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The Application of Passive Energy to Production Optimization; Stabilizing the Micelle Structure in Oil to Prevent Deposition of Paraffin, Asphaltenes, and Mineral Scale and Reduce Well-head Viscosity in Heavy Oil

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Abstract

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Micellization, a phenomenon originally observed in the self association process of the surface active materials in aqueous solutions, is the underlying culprit for some of the most common production problems associated with paraffinic oils, heavy oils, asphaltenes and mineral scale deposition from carbonate-rich, high water-cut wells. The critical issue is the physical and chemical changes that occur to the oil because of the drop in temperature and pressure as the oil enters the wellbore at the onset of production. These changes destabilize the micelle structure of the oil as it exists in the reservoir, leading to paraffin deposition from paraffinic oils, asphaltene deposition from asphaltene-rich oils, increased viscosity in heavy oils and scale deposition from wells with carbonate-rich high water cuts.

Because micellization is fundamentally initiated by electrokinetic effects (an excess of positively charged particles) such as occurs with fluid flow in conjunction with pressure and temperature flux, it should be possible to arrest or reverse micellization and its associated detrimental effects on oil production by exposure to passive energy (net negative charge). The Enercat technology is a downhole production tool that vibrates at the far end of the infrared spectrum and imparts a passive energy at the reservoir/well bore interface, stabilizing the micelle structure of the oil as it enters the wellbore. Case histories of the deployment of this tool in varied oil provinces and oil chemistries around the globe demonstrate the relevance of this fundamental science to production optimization and efficacy of the tool in paraffin, heavy oil, asphaltene and mineral scale deposition applications.

Introduction

Crystallization and deposition of paraffin waxes on production tubulars and pumping equipment during crude oil production is a problem well known to the oil industry, costing billions of dollars worldwide through lost production and the expense of remedial actions (Misra and others, 1995). Choking of production tubulars and flowlines by asphaltenes and or mineral scale deposition also obstructs oil production and is similarly costly to the oil industry. In heavy oils, very high viscosity impedes fluid flow in production tubulars and transport pipelines, leading to substantial technological challenges to their economic development. These production problems are common to paraffinic oils, heavy oils and asphaltenes and fundamentally occur because of the destabilization of the micelle structure (micellization) of the oils as they enter the wellbore at the onset of production. Deposition of mineral scale from fields experiencing high, carbonate-rich, water cuts is also a production problem related to the micellization process.

Micellization is a phenomenon that was originally observed in the self association process of surface active materials in aqueous solutions. Micellization is initiated by the electrokinetic effect of the interaction of an excess of positively charged particles when fluid flows in conjunction with pressure and temperature flux, such as typically occurs when oil enters a wellbore. Lichaa and Herrera (1975) and Mansoori (1994) also documented this electrokinetic effect of oil flowing through a conduit on deposition of colloidal heavy organic constituents. The motion of charged colloidal particles like asphaltene flowing in a conduit (pipeline) generates an electrical potential difference along the length of the conduit and can cause the asphaltenes to flocculate and aggregate and deposit within the pipeline.

Because micellization is essentially initiated by an excess of positively charged particles, it should be possible to arrest or reverse the process by introducing negatively charged particles (passive energy). The Enercat, a downhole production tool that vibrates at the far end of the infrared spectrum, is an example of a technology that imparts passive energy at the reservoir/well bore interface, stabilizing the micelle structure of the oil as it enters the wellbore. Numerous examples from around the world are presented where application of this technology resolved paraffin and scale deposition problems and reduced oil viscosity at the well head, demonstrating the efficacy of the tool and its application in production optimization.

Crude Oil Characteristics and Micelle Structures

Crude oil is composed of four major fractions: saturates (including waxes), aromatics, resins and asphaltenes. The chemical and physical properties of crude oils depend significantly on the relative amounts of each fraction and their properties. The asphaltenes usually contain more condensed aromatic compounds than do the resin and oil fractions. The resins contain aromatic or naphthenic hydrocarbons and components of oil fractions may have naphthenic or paraffin structures. In paraffinic crudes, the center of the stable micelle can be metal, clay or water. The essential feature is that the polar groups (such as S^- and/or N^- and/or O^- containing groups) are concentrated towards the center. This is often termed oil external-water internal or water-in-oil emulsion. When paraffinic crude oils flow into the wellbore, pressure and temperature are reduced, the micelle structure is destabilized and the paraffin changes to solid form, depositing on the tubular and obstructing fluid flow.

