Experimental study of displacement mechanism of foamy oil flow in heavy oil using CO_2

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Summary

In our study, a hypothesis is raised to investigate the mechanisms of foamy oil generation in the heavy oil reservoir. Injected gas is predicted to override on the top of heavy oil. Due to gravity difference, gas will peel-and-sweep the surface of the contacted heavy oil, which finally leads to foamy oil generation. In this study, gas displacement process was presented in CO_2 injection tests, which was conducted in a square-of-a-five-spot visible heavy oil system. Experimental results characterize the phenomenon of gravity override and peel-and-sweep mechanism of injected gas. CO_2 injection strategy was optimized by identifying key parameters including gas injection rate, gas injection pressure, and contact time. The best recovery factor of 36.65% was reached.

Introduction

The concept of foamy oil was developed by Maini in 1993 to describe a dispersed gas-liquid two-phase flow in high viscous oil reservoir at the primary stage. This phenomenon has been discovered in western Canada, Venezuela, China, and Oman. Numerous papers published have explained possible mechanisms leading to high recovery factor of foamy-oil flow (Liu 2008; Xiao and Zhao 2013). Most of the previous laboratory experimental tests mainly focused on investigating parameters including oil type, saturation pressure, pressure depletion rate, and gas oil ratio (GOR), which might affect solution-gas-drive foamy-oil production (Bashir et al, 2017). There has no published work studying displacement process of foamy oil flow after gas injection in the heavy oil reservoir. To clarify the foamy oil mobilization process, CO_2 was injected into the designed experimental model. Gas injection parameters are evaluated afterward including gas injection rate, gas injection pressure and contact time of gas with heavy oil.

Theory and/or Method

The behavior of foamy oil flow and oil production scheme is proposed with an assumption of a CO_2 gas dissolution layer. Enormous differences of physical properties such as density and viscosity between gas and heavy oil can lead to gas gravity override the top of heavy oil. The phenomenon of foamy oil generation is based on an assumption that overriding gas will react with connected heavy oil and generate foamy oil when flow on the oil surface. The displacement process of this assumption is shown in Figure 1.

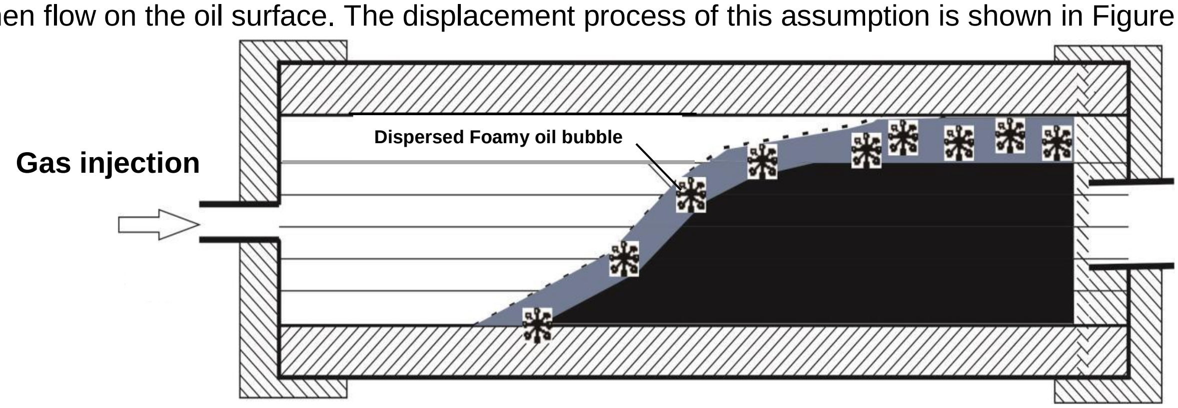

Figure 1. Displacement process of foamy oil after gas injection in heavy oil reservoir

Due to the large connecting area, gas can dissolve into and have mass transferred with heavy oil, thus finally sweep formed foamy oil with continuing gas injection. As time passes by, heavy oil on the connect surface will be peeled layer by layer by injected gas and generated foamy oil will flow to the production well. Foamy oil has a stable structure and low viscosity, which contributes to increasing the mobility of heavy oil. Thus, relative rates between injected gas and displaced heavy oil are altered and gas channeling can be controlled. In this way, high sweep efficiency and favorable recovery factor can be achieved. In this study, visible physical heavy oil model had been designed to simulate foamy oil scheme after gas injection. To better observe gas peel-and-sweep phenomenon on the top of the heavy oil, a quarter-of-a-five-spot pattern had been used. Three type of marble chunks with different relative permeability was used to imitate a positive rhythm vertical heterogenous formation, as shown in Figure 2. Improvement had been made after few experiments to get an obviously visible model with successful foamy oil production.

