Annotated bibliography on

Reducing the Corrosion of Coated Carbon Steel Pumps Under Present Conditions of Temperature, Pressures, Flow Rate and Fluid Composition of Injected Waters.

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Introduction:

The field operators in the oil and gas sectors often prefer to have a continuous supply of oil and gas to the export or processing sites during exploration and production activities. Due to varied well conditions, including fluid composition changes, wells that have soured over time, changes in pressure and temperature during operation, and changes in temperature and pressure, lines, and their component fittings experience material deterioration.

Any part of every oil and gas field is subject to corrosion, which is the degradation of a metal or its qualities. From drilling through to abandonment, from casing strings to production platforms, corrosion is a foe deserving of all the cutting-edge technology and research we can direct. Most of the facilities in the oil industry are significantly impacted by corrosion economically and environmentally. Carbon steel is one of the most frequently employed materials in these facilities. Corrosion and cracking in the well motor housing of electrical submersible down whole pumps (ESP), used to inject water and hence increase production pressure, are significant issues for the oil industry. The present coating epoxy covers the carbon steel that makes up most of the pumps' construction to prevent corrosion.

This annotated bibliography aims to assist the Petroleum Research Center, mainly the Corrosion Assessment and Migration Technology (CAMT) program, by providing articles examining the corrosion of coated carbon steel under the current parameters of temperature, pressures, flow rate, and fluid composition of injected fluids while screening alternative coating to the present coating (epoxy).

This annotated bibliography contains articles abstracts from 2020-2022.

E-resources used: Scopus – OnePetro.

Contact NSTIC to request full-text articles

Articles Abstracts:

1. Al Khalifah, J. M., Aleissa, M. A., AlMutairi, K. M., & Alquwizani, S. A. (2022). An Effective Solution to Extend the ESP Run Life in Sour Fields. Paper presented at the *Society of Petroleum Engineers - SPE Middle East Artificial Lift Conference and Exhibition 2022, MEAL 2022.*

Abstract: Throughout the past decades, the Electrical Submersible Pumps (ESPs) have been deployed across different oil fields in an Arena of Artificial Fields. It was a proven fact that the typical run life of an ESP can exceed multiple years. However, that fact could be reversed especially in designated fields with high Hydrogen Sulfide (H2S) partial pressure; where specialized ESP design is required. The presence of the Hydrogen Sulfide (H2S) can result in various and vast forms of corrosion products attacking the ESP components which eventually resulted in an ESP shorter run life compared to average. Hydrogen Sulfide (H2S) can also react with formation water (H2O) and form Sulfuric Acid (H2SO4) or free Sulfur; which is another source of corrosion product affecting the installed ESP system. As part of continuous improvement in equipment's reliability, several Dismantle inspection and failure analysis (DIFA) were done for ESP premature failures to identify the root causes along with the recommendations and forward plan to enhance ESP run life. The results of these DIFAs indicated a common root cause of ESP failures are related to Hydrogen Sulfide (H2S) presence and well fluids entering the ESP internal components. In particular, the packer penetrator, Motor-Lead-Extension (MLE), and the pothead interface were found to be the main reasons. Consequently, an effort was rolled out to control the Hydrogen Sulfide (H2S) presences at these three locations in order to maintain the ESP reliability and prolong its run life. This presented paper will demonstrate the methodologies and fit-to-purpose ESP design that contributed in extending the ESP run life in a high Hydrogen Sulfide (H2S) pressure fields. Also, a captivated practice along with related technologies have been adapted for the sour environment which resulted in sustaining the ESP run life.

