FIELD PERFORMANCE REVIEW OF HIGH STRENGTH STAINLESS STEEL AND LOW ALLOY STEEL SUCKER ROD IN HARSH ENVIRONMENTS

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ABSTRACT

Corrosion and fatigue are the primary causes of sucker rod failures in artificial lift systems. Harsh well fluid conditions lead to material loss and detrimental pitting which then lead to initiation points for fatigue fractures to occur.

Production in aggressive service environments with higher acid gas concentrations associated with increased levels of hydrogen sulfide (H_2S) and carbon dioxide (CO_2) requires good fatigue life associated with corrosion resistance.

Manufacturers have therefore been challenged to improve products in order to provide reliable technology to overcome industry needs extending production feasibility as long as possible.

High Strength Low Alloy (HSLA) steels have been widely used in decades to provide fatigue resistance, however the corrosion resistance of such steels is of concern. High-chromium steels have recently been utilized to improve performance, but their corrosion resistance is limited along with their fatigue performance. The development of a true martensitic stainless-steel grade aims to improve corrosion resistance, extend fatigue life of sucker rods and reduce overall operating costs.

This paper presents the development of a true stainless-steel chemistry with field performance in successful applications throughout Permian Basin and Bakken.

INTRODUCTION

Sucker rods have been used as a proven cost-effective solution within artificial lift systems (ALS) for several decades. Lately, production in deeper and deeper wells has increased the loading conditions, and therefore the strength of sucker rod materials. Along with the increase of the depth of the wells is the aggressiveness of the service environments, i.e. higher acid concentrations associated with increased levels of carbon dioxide (CO_2) and hydrogen sulfide (H_2S).

These characteristics associated have challenged manufacturers in two ways: (1) developing high strength rods maintaining the same dimensions of the standard sucker rods and (2) improving corrosion and cracking resistance in high strength sucker rods.

High Strength Low Alloy (HSLA) steels have provided fatigue resistance in such environments, however its corrosion resistance is of concern. In order to overcome the issues with HSLA steels, a martensitic stainless-steel (SS) grade was developed to improve corrosion resistance and extend fatigue life of sucker rods, reducing overall operating costs.

The deployment of a patent pending chemistry with heat treatment controls to offer a high strength, high toughness corrosion resistant alloy (CRA) aims to respond industry needs towards advanced technology with state-of-the-art engineering.

A review of the metallurgical factors affecting fatigue life and corrosion resistance is given and the field performance of these alloys is presented in this paper.

FATIGUE LIFE AND CORROSION RESISTANCE

Corrosion and fatigue are the most common sucker rod failure modes. Several application factors can affect fatigue life and corrosion resistance, e.g. operational loads, environmental characteristics, etc. Although these characteristics may be controlled by means of operational practices such as a quality chemical inhibition program adjustment or alternate loading conditions, this can increase operating costs making production unfeasible.

In order to avoid operational constraints during a sucker rods life cycle, metallurgical features can be enhanced to minimize some of the effects encountered downhole. Material grade, properties, as well as microstructure control throughout heat treatment are the main features that can be worked on to extend sucker rods' lifetime.

According to API 11B specification sucker rods are distinguished per chemical composition and tension capacity into K, C and D grades. Grade "K" is a low alloy steel with additions of Molybdenum and Nickel. Grade "C" and "D carbon" are conventional carbon steels. Grade "D alloy" is a Chromium-Molybdenum low alloy steel, while "D special" is a Chromium-Molybdenum-Nickel low alloy steel. Chromium and Stainless Steels are not in the scope of API 11B.

Carbon steels (Grades C and D carbon) are the cheapest and most common solution deployed in sucker rod strings. Low alloy steels (Grades K and D alloy) have been widely used to provide fatigue resistance, however the corrosion resistance of such steels is of concern. High-chromium steels have recently been utilized to improve performance, but their corrosion resistance is limited along with their fatigue performance.

Stainless steels are alloys with a minimum of 11% chromium content by mass and are well known throughout the industry to provide enhanced corrosion resistance due the chromium oxide layer (Cr_2O_3) formed onto its surface.

Exploration and Production (E&P) in deeper wells have required manufacturers to develop high strength rods in order to assist with the higher loading conditions, while maintaining the same dimensions of the standard sucker rods established in the market.

However, the greater the strength, the more prone to corrosion and cracking the rods can become. Failure reports of broken rods identified a strong sensibility of high strength rods (special services, non-API) to the presence of small superficial defects caused mainly by corrosion pitting or gouges during transport and handling. Different behaviors have been observed for rods grade C and K, which can expect larger superficial defects before a fatigue crack starts to grow (even in severely sweet corrosion environments).

Several metallurgical characteristics can be improved to minimize the impacts of strengthening increase, e.g. toughness, microstructure and surface condition. These features tend to extend fatigue life and corrosion resistance.

In order to provide a product that combines extended fatigue life limits and corrosion resistance, a high strength and high-impact true stainless-steel sucker rod was engineered. After several lab tests including corrosion, fatigue and combined corrosion-fatigue tests, extreme service fields were selected to operate with the rods.

FIELD SELECTION CRITERIA

Permian Basin and Bakken fields are well known by a low Mean Time Between Failures (MTBF) ratio, which are commonly associated with increased levels of hydrogen sulfide (H_2S) and carbon dioxide (CO_2).