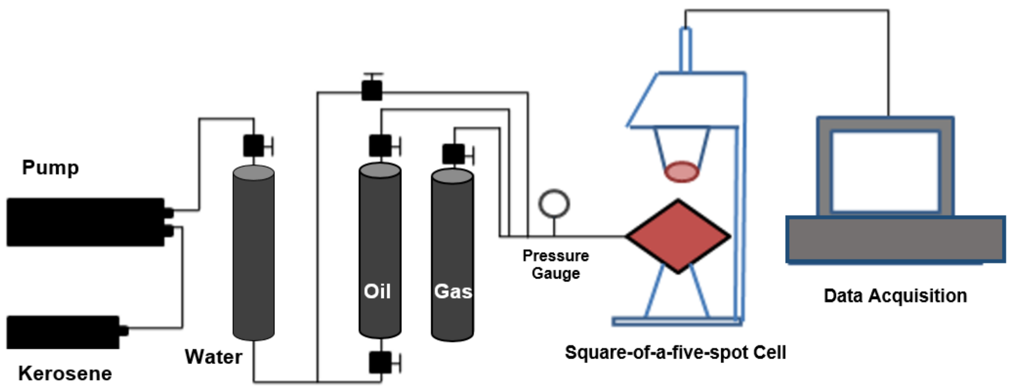

Figure 2. Experimental apparatus for foamy oil tests

Examples

To prepare the model, water was injected and pore volume (PV) was calculated by model weight difference. Two kinds of heavy oil samples from Shengli Oilfield (1281-B) with a viscosity of 15697mPa·s and Xinjiang Oilfield (92623) with a viscosity of 11891mPa·s had been used in the experiment separately. The dead oil displacement process was performed until no water was produced. Model properties after filled with these two dead oil are listed in Table 1.

Table 1. Experimental mode properties

Area	Dry weight, Kg	Wet weight, Kg	Pore volume, PV	Saturated oil volume, mL	Porosity, %	Oil saturation, %
Shengli Oilfield (1281-B)	2.188	2.227	39.0	25.5	11.8	65.38
Xinjiang Oilfield (92623)	2.205	2.244	39.0	25.5	11.8	65.38

After fully preparation, core-flood tests using CO_2 were carried out at 4ml/min at 2.5MPa for 4 hours. Thereafter, properties of produced foamy oil were examined including viscosity, quality, and stability, which are listed in Table2. From results of both experiments, the oil viscosity effectively decreased after gas injection, and satisfactory recovery factor was obtained. Foamy oil was successfully formed with good quality and stability, the produced foamy oil was collected. From the results, experiments using oil sample from Shengli Oilfield (1281-B) achieved higher recovery factor. However, when evaluating foam properties including viscosity reduction and foam stability, oil sample from Xinjiang Oilfield (92623) showed better performance.

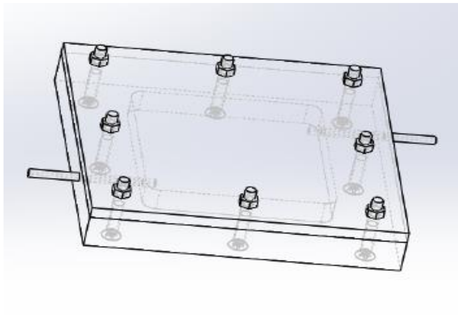

Figure 2. Visible experimental model

Figure 3. Experimental model before gas injection and during gas injection

Table 2. Properties of produced foamy oil after CO_2 injection

Area	Recovery factor, %	Viscosity, mPa·s	Foamy quality, %	Half-life period, h
Shengli Oilfield (1281-B)	29.63	13082	12.58	11.3
Xinjiang Oilfield (92623)	26.61	8962	15.31	10.2

Displacement profile of remaining heavy oil during the CO_2 core-flood process and collected produced foamy oil are shown in Figure 4. As gas injected in, a gap showed up in the middle of the pore channel and was torn bigger and bigger by continuous gas injection. This gap tended to grow in multiple directions and foamy oil bubble started to generate on the surface of heavy oil in contact with the injected gas. When the gap got big enough to connect with each other, gas would flow in those shortcuts and stop peeling the surface of the heavy oil. This profile proves that the gas peel-and-sweep phenomenon does exist at the contacted surface with heavy oil, following with foamy oil production when gas is continuously injected in. From Figure 4, gas override existence can be speculated from the appearance that the upper part of heavy oil surface was firstly peeled away by CO_2 because of density difference.