2. Al Asmi, A., Landgraf, C., Abri, H. A., Montilla, B., Caridad, J., Perez, P., & Wyninegar, W. (2022). Improving Run Life in PCP Wells with CO2 and H2S Concentrations Using Tungsten-Alloy-Coated Rods and Couplings. Paper presented at the *Society of Petroleum Engineers - SPE Middle East Artificial Lift Conference and Exhibition 2022, MEAL 2022.*

Abstract: The company Petrogas E&P was established in 1999 by acquiring onshore block 7 in Oman. Over 23 years, Petrogas E&P has continuously grown by acquiring several blocks in Oman, India, Mozambique, Egypt, Netherlands, Germany, Denmark and in the United Kingdom. The main operations are in Oman, Netherlands and in the UK. Since 2007, Petrogas is the operator of Rima Cluster small fields in southern Oman. Artificial lift, mainly rod driven Progressive Cavity Pumps (PCPs) and Beam Pumps (BPs), is required to produce oil with an average specific gravity of 21 °API to surface. Parted rods are the main reasons of well failures and rods present the weakest part of the completion. Some of the wells in Petrogas Rima show high angles of inclination, complex trajectories and certain levels of hydrogen sulfide (H_2S) & carbon dioxide (CO_2). Completion failures due to parted rods lead to production deferment and workover interventions because of required rod string replacement. In general, sucker rods are made of a certain grade of steel and these steels are prone to corrosion in an aggressive environment due to the presence of carbon dioxide and sulfide in the crude oil. A coating solution for sucker rods and couplings was implemented to reduce the influence of corrosive environment in some wells. The lower coefficient of friction resulting from the coating reduces the abrasion between the coupling and the tubing. In that way, the risk of tubing holes can be reduced. After a coating solution was implemented in selected problematic wells, the rod run life could in average been tripled with no failures observed as of this writing.

3. Al-Khalifa, M., Pessoa Rodrigues, R., & Sinclair, D. (2022). Electrical Submersible Pump Design Enhancements for Hydrogen Sulfide Harsh Environments. *SPE Production & Operations, 37*(4), 603-615.

Abstract: Summary Electrical submersible pumping (ESP) remains the preferred artificial lift method for high rate production when technically viable. ESP, on the other hand, is sensitive to downhole conditions and pumped fluid. Sour fields, in particular, are considered as a major challenge for producing facilities and well completion elements. Reservoirs producing fluids with hydrogen sulfide (H2S) present a special challenge to ESP systems. This paper uses ESP field observations and pulled equipment findings from many dismantle inspection and failure analyses (DIFAs). The findings confirmed H2S behavior and root causes of electrical and mechanical failures within multiple ESP components. The outcome of these investigations and the recommended system upgrades to enhance ESP reliability in corrosive environments will be illustrated. Critical ESP system materials will deteriorate and fail when subjected to sour environments. H2S can penetrate the pump's cable insulation, attack the copper, and react to form copper sulfide, resulting in electrical failure. It can also permeate the seal bags and o-rings, diffuse in the seal dielectric oil, and attack the bronze and copper components in the seal and the motor. To improve reliability, a new version of motor lead extension (MLE) using three individually armored connectors and a seal with H2S sacrificial anode scavenger inside each chamber were introduced. The improved design encapsulated the insulated conductors individually within metal tubes made of high nickel alloy. The tubes can be terminated individually at the motor and above the production packer with proven swage type connectors. By utilizing high nickel alloy tubes as barriers against H2S and removing all connections below the packer, the H2S effect has been eliminated. On the other hand, the seal with H2S passive scavenger will retain most of the H2S in the dielectric oil before it reaches the motor. These novelty technologies resulted in a threefold improvement, leading to longer up time, less workover jobs, and more sustainable production.

4. Almubarak, T., Almubarak, M., Rafie, M., & Almoajil, A. (2022). Turning the Most Abundant Form of Trash Worldwide into Effective Corrosion Inhibitors for Applications in the Oil and Gas Industry. Paper presented at the - *Adipec,* D011S028R004.

