IOP Conf. Series: Materials Science and Engineering **394** (2018) 042130 doi:10.1088/1757-899X/394/4/042130

Experimental Study of Primary Production in Shale

Wenwen Zhai[1], Mingshan Zhang[1], Houjian Gong[1], Yajun Li[1] and Mingzhe Dong[2, *]

[1]School of Petroleum Engineering, China University of Petroleum (East China), Qingdao 266580, China
[2]School of Chemical and Petroleum Engineering, University of Calgary, Calgary T2N 1N4, Canada

*Corresponding author e-mail: dong111mz@126.com.

Abstract. In order to study the flow mechanisms in porous media of shale reservoirs in the process of primary production, the shale cores from the Jiyang sag of Dongying district were selected to conduct the experiments under 15MPa and 25℃ condition. As comparison, experiments were also performed with tight sandstone cores. Results indicate that the production decreases fast for sandstones, and the oil production cycle is short, generally less than one hour. While for shale samples, oil recovery shows the same tendency in the early stage, followed by a very slow and long production cycle which can last up to 150 hours or more. Based on experiment results, the conventional flow model is modified by taking the desorption process into account, which can describe the flow mechanism in shale accurately.

1. Introduction

Unconventional oil and gas resources such as tight oil, shale gas, coalbed methane (CBM) are now becoming important parts of new oil and gas exploration and development with the breakthrough have made in oil and gas research theory and exploration technology [1-2]. China has abundant reserves of unconventional resources and a huge potential for development [3-4], the recoverable reserves of unconventional gas are $34.7 \sim 48\times10^{12}$ m^3, the tight oil are $13\times10^8 \sim 14\times10^8$ t. With the significant progress made in the development of shale gas, relevant researches on shale oil have also started to emerge. Shale oil is a kind of non-gaseous hydrocarbon which exits in effective hydrocarbon-generating shale formation. It exits in a variety of ways including not only free oil stored in inorganic pores, but also absorbed and dissolved oil in organic matters. A shale oil reservoir belongs to the self-generation, self-reservoir, and self-accumulation type [5-6]. It also has characteristics of low permeability, low porosity, well-developed nano-pores and kerogen [7]. Many scholars have done a great deal of works on the main organic matters in shale including on its type, composition and spatial structure [8-9]. Moreover, some scholars have studied the adsorption characteristics of kerogen and organic nanomaterials by means of molecular simulation. These works provide references for further understanding of the occurrence status of kerogen [10-11]. However, most of the researches are confined to the simulation stage at present, and the experimental verification is less. The effect of kerogen on the process of shale exploitation is not considered in the experiments. Therefore, experiments considering the effect of adsorption and desorption in kerogen are necessary, which attribute to understanding the flow mechanisms in shale and providing practical and guiding significance on Chinese shale exploitation.

2. Primary production experiments

2.1. Test samples
Two shale cores and two tight sandstone cores were collected from Luo 67 well in Shengli Oilfield, Jiyang sag of Dongying district for primary production experiments. The parameters of the four samples are shown in Table 1.

Table 1. Parameters of the cores

Cores	#1	#2	#3	#4
Lithology	shale	shale	sandstone	sandstone
Length (cm)	4.98	4.95	4.92	4.8
Diameter (cm)	2.48	2.49	2.48	2.51
Weight (g)	60.54	59.97	52.92	54.82
Porosity (%)	7.7	6.5	12.4	6.3%
Permeability ($10^{-3}\mu m^2$)	0.065	0.072	0.73	0.0085
TOC (wt. %)	2.11	3.58	0	0

2.2. Experimental principle and method
Before the experiment, the samples were put into core holders, and the air were removed from the system. Because of the compressibility of gas, its existence will have a great impact on the experiments. At a constant temperature, the cores were saturated with oil under 15 MPa for 7 days to ensure the oil saturated in the samples adequately. After that, the outlet valve was opened, and the data of oil production and time were recorded. Then the curve of oil recovery and time was drawn. Due to the low saturation of the core, conventional measure methods are not suitable, so a special method of measuring oil production is needed. In the experiment, a combination of transparent tube and label paper with scale is used, one can calculate oil amount at different times accurately by recording the moving distance of the oil and air interface in the tube. The experimental apparatus is shown in Figure 1.

