Research Progress on Nonlinear Flow of Heavy Oil in Porous Media

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Summary

Heavy oil reservoir is a special type of oil reservoir that is different from conventional reservoir. Heavy oil has nonlinear flow characteristics, which hinders the transmission of drive energy and the migration of fluid and leads to more consumption of the formation energy, hence, these characteristics has made the development of Heavy oil reservoir more complicated and difficult. Therefore, it is necessary for the researchers to correctly understand the flow of heavy oil in porous media in order to effectively and efficiently develop heavy oil reservoir. This paper summarizes the influencing factors, mechanisms and applications of nonlinear flow of heavy oil in porous media, and it provides theoretical reference for better development of heavy oil reservoir.

Introduction

The reserves and production of conventional crude oil have significantly reduced with the oil field exploitation and the rapid increase of oil demand, which forces the development of some unconventional reservoirs. Some studies estimated that the current remaining amount of conventional oil was about 100 billion tons, while the geological reserve of heavy oil was approximately 700 billion tons in the world. As a result, the development potential of heavy oil has attracted many crude oil companies, but they encountered many problems in the development process of heavy oil reservoir. A large amount of on-site production, laboratory experiments and researches showed that the flow of heavy oil was different from that of conventional crude oil - it was no longer linear but nonlinear. Wang et al. (2006) discovered that the threshold pressure gradient existed in the heavy oil reservoir and Zaoyuan heavy oil can only flow when the pressure gradient overcame the threshold pressure gradient, and the result is shown in Fig.1. Dong et al. (2013) found that heavy oil had a threshold pressure gradient and presented nonlinear flow characteristics at low temperature, but the threshold pressure gradient no longer existed when temperature reached a certain temperature limit, as shown in Fig. 2.

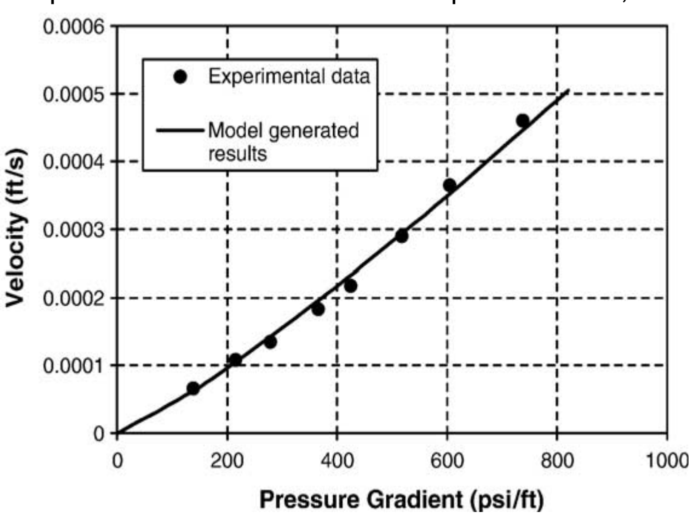

Fig. 1 Heavy oil flow through porous media, Well 1282-2, T =60 °C.

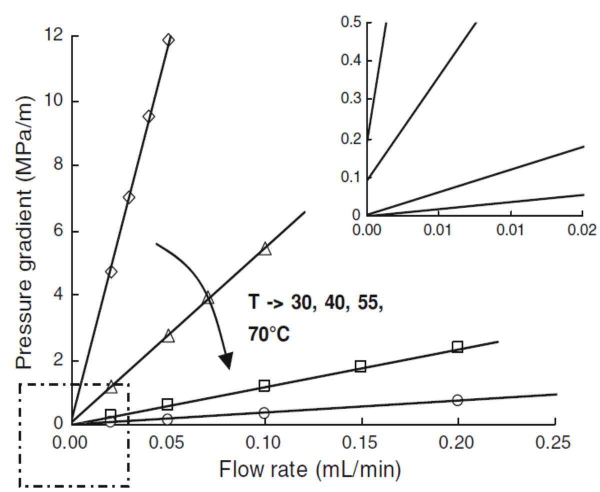

Fig. 2 Heavy oil flow through porous media, Well 13161, K = 9,180 ×10^{-3} μm^2

Influencing factors and mechanism

There are two main reasons for existence of the nonlinear flow. One is the non-Newtonian property of fluid: the quasi plastic, viscoelastic as well as the other non-Newtonian fluid existing in the heavy viscous crude oil. The other reason is the permeability of the medium: the interaction with the media can hinder the flow of fluid, which causes the nonlinear characteristics of fluid in the low permeability reservoir. Therefore, nonlinear flow characteristics mainly exist in heavy oil reservoirs and low permeability reservoirs. This paper only studies the nonlinear flow of heavy oil. Nowadays, numerous experimental and theoretical researches are about nonlinear flow, and the studies of influencing factors and mechanism of heavy oil nonlinear flow mostly focused on the composition of crude oil and the temperature.

