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Problems and Solutions for Asphaltene Precipitation in High API Oil Reservoirs-Case Histories

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Abstract

This study addresses the challenges associated with asphaltene precipitation in reservoirs containing high API gravity oil. Using case histories from the Western Desert in Egypt, the paper discusses problems associated with asphaltene deposition and solutions to mitigate production problems. Many Western Desert reservoirs produce moderate to high API oil with low asphaltenes content. However, solids/asphaltene precipitation was observed to cause plugging of the artificial lift systems. In many cases, this blockage led to a sharp decrease in oil production rate and a significant increase in the operating cost. The current failure analysis procedure was insufficient in effectively determining the causes of the blockage. A new integrated failure analysis approach revealed that the problem was asphaltene deposition. Solutions were suggested and treatments were implemented to restore production for twelve wells with minimum costs. This paper provides insights and learnings in these case histories.

The integrated analysis approach was applied to several reservoirs in the Western Desert and appropriate treatments were designed and pumped in these wells. After the appropriate treatment, field applications results showed a significant increase in oil production rate by three to five times on average. Moreover, the operating cost significantly decreased from 5 to less than 0.5 $/STB. The field applications indicated that the continuous downhole injection of asphaltenes dispersant using a capillary tube with ESP completions is highly efficient and more efficient than continuous injection of diesel and/or periodic diesel backwash jobs. Moreover, the time between failures was increased from two months to more than 18 months for some of these wells. This technique was successfully used in five fields and restored production of around 12,000 BOPD with increased pump run life.

Keywords Asphaltenes deposition. Asphaltenes instability. Asphaltenes dispersant. ESP plugging. Downhole treatment.

1. Introduction

Asphaltene is a solid constituent in the crude oil that can cause many operational and production problems (Fakher et al. 2020). For the reservoir engineer, asphaltene deposition can signify the occurrence of formation damage and pore plugging. When asphaltene deposition is mentioned, the production engineer may immediately think of formation damage near the wellbore and plugging of both surface and subsurface equipment. From the perspective of a refining engineer, asphaltene deposition is viewed as a challenging situation leading to issues such as distillation column plugging, equipment plugging, reduced tank capacity, and catalyst deactivation. The transportation engineer associates asphaltene deposition with pipeline plugging and decreased capacity. Regardless of the specific concerns or perspectives related to asphaltene deposition, it is evident that this phenomenon poses significant flow assurance challenges (Sulaimon et al. 2020; Shoukry et al. 2020).

Currently, it is estimated that twenty percent of Artificial Lift (AL) pumps utilized in the world's oil production process are electrical submersible pumps (ESPs). For reservoirs with high to moderate fluid rates, ESP is an affordable AL technique; however, it is ineffective when used in a solid deposition environment (Iranzi et al. 2024). Asphaltenes deposition can damage ESP components, reducing their lifetime and increasing maintenance costs. The centrifugal forces present in electrical submersible pumps (ESPs) can enhance the precipitation of asphaltenes (Abdelazim et al. 2021; Limanowka et al. 1999). Asphaltenes are prone to accumulate in various locations, including the wellbore, perforation tunnels, well tubing, flowlines, separators, pumps, tanks, and other production apparatus. Factors affecting the asphaltene precipitation include changes in pressure and temperature, crude oil composition, presence of CO2, and tubing restrictions. As per the findings of multiple researchers, asphaltenes are commonly defined based on their solubility. Asphaltenes are soluble in aromatic hydrocarbons like toluene but insoluble in aliphatic hydrocarbons like n-heptane or n-pentane. Alternatively, asphaltenes are thought of as insoluble precipitates that are extracted from petroleum solutions containing low molecular weight alkanes such as pentane, hexane, and heptane. (El-hoshoudy et al. 2020; Fakher 2019).

The stability of the asphaltenes is influenced more by the ratio of asphaltenes to resin than by the concentration of asphaltenes to the crude oil. Insufficient resins to provide stabilization may lead to precipitation, flocculation, and deposition of asphaltenes in light crude oil ((Haskett and Tartera 1965).; Ali et al. 2021). Despite having a low asphaltene content of 0.062 wt.%, the Algerian Hassi-Messaoud crude oil encounters challenges with asphaltene deposition, whereas the Venezuela-Boscan crude oil, with a high content of 17.2%, does not experience asphaltene precipitation issues (Leontaritis and Mansoori 1988).