Abstract: There is a big concern regarding waste materials that are generated daily. Cigarette butts are one of the most common forms of trash. Trillions of cigarette butts are thrown from car windows, discarded on sidewalks and beaches every year. They accumulate in landfills with minimal recycling solutions and have been known to cause severe damage to plant and aquatic life environments. Fortunately, the oil and gas industry are continuously trying to find methods to utilize such materials in our well treatments as they are cheap and would contribute to a cleaner world. Corrosion in the oil and gas industry causes well integrity issues totaling billions of dollars annually. Consequently, it is intuitive to include corrosion inhibitors in well treatments which are corrosive in nature to protect our equipment. Corrosion inhibitors are molecules that can stick and create an impermeable film on the surface of metal, thereby reducing contact with corrosive substances. Cellulose acetate filters (CAF) are the main component in cigarette butts, and they retain over 7000 compounds resulting from the combustion of tobacco. Many of these compounds contain chemical functional groups that can provide corrosion inhibition properties.The goal of this project is to test the chemicals extracted from CAF for potential applications as corrosion inhibitors.The CAF were soaked for 24 hours in solvents such as ethanol, methanol, water, isopropyl alcohol, n-hexane, dichloromethane, and a methanol/chloroform azeotrope to extract chemical compounds using a continuous Soxhlet extraction method. To determine the inhibition efficacy, T-95 low carbon steel coupons were exposed to 15 wt.% HCl solution for 6 hours with 5-60 gpt of the CAF extract at temperatures between 77-350°F. A control solution containing no corrosion inhibitor was used to establish a corrosion rate for a base case. Fourier Transform Ion Cyclotron Resonance Mass Spectrometry (FT-ICR MS) and gas chromatography/Mass Spectrometry (GC/MS) were utilized to identify molecules in the CAF extracts.At room temperature, CAF extracts were observed to provide more than 97% corrosion inhibition efficiency. At 150°F, the control solution showed a corrosion rate of 0.0985 lb/ft2, whereas the solutions containing CAF extracts were observed to maintain good corrosion inhibition efficiency at 0.0138 lb/ft2. At 200, 250, 300, and 350°F the corrosion rates observed were as low as 0.0014 lb/ft2, 0.0010 lb/ft2, 0.01 lb/ft2, and 0.0146 lb/ft2, respectively. Chemical compounds such as nicotine, benzenes, and aromatic amines are present in CAF, so it comes with no surprise that the extracts can provide corrosion inhibition properties.These results show that waste products can be used as corrosion inhibitors. Due to their low inherent value, this form of trash may provide a cheap alternative to commercial corrosion inhibitors while simultaneously protecting the environment by reducing pollution.

5. Caridad, J., Alamoudi, M. M., Guang Lim, L. Z., & Alyami, S. F. (2022). Bottom Intake ESP for Slim Wells Applications. Paper presented at the *Society of Petroleum Engineers - SPE Middle East Artificial Lift Conference and Exhibition 2022, MEAL 2022.*

Abstract: In certain oil fields, slim wells are common due to corrosion or erosion in 7-in. casing and sidetracks to evaluate secondary reservoirs. Efforts to produce such wells by electric submersible pumps (ESPs) pose several challenges such as early failures and insufficient pressure to reach target flows due to the limited casing clearance which also limits the pump size. This paper discusses the successful installation and a production test of a bottom intake ESP. In comparison, conventional slim electric submersible pumps had been installed in the same field

with limited success in the same type of slim wells. The slim ESPs have shorter run life compared to standard ESPs, mainly because of equipment damage while running in hole (RIH). The motor lead extensions (MLE) are particularly vulnerable given the tight clearance available, which precludes the use of MLE cable protectors along the ESP. Production is also limited because of the smaller diameters that conventional slim ESPs require to fit into the slim (4.5-in. and 5-in.) casings. To tackle these challenges, an operator and an energy technology company collaborated to devise a solution using a bottom intake slim ESP architecture. The objective was to modify the conventional slim ESP to maximize clearance thereby improving the reliability of the ESPs and increasing the production rate in slim wells. By combining conventional slim ESP technologies and the inverted architecture used in coiled-tubing-deployed ESP, the challenges described were addressed. The bottom intake slim ESP was designed with MLE to be installed along jointed tubing. Since it is terminated at the top of the ESP string, risk of damage to the MLE while RIH is eliminated, and a larger pump can also be installed. The larger pump outside diameter results in a substantial production increase. The bottom intake slim ESP can operate on higher drawdown compared to conventional ESPs as it can be set deeper. The objective was to prove bottom intake slim ESP technology as a solution to produce 3,500 to 7,000 BPD in 5-in. casing wells, while eliminating the risk of MLE damage during RIH in the operator slim wells. Moreover, based on erosion simulation, the effect of discharge velocity on the casing was negligible, and by utilizing plug-and-play technology, human error and rig time were reduced.