Composition of heavy oil plays an important role in the flow of heavy oil, especially asphaltene and resin, which are the main cause for high viscosity. The flow characteristics of heavy oil is also closely related to the temperature. Heavy oil presents nonlinear flow at low temperature but the flow pattern of heavy oil starts to be linear flow with the increase of temperature. Luo et al. (2007) presented an experimental study about the specific effect of asphaltene content on the heavy oil viscosity at different temperatures, and the results are shown in Fig. 3 and Fig. 4. It is clearly seen from Fig. 3 that the asphaltene content in heavy oil played an important role in determining its high viscosity, particularly at low temperatures, where the absolute viscosity of the reconstituted heavy oil sample rose with the increase of asphaltene volume fraction. Fig. 4 shows that the relative viscosity of the reconstituted heavy oil sample increased slowly with the increase of asphaltene volume fraction in the diluted region but the relative viscosity increased most quickly and became most sensitive to the temperature at the tangled region, because the dispersed asphaltene particles with strong inter-particle interactions were close to each other and become tangled.

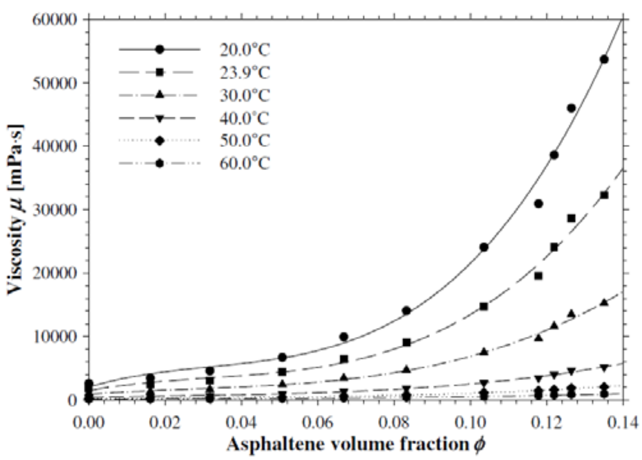

Fig. 3 Measured viscosity of the reconstituted heavy oil sample versus the asphaltene volume fraction at different constant temperatures.

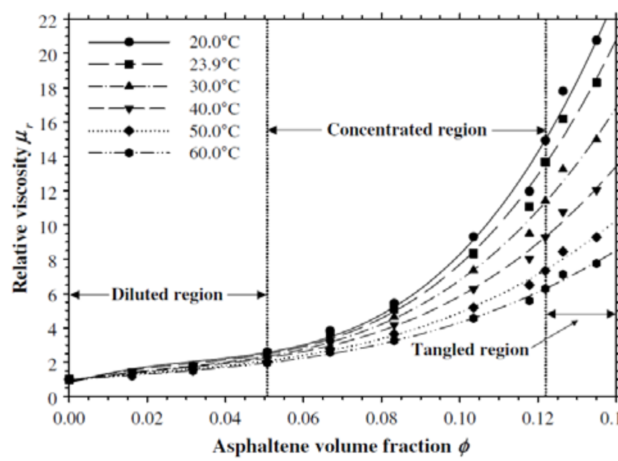

Fig. 4 Measured relative viscosity of the reconstituted heavy oil sample versus the asphaltene volume fraction at different constant temperatures

Pattern and application

For the better development of heavy oil reservoir, researchers have been paying more attention to the flow pattern of heavy oil and analyzing various factors (permeability, oil viscosity, mobility and temperature) that influenced the flow pattern of heavy oil through a large number of experiments. Xu et al. (2011) obtained the curve about the threshold pressure gradient of heavy oil, permeability (K) and mobility (K/μ) through an indoor experiment, as shown in Fig.5 and Fig.6. From Fig. 5, the threshold pressure gradient rapidly decreased with the increase of permeability, and the curves became flatter after the permeability outnumbered 600 mD. The threshold pressure gradient also decreased with the decrease of oil viscosity under the same conditions. Fig. 6 reveals that the threshold pressure gradient decreased with the increase of mobility, and the reduction amplitude decreased when the mobility exceed 25 $\mu m^2/(Pa \cdot s)$. They also built up single-phase unsteady flow model and two-phase 2-D unsteady flow model with the consideration of threshold pressure gradient, and established an analytical method for solving nonlinear flow model. XX oil field actual geological and fluid parameters were used in the model, and the results indicated that the threshold pressure gradient affected the transmission radius and propagation speed of the effective pressure greatly, as shown in Fig.7. Xin et al. (2015) improved the mathematical model considering the nonlinear flow characteristics of heavy oil, compiled the nonlinear flow module, and simulated the influence of threshold pressure gradient of heavy oil on the production index, as shown in Fig. 8. It is seen from Fig. 8 that the threshold pressure gradient had a great influence on the oil recovery.