Limanowka et al. (1999) recommended new production techniques for preventing asphaltenes precipitation in ESP completion. His approach includes using Variable Speed Drive (VSD) with oversized pumps and increasing the vein height of pump impellers, coating internal pump surfaces, in order to reduce pressure drop at pump intake. It is important to highlight that using this technique (VSD with oversized pumps and increased impeller vein heights) can significantly reduce asphaltene, enhance pump efficiency, and prolong ESP running time. Additionally, applying a coating to the internal surfaces of the pump stages, pump intake, and pump discharge plays an important role in effectively combating asphaltenes precipitation. This process helps eliminate surface imperfections and creates internal surfaces with desirable properties and low friction (Kelland 2016; Limanowka et al. 1999).

It is essential to note that using production tubing with a rough surface can induce turbulent flow, resulting in increasing pressure drops within the tubing string. This issue can be solved by enlarging the screen area of the pump intake and selecting high-quality production tubing to reduce the pressure drop in the wellbore, thereby limiting asphaltene deposition. Notably, significant improvements in the running time of the electrical submersible pump (ESP) are rarely achieved through a single technique; instead, they are typically realized through a combination of various methods. The selection of production techniques is made on a case-by-case basis to enhance pump efficiency, maximize production rates, extend the pump's lifespan, and minimize operational costs.

The use of thermodynamic calculations is a more prevalent method in the modeling of asphaltenes. Various thermodynamic models can be found in literature that are founded on thermodynamic and chemical principles. These models consist of the Perturbed-Chain Statistical Associating Fluid Theory Equation of State (PC-SAFT-EoS), Cubic Plus Association Equation of State (CPA-EoS), and cubic solid Equation of State (EoS). (Shoukry et al. 2019; Li and Firoozabadi 2010; Sabbagh et al. 2006; Abouie et al. 2016;). They are utilized to forecast the precipitation of asphaltenes under varying operational circumstances. These established models can be used to model asphaltene precipitation tendencies at a variety of downhole and surface conditions.

This study provides a full-field application for treating the asphaltene precipitation problem in ESP oil wells. In this paper, we discuss the different methodologies used for treating asphaltene precipitation in high API oil with low asphaltene content. These techniques are categorized into five groups and were implemented in forty wells across five different fields in Egypt's Western Desert. These categories include: (1) conducting regular diesel backwash jobs (DBW) by mixing acid, xylene, and diesel in various ratios to periodically clean pump components; (2) DBW combined with continuous diesel injection from the annulus; (3) DBW, down-grading the pump from ESP to SRP, and injecting downhole asphaltene dispersant (AD); (4) injecting downhole AD after DBW; and (5) injecting AD from the start of production. The results were documented for each category including details of the impact on oil production rates and the operating costs per barrel.

2. Procedures for the Identification of Asphaltenes

Abdelazim et al. 2021 proposed a comprehensive approach for diagnosing and treating asphaltene precipitation problems. This paper used the same technique presented in Abdelazim et al. (2021) to determine the chemical composition of solid deposits and evaluate the extent of asphaltene precipitation, in addition to presenting the findings from the Asphaltene Dispersant Test (ADT). The interested reader is advised to consult the previous work for details on the asphaltene problem diagnosis methodology.

2.1 Composition Analysis of Solid Deposits

The chemical analysis of solid deposits can be identified using several methods, such as: X-Ray Diffraction (XRD), X-Ray Fluorenes (XRF), Infrared (IR) spectrum (Peksoz et al. 2011)., and Saturates, Aromatics, Resins, and Asphaltenes (SARA) analysis (for organic scale deposits) (Ekholm et al. 2002; ASTM 2007-2007; ASTM D4124–09 (Mahmoudi, and Zare-Reisabadi, 2015).

2.2 Severity of the Asphaltenes Precipitation

There are various approaches and methodologies employed in evaluating the extent of asphaltene precipitation. The primary techniques include the de Boer plot (Boer et al. 1995), Colloidal Instability Index (CII) (Ashoori et al. 2017), Colloidal Stability Index (CSI) correlations (Ali et al. 2021), and oil density correlations (Sulaimon et al. 2020). These techniques offer screening criteria to determine the propensity of asphaltenes to precipitate from crude oil (Punase et al. 2016).

2.3 ADT Procedures and Theory

Asphaltene dispersants (ADs) are utilized to control asphaltene deposition in oil wells. Unlike asphaltene inhibitors that prevent precipitation, dispersants reduce the size of asphaltene particles and keep them suspended in the oil, minimizing deposition. These dispersants can be applied via formation squeeze, batch, or continuous injection. The selection of the appropriate dispersant and application method depends on the crude oil's specific characteristics and the well's operational conditions (Juyal et al. 2011).

