneous tight sandstone reservoirs. Thus, quantitative analysis model for this is imperative.

In the process of oil and gas developing, the heterogeneity changes with effective stress, thereby influences the oil recovery of resevoirs[9-12]. In this study, a capillary model for tight sandstone was introduced to characterize the stress sensitivity of capillary and porous media; the stress-dependent permeability quantitative analysis model in the tight sandstone was verified by a group of experiments of permeability stress sensitivity of tight sandstone, based on which, the permeability variation with increasing effective stress has been analyzed.

Theory

The stress sensitivity calculation model assumes that the pores of tight sandstone reservoir can be simplified as piled by ball shaped grains, the grain deforms due to effective stress, the deformation obeys the Hertz contact deformation law.

Effective stress on capillary pore is [13]:

$$\sigma = \frac{1}{\pi}\begin{pmatrix} \frac{F_1}{R_1^2 - a_1^2} + \frac{F_1}{R_2^2 - a_1^2} + \\ \frac{F_2}{R_1^2 - a_2^2} + \frac{F_3}{R_2^2 - a_3^2} \end{pmatrix} + \sigma_0 \tag{1}$$

where the F_1 is the stress exerted on grain1, N; F_2 is the stress exerted on grain 2, N; F_3 is the stress exerted on grain3 , N; R_1 is the grain diameter of the cores with high permeability, mm; R_1 is the grain diameter of the cores with low permeability, mm;a_1，a_2, a_3 are the contact diameter between grains respectively, mm; σ is the effective stress, MPa；σ_0 is the initial effective stress, MPa.

Permeability decreasing rate after deformation is：

$$\gamma = 1 - \frac{K'}{K} = 1 - \frac{\varphi' S'(R,\sigma)}{\varphi S(R,\sigma)} = 1 - \left[\frac{S'(R,\sigma)}{S(R,\sigma)}\right]^{\frac{5}{2}} \tag{2}$$

where the; K′ is the permeability after pore deformation, 10^{-3} μm^2; K is the initial permeability before pore deformation, 10^{-3} μm^2; S′ is the pore area after pore deformation, m^2; S is the pore area before pore deformation, m^2; ϕ′ is the porosity after pore deformation; ϕ is the porosity before pore deformation.

Stress dependent permeability experiments have been conducted on 2 sets of laboratory-made tight sandstone cores, each containing two homogenous cores and one heterogeneous core. The heterogeneous one has a permeability contrast as the permeability ratio of the two homogenous ones. Parameters are shown in Table1.

Table 1. Basic parameters of cores

Set No.	Type	Diameter/mm	Length/mm	Porosity/%	Permeability/10^{-3} μm^2
1	homogeneity	25.00	41.22	16.02	17.97
	heterogeneity	25.00	41.22	15.0	9.83
	homogeneity	25.00	41.22	10.92	0.096
2	homogeneity	25.22	43.96	14.79	4.59
	heterogeneity	25.22	43.96	14.18	2.47
	homogeneity	25.22	43.96	10.85	0.082

According to SY/T 6385—2016, permeability stress sensitivity tests were done using unsteady-statement method. Permeability is recorded when effective stress reaches steady at 6Mpa, 8Mpa, 10Mpa and 12Mpa respectively for each core, the permeability loss rate are calculated based on experimental results.

The effective stress can be calculated by [6]:

$$\sigma = \sigma_c - \eta p \tag{3}$$

Where σ is the effective stress, MPa; σ_c is the confining pressure, MPa; p is the fluid pressure, MPa; η is the effective coefficient.

Fig.1 shows permeability loss rate with increasing effective stress. It can be seen that permeability decreases faster in high permeability cores than it does in the lower permeability cores, and the permeability decrease for heterogeneous cores lie between these two. Permeability contrast of heterogeneous cores will influence its stress sensitivity, the greater the contrast is, the more alike the curve for heterogeneous cores with the low permeability one will be.

Results

Based on the stress dependent quantitative stress sensitivity model, the resulting permeability loss rate with the variation of effective stress is depicted in Fig.2, the input parameter used are the parameter of set 1 shown in Table 1.

Fig.2 suggests the same change trend with the experimental result is predicted by the model: with the increasing effective stress, the loss rate of permeability is increasing. The rate increases more quickly in low permeability cores than in high permeability ones, and for heterogeneous core, this rate lies between the former two. Also, the comparison between the experimental results with model results offers a relative error for stress dependent permeability loss rate in heterogeneous tight sandstone reservoir lies within 13.6%, meaning the model can fairly accurately do the analysis of stress sensitivity of tight sandstones.

Results show that the model can quantitatively describe the permeability loss of tight sandstone reservoir due to effective stress fairly precisely. Permeability varies with the effective stress in different cores. The lower the rock permeability is, the faster the permeability declines.

Moreover, the permeability declining speed of the heterogeneous rock lies between those of the high permeability layer and the low permeability layer. When the permeability ratio increases, the stress-dependent permeability curves of heterogeneous rock are closer to that of the low permeability layer in rock.

Novel Information

In this work, stress sensitivity experiments have been conducted to verify the stress-dependant quantitavie model, and based on the friendly result we conclude that the model introduced in this work can predict the permeability variation with increasing effective stress fairly accurately, which can provide a guiden for oil recovery of tight sandstone reservoirs.

Acknowledgements

The authors are grateful for financial support from the National Science and Technology Major Projects of China (Grant No.2016ZX05037-003).

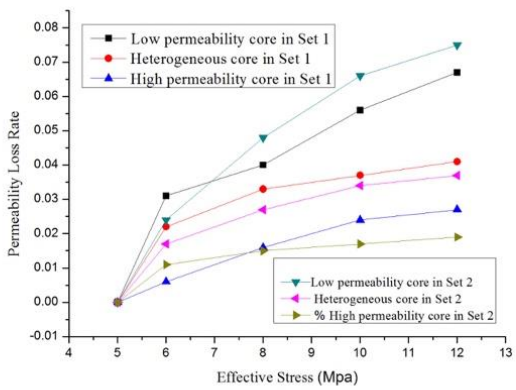

Fig. 1. Experimental results

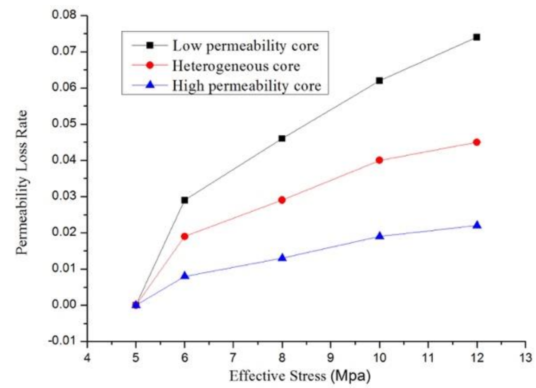

Fig. 2. Model results

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