6. Palliparambil, R. C., Caridad, J., Dector, E. G., Khade, S., Atiencia, N., Gewily, A. A., Al-Owairi, S., & Al-Yafei, A. A. (2022). Improving Run Life of Coiled-Tubing-Deployed ESP in Harsh Environment for Qatar's Al Karkara Field. Paper presented at the *Society of Petroleum Engineers - SPE Middle East Artificial Lift Conference and Exhibition 2022, MEAL 2022.*

Abstract: Alternative deployed ESP Systems are strings that are deployed in the well on other than conventional tubulars. Coiled Tubing (CT) deployed Electric Submersible Pumps is one of the most common configurations and has been used successfully in Al Karkara field to reduce intervention cost. As part of a closed loop product improvement workflow, utilizing data from dismantle, inspection and failure analysis of equipment, design improvement were suggested and

implemented to address root causes and maximize life in Al Karkara. As part of this work, the main challenges of the application as well as weaknesses identified on the different sections of the string are explained in detail. Moreover, the design and specification changes incorporated because of said observations are also covered, including improvements on the power cable, lower connector, multisensor, motor, bottom intake, and base protectors, among others. Through implementation of downhole equipment ESP upgrade and enhancing the operating philosophy, this improved the run life of Al Karkara field by more than 300%. With the industry shifting into a drastic reduction of total cost of ownership (TCO) approach and with the volatility of oil price, the rigless ESP deployment through coil tubing will help to eliminate the cost of a work over rig while reducing the deferred oil production. This paper showcases the ESP capabilities in this corrosive and high temperature environment. © 2022, Society of Petroleum Engineers.

7. Panbarasan, M., Sankar, S., Venkateshbabu, S., & Balasubramanian, A. (2022). Characterization and performance enhancement of electrical submersible pump (ESP) using artificial intelligence (AI). *Materials Today: Proceedings*, *62*(P12), 6864-6872.

Abstract: Electrical submersible pump (ESP) technology is the first choice of artificial lift for the operators both in offshore and onshore to increase the rate of production in all types of reservoirs. Even though, the ESP was designed, engineered and fabricated to withstand in harsh subsurface natural and man-made environment such as corrosion, high temperature and extreme pressure but it fails under these circumstances without any prerequisite signal. Even the monitoring systems in place failed to notify the failure of ESP. These ESP failures cut off the production and revenue circulation in the firm. The cost required for the repair and replacement of the ESP is also high and is time consuming. The prevention of ESP failures using machine learning technique is discussed.

8. Perri, A. C., & Sultanian, A. (2022). Anodic Coiled Rod Mitigates Corrosion Damage in Well with Aggressive CO2, H2S Conditions. Paper presented at the *Society of Petroleum Engineers - SPE Artificial Lift Conference and Exhibition - Americas 2022, ALCE 2022.*

Abstract: The objective of this paper is to share insights on mitigating sucker rod corrosion damage in vertical, horizontal, and deviated wells with aggressive corrosive conditions such as