3. Approach

Abdelazim et al. (2021) presented a detailed and practical method for diagnosing and resolving downhole asphaltene precipitation issues. Their approach includes the following key steps:

1. Diagnosing the problem (Ilk et al. 2007; Anderson and Thompson 2014).
2. Collecting data and performing laboratory analysis (Mullins et al. 2007; Williams 1994; Akbar and Saleh 1989).
3. Developing and validating a thermodynamic model (Abouie et al. 2016; Sabbagh et al. 2006; Shoukry et al. 2019).
4. Evaluating potential solution options (Abdallah et al. 2010).
5. Adjusting operating conditions.
6. Applying chemical treatment solutions.
7. Implementing a pilot program, monitoring well performance, and conducting an economic evaluation.
8. Rolling out full-field implementation.

4. Fluid and Solid Properties Results

Five reservoirs with around 40 wells were investigated in this study. All these wells suffer from production problems, pump failures, and increased operating costs. Due to the high wax content of the crude oil samples, it was originally thought the production problems were due to wax deposition. The preliminary analysis and screening criteria for surface and downhole samples provided by Abdelazim et al. 2021 in the "Analysis of the laboratories Results" section was conducted for available samples from the 40 wells. The SARA analysis results for the five reservoirs indicated that the asphaltenes content in the crude oil samples is relatively low, with values ranging from 0.3 to 1.29 weight percent. Moreover, the wax content ranges from 9 to 19.1 weight percent (indicating waxy oil) with API oil gravity ranging from 37 to 41.5º, and a low pour point ranging from 85 to 94ºF. The basic crude, SARA, and chemical composition of solid deposition concluded that the main challenge in these reservoirs is the presence of asphaltenes as depositional material along with associated compounds.

5. Full Field Application

After the pilot implementation showed good results in two wells from two different reservoirs, the same methodology summarized above was implemented in a total of 40 wells, which suffer from production problems, from 5 reservoirs. All these wells produce oil with high API and low asphaltene content. Traditionally, these wells were treated with some form of diesel backwash. After this study was initiated and field work was conducted in many wells, the 40 wells can be classified in 5 main categories as follows:

1) Conducting periodic diesel backwash jobs (DBW)
2) Conducting both diesel backwash and continuous diesel injection (DBW & D. Inj.)
3) Conducting diesel backwash, replacement of ESP by SRP, and injecting AD after installing ESP (DBW-SRP-ESP) (after the study recommendations)
4) Conducting diesel backwash followed by AD (after the study recommendations)
5) Conduct AD since the start of production (after the study recommendations)

Fig. 1 shows the number of wells in each one of the 5 categories. The following paragraphs provide the details and results of each category to provide the basis for comparison between the different techniques.

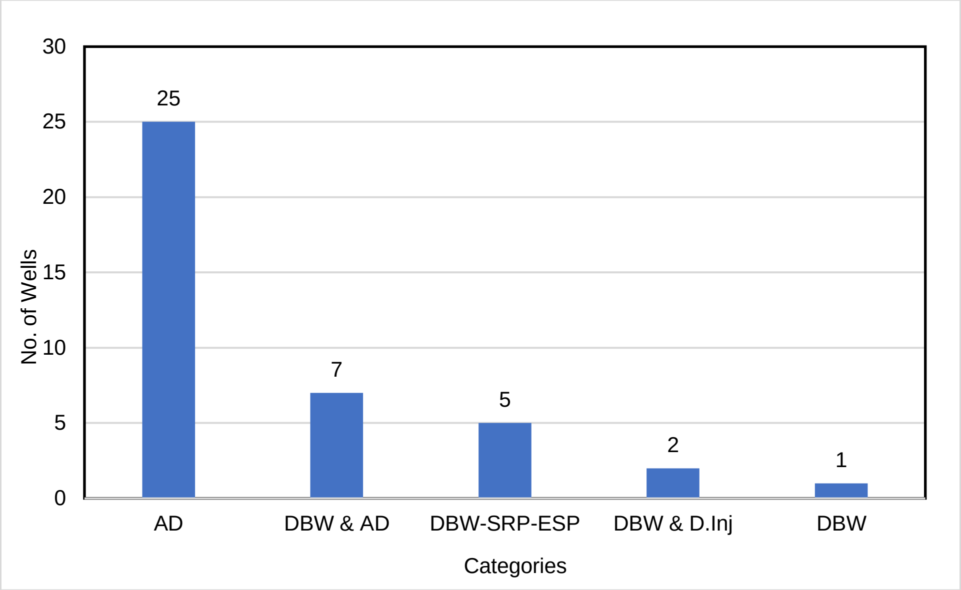

Fig. 1 - Field Application Categories for solving the Asphaltene precipitation.