In heavy crudes, the asphaltene particles are believed to exist partly dissolved and partly in steric-colloidal and/or micellar forms depending on the polarity of their oil medium and presence of other compounds in oil (Priyanto and others, 2001). A steric colloid is formed when a large non-soluble particle (asphaltene) is stabilized in the solution by adsorption of grafted polymers (resin) on its surface. The layer(s) of resin on large asphaltene particles will then repel each other, overcoming the van der Waals attraction so that the asphaltene particles will not aggregate. A micelle consists of a reversible assembly of molecules such as surfactants (asphaltene) that assemble together in a solution. As previously mentioned, micellization is a phenomenon originally observed due to the self association process of the surface active materials in aqueous solution and in asphaltenes this self association is generally thought to occur through hydrogen bonding (Chang and Fogler, 1994 a, b; Auflem, 2002). Stupp and others (1997) showed that as micelles grow, there are sharp transitions in many physical properties of the solution such as surface tension, viscosity, conductivity, and turbidity.

Asphaltenes are known to self-associate due to pressure depletion (Hirschberg and others, 1984; Hammami and others, 2000; and Peramanu and others, 2001). As described by Auflem (2002), at the pressures in the reservoir, the asphaltenes are dissolved in the monophasic crude oil. When the pressure is reduced the molar volume and the solubility parameter difference between asphaltenes and the crude oil increases towards a maximum at the bubble point of the crude oil. As a result of the reduced solvating power, the asphaltenes may start to precipitate at some onset pressure higher than the bubble point. Prior to the precipitation a stepwise association of the asphaltene molecules will take place. The final precipitation is due to a strong attraction between the colloidal particles and the formation of agglomerates (micelles). The nature and shape of the resulting aggregates will determine their effect on the behavior (eg., viscosity) of the petroleum fluids (Park and Mansoori, 1998; Mukhametzyanov and Kuzeev, 1991; and Kim and others, 1994).

Deposition of mineral scale, while unrelated to crude oil characteristics, is still a function of electrokinetics and destabilization of micelle structures. The detrimental effects of scale deposition, of which calcium carbonate is the most common, are widely recognized and include severe fluid flow impedance from occlusion of production tubulars, stress on production equipment, and in the case of corrosion, premature failure of production equipment. Calcium carbonate is poorly soluble in pure water at normal atmospheric CO_2 partial pressure (47 mg/litre) and is given by the equation:

$$CaCO_3 \rightleftharpoons Ca^{2+} + CO_3^{2-}$$

However, calcium carbonate solubility is also affected by the equilibrium of carbon dioxide with water because some of the CO_3^{2}- ions combine with H+ ions given by the equation:

$$HCO_3^{-} \rightleftharpoons H^{+} + CO_3^{2-}$$

Some of the HCO_3- ions combine with H^+ in solution according to:

$$H_2CO_3 \rightleftharpoons H^{+} + HCO_3^{-}$$

And some of the H_2CO_3 breaks up into water and dissolved carbon dioxide according to:

$$H_2O + CO_2 \text{ (dissolved)} \rightleftharpoons H_2CO_3$$

Finally, dissolved carbon dioxide is in equilibrium with atmospheric carbon dioxide according to the equation:

$$\frac{P_{CO2}}{[CO_2]} = k_H$$

where K_H = 29.76 atm/(mol/L) at 25° (Henry constant), P_{CO2} being the CO_2 atmospheric partial pressure and $[CO_2]$ being dissolved CO_2

Thus, as subsurface waters enter a well bore, dissolved CO_2 equilibrates with atmospheric CO_2 partial pressures. If the subsurface waters are rich in Ca^{2+} and CO_3^{2-} ions, calcium carbonate will precipitate because calcium carbonate is poorly soluble at atmospheric CO_2 partial pressures.

Application of Passive Energy to Stabilize the Micelle Structure

Applying passive energy at the reservoir/wellbore interface cancels out the excess of positively charged particles and arrests or impedes destabilization of the micelle structure of the oils. In paraffinic oils, the passive energy stabilizes the water-in-oil emulsion structure and prevents paraffin from being released from the micelle structure and forming solid states. In heavy oil, the heavy constituents, asphaltenes and preasphaltenes are contained within the monophasic crude oil mixture and the viscosity characteristics of the oil as it exists in the reservoir condition is maintained. In the case of mitigating mineral scale deposition, the application of passive energy modifies the molecular structure of the water into long thin molecules as compared to their normally more spherical molecular structure. The modified shape increases the van der Waals dispersion forces and dipole-dipole attractions within the water molecules, effectively increasing the $CaCO_3$ solubility at atmospheric CO_2 partial pressures. Molecular shape is well known to affect van der Waals dispersion forces (Clarke, 2000) and long thin molecules develop greater dipole-dipole attractions than do spherical ones. Moreover, long thin molecules can lie closer together, further intensifying dispersion forces.