In order to provide comparison results, several wells in these areas were selected to run stainless steel rods. The wells identified as candidates for the stainless-steel rod trials were those with repeated interventions of more than three (03) rod failures per year.

The failures observed in these candidate wells were sucker-rod related failures more specifically corrosion-fatigue related. Another selection criteria in the search for these wells was focused on deviated, slant or horizontal reciprocating-rod-lift wells with a mild to aggressively corrosive environment.

During the selection of these wells, the rod string failure history was provided by the customer which contained the past failures, identification of root cause of failure, specific run-time, and chemical program used.

Based on the overall information provided from each target well, Key Performance Indicators (KPI) were calculated. The KPI's were strategically set to be double the MTBF ratio for each specific target well. Once the KPI's were set, the stainless-steel string was installed and only the active well time was recorded. Any interventions to the well which would require a shut-off were subtracted from the overall run-time.

FIELD TRIALS

From the field selection criteria presented above, a total of 9 wells were identified as stainless-steel rod trial wells. The KPI's were set for each according to the MTBF observed, as discussed in the field selection criteria the goal was to double the run-time. A list of the wells tested with details on the conditions is described below.

Well 1 was a deviated well in the Permian Basin area, with a depth of 9,000' and repetitive corrosion related failures; the MTBF was identified as 180 days and the KPI set was 360 days. The taper installed was an 76 hybrid taper (WFT 7/8" HS 0-2500', ¾" HS 2501-5000', ¾ EX Guided 5001-8300' and a chemical program was in place in the form of batch treatment. The current run-time has surpassed the MTBF by 95 days with no failures present.

Well 2 was a deviated well in the Permian Basin area, with a depth of 9,500' and repetitive corrosion related failures; the MTBF was identified as 90 days and the KPI set was 180 days. The taper installed was an 86 taper and a chemical program was in place in the form of a capillary string. The current run-time has surpassed the MTBF by 160 days with no failure present; which was found to be non-corrosion related and the same stainless string was run back in the well. The KPI was met and surpassed in this well.

Well 3 was a deviated well in the Permian Basin area, with a depth of 7,600' and repetitive corrosion related failures; the MTBF was identified as 120 days and the KPI set was 240 days. The taper installed was a 76 taper and a chemical program was in place in the form of batch treatment. The current run-time has surpassed the MTBF by 113 days with one failure present, which was found to be tubing related with no effect on the rods.

Well 4 was a deviated well in the Permian Basin area, with a depth of 10,700' and repetitive corrosion related failures; the MTBF was identified as 220 days and the KPI set was 440 days. The taper installed was an 86 EX taper and a chemical program was in place in the form of batch treatment. The current run-time has surpassed the MTBF by 4 days with no failures present.

Well 5 was a deviated well in the Louisiana area, with a depth of 5,900' and repetitive corrosion related failures; the MTBF was identified as 120 days and the KPI set was 240 days. The taper installed was an 86 taper and a chemical program was in place in the form of batch treatment. The current run-time has surpassed the MTBF by 70 days with no failures present.

Well 6 was a deviated well in the Louisiana area, with a depth of 5,000' and repetitive corrosion related failures; the MTBF was identified as 120 days and the KPI set was 240 days. The taper installed was an

86 taper and a chemical program was in place in the form of batch treatment. The current run-time has surpassed the MTBF by 68 days with no failures present.

Well 7 was a deviated well in the Louisiana area, with a depth of 10,000' and repetitive corrosion related failures; the MTBF was identified as 90 days and the KPI set was 180 days. The taper installed was an 76 hybrid taper, 50% 7/8 KDP and 50% ¾ EX taper, this decision was made by customer since most of the corrosion problem was seen in the ¾" section, the chemical program in place is in the form of batch treatment. The current run-time has surpassed the MTBF by 97 days with no failures present.

Well 8 was a deviated well in the Permian area, with a depth of 7800' and repetitive corrosion related failures; the MTBF was identified as 180 days and the KPI set was 180 days. The KPI was set for 180 days for evaluation period, they will intervene well even if no failure has occurred to measure the performance of the EX technology. The taper installed was an 87 taper and a chemical program was in place in the form of batch treatment. The current run-time is 25 days away from surpassing the MTBF ratio with no failures present.

Well 9 was a deviated well in the Permian area, with a depth of 700' and repetitive corrosion related failures; the MTBF was identified as 90 days and the KPI set was 180 days. The taper installed was hybrid, Upper section with 3950' Calabar bottom 700' with 1" EX rod taper and a chemical program was in place in the form of batch or capillary. The current run-time is 9 days away from surpassing the MTBF ratio with no failures present.

CONCLUSION

High strength and high impact true stainless-steel sucker rods have proven to work successfully in some of the most severe wells along Permian Basin and Bakken fields.

Nine (09) wells reporting a mean time between failures of 135 days average were selected to work with the stainless rods. The majority of them have already doubled the MTBF and others are still running with no failures reported.

The combination of toughness, uniform microstructure and mechanical properties as well as the corrosion resistance provided by the chromium oxide layers inherent of true stainless steels is key for performing and extending run time in severe service environments.