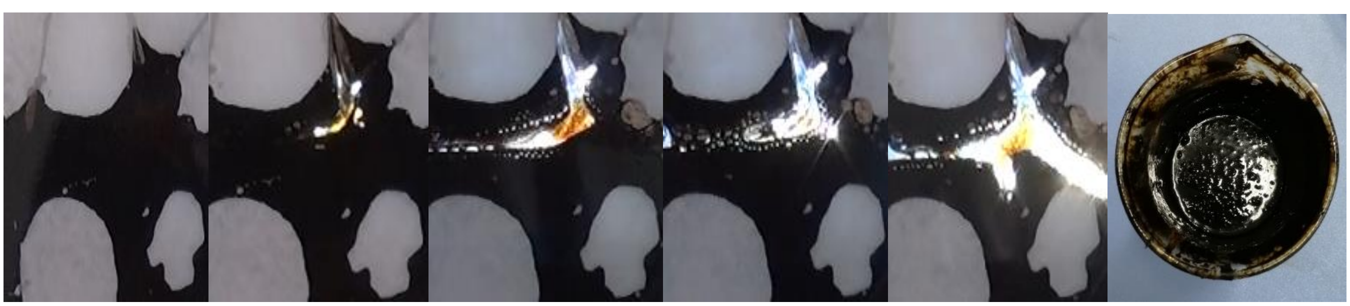

Figure 4. Pore displacement profile during gas injection process and produced foamy oil

In order to get better foamy oil production before shortcuts formed, injection parameters need to be investigated. Pressure depletion rate of primary foamy oil recovery has been proved to be the most influential parameter to increase the amount of foamy oil recovered in previous research (Pengcheng Liu, 2016). To analyze what parameters can control foamy oil recovery after gas injection, parameters including gas injection rate, gas injection pressure, and contact time were studied. The pore volume of our experimental model is 39 mL, so oil recovery factor of all experiments was calculated by dividing produced oil volume by original oil volume in the prepared oil saturated model in each experiment. Five values of gas injection rate of 1 mL/min, 2 mL/min, 4 mL/min, 8 mL/min, and 10 mL/min were tested for both oil samples separately. From Figure 5, the injection rate of 2 mL/min should be the best injection for both oil samples from Shengli Oilfield and Xinjiang Oilfield. Gas injection pressure was adjusted ten times based on the best gas injection rate of 2 mL/min at 0.5 MPa to 5 MPa. The best oil recovery factor can be obtained at the pressure of 4.5 MPa, although foamy oil bubbles will have better properties under higher gas injection rate. Time of contact was set as 1 hour, 2 hours, 4 hours, 6 hours, and 8 hours at an injection rate of 2 mL/min under 4.5 MPa. Results in Figure 5 indicates contact time of injection gas and heavy oil has no relation to oil recovery factor.

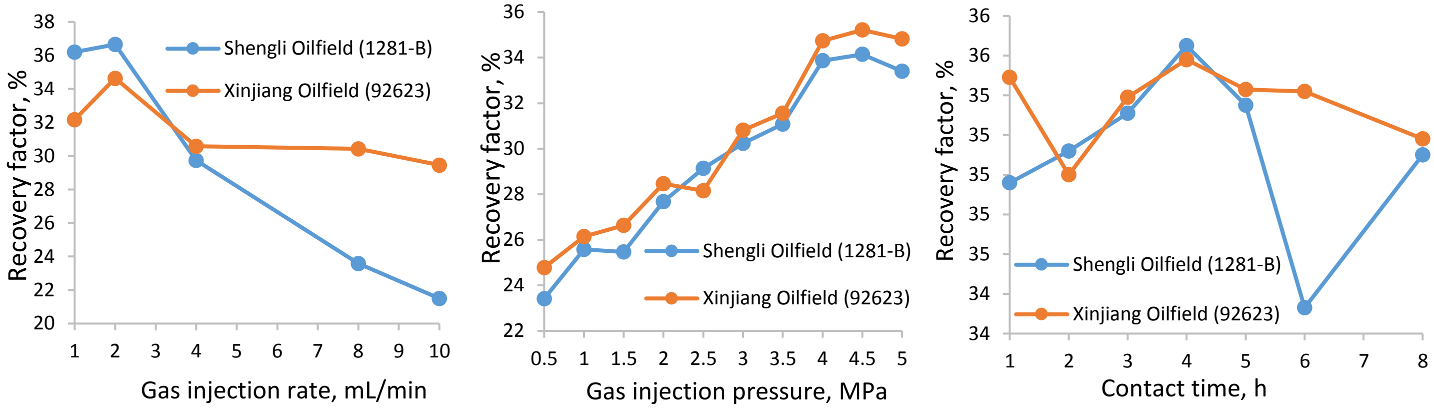

Figure 5. Oil recovery factor versus gas injection rate, gas injection pressure and contact time

Conclusions

In this paper, we proposed a new solution-gas-drive displacement mechanism of foamy oil recovery in the heavy oil reservoir. A visible square-of-a-five-spot model was designed and gas flooding tests, foamy property measurement, and gas injection strategies optimization were conducted. The phenomenon of gas gravity override and peel-and-sweep heavy oil was successfully identified with generation and production of foamy oil. Optimized parameters of 2 mL/min gas injection rate and 4.5 MPa injection pressure are obtained for oil samples form Shengli Oilfield and Xinjiang Oilfield.

Acknowledgements

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