5.1 Conducting periodic diesel backwash (DBW)

Well-A has been put on production utilizing an Electric Submersible Pump (ESP). The performance of well A is illustrated in Fig. 2. It is clear that the oil production from Well-A abruptly decreased from approximately 900 to 180 STB/D within 35 days of commencing production. It was also noted that the decline in the oil production rate coincided with a sharp increase in the pump intake pressure, which was attributed to organic and inorganic solid precipitation on the pump intake. After that, the diesel backwash job was conducted for restoring the well's production. The diesel backwash jobs were conducted by injecting a mixture of diesel, acid, and xylene from the tubing side, and producing the well again with the pump after some soaking time. It is intended to clean the pump components of any solid material and deposits.

The well was back to normal production around 900 STB/D for two days. Subsequently, the issue with plugging reemerged, resulting in a further decline in production, as illustrated in Fig. 2. The well was produced again for a couple of days at low rate, then it was stopped due to complete plugging for the second time. The ESP Pump was replaced again by a new one. The well was put on production, producing 950 STB/D for twenty-eight days, then suddenly decreased to 300 STB/D. Two periodic diesel backwash jobs were implemented, showing improvement for three to five days, but the well experienced repeated downhole problems resulting in significant and abrupt decrease in production rate. As a result of organic and inorganic material precipitation inside the pump parts and pump intake, the ESP lifetime for these kinds of wells was approximately 45 days. An economic model assessed the additional costs incurred from four diesel backwashes and one ESP string over three months. The economic model analysis for Well-A indicated an extra cost of $4.28 per STB, in addition to a deferral of 71 MSTB in production. Consequently, it was recommended to recomplete the well for another zone until this issue is further studied. It was concluded that operating similar wells with repeated DBW and pump replacement was not economic.

5.2 Conducting both diesel backwash (DBW) and continuous diesel injection

Fig. 3 illustrates the oil production performance for Well-B. Notably, the oil production rate dropped sharply from 2000 to 900 STB/D within ten days of starting production, leading to shutting in the well to protect the downhole pump. This continuous decline in oil production was accompanied by a significant increase in the bottom hole flowing pressure (BHFP), which increased from 1340 to 2350 psi. The drop in production and the increase in (BHFP) were attributed to either organic and/or inorganic solids precipitation in the pump intake and inside the pump stages as described by Abdelazim et al. (2021). Upon investigation after pulling the pumps to surface, these ESPs equipment were completely blocked and damaged. Similar to Well-A. Four diesel backwash jobs were conducted to remove the asphaltene deposits along with continuous injection of diesel from backside (from the annulus). The diesel injection commenced at a rate of 50 barrels per day and was subsequently gradually increased to reach 300 barrels per day. The diesel injection in the annulus was intended to lighten the oil column and help remove solids from the pump components. The diesel backwash treatments demonstrated temporary production enhancement; however, the issue of plugging remained persistent.

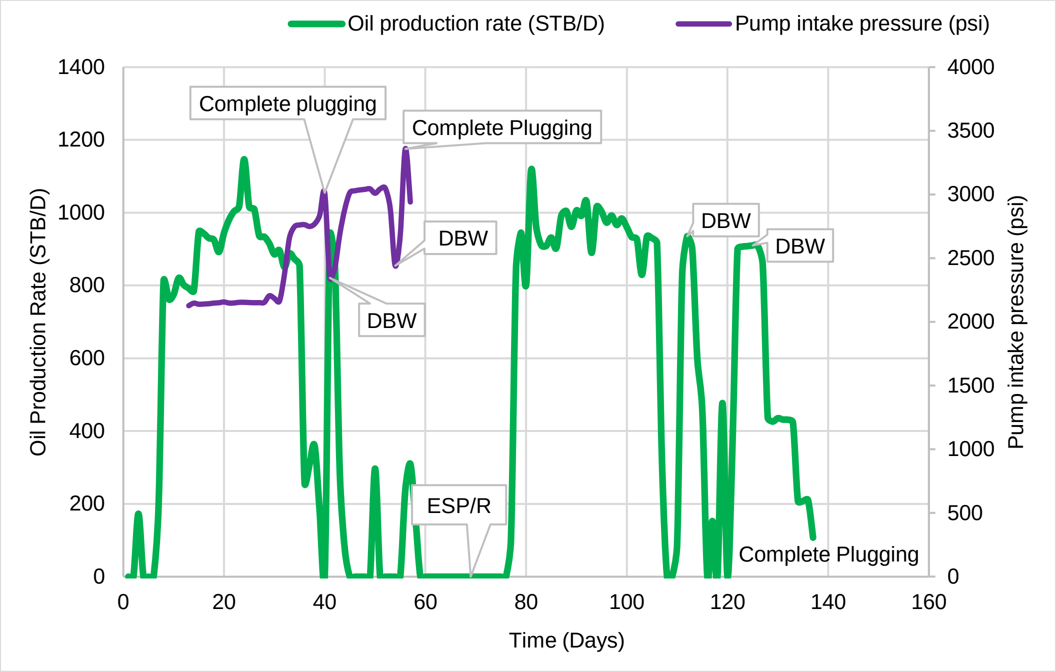

Fig. 2 - Performance of well-A before and after periodic diesel backwash job.

