CSCanada

Advances in Petroleum Exploration and Development
Vol. 5, No. 1, 2013, pp. 37-41
DOI:10.3968/j.aped.1925543820130501.1058

ISSN 1925-542X [Print]
ISSN 1925-5438 [Online]
www.cscanada.net
www.cscanada.org

A Case Study on Foamy Oil Characteristics of the Orinoco Belt, Venezuela

SUN Xiaofei[a],*; ZHANG Yanyu[a]; LI Xingmin[b]; CUI Guoliang[a]; GU Jianwei[a]

[a] College of Petroleum Engineering, China University of Petroleum, Qingdao, Shandong, China.
[b] Research Institute of Petroleum Exploration and Development, PetroChina, Beijing, China.
* Corresponding author.

Supported by Fundamental Research Funds for the Central Universities (NO.11CX06022A) and Major National Science and Technology Programs (NO.2011ZX05009-003).

Received 22 December 2012; accepted 2 March 2013

Abstract

With a current recovery of less than 11%, the Orinoco Belt in Venezuela still contains potentially more than 1.3 trillion barrels of reserves of "three highs, one low" oil at a depth of 100 to 1500 m. 5 joint projects and one project of Petroleos de Venezuela SA are making plans to improve oil recovery in the area. So it is important for them to have a thorough knowledge of foamy oil characteristics. This reservoir has a peculiar behavior called as a foamy phenomenon. In order to characterize the properties of the foamy oil, this paper discussed unconventional test methodology and the detailed suite of laboratory procedures including PVT and pressure depletion tests used to examine the Orinoco heavy oil. The results showed substantial differences in characteristics of foamy oil and conventional oil studied, not only in terms of PVT behavior but also in terms of the production performance during pressure depletion tests. The foamy oil compressibility was between 10-120×10^{-4} mPa^{-1}, which was obviously higher than that of conventional oil. Differential liberation experiments of the oil, with obvious high formation volume factor, stable GOR, and low density showed a strong tendency to foam below the bubble point. Other notable observations were that more efficient oil recovery was achieved at high depletion rates while less free gas was produced.

Key words: Foamy oil; Unconventional tests; The Orinoco Belt; PVT; Pressure depletion tests

Sun, X. F., Zhang, Y. Y., Li, X. M., Cui, G. L., & Gu, J. W. (2013). A Case Study on Foamy Oil Characteristics of the Orinoco Belt, Venezuela. *Advances in Petroleum Exploration and Development*, *5*(1), 37-41. Available from: URL: http://www.cscanada.net/index.php/aped/article/view/j.aped.1925543820130501.1058
DOI: http://dx.doi.org/10.3968/j.aped.1925543820130501.1058

INTRODUCTION

The Orinoco Oil Belt is located along the southern margin of the Eastern Venezuela Basin, covering an area of approximately 55,000 km^2. It is 600 km in length and 90 km in width. Within it lies one of the largest oil deposits in the world, roughly 1.3 trillion barrels of "oil in place" (Villarroel, 2008). The area is divided into four distinct production zones: Machete, Zuata, Hamaca and Cerro Negro according to the structural and sedimentary characteristics. Currently, 5 joint projects and one project of Petroleos de Venezuela SA are running in the Orinoco heavy oil belt. The daily oil production of the six projects is more than 11.7×10^4 t and the producing percentage is less than 11% (Hernandez *et al*., 2008).

The main purpose layer is at depths of 100 to 1500 m, which is a suite of unconsolidated sandstones with net thickness ratio of 0.5, and net pay varying areally from 5 to 100 m. Porosity and permeability measurements made on several wells reveal porosities are higher than 32%, and permeabilities are higher than 3000×10^{-3} μm (Hernandez *et al*., 2008; Dusseault *et al*., 2008; Gipson *et al*., 2002; Gina, 2011).

The heavy oil of Orinoco has great difference from other heavy oils in the world. It has the characteristics of high density (934-1050 kg/m^3), high sulfur (average 35000 mg/L), high heavy metal nickel and vanadium (>500 mg/L) and low viscosity (generally lower than 20 Pa·s), which can form easily foamy oil. The oil can flow and the single well production is very high under cold production. The production of the horizontal well under the cold production can be up to 200 t/d.

1. FOAMY OIL PVT STUDIES

Foamy oil behaviour is a unique phenomenon associated with production of heavy oils. It is believed that this mechanism contributes significantly to the abnormally high production rate of heavy oils observed in the Orinoco Belt. This portion of the paper describes the unconventional test methodology and procedures used in the laboratory program conducted to characterize the oil of Orinoco and reveal the physical properties of heavy oil such as compressibility, density and GOR. Foamy oil PVT studies include the unconventional constant-volume depletion and differential liberation experiments.