H_2S and CO_2, particularly those with histories of corrosion-related rod and tubing failures. Corrosion is a common problem in production operations, accounting for two-thirds of all rod string failures and costing hundreds of millions annually to remediate downhole tubing damage alone, according to NACE International. This paper presents the development and initial field application results of a continuously applied metallic coating that actively participates in the electrochemical aspects of corrosion in carbon and low-alloy steels. Moreover, the solution protects uncoated segments of rod and other steel components in the wellbore while reducing abrasion by enhancing friction properties compared to bare steel. The authors outline the key properties and characteristics of this coating, including evaluating its performance relative to traditional corrosion protection measures such as barrier coatings. Rather than acting as a barrier layer, the metallic coating actively protects against corrosion and has inherent physical properties that self-heal surface scratches and abrasions. This is particularly valuable in horizontal and directional wells with high dog leg severities and sideloading forces that contribute to rod/tubing abrasion. Results are presented from laboratory testing as well as initial trial applications in wells with histories of rod failures due to corrosion, typically requiring interventions with workover rigs. In one such trial, the metallic coating was applied to a coiled rod string installed in a high-CO_2 content well on progressing cavity pump. The coated coiled rod string was installed in January 2019. After five months of service, the coated string was pulled to inspect its condition. The examination revealed that the rod was unaffected by corrosion. A second inspection after nine months found evidence of rod string wear but no corrosion damage. The well has been in operation for 140 weeks (and counting), achieving a ten-fold improvement in the average run time before installing coated coiled rod. The novelty of this approach is the application of an advanced materials science-based coating to extend rod string service life in corrosive environments through active protection. In addition, it requires no special handling or installation equipment, and the metallic material allows rod strings to be recycled (eliminating potential environmental and downstream damage risks associated with barrier coatings). As supported by lab and field case study data, the results of deploying this method include increased production uptime, reduced workover frequencies and associated remediation costs, and lower overall LOE and lifting cost per barrel of oil produced.

9. Pessoa Rodrigues, R. F., & Alsaif, A. A. (2022). Advances in the Understanding of H2S Paths into the ESP Electrical System. Paper presented at the *Society of Petroleum Engineers - SPE Middle East Artificial Lift Conference and Exhibition 2022, MEAL 2022.*

Abstract: One of the challenges electric submersible pumps (ESPs) face in harsh environments is the corrosion of copper electric components caused by H_2S. Copper is aggressively and quickly corroded by H_2S, compromising the electrical integrity of the system. ESP improvements, such as the metal-to-metal motor lead extension (MLE), has had a positive impact in the ESP's run life in sour environments, and it sparked the creativity for further similar enhancements throughout the ESP system. Understanding the path of the H_2S into the motor is of paramount importance to effectively aim the resources for these additional enhancements. This paper offers an outlook of the components that play a key role in allowing the H_2S to enter the electrical system. It is supported by evidence from the dismantle, inspection and failure analysis (DIFA) of motors, MLEs, and seal sections with and without H_2S scavenger, and having different times of exposure based on their run life. For the objective of this paper, all observations are to revolve around the electrical integrity of the ESP. When examining the copper end rings of motor rotors, it has been observed that the H_2S attack is concentrated at the top of the motor. Similarly, from tandem seals with bags in series and H_2S scavengers, where the scavenger (copper tube) in the top chamber was corroded more severely than in the bottom chamber. Furthermore, in ESP systems where the H_2S had been successfully scavenged at the top of the motor or the seals no further corrosion was observed in the lower parts of those components. These observations indicate that the source of the contamination is at the top of the seal section, with no concerning H_2S entrance happening below (i.e., flanges and threaded parts relying on o-rings). For all practical purposes, these conclusions are of great benefit in determining the components that require enhanced H_2S protection. They also suggest that developing and implementing metal-to-metal connections all along the ESP components is either not necessary or of least priority. The findings of this paper are intended to help direct the efforts of future ESP improvements in terms of H_2S resistance toward key components. The analysis of the novel information presented here confirms that the main entry point for H_2S in the ESP electric system is the top of the seal section. The shaft mechanical seals are a particular suspect. If so, vibration could be a major contributor, but further study is required to understand the effect of vibration on the rate of contamination through the shaft mechanical seals.

10. Paredes, M. P., da Silva, L. B. M., Del Rosario Egas, L., Endara, E. A., Escalona, P. L., Maulidani, O. A., Pineda, A. J., Estevez, D. R., Guaman, J. C., Carrion, J. J., Freire, C. J., & Villamar, F. A. (2021). A novel chemical treatment and well completion strategy to prevent scale and production losses in Shushufindi Aguarico field. Paper presented at the *Society of Petroleum Engineers - SPE/IATMI Asia Pacific Oil and Gas Conference and Exhibition 2021, APOG 2021*.

