Foamy Oil Behavior of an Iranian Heavy Oil Reservoir

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Foamy oil expression has puzzled many reservoir engineers in characterizing some heavy oil reservoirs. The strange fluid behavior of such reservoirs is considered as the reason of abnormally high flow rates and (the higher than expected) recovery factors. The authors aimed to briefly elaborate the foamy oil concept, review methodologies and laboratory experiments for identifying foamy oil behavior, and present a modified methodology for laboratory investigation of foamy behavior. The concern here is an Iranian heavy oil reservoir whose foamy nature is under debate (according to some production reports). Experimental results indicate that the studied crude oil acquires foamy characteristics, which makes it the first heavy oil reservoir with foamy behavior in the Middle East region.

Keywords: heavy oil, foamy crude, supersaturation, critical supersaturation, pseudo bubble point pressure

INTRODUCTION

Foamy oils are classified as a subgroup of heavy oil reservoirs in which the cold production of their viscous crude associates with the generation of foam within the crude (Bura, 1998). On the surface, foamy oils are characterized by their chocolate mousse like oil-continuous foam production at the wellhead (Albartamani and Ratulowski, 2000). There is almost no difference between a typical heavy oil reservoir and a foamy one when operating above the bubble point pressure. However, while the pressure declines lower than the bubble point, the foamy behavior takes the lead and causes phenomenon differences. Foamy reservoirs behavior contributes significantly to the abnormally high production rates unexpected for such viscous crude oils (Bennion et al., 2003). Production rates of foamy reservoirs can be up to 50–300 times greater than the rate predicted by Darcy equation (Yeung, 1996; Tremblay et al., 1997). The ultimate recovery of these reservoirs under the solution gas drive mechanism is also remarkable; the recovery can reach the value of 25% of original oil in place in some cases (Bura, 1998).

FOAMY OIL BEHAVIOR

Foamy oil behavior (or specifically the solution gas mechanism of foamy oil) is mainly affected by what is commonly termed as pseudo bubble point pressure (Bennion et al., 2003). To have a better understanding of this concept we need to introduce some terms in advance.
Super saturation

For reservoir fluids, as the pressure drops below the bubble point pressure, the saturated fluids (with dissolved gas) turn into supersaturated state. Supersaturation is the driving force for bubble nucleation. The supersaturation may be defined as the difference between the liquid pressure at which the liquid and gas phases are at equilibrium and the prevailing system pressure at a given time (Zhang, 1999).

Critical Supersaturation

Critical supersaturation is defined as the liquid pressure difference between the equilibrium liquid-vapor pressure (at the initial composition and temperature) and the pressure at which bubble nucleation initiates. Critical supersaturation is a threshold level of supersaturation required before bubble nucleation (Goodarzi, 2003).

Bubble Nucleation and Growth

After reaching critical supersaturation, the liquid phase starts to release its dissolved gas in form of small bubble nucleases. Then, mass transfer of the dissolved light components to the free gas phase, by molecular diffusion, contributes to the bubble growth stage (Goodarzi, 2003). Conventional oil reservoirs have negligible critical supersaturation values. They release their dissolved gas immediately after reaching bubble pressure and it rapidly coalesces into large bubbles. Therefore, the bubble point of the conventional or nonfoamy oils is the same as the true (thermodynamic) bubble pressure (Bennion et al., 2003). For foamy oils, however, the critical supersaturation is considerable. The gas bubbles cannot immediately escape from the liquid phase and coalesce together to form large gas bubbles. The point at which the bubbles of free gas can finally start to escape from solution as a distinct free gas phase is known as the pseudo bubble point (Bennion et al., 2003). The critical supersaturation, therefore, can be defined as the difference between the true bubble and pseudo bubble pressures.

**FOAMY OIL PVT TESTS METHODOLOGY**

The mentioned special bubble generation strategy of foamy oils as well as their property, which tends to keep the released gas phase (as a continuous dispersed gas-oil emulsion with a high concentration of bubbles) trapped within the oil cause a special behavior for these types of crudes bellow the bubble point pressure (Bennion et al., 2003). Foamy oil behavior can be identified in laboratory throughout some sets of time-dependent PVT tests. Foamy oil behavior is strongly related to depletion rate. Rapid pressure reduction provides little time for bubble nucleation and promotes the foaming behavior by lowering the pseudo bubble point pressure and increasing supersaturation. Lower depletion rates, on the other hand, allow more time for gradual evolution to occur and permit gravity and IFT forces to coalesce the liberated gas phase. In theory, if a foamy reservoir is depleted infinitely slowly, performance approximates the conventional cases (Bennion et al., 2003). Among all the PVT experiments, the most outstanding ones for indicating foamy behavior are the gas oil ratio (GOR), formation volume factor (FVF), and viscosity tests, which are described briefly as follows.
Gas Oil Ratio

GOR test indicates the amount of gas dissolved in solution at every specified pressure. For conventional crudes the GOR starts declining at the exact bubble point pressure. For foamy crudes, however, the depletion rate at which the test is being executed controls the start point (or the pseudo bubble pressure; Bennion et al., 2003). The GOR plot of a typical foamy oil reservoir is presented in Figure 1.