Case Histories of the Application of Passive Energy to Production Optimization

The intricacies of delivering complex hydrocarbon fluid chemistries at *in situ* reservoir conditions to atmospheric surface conditions via conventional well bore technologies are not easily reproduced or tested in the laboratory setting. Accordingly, we rely more appropriately on empirical evidence to demonstrate the validity and efficacy of applying passive energy to the most common production problems of deposition on production tubulars of paraffin, asphaltene or scale as well as the impedance of hydrocarbon fluid flow rate caused by high viscosity of heavy oils. The following case histories are a substantially abridged subset of myriad successful examples of applying passive energy to the most common production problems.

The Anaco field in Eastern Venezuela has severe paraffin deposition problems and wells there typically wax-off weekly. The following case history illustrates how deployment of passive energy technology at the wellbore interface eliminated paraffin deposition and established continuous oil production during the 4-month period of the test. The production profile of the well before and after installation of the Enercat tool is illustrated in figure 1. Management at Anaco analyzed the economic benefits of the passive energy technology and concluded that the technology paid for itself within 3.3 months at a time when prevailing oil price was only $17.55 (figure 2).

The efficacy of applying passive energy at the wellbore interface to alleviate high viscosity of heavy oils is demonstrated by the installation of the Enercat tool in OXY's heavy oil asset in Argentina. Laboratory measurements of oil viscosity at the wellhead before and after installation of the tool demonstrate a remarkable reduction in wellhead oil viscosity from 7,730 cps before installation (figure 3) to 1,807 cps after installation of the technology (figure 4). Based on the reduction of wellhead viscosity, engineering simulations predict that heavy oil production flow rates could increase from 31 to 41 % depending on initial reservoir temperature and depth.

As an example of the successful application of passive energy to mineral scale deposition, the best demonstration is the testimonial of an oil and gas producer, Ian Henderson, Manager Insitu Oil Sands

Development, Shell Canada Limited…..“The Enercat tool was first used at our thermal Oil Sands project in Peace River, Alberta in a well which had a history of chronic pump failures (seizing) as a result primarily of scale build-up. This particular well was subject to scale build-up within three to six weeks of start-up operation. Based on the positive initial experience, three additional wells were equipped with Enercat tools and these pumps are currently still performing. Our experience with all the wells using the tool is that our pump change frequency is significantly reduced to the point that we have not had any pump failure while operating within the designed gross fluid rate for each application. In addition, we have seen significant improvement in the gross fluid production of these wells and consequently in the oil production.”

Conclusions

Application of passive energy at the reservoir/well bore interface has been demonstrated to stabilize the micelle structure, overcoming the detrimental effects of micellization, in a broad range of oil types and calcium carbonate rich waters. The science that underpins the phenomenon is straightforward and well known; self association of surface active materials in aqueous solutions occurs because of the electrokinetic effects of an excess of positively charged particles in the solution. Passive energy can now be delivered downhole where micellization is initiated via technology production tools, providing simple and cost-effective solutions to some of the most common production problems of paraffin, asphaltene and mineral scale deposition as well as fluid flow inhibiting high viscosity of heavy oils.

Figures

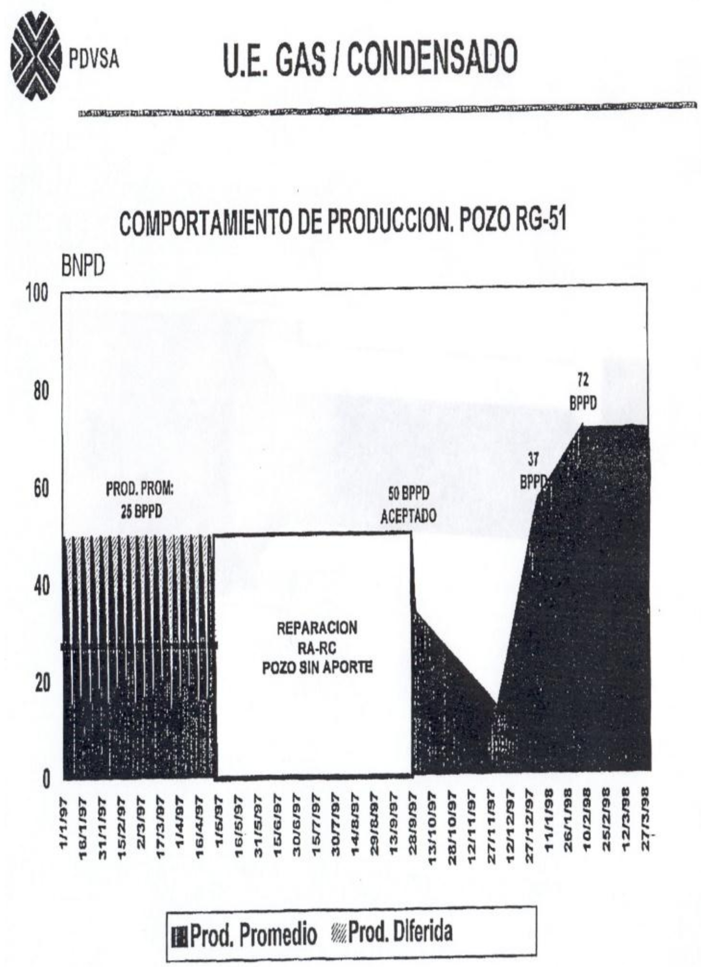

Figure 1. Production performance of a well experiencing paraffin deposition problems before and after application of downhole passive energy technology.