Abstract: In this case study, EP Petroecuador and Consorcio Shushufindi evaluate a chemical treatment and completion strategies to reduce the extensive impact of bottomhole scale deposits on oil production, electrical submersible pumps (ESP) run life, and operating costs of wells completed in the high-scaling tendencies reservoir. The positive impact on oil production optimization resulting from these strategies will also be discussed and the advantages, lessons learned, and constraints of this work. Conventionally, corrosion and scale chemical inhibitors are deployed through capillary lines; this method is effective up to the pump depth but does not prevent deposits at the perforations or at the lower completion and near wellbore. Rapid production decline or complete loss of production is observed, requiring costly well interventions. Laboratory analysis and evidences from the interventions show that lower T-sand fluids present a high-scale tendency at the bottomhole; therefore, a process to identify candidates and deploy chemical treatment in the rathole to prevent scale deposits was defined and proved. The technology selected was encapsulated scale inhibitors (microcaps). Based on the process, two wells were selected from a portfolio of 12 wells that match the criteria to apply the method to deploy the technology. The following observations were drawn: - Calcium carbonate ($CaCO_3$) is the most common scale - ESP parameters and production surveillance are essential for early detection of problems associated with scale deposits at bottomhole - The action of microcaps and the installation of a pipe tail below the ESP base sensor allowed to deepen the continuous dosage of scale inhibitor and has already doubled the run life of the ESP equipment, with direct savings on operations costs (approximately USD 240,000) in the short time and continue and can continue to yield more. - According to post workover (WO) production tests of the two candidates and the performance of ESP parameters, the application of this strategy made possible to restore the productivity indexes and sustain them over time. This leads to reduction in production losses of 310 BOPD or 60% of the actual production in the similar period before the treatment. - The microcaps can be applied and refilled through rig-less annulus - It is a low-cost solution for scale problems at bottomhole.

This document presents an analysis to reduce operating costs in wells that produce fluids with a high-scaling tendency at bottom hole, through an unconventional and low-cost strategy of chemical treatment from the sand face to the wellhead. This novel process and microcaps application can be used in wells in remote and difficult areas to service on a regular basis.

11. Al-Majdli, A., Martinez, C. C., & Al-Dughaishem, S. (2021). Corrosion challenges on electrical submersible pump wells in the North Kuwait field. Paper presented at the *Proceedings - SPE Annual Technical Conference and Exhibition,2021.*

Abstract: Oil production in North Kuwait (NK) asset highly relies on artificial lift systems. The predominant method of artificial lift in NK is electrical submersible pump (ESP). Corrosion is one of the major issues for wells equipped with ESP in NK field. Over 20% of the all pulled ESPs in 2019 and 2020 in NK field were due to corrosion of the completion or the ESP string. With an increase in ESP population in NK, a proactive corrosion mitigation is essential to reduce the number of ESP wells requiring workover. Historic data of the pulled ESPs in NK revealed that most of the corrosion cases were found in the tubing as opposed to the ESP components. Although there are multiple factors that can cause corrosion in NK, the driving force was identified to be the presence of CO_2 (sweet corrosion). Corrosion rates have been enhanced by other factors such as stray current and galvanic couples. In this paper, multiple methods have been suggested to minimize and prevent the corrosion issue such as selecting the optimal completion and ESP metallurgy (ex. corrosion resistant alloy), installing internally glass reinforced epoxy lined carbon steel tubing, and installing a sacrificial anode whenever applicable.

12. Al-Moubaraki, A. H., & Obot, I. B. (2021). Corrosion challenges in petroleum refinery operations: Sources, mechanisms, mitigation, and future outlook. *Journal of Saudi Chemical Society*, *25*(12).