Fig. 3 indicates that the oil production performance and the bottom hole flowing pressure (BHFP) were not impacted by the injection of diesel. These findings are in agreement with the research of Abdallah et al. (2010), which indicated that the use of diesel to mitigate asphaltene precipitation was ineffective and resulted in high operating cost. In contrast, the application of aromatic solvents has been shown to enhance cleaning efficiency and decrease soaking time. It is observed that water production from the reservoir acts as a diluent for asphaltene due to the high temperature. This category has two wells. The economic analysis indicates that the total additional operating cost is $2.5 million. This cost arises from conducting four diesel backwash operations per well and injecting a total of 39.7 MBBLS of diesel. These operations cause an extra cost of $6 per barrel. Moreover, the production deferral is 228 MSTB for these two wells.

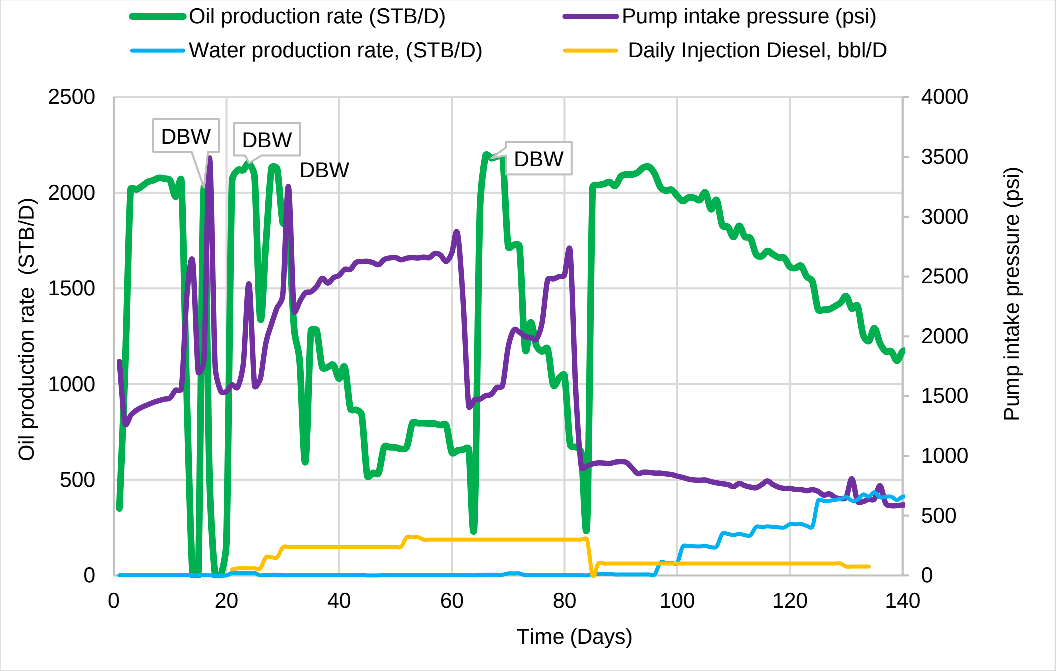

Fig. 3 - Performance of Well-B before and after periodic diesel backwash jobs.

5.3 Conducting diesel backwash, and AD after installing ESP again.

An example well performance of this category is shown in Fig. 4 (Well-C). The well was put on production utilizing ESP to produce +/- 2400 STB/D. Two months later, the oil rate decreased from 2250 to 840 STB/D The decreased in production was accompanied with sharp increase in BHFP (measured by the pump sensors), which increased from 1230 to 1670 psi. This reduction in oil production rate and increase in BHFP were attributed to organic and inorganic solid precipitation in the pump parts. Similar to Well-A and Well-B, seven diesel backwashes were performed to eliminate asphaltene deposits during the first six months. Although these backwashes provided temporary relief, the plugging issue persisted, as shown in Fig. 4. Consequently, and based on the pilot results from previous wells, it was decided to operate the wells at a lower pump intake pressure with continuous injection of asphaltene dispersant (AD). Seven months after initiating the production, a selected asphaltenes dispersant (AD05 type) was injected through a capillary tube at a concentration of 200 ppm. This application successfully stabilized the oil production rate at 2000 STB/D, as shown in Fig. 4.

