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Back to the oil migration history for asphaltene flow assurance engineering in uneven asphaltene precipitating risk distributed oilfield

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ABSTRACT

This work was motivated from inconsistent asphaltene onset pressure (AOP) measurement results in which AOPs could be detected from some samples but notfrom others, even fluid samples were collected from the unique carbonate oilfield. Our initial challenge, applying a general rule-of thumbs that has been widely used in the industry (based on compositional gradients and sampling horizons dependency), failed to provide understanding into the probable causes of the AOP result variations. Then, a multi-disciplinary approach aiming for synergy between engineering and geoscience was developed to re-assess the uneven distribution of asphaltene precipitation risk. Finally, incorporating the geosciences aspect succeeded in explaining the correlation between the asphaltene precipitation risk distribution and hydrocarbon migration history. In support of this finding, numerical models that applied the Cubic Plus Association (CPA) equation of state (EoS), were generated by treating the geological heterogeneity as a variation of asphaltene content. The models reproduced asphaltene precipitation envelopes (APE) that matched the overall trend of the experimental AOP data. This work has reduced the uncertainty around understanding the asphaltene precipitation risk. It has also added useful discussion to the field of asphaltene flow assurance engineering from a potential cost saving perspective.

1. Introduction

Many alerts have been reported that lighter oil precipitates asphaltene more easily than heavy oil because of its lower solubility, even though heavy oil has much higher asphaltene content (Alian et al., 2011; Alta'ee et al., 2010; Sarma, 2003). The essence of stronger asphaltene precipitation tendency in lighter oil is generally illustrated by de Boer's supersaturation index plot (de Boer et al. 1995). An example of the severe impact on production is provided by the Hassi-Messaoud field in Algeria, which contains extremely light oil, 42.3°API, with very low asphaltene content; 500 mg per liter stock tank oil (Haskett and Tartera, 1965). This field acts as a reminder that asphaltene can eventually precipitate a considerable amount of deposit in production tubings and facilities, despite the low content. Experimental work on Hassi-Messaoud, based on coreflood tests, also showed reduce permeability due to asphaltene deposition (Minssieux et al., 1998). Furthermore, according to recent work by the Fogler Research Group comparing solvency-powers for various asphaltene containing oils (Akbari et al., 2014), the mechanism of self-stabilizing asphaltene could work in heavier oils, wherein unstable asphaltenes could be stabilized by stable ones. This is because asphaltenes are more structurally similar to aromatic solvents, such as toluene, that could act to increase the overall solvency power of the solution for those that are unstable. However, the self-stabilizing mechanism was considered less effective in lighter oils. Therefore, more careful asphaltene evaluation should be done for light oil cases. However, this evaluation would be more difficult to achieve because the asphaltene content is decreased for the lighter oils. Currently, a visual approach is improved to administer light oils containing a very small amount of asphaltene, whereby oil transparency changes are observed by taking high pressure microscopic snapshots with reasonable accuracy.

In recognition of the above alerts, for our light oil case (42–44°API), we initiated evaluation of the risk since the development phase for robust asaphaltene flow assurance engineering. Seven fluid candidates were selected to measure AOP values from wells X1, X2, X3, X4, X5, Y2, and Z4. The assessments were originally planned as isothermal depressurizing tests at the reservoir temperature, followed by tests over an expanded temperature range

Abbreviations: AOP, asphaltene onset pressure; APE, asphaltene precipitation envelope; CAPEX, capital expenditure; CPA, cubic plus association; EoS, equation of state; GOR, gas oil ratio; HC, hydrocarbon; HPM, high pressure microscope; MOL, main oil line; MW, molecular weight; OPEX, operating expense; OSS, organic solid system; PI, productivity index; PTL, power of transmitted light; PVT, pressure–volume–temperature; SARA, saturate, aromatic, resin and asphaltene; SCN, single carbon number; SDS, solid detection system; SG, specific gravity; SRK, Soave–Redich–Kwong; TOC, total organic carbon

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from the reservoir to that of the surface facility's operating conditions, so as to achieve a detailed and realistic evaluation. Isobaric cooling tests were subsequently implemented in case the AOP was not detected at the reservoir temperature. Prior to these assessments, accumulation of such fundamental data had been considered useful for comprehensively understanding asphaltene science in the field; however, the results obtained herein show this consideration to be misplaced because the detected AOPs so obtained varied and depended on the fluid samples. Three AOPs were detected for fluid samples from wells X1, X2, and X3 at the reservoir temperature but not for three fluid samples from wells X4, Y2, and Z4 at the reservoir temperature while detected below. The measurement was canceled for a fluid sample of well X5 because little asphaltene content was shown to be present via pre-screening.

It was a major challenge to seek the cause of these contradicting results and thus provide appropriate understanding to asphaltene flow assurance engineering in the field.