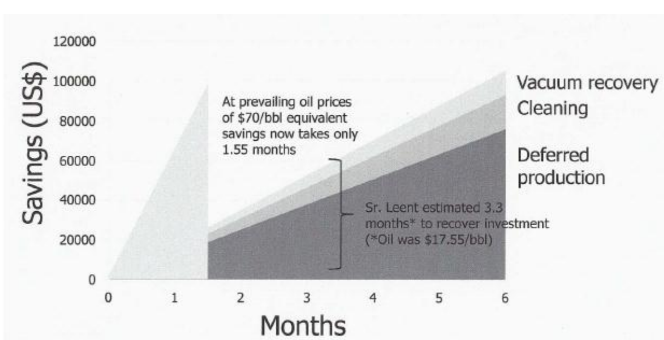

Figure 2. Economic benefits of downhole passive energy technology in paraffin applications.

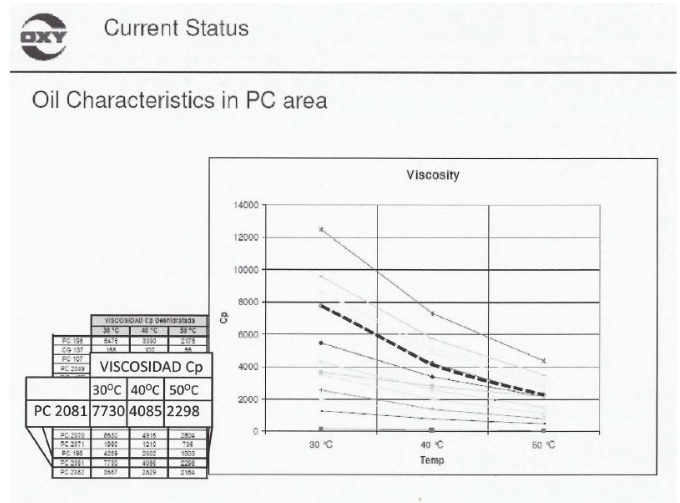

Figure 3. Viscosity measurement at the well head in PC 2081 before installation of the downhole passive energy technology tool.

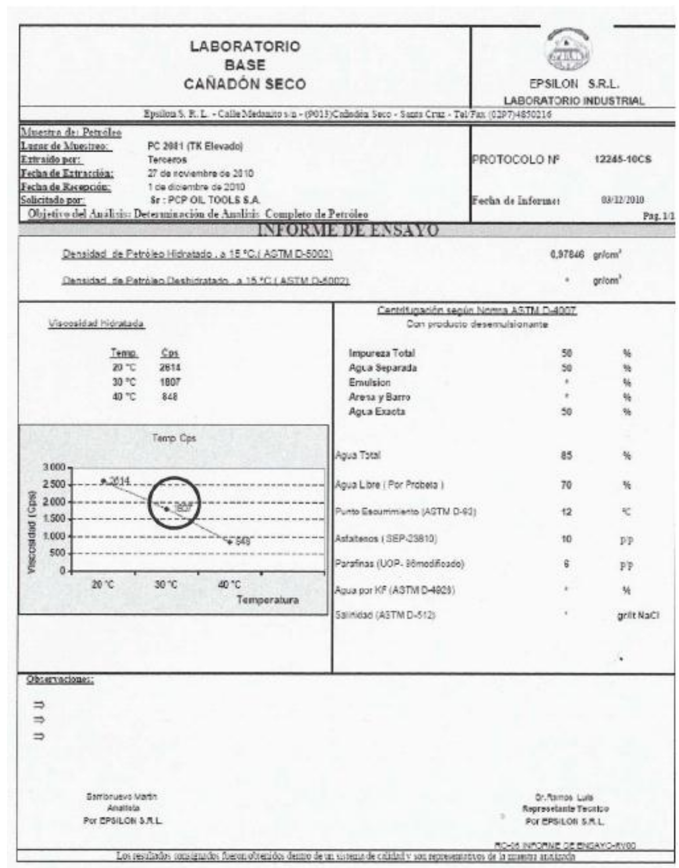

Figure 4. Laboratory measurement of viscosity at the well head after installation of the downhole passive energy technology tool. Well head viscosity was reduced from 7730 cps to 1807 cps following installation of the downhole tool.

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