This category includes seven wells across five different fields. An economic model was developed to compare the old and new treatment methods for these wells. The old method involved costs for diesel backwash operations and workover jobs for ESP replacement. In contrast, the new method's costs were limited to the capillary tube string and the asphaltenes dispersant costs. The economic model results indicated a significant reduction in the average operating cost from $2.5 to $0.43 per STB, along with enjoying continuous production without the need to shut in the wells for diesel backwash or pump replacement.

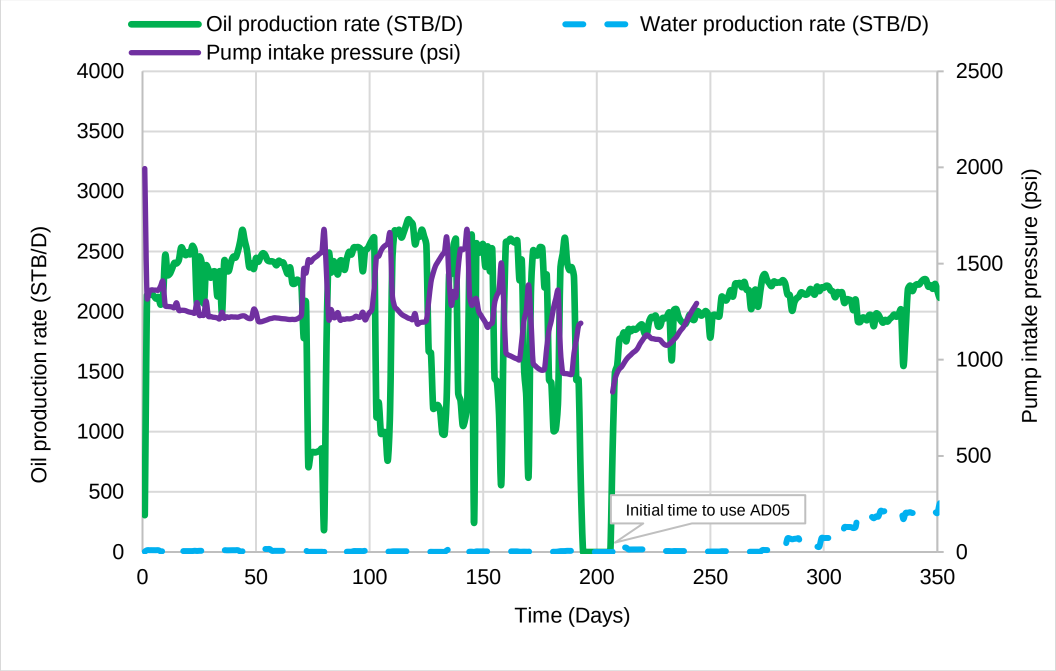

Fig. 4 - Performance of Well-C before and after the injection of AD05 type.

5.4 Conducting diesel backwash (DBW), replacement of ESP by SRP, and AD after reinstallation of the ESP.

As illustrated in Fig. 5. The example well was put on production utilizing ESP to produce 800 STB/D. Eleven days later, the oil rate sharply declined to 570 STB/D and the BHFP increased by 760 psi. Five diesel backwash jobs were conducted to remove the asphaltene precipitation. The diesel backwash jobs showed short-lived production improvement for few days (Fig. 5). It was observed that when the pump intake pressure ranged between 2200 to 2500 psi, the oil production rate remained stable between 300 and 200 STB/D for two months, as illustrated in Fig. 5. This stability is likely due to the absence of significant asphaltene accumulation at pressures above 2200 psi, indicating that the pump intake pressure at this level is above the Asphaltene Onset Pressure (AOP). However, the ESP failed after approximately 100 days on production, the root cause of the pump failure was due to the pump was operating below its recommended operating point (i.e. the ESP was operating below its down thrust rate).