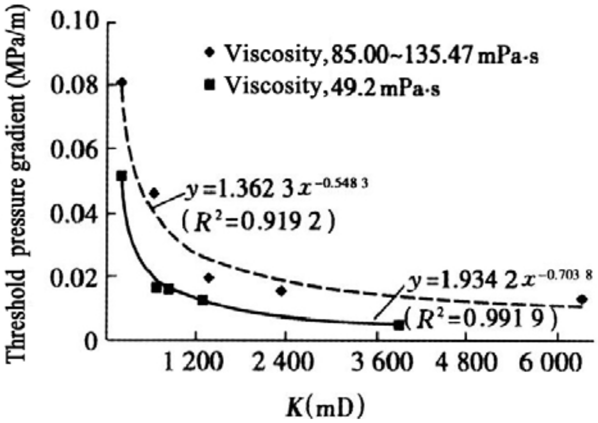

Fig.5 Threshold pressure gradient versus permeability.

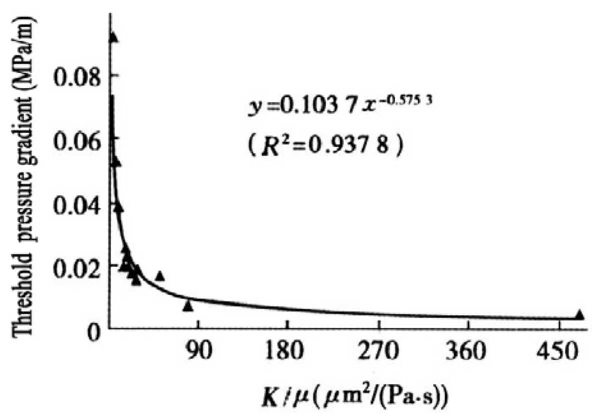

Fig.6 Threshold pressure gradient versus mobility

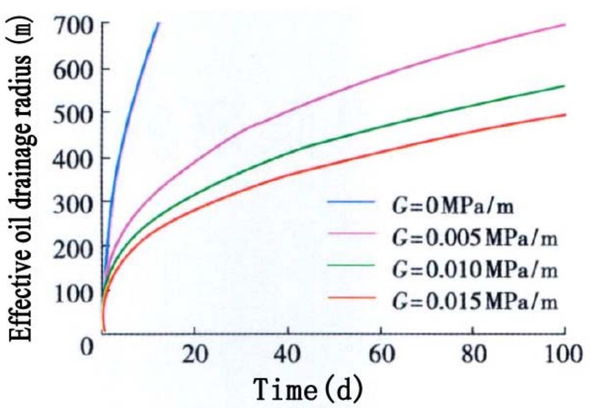

Fig.7 Effective oil drainage radius versus time at different threshold pressure gradient

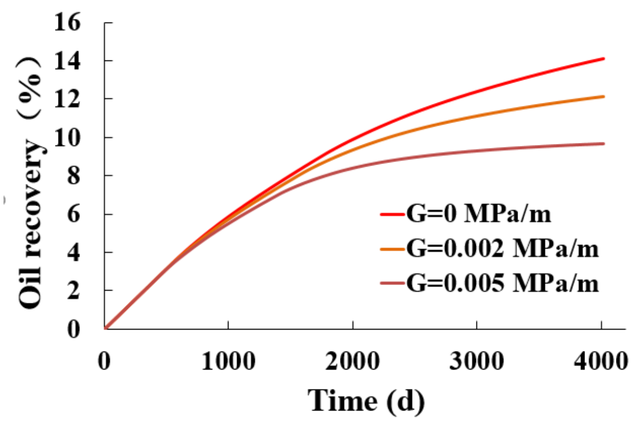

Fig.8 Oil recovery versus time at different threshold pressure gradient

Conclusions

At present, existence of the threshold pressure gradient in heavy oil reservoir is quite clear, and many scholars have recognized it. There have been many experiments and researches studying the nonlinear flow of heavy oil but not enough quantitative research now, and thus, more experiments need to be conducted in improving the research in this area. Numerical reservoir simulator considering the nonlinear flow of heavy oil is inadequate. Many factors have to be considered in order to improve the simulator, therefore, continuous attention and further researches are required in the numerical simulation of heavy oil reservoir.

Acknowledgements

The author thanks the scholars mentioned in this article and their researches. This paper mainly summarizes the mechanism and application of nonlinear flow of heavy oil in porous media in order to provide reference for the researchers working in this area.

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