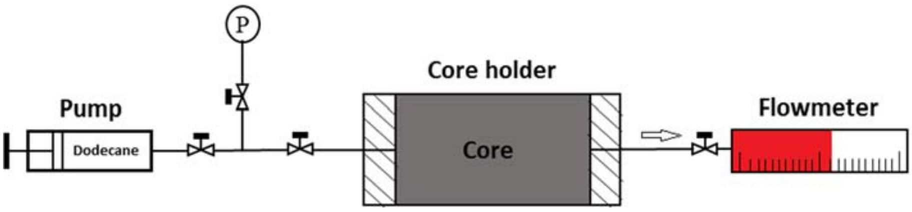
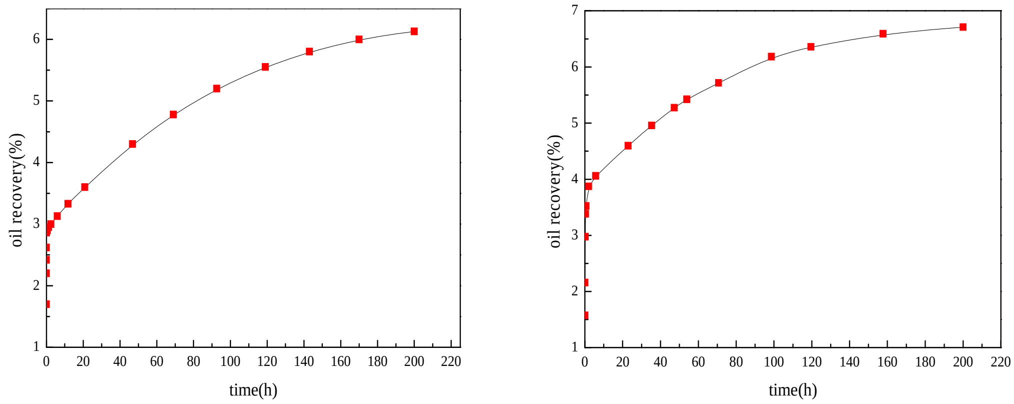


Figure 1. Core primary production apparatus

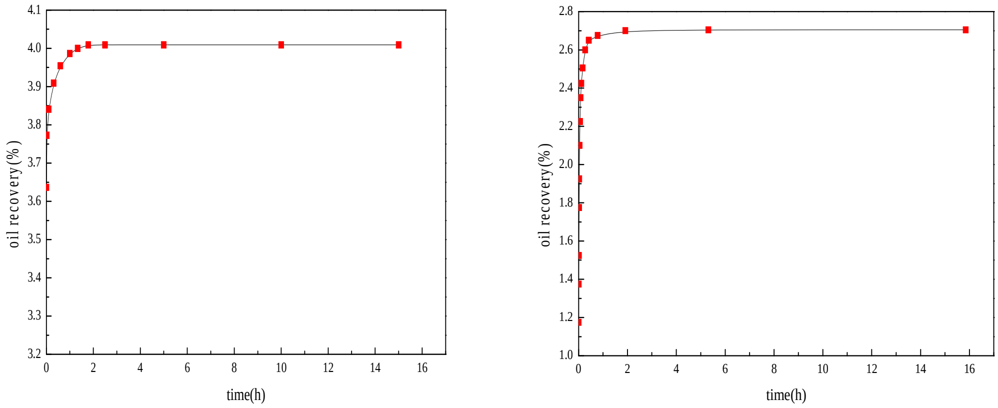
In order to study the characteristics of a shale reservoir exploited by elastic energy, the oil in this experiment used is n-dodecane which purity is 99.99%. The experiments were going under 15 MPa and 25℃ condition.

3. Experimental results and analysis
The results of primary recovery of four cores are obtained and the oil recovery curves can be plotted. The results of shale cores and tight sandstone cores are shown in Figure 2 and Figure 3 respectively.



(Core #1) (Core #2)

Figure 2. Accumulative oil recovery curves of core #1 and #2



(Core #3) (Core #4)

Figure 3. Accumulative oil recovery curves of core #3 and #4

From Figure 2 and Figure 3, it can be seen that the oil recovery is not high, ranging from 1.2% to 6.5%, indicating that primary recovery is relatively inefficient and some incremental measures are necessary at later period to enhance oil recovery and oil production rate. All the sandstone samples in the experiment showed that the oil production rate decreased quickly and the oil recovery cycle was very short, and production was almost stopped in less than 1 hour. While for the shale samples, the production rate was very fast in the early stage of exploitation, followed by a very long and slow recovery cycle, which resulted in much higher oil recovery. The recovery cycle of core #1 and core #2 were more than 200 hours. Among them, the oil recovery in the slow reflow stage can account for about 50% of the final recovery.

The existence of kerogen in shale may be the main reason for this reflow phenomenon. The oil in shale includes not only free oil stored in inorganic pores, but also absorbed and dissolved oil in organic matters. In the process of exploitation, with the reduction of the pressure, free oil is recovered by nature energy, however, due to the intermolecular force, the absorbed and dissolved oil in kerogen can only flow by the way of desorption slowly. Therefore, in the early stage of exploitation, free oil is mainly mined out and the oil production rate is very fast. While dissolved oil in kerogen played a major role in the later stage.