2. Experimental section

2.1. Apparatus

AOP tests were performed using a type of PVT cylinder through which the fluid content was visible. Typical apparatus usually consists of two piston controlled cylinders, with each having a mixer on the bottom to facilitate the mixing process. One cylinder, equipped with fiber optic light transmission probes (source and detector), is termed the Solid Detection System (SDS) cylinder, and the other is the receiving cylinder. Both cylinders can be set to specific temperatures and pressures. After the pre-cleaned SDS cylinder was evacuated, a certain amount of reservoir fluid can be charged into it using a displacement pump. When the reservoir fluid is displaced slowly from the SDS cylinder to the receiving cylinder, the fluid path is measured via the High Pressure Microscope (HPM). The flow rate can be controlled by the application of a restricted pressure gradient. As the fluid is transited through the HPM cell, it is video-recorded and the HPM photomicrographs are digitally captured. The SDS cylinder could provide additional, independent identification of any solids onset and growth through recording of the power of transmitted light (PTL). The measurement principle of the SDS is based on the transmittance of a laser light through the test fluid while the pressure or fluid composition changes. During tests, the onset of asphaltene precipitation can be determined at the point at which a sharp drop in transmittance occurs in the plot of PTL, or by images taken by the HPM.

2.2. Materials and conditions

Single-phase reservoir fluid samples collected from five wells (X1, X2, X3, X4, and Y2) with keeping pressurized condition, and surface fluid samples from wells X5 and Z4 were originally proposed for assessment. However, analysis was canceled for the well X5 fluid because of the little amount of asphaltene content present, as judged by pre-screening. Consequently, six fluids were evaluated. The early assessment plan focused on the reservoir temperature (100 °C) as a testing condition; however, progressive assessment covered an overall temperature range from the reservoir to the surface facility's operating conditions (ca. 100–65 °C). Specifically, the AOPs of wells X1, X2, and X3 were measured at the reservoir temperature only in the early phase assessment, while later tests were carried out at the reservoir and lower temperatures for fluids from wells X4, Y2 and Z4. The early assessment was performed by the isothermal method at two fixed temperature steps of 100 and 80 °C, and then the isobaric cooling test was applied to efficiently detect AOP in the later assessments.

2.3. Isothermal measurement

Fluid was left in cylinders at a specified pressure as a starting-pressure, usually higher than reservoir pressure, and at a constant temperature; i.e., reservoir temperature (100 °C) or other operating temperatures (75 or 80 °C), for a certain period of time (typically 12 h) to establish equilibrium checked by monitoring that no particles could be observed. Then, the isothermal pressure depletion test was commenced. The experiment was stopped at an end-pressure before reaching saturation pressure. Fluid passing through the HPM was visually examined at certain time steps. At the reservoir temperature, sharp drops on the PTL plots were observed for the samples from wells X1, X2, and X3, but similar drops were not easily observable for the samples from wells X4 and Z4. Finally, no AOP for well X4 could be confirmed using either HPM images or the PTL profile. Analysis for the well Z4 fluid was made on the basis of the PTL result only because the test was performed without HPM equipment. Thus, further tests are recommended by HPM to support the current conclusion that no AOP is detectable for Z4 fluid. Typical examples of SDS signals are shown in Fig. 1. The tests at 100 °C revealed AOPs of around 7250 psia and 9900 psia for fluids from wells X2 and X3, respectively. Though it was concluded that no asphaltene precipitated at the reservoir temperature, the re-test using well X4 fluid showed a drop at 9300 psia on the 80 °C PTL plot. Similarly, well Z4 fluid was re-tested and showed an AOP at 5300 psia at 75 °C after the 100 °C test.

2.4. Isobaric cooling test at constant pressure

As mentioned for the series of isothermal assessments, an AOP could be detected from the subsequent test at lower temperature (80 °C) for fluid from well X4, while no AOP was detected by the initial test at the reservoir temperature (100 °C). Even in such a case, where no AOP was detected in the first experiment, the isothermal approach can ascertain asphaltene precipitation conditions by carrying out further tests at other temperature. Ideally, the number of these subsequent tests should be minimized to achieve fast track approach. However, engineer can find it difficult to select an appropriate testing temperature for the second test after a result such as that mentioned for the first test. Nobody doubts it should be desirable, as much as possible, to detect an AOP at higher temperature conditions because the upstream information is more critical for obtaining robust production management. It is possible to surely predict an appropriate temperature setting in cases where sufficient asphaltene characteristic data has been accumulated; however, such cases are rare. Thus, there is an engineer's dilemma in which an excessive desire for a higher temperature AOP may result in failure to detect the AOP. To avoid this, an isobaric cooling test was applied for well Y2 fluid that did not show an AOP at the reservoir temperature. The apparatus used was identical to that for the isothermal depressurization test, namely the SDS plus HPM was used to identify the onset of solids formation from a fluid sample during the isobaric cooling process. The PTL was measured and recorded continuously when the temperature was reduced while maintaining a constant pressure. The experiment was carried out at two constant pressure conditions: the first being 240 psi higher than the saturation pressure that was the same as the end-pressure in the isothermal depressurization test, and the second condition of 4050 psi higher than saturation pressure but which was lower than the reservoir pressure. After stabilization at each starting condition, each experiment commenced from 100 °C and stopped at 35 or 40 °C at a rate of 5 °C/h. The test at the first condition was completed once,

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