1.1 Test Methodology

For foamy oils, due to the high viscosity of the oil, the gas bubbles cannot immediately coalesce together to form bubbles large enough to allow gravitational forces to separate gas from the oil when the pressure is below the buble point pressure. A large volume of the released gas is trapped within the porous media forming foamy oil (Huerta *et al*., 1986; Lago *et al*., 2000). For this reason the foamy oil is not a thermodynamic equilibrium system. That's why non-conventional tests are needed to simulate more realistically heavy and extra heavy oil field behavior rather than conventional method.

The main difference between the new method and the conventional one is that during the non-conventional test, the PVT cell was not shade, avoiding a rapid artificial nucleation of the gas micro bubbles and hence forming a separated gas phase. Due to the fact that foamy oil tendencies are more pronounced at rapid depletion rates, the rapid depletion test is conducted first to ascertain if the oil exhibits any foamy oil tendencies. If no foaming tendencies are observed, further lower rate depletion tests are not required, and the data from the first test will provide a suite of conventional black oil differential liberation data for the oil being examined. If foamy oil tendencies are observed, additional tests are then conducted at slower depletion rates to note the effect on pseudo bubble point pressure and oil properties.

1.2 Procedure

Reservoir crude oil (24715 mPa·s) was recombined with methane gas and carbon dioxide at the reservoir temperature of 54.2 ˚C to yield recombined reservoir oil with a gas-oil ratio of approximately 15.58 m^3/m^3 for use in the laboratory program. Oil formation volume factor of reservoir oil is 1.173 under reservoir condition. The recombined reservoir oil composition shows very high heptane plus (C_{7+}) content, 73.91%. This oil was a common feedstock for all of the PVT and coreflood tests conducted.

For this program, we conducted four complete PVT studies, with the only variation being the speed of the pressure reduction during constant-volume depletion and differential liberation experiments. These tests were classified as"rapid-rate" (60 minutes per depletion step), "mid-rate" (12 hours for each depletion step), "slow-rate" (1 days for each depletion step) and"equilibrium" (5 days per depletion step with agitation). Pressure was monitored versus time for each change in volume of the PVT cell. Density was measured using a PAAR digital density meter, and viscosity was measured by a capillary tube viscometer.

1.3 Results

1.3.1 Constant-Volume Depletion Experiment

Figure 1 shows the measured results of the relative volume for the four different rate depletion which demonstrates that foamy oil tendencies are pronounced. The relative volume versus pressure curves move to the direction of pressure reduction with increasing depletion rate. The buble point pressure and pseudo bubble pressure can be determined from intersections of two slopes in relative volume versus pressure curves shown in Figure 1. Bubble point pressure can be estimated from conventional PVT test (equilibrium). Pseudo bubble point pressure(The point at which the bubbles of free gas can finally start to escape from solution as a distinct free gas phase)can be estimated likewise but from non-conventional PVT results. Figure 1 shows that bubble pressure is 4.95 MPa, and pseudo bubble pressures for the three different depletion rates are 3.44 MPa, 2.74 MPa, and 1.89 MPa.

