Effect of depletion rate on solution gas drive in shale

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Abstract. Solution gas drive process has been studied extensively in sand rocks and heavy oil reservoirs for a long time. Oil recovery is affected by several factors, such as depletion rate, initial GOR (gas oil ratio), oil viscosity, and temperature and so on. Before the solution gas drive tests, elastic drive without dissolved gas was carried out as a reference, which shows a limited oil recovery. Solution gas drive experiments were conducted in shale to study oil recovery with various depletion rates. Results show that oil recovery increases with the decrease of depletion rates because of the low permeability and desorption of methane.

1. Introduction

With huge potential and abundant reserves [1-3], exploitation of shale gas and oil has become a hot issue all over the world [4-6]. Compared with the conventional reservoirs, the shale formation presents unique characteristics, with the low permeability and extremely tiny pores (on nanometer scale) [7-9]. Besides, the shale contains kerogen and the amount of total organic content is generally in the range of 1%-14% [10-12].

Pressure depletion rate as a primary influencing factor for hydrocarbon recovery by solution gas drive, has been studied extensively in the early years [13-15]. Copper [16] drew the conclusions that oil producing rate or pressure draw down has no influence on solution gas drive recovery. By contrast, Connaughton [17] et al indicated the recovery is sensitive to the depletion rate. Handy conducted core depletion experiments and reported that increase of the pressure depletion rate is beneficial for improving oil recovery [18]. Several researchers argued that more bubbles are formed at high pressure-decline rates because of greater supersaturation and nucleation rate [19-20]. Kumar investigated the effects of depletion rate during solution gas drive in heavy oil and suggested that more oil recovery was achieved at high depletion rates [21]. Gas–oil dispersion flow has been successfully demonstrated in heavy oil with higher pressure gradients which contributes to higher recovery factors [22-23].

In this work, the comparison of primary depletion without dissolved gas and solution gas drive was analyzed. Depletion test of the shale core were carried out at different draw-down rates to study how the factor influences the ultimate oil recovery.
2. Experimental

2.1. Core samples and fluids

The cores samples used in the experiments were obtained from well L67 in Sheng li field in Dong ying. Geologic map of the Zhanhua sag is shown in Fig. 1. The main parameters of the cores are shown in Table 1.

| Core | Lithology | Length (cm) | Diameter (cm) | Mass (g) | Porosity (100%) | Permeability ($10^{-3} \mu m^2$) | TOC (wt.%) |
|------|-----------|-------------|---------------|----------|-----------------|-----------------|------------|
| L67  | shale     | 4.98        | 2.48          | 60.54    | 7.7             | 0.065           | 2.11       |

2.2. Primary depletion tests

The depletion tests without solution gas of shale core were carried out before the solution gas drive. Fig. 1 shows a schematic of the primary depletion test of core samples. The experimental setup consisted of a high pressure core holder, a high pressure pump with n-decocane, a digital pressure gauge with an accuracy of ±0.065% of the full-scale span (30 MPa), and a high-precision oil-flow meter with an accuracy of 0.01mL.

![Figure 1](chart1.png)

**Figure 1** diagram of primary depletion test.

2.3. Solution gas drive tests

![Figure 2](chart2.png)

**Figure 2** diagram of solution gas drive.

Fig. 2 shows a schematic of the solution gas drive test of core samples. The main component of this setup is the core holder with the length of 8cm and inner diameter of 2.5cm. A back pressure regulator is connected to the outlet of the core holder to control the system pressure with a pressure open error of less than 0.2 MPa. A hand pump was used to reduce the pressure of the BPR during the depletion tests. To minimize the error caused by tiny oil saturation in the core, an oil–gas separator was specially designed to separate the oil and gas during the production process. Oil is measured using a high-
precision graduated cylinder, accuracy±0.02 mL and the gas is collected by a graduated apparent, 
accuracy of which is 0.1mL. The volume of pipe volume is subtracted for the calculation of ultimate 
oil recovery. All the tests were conducted at the temperature of 23.5±0.5°C.

3. Results and Discussion

3.1. Comparison of dead oil primary depletion and solution gas drive

Primary depletion and solution gas drive test with an initial GOR of 28 mL/mL was carried in the core. 
Both tests started from initial saturation pressure of 15MPa and terminated at atmosphere. The result 
of oil recovery was shown in Fig. 3. As can be seen from Fig. 3, the ultimate recovery efficiency is less 
than 4% with production time lasting more than 150 hours. For solution gas drive the oil recovery can 
reach 25% much higher than primary depletion process.

3.2. Pressure decline depletion of solution gas drive

A series of solution gas drive tests were carried out. For this core depletion tests were conducted with 
depletion rates of 0.25, 0.5, 1, 4MPa/h and GOR of 30mL/mL. All the tests were terminated at the 
atmosphere. Fig.4 shows the oil recovery increases with the decrease of depletion rate. The highest oil 
recovery is obtained at the slowest rate of 0.25MPa/h. The low permeability and desorption of 
methane may attribute to this anomalous phenomenon. As pressure drops to the bubble point, the gas 
bubbles starts to nucleate in the pore and grow with the time until they form a continuous phase[19- 
20].With the growth of bubbles, oil is displaced by the increase of bubble size. When the rock is tight, 
the movement of gas bubbles is slow due to the high capillary, which delays the coalescence process. 
Thus a slower depletion rates means a maximum growth of bubbles, which results in a high recovery. 
During the depletion process, CH₄ will desorb from the kerogen and diffuse into the oil, reducing the 
viscosity of oil. Diffusion of CH₄ in the tiny pores is slow [31-32], therefore it takes a long time for a 
dynamic equilibrium between gas and liquid. Even though the depletion experiments are carried out at 
a slow rate, they are still not in equilibrium [33-34]. Therefore a slower depletion allows for enough 
desorption and diffusion of CH₄.

![Figure 3](image-url)
Figure 4 cumulative oil with different pressure stages.

Semi-log produced GOR curves with time are shown in Fig. 5. When the pressure is higher than the bubble point, produced GOR equals to the initial GOR, which is the elastic recovery stage. For the second stage where most oil was produced, there is a decrease in produced GOR after a constant value. Gas nucleating in the pore cannot move with the oil because of the capillary and grow gradually. In the third stage, gas gathers together to form a flow channel, therefore, produced GOR increases rapidly and fluctuate wildly. It can be seen that duration time of stage 2 is various with different rates. For this core, the second stage lasts 1320, 120, 60, 6 mins at the rate of 0.25, 0.5, 1, 4 MPa/h. In this stage, the gas bubble was confined in the pore and grow slowly, which is beneficial for oil production.

Figure 5 Produced GOR curve with different rates.

4. Conclusion
1. The primary oil recovery without gas in shale is about 4% far lower than oil recovery of 25% OOIP when there exists gas in shale reservoir. A higher oil recovery can be obtained at a slow depletion rates in shale solution gas drive due to the low permeability and desorption of methane.

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