4. Mathematical model and analysis

Free oil stored in inorganic pores satisfies the normal flow equation, while absorbed and dissolved oil in kerogen flows by the way of desorption when exploited. In order to study the effect of adsorption and desorption in kerogen, some improvements are necessary to the conventional flow model.

Assumptions:

1) Since the size of core is small, the pressure wave spreads to the boundary in a very short period of time. Therefore, it can be considered that absorbed oil in different locations desorbs from kerogen simultaneously and the amount of desorption is only a function of time.

2) The distribution of kerogen in the core is uniform

Suppose the adsorption saturation is Γ_∞ when approaching the adsorption equilibrium. Γ_∞ can be determined by the experiment, and this parameter is related to kerogen content. The relationship between the amounts of desorption and time satisfies the equation:

$$\Gamma = \Gamma\infty(1-(\frac{1}{t+1})^b) \tag{1}$$

Where b is the desorption coefficient, it reflects the speed of desorption. Deriving the equation between the amount of desorption and time, the equation for the relationship between desorption rate with time can be described as follows:

$$q = b\times\Gamma_\infty(1+t)^{-1-b} \tag{2}$$

Considering the desorption rate as a source term and add it to the conventional flow equation model, flow equation considering the kerogen adsorption effect in shale can be described by the following equation:

$$\frac{\partial^2 p}{\partial x^2} = \frac{1}{\eta}\frac{\partial p}{\partial t} - q \tag{3}$$

Where q is a source term that represents the adsorption effect in kerogen.

The corresponding boundary and initial conditions of the model are given by:

$$\begin{cases} \dfrac{\partial^2 p}{\partial x^2} = \dfrac{1}{\eta}\dfrac{\partial p}{\partial t} - q \\ p\big|_{x=0} = p_0 \\ p\big|_{t=0} = p_i \\ \dfrac{\partial p}{\partial x}\Big|_{x=5} = 0 \\ q = b\times\Gamma_\infty(1+t)^{-1-b} \end{cases} \tag{4}$$

Using numerical difference method by Matlab software, one can solve the above model. Figure 4 shows the comparison between the improved flow equation model and the conventional flow equation model.

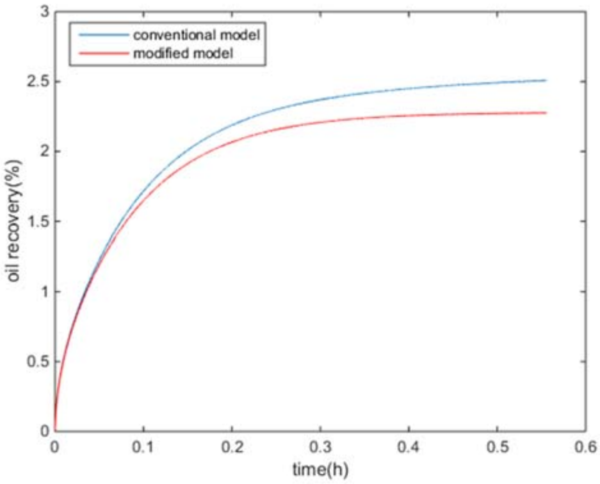


Figure 4. Mathematical model of conventional reservoirs and shale reservoirs

It can be seen from Figure 4 that the primary production has a short duration without considering the desorption effect in kerogen. When considering the effect of adsorption and desorption in kerogen, the primary production performance appears to be a very long period of reflow stage. The simulation results are very consistent with the experimental results, indicating that the model can be used to simulate the primary production in shale oil to some extent.

5. Conclusion and recommendations

1) The sandstone and shale have different characteristics when exploited by elastic energy, the recovery cycle of tight sandstone is short, while shale has a very long period of reflow stage and a long recovery cycle.

2) The existence of organic matters such as kerogen in shale is the main reason leading to this phenomenon. A part of absorbed and dissolved oil desorbs from kerogen when the pressure decreases and greatly prolongs the shale recovery cycle.

3) By considering the desorption effect in kerogen, the conventional model of primary production has been improved, and the improved model can well simulate the process in shale exploited by elastic energy.

4) During production of shale oil, the process of adsorption and desorption in kerogen is needed to be taken into account to obtain a more accurate prediction of shale oil production dynamics.

Acknowledgments

We gratefully acknowledge financial support from the National Science and Technology Major Project (2017ZX05049-006), the National Basic Research Program of China “973 Program” (No. 2014CB239103), the National Natural Science Fund project of China (51774310), and the Fundamental Research Funds for the Central Universities (17CX05005).

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