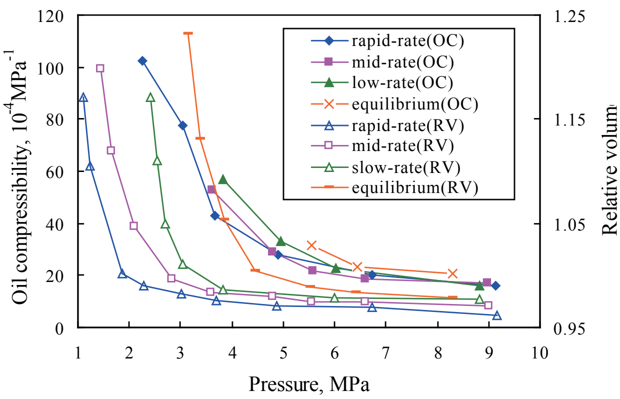

Figure 1
Oil Compressibility and Relative Volume Versus Pressure

Oil compressibility data increase gradually with the reducing of pressure at all four depletion rate sets of data because of the existence of foamy oil phenomenon. When the pressure is between bubble point pressure and pseudo bubble point pressure, the oil compressibility data increase sharply. The foamy oil compressibility is between 10-120×10^{-4} MPa^{-1}, which is obviously higher than that of conventional oil. When the pressure is above the bubble pressure, the difference of oil compressibility data between the four depletion rate tests is small. However, when the pressure is between bubble point pressure and pseudo bubble point pressure, higher foamy oil compressibility data are observed in the slow-rate depletion test compared with those in the rapid-rate depletion at the same pressure. The reasons for such phenomenon are that both conventional and non conventional tests are in a similar fashion above the bubble point. Pressure as all gas is solubilized in the oil and no free gas phase exists. However, the gas micro bubbles retained in the oil produces a greater compressibility in the non-conventional test when the pressure is between bubble pressure and pseudo bubble pressure, and the slower the rate, the phenomenon of foamy oil is more obvious.

1.3.2 Differential Liberation Experiment

The formation volume factor data, gas-oil ratio, density and viscosity data from all four depletion rate sets of data have been plotted and appear as Figures 2 and 3.

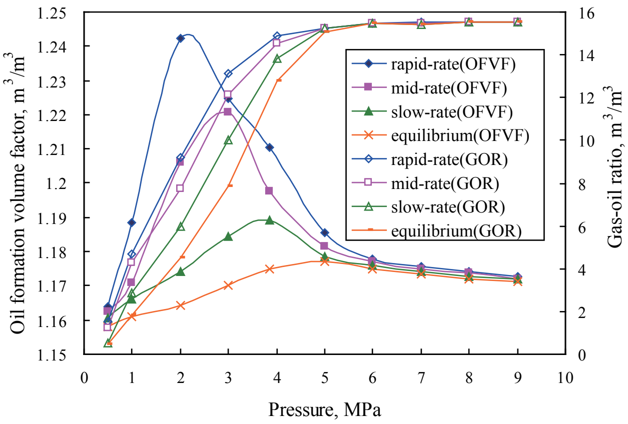

Figure 2
Gas-Oil Ratio and Oil Formation Volume Factor Versus Pressure

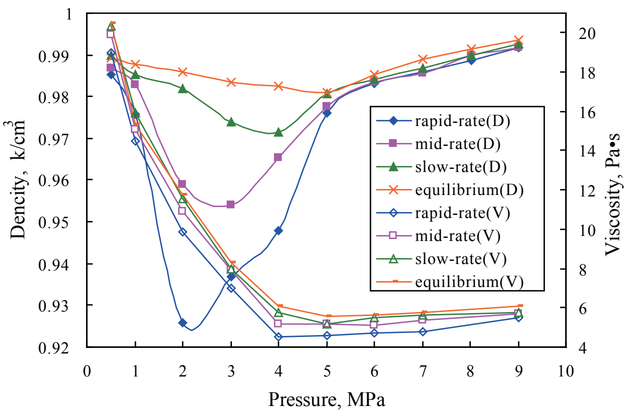

Figure 3
Viscosity and Density Versus Pressure

Figures 2 and 3 show that the formation volume factor data, gas-oil ratio, density and viscosity data from all four depletion rate is essentially the same above buble pressure regardless of depletion rate because all gas is solubilized in solution in the oil and no free gas phase exists. However, examination of the data between bubble point pressure and pseudo-bubble point pressure indicates the expected foamy oil behaviour with obvious increases in formation volume factor and the accompanying stability of GOR. Reductions in density are observed in the rapid rate depletion test in comparison to the slower rate and equilibrium rate experiments. At the pseudo bubble point pressure of different depletion rate tests, the formation volume factor and density will reach their maximum value, and below this pressure it decrease due to gas liberation. The viscosity profile did not appear to be strongly affected by the depletion rate for the oil.

2. PRIMARY PRESSURE DEPLETION TESTS

The objective of this study is to conduct primary depletion tests in a sandpack and determine the effect of depletion rate on foamy oil production.

2.1 Setup

The schematic of the experimental setup is shown in Figure 4. It consists of: (a) a 50-cm-long sandpack equipped with three pressure ports; (b) a mixer for preparation of live oil; (c) back pressure regulator; (d) oil and gas collectors, (e) a data acquisition system which is used to record data from various instruments during the experimental run.