Formation Volume Factor

FVF is affected strongly by foamy oil behavior. For foamy reservoirs, it is believed that FVF is one of the major contributing factors to enhanced productivity. Between the true bubble point and the pseudo bubble point pressures, the highly compressible gas is released out of solution while it still remains as a trapped phase within the oil. This causes the foamy oils to expand rapidly within the mentioned pressure range. The pseudo bubble point, therefore, can be determined from the inflection point of the formation volume factor curve. Figure 2 shows a typical FVF curve for a foamy crude under various depletion rates (Bennion et al., 2003).
Viscosity

Foamy oil viscosity is another contributing factor in the outstanding production of such reservoirs. For conventional reservoirs the viscosity increases as the pressure decreases below the bubble point (and the gas evolves from the oil). For a foamy crude, however, the gas-liquid foam rheology controls the viscosity (Bennion et al., 2003). Many investigators have suggested that the foam generation in the crude reduces the oil viscosity (Zhang, 1999). Shen and Batycky (1996) introduced the in situ produced foam as a mobility enhancing agent as it reduces the fluid viscosity.

EXPERIMENTAL

The initial production history as well as the generation of stable foam in the separators of one Iranian offshore heavy oil reservoir intrigued us to investigate whether the crude is foamy or not. To implement a rapid primary indication of the foamy crude, a special PVT test was designed. In this test instead of performing the experiment with very slow (and time consuming) pressure depletion steps, a mixer was applied. Primarily a pressure decline rate of 150 psi/h was selected and the initial base test was performed without any mixing. This test could be classified as the rapid test (or nonequilibrium state) in a typical foamy oil PVT study. Then the next two experiments were executed with the same pressure depletion rate while the PVT cell mixer was turned on and was set on slow and high rates of mixing consequently. The slow mixing rate could be considered as intermediate depletion and the rapid mixing helps the crude to reach equilibrium completely and may be considered as slow depletion test of typical studies. Using this methodology we can reach our goal (which is to determine whether the crude shows foamy behavior or not) and we have also saved huge amount of time and budget. Finally, to ensure our experiments’ repeatability, the test for no mixing state was conducted once again.
LABORATORY TESTS RESULTS AND ANALYSIS

As explained previously, our experiments were executed under conditions of rapid depletion rate (150 psi/h) and various states of mixing (no mixing \(2 \times\), slow mixing, and rapid mixing). The mixing helps the crude to reach the equilibrium and acts as if the crude has given an expanded amount of time. The pressure volume curves of the performed experiments are presented in Figure 3. As we expected for our tests, when the pressure is above the bubble point, all the cases follow the same trend. After the true bubble point pressure, however, the observed behavior of the crude is different for various mixing states (or various equilibrium states). For rapid mixing (or near equilibrium) case the pseudo bubble is close to the true bubble pressure while for no mixing (or rapid depletion) case the pseudo bubble is far lower than the true bubble pressure. The pseudo bubble point observed for slow mixing (moderate depletion rate) lies between the two other observed points, which confirms the dependency of our crude to the mixing rate (or time). This observed behavior is the typical one expected only from the foamy crude oil samples. We can, therefore, confirm that the studied crude may have the heavy oil foamy characteristics.

There is also a perfect repeatability observed for the two tests performed in no mixing state, one as the first experiment and the other as the last performed one.

CONCLUSIONS AND RECOMMENDATIONS

Foamy oil crudes show different behavior under various production conditions. To investigate the foamy nature of a suspicious Iranian heavy oil crude, a series of modified PVT experiments was performed. The experiments indicate that the crude presents various bubble point pressures under different depletion rates, which may be a strong indication of its foamy characteristics. As foamy oil behavior affects the whole stages of reservoir production and also this is the first time that foamy oil behavior is reported in the Middle East region, it is strongly recommended that similar reservoirs undergo suitable investigations for their foamy characteristics detection. A full typical time-dependent PVT study is also recommended for this special reservoir.

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