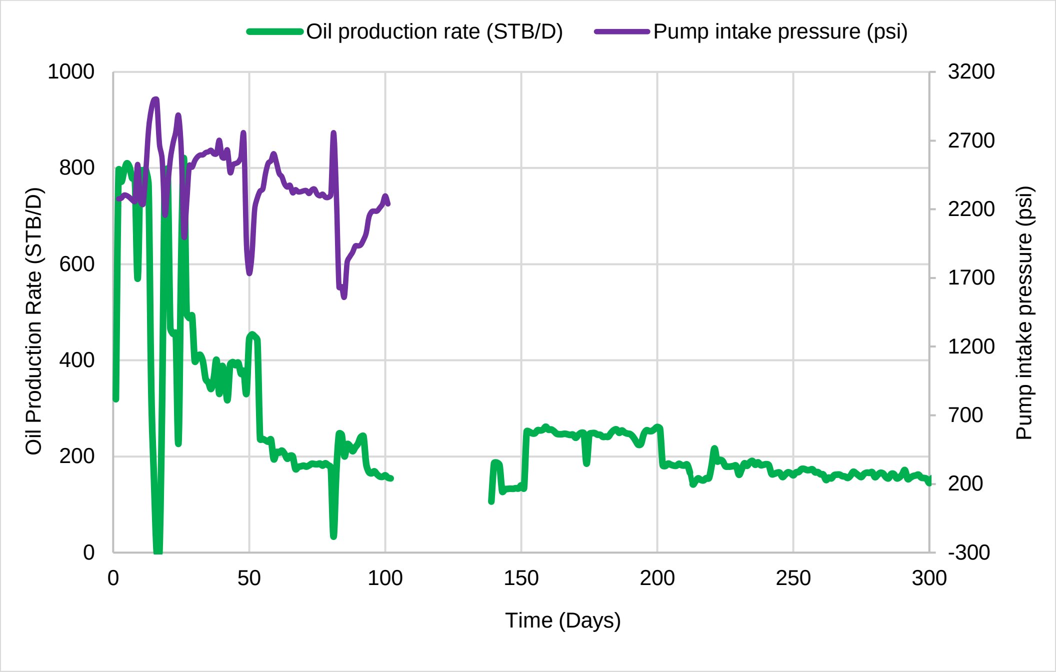

Fig. 5 - Performance of Well-D during diesel backwash and after the replacement of the ESP by SRP.

It is important to emphasize that operating the well with a pump intake pressure exceeding +2200 psi has a significant impact on the oil production rate which was far less than the desired production rate based on the well's inflow performance relationship (IPR). Consequently, operating the well with a high pump intake was not the most effective approach for the production strategy and the design rate of the electric submersible pump (ESP). Therefore, the pump is downgraded from ESP to SRP to produce 250 STB/D instead of +/- 200 utilizing an ESP. The production rate using the SRP started with 250 STB/D and gradually declined to 70 STB/D over more a period of 1150 days. After 1300 days, a new interval for the same reservoir was added and the AL system was changed from SRP to ESP again. With this recompletion, asphaltene dispersant AD05 type was continuously injected. The well performance shows stable and high rate until the water cut started to increase as shown in Fig. 6.

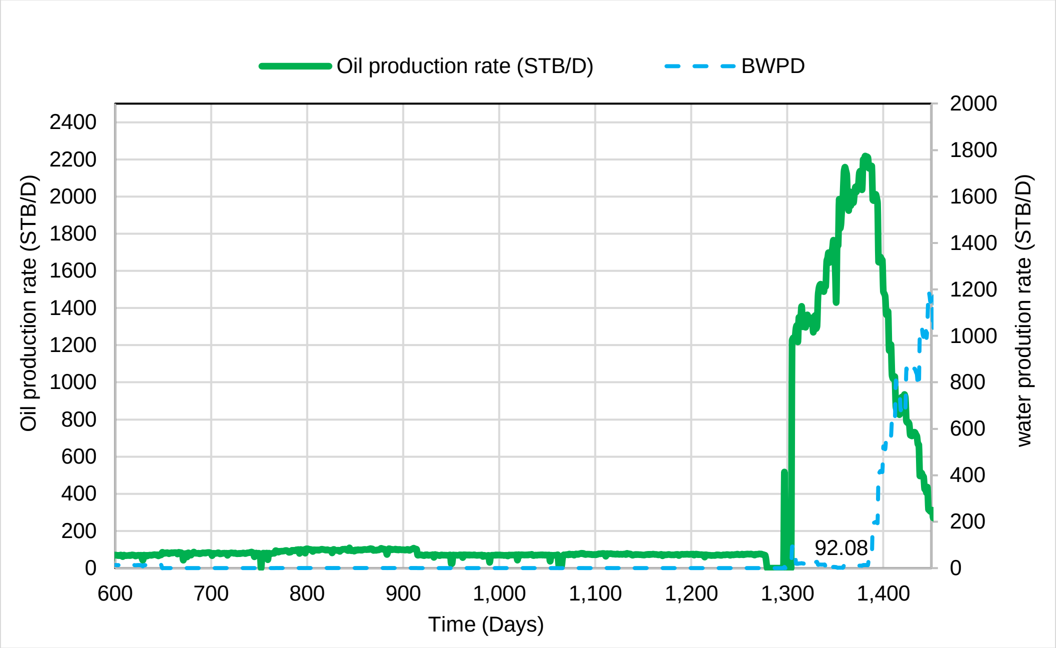

Fig. 6 - Performance of Well-D during SRP, and after continuous injection of the AD05 type.