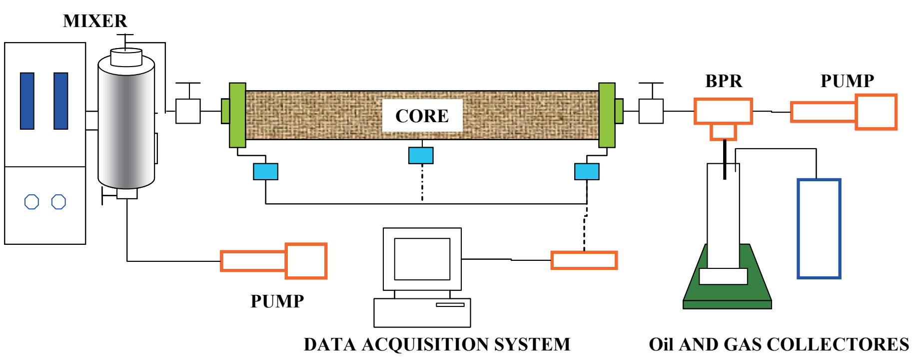

Figure 4
Schematic of the Experimental Setup

2.2 Sand Pack Preparation and Fluid Data

According to the average porosity, average permeability and grain composition of the Orinoco Belt, the sand packs were made of clean sand with a grain size between 60 and 80 mesh. To prepare the sand packs, after pulling a vacuum, the sand packs were first saturated with water. The volume of water imbibed were a measure for the initial pore volume. The permeability was measured by flowing water through the sand-packs. The water saturation was established by a subsequent dead oil flood. A material balance calculation determined the initial oil saturation and the irreducible water saturation. Sand packs under different depletion rate are summarized in Table 1. Live oil was the same as the oil used in the foamy oil PVT studies.

Table 1
Properties of the Sand-Packs

Depletion rate /(MPa/h)	Length /cm	Core diameter /cm	permeability /(10^{-3}μm^2)	Porosity /%	Pore volume /ml	Oil saturation /%
0.4	50	3.8	7157	42	248	96.3
0.8	50	3.8	7107	41.8	243	95.8
1.6	50	3.8	7056	41.3	237	97.9

2.3 Procedure

The test procedure was as follows:

(1) Mounting a preserved or restored state core stack heats to reservoir temperature, brings to reservoir pore pressure via dead (de-gassed) oil injection.

(2) When reservoir pore pressure sets at some value greater than the true bubble point of the oil of interest, live oil was injected at a low flow rate until the pressure drop reached a constant value and the production GOR was the same as the initial solution GOR (15.58 m^3/m^3).

(3) Once the sandpacks were filled with live oil, they were ready for the depletion experiments. The displacement pump was operated at constant-flow refill mode. The depletion experiments were done at rates of 0.4, 0.8, and 1.6 MPa/h.

(4) Track and record the produced oil and gas volumes.

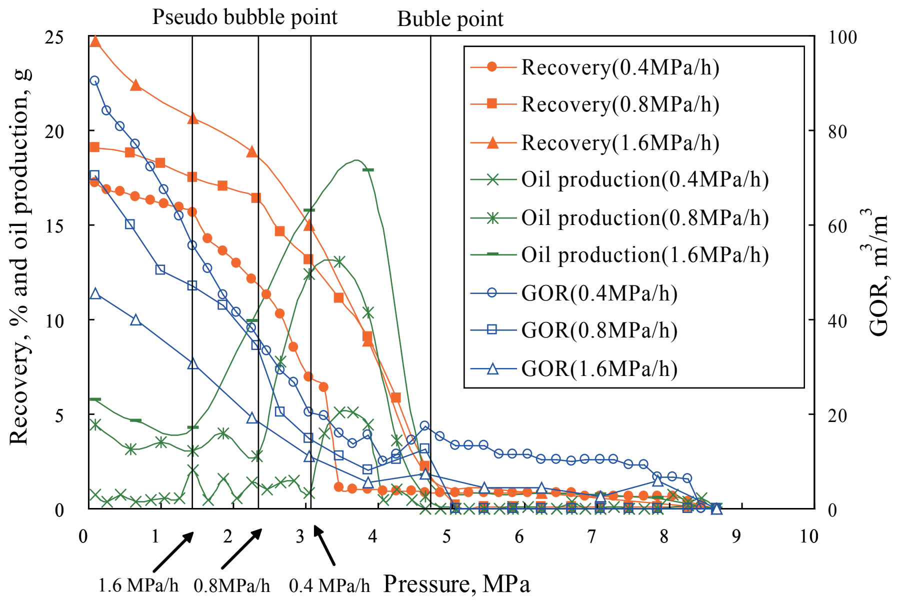

Figure 5
Pecovery, Oil Production, and GOR Versus Pressure

2.4 Results

The results (recovery, oil production, and GOR vs. pressure) have been plotted for each of the tests and appear as Figure 5. In summary, they are:

(1) The results from Figure 4 indicates that when the depletion rate was 0.4, 0.8, and 1.6 MPa/h, the final recoveries was 17.2%, 19.1, and 24.6. The maximum of oil production was 5.07, 13.07, and17.87 g, and the final GOR were 90.5, 70.2, and 45.6 m^3/m^3. So as depletion rate increases, recovery and the maximum of oil production also increases. However, final GOR decrease. The production performance of foamy oil is related with the depletion rate. This is because rapid reductions in pressure allow little time for the gas bubbles to nucleate and promote more foaming and slower depletion rates allow more time for gravity and IFT forces to coalesce the liberated gas phase and for gradual evolution to occur.

(2) The pseudo bubble point should be observed

by tracking the GOR, oil recovery and oil production. Between the true and pseudobubble points, the evolved gas should remain trapped in the in situ and expelled oil. This means that, even though oil is being displaced from the matrix by the expansion of in situ gas bubbles trapped as a dispersed phase inside the oil, the GOR of the produced fluid will not increase sharply, and the oil recovery and oil production increase rapidly(having a protruding part) because of the mechanism of foamy oil. For this reason, the pseudo bubble point at the three depletion rate can be determined from Figure 4 which are 3.0 MPa, 2.4 MPa, and 1.5 MPa. We can see that the pseudo bubble point decreases with depletion rate increasing, demonstrating a longer production process of foamy oil.

CONCLUSIONS

(1) The relative volume versus pressure curves moved to the direction of pressure reduction with increasing depletion rate. Bubble pressure was 4.95MPa, and pseudo bubble pressures for three different depletion rate tests were 3.44 MPa,2.74 MPa, and 1.89 MPa.

(2) The foamy oil compressibility was between 10-120×10^{-4} MPa^{-1}, which was obviously higher than that of conventional oil. Higher foamy oil compressibility data were observed in the slow rate depletion test compared with those in the fast rate depletion at the same pressure.

(3) Differential liberation experiments of the oil, with obvious high formation volume factor, stabe GOR, and low density showed a strong tendency to foam below the bubble point.

(4) More efficient oil recovery was achieved at high depletion rates while less free gas was produced.

(5) The use of a combination of multiple depletion rate PVT studies, as well as depletion test procedures in porous media, allow a much better understanding of the characteristics of foamy oil in the Orinoco Belt, Venezuela.

REFERENCES

[1] Villarroel, T. (2008). New Developments in Orinoco Oil Belt Projects Reflect a Positive Effect on the Areas Reserves. In *Proceedings world heavy oil congress*, *Edmonton*, 10–12 March, 2008.

[2] Hernandez, E., Bauza, L., & Cadena, A. (2008). Integrated Reservoir Characterization and Oil in Place Estimation for Ayacucho Area, Orinoco Oil Belt Venezuela. In *Proceedings World Heavy Oil Congress*, *Edmonton*, 10–12 March, 2008.

[3] Dusseault, M. B., Zambrano, A., Barrios, J. R., & Guerra, C. (2008). Estimating Technically Recoverable Reserves in the Faja Petroliferadel Orinoco-FPO. In *Proceedings World Heavy Oil Congress*, *Edmonton*, March 10–12, 2008.

[4] Gipson, L. J., Owen, R., & Robertson, C. R., *et al*. (2002). Hamaca Heavy Oil Project: Lessons Learned and an Evolving Development Strategy. In *SPE International Thermal Operations and Heavy Oil Symposium and International Horizontal Well Technology Conference*, 4-7 November 2002, Calgary, Alberta, Canada.

[5] Gina, V. R. (2011). Steam Injection Experiences in Heavy and Extra-Heavy Oil Fields, Venezuela. In *SPE Heavy Oil Conference and Exhibition*, 12-14 December 2011, Kuwait City, Kuwait.

[6] Huerta, M., Otero, C., & Rico, A. *et al*. (1986). Understanding Foamy Oil Mechanisms for Heavy Oil Reservoirs During Primary Production. In *SPE Annual Technical Conference and Exhibition*, 6-9 October 1996, Denver, Colorado.

[7] Lago, M., Gomes, R., & Huerta, M. (2000). Visualization Study During Depletion Experiments of Venezuelan Heavy Oils Using Glass Micromodels. In *Proceedings Petroleum Society's Canadian International Petroleum Conference 2000*, Calgary, Alberta, June 4-8, 2000.