5.5 Continuous injection of AD since the start of production

Following a thorough analysis of the offset fields that share similar fluid properties, it was recommended to implement a capillary tube with the ESP completion string and start the injection of AD05 from the beginning of the production phase. This methodology was applied in 25 wells distributed in five reservoirs. Comparing these 25 wells with their offsets showed that their operating cost dropped from 5 to less than 0.5 $/STB. It is becoming customary to equip new completions for wells producing these reservoirs with the capillary tube and AD injection capabilities. Well-F is an example well belonging to this category. Fig. 7 shows normal performance of a well equipped with AD injection from the start.

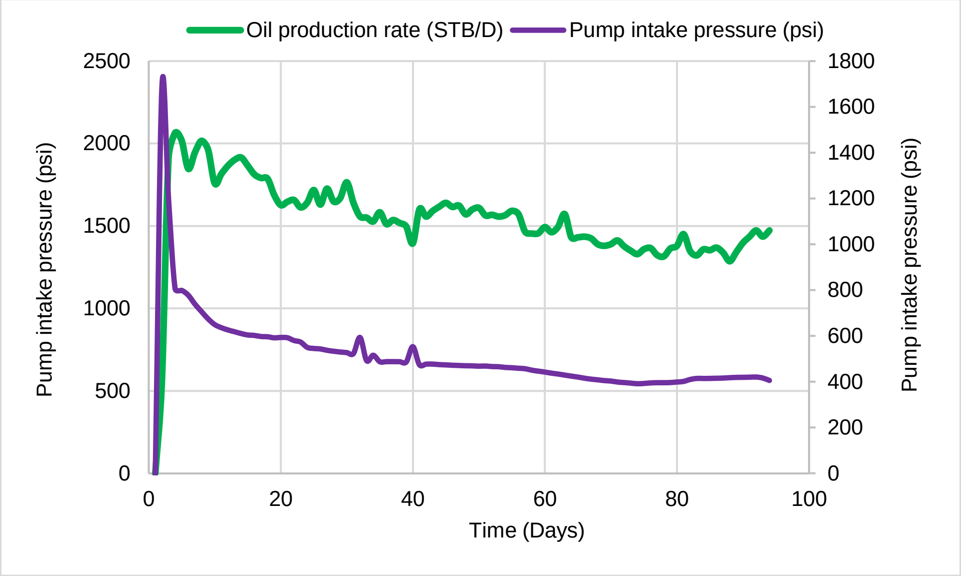

Fig. 7 - Performance of Well-F showing normal performance for a stable production with AD05 type injection from the start.

Conclusions and Recommendations

Crude oils with high API gravity and low asphaltene content can still exhibit asphaltene precipitation problems. Applying a methodological technique in diagnosing the problem and implementing the appropriate solution, as the one suggested in this paper, should be followed. The approach discussed in this paper can lead to significant cost savings and elimination of some production deferment.

The severity of asphaltene precipitation problems is affected by the production mechanism of ESP (centrifugal forces, the drawdown and pump intake pressure). In contrast, the downhole produced water and high pump intake pressure were observed to reduce the severity of asphaltene precipitation problems.

The field applications presented here have demonstrated that the continuous injection of asphaltene dispersant downhole via a capillary tube with ESP completions is considerably more effective than continuous diesel injection, periodic diesel backwash operations, or switching the artificial lift from ESP to SRP. The proposed treatment was applied in 32 wells and oil production was successfully restored to normal levels before asphaltene precipitation occurred. The average cost of using asphaltene dispersant (AD) downhole (instead of other techniques) significantly reduced operating expenditures (OPEX) from $5 to less than $0.5 per STB.

Abbreviations

AD	Asphaltenes Dispersant
API	American Petroleum Institute
AL	Artificial Lift
ADT	Asphaltenes Dispersion Test
AOP	Asphaltenes Onset Pressure
API	American Petroleum Institute
ASTM	American Society for Testing and Materials
BHFP	Bottom-Hole Flowing Pressure
CII	Colloidal Instability Index
CSI	Colloidal Stability Index
CPA	Cubic Plus Association
DHT	Down Hole Temperature
ESP	Electrical Submersible Pump
EoS	Equation of State
IPR	Inflow Performance Relationship
IR	Infrared
OPEX	Operating Expenditure
PC-SAFT	Perturbed-Chain Statistical Association Fluid Theory
POOH	Pull Out of Hole
SARA	Saturates, Aromatics, Resins, and Asphaltenes
VSD	Variable Speed Drive
WAT	Wax Appearance Temperature
WHFP	Well Head Flowing Pressure
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence

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