Abstract: Corrosion is one of the most important challenges facing petroleum refineries. It has received wide attention in recent decades due to the continued dependence of the global economy on industries based on oil and natural gas. With annual corrosion cost estimated at billions of dollars, suitable corrosion mitigation approaches are required to prevent assets failure due to the

menace of corrosion. A vast amount of information on corrosion mitigation in the petroleum refinery is available. However, it is spread in various scientific publications, and gathering such information is critical in building a body of knowledge on the corrosion issues arising from refinery operations. A perusal of the literature reveals that a review focused on corrosion mitigation in the refinery is scarce. So, a comprehensive and up-to-date review of corrosion mitigation in the refinery is timely. In the present review, the corrosion issues at the different units of the refinery are presented. Physicochemical basics in corrosion at refinery units have been considered. In addition, the sources of the corrosion problem and the current mitigations approaches such as engineering design, cathodic protection, the use of corrosion inhibitors and metal coating were discussed. Finally, the existing knowledge gaps were identified, and future research directions were proposed. The review concludes that corrosion in the refinery has not received wide attention in the literature like other corrosion issues in the petroleum industry. The advancement of research in the area of real time and accurate prediction models, collection of sufficient data regarding ammonium bisulfide (NH4HS) corrosion in the refinery plant, development of novel smart nanomaterials coating, and environmentally friendly high temperature corrosion inhibitors are needed for effective mitigation of refinery corrosion.

13. Ivanovskiy, V. N., Sabirov, A. A., Degovtsov, A. V., Gerasimov, I. N., Mazein, I. I., Merkushev, S. V., & Krasnoborov, D. N. (2021). Improving the efficiency of oil production through the introduction of digitalization. *Neftyanoe Khozyaystvo - Oil Industry, 2021*(7), 118-124.

Abstract: The intensification of oil production is accompanied by complicated well operation conditions. The most widespread problem in the operation of ESP today are mechanical impurities, salt deposits, corrosion, free gas, complex inclinometry, asphalt-resin-paraffin deposits, high-viscosity oil emulsions. To ensure the efficiency of oil production in these conditions, it is necessary to use modern smart field systems, develop and apply clear recommendations on the design and technology of using well equipment. These recommendations should be based on the rapid determination of all operating parameters of the formation-well-pumping unit system, first of all-the flow rate of wells. Rapid and accurate determination of the well flow rate in the on-line mode allows to increase oil production, reduce operating costs of electricity and chemical regents, and optimize field development. The use of flow rate values in the on-line mode also provides progress in the creation of digital twins of digital well elements due to the operation of algorithms for determining the degradation of the performance characteristics of well pumping units. All this leads to the possibility of creating a system of predictive analysis of the operation of electric drive vane pumps for oil production, the main purpose of which is to determine the physical and probabilistic time to failure of equipment under complicated operating conditions. The results of theoretical and experimental studies in the development of new designs and technologies should be based on the collection, processing, analysis of field data and data on the operation of oil well production equipment.

14. Minchenko, D. A., Noskov, A. B., Yakimov, S. B., Bylkov, V. V., Ivanovsky, V. N., Sabirov, A. A., Dolov, T. R., Kuznetsov, I. V., & Garifullin, A. R. (2021). Comprehensive tests of electric submersible pump units stages for oil production. *Neftyanoe Khozyaystvo - Oil Industry,* (11), 48-53.

Abstract: Analysis of Rosneft's mechanized well stock has shown that the main causes of failures of electric submersible pump (ESP) units are mechanical impurities, salt deposits and corrosion. Average mean time between failures of the equipment depends not only on well conditions, but also on the design of the pump, materials used for ESP stages, as well as the construction of ESP stages themselves. However, the essential difference of the data about the reasons of failures and operating conditions does not allow to provide the accurate analysis of the influence of the design of the pumps and the materials used on the ESP performance up to failure. In order to clarify the influence of negative factors on the ESP performance, a methodology and stands for comprehensive comparative testing of ESP units were developed within the framework of a targeted innovative project. The test results allow us to answer the questions about the applicability of ESP assembly materials and designs for operation in different field conditions with due regard to the complicating factors. The main statements of the methods are presented, including the methods of determining partial and integral equipment quality indices; the construction schemes of stands for hydrodynamic and endurance tests of ESP components and parts are shown. The results of the bench tests became the basis to draw conclusions about the construction of ESP stages and bearings preferable for working in the wells in the presence of complicating factors.

The results of the bench tests have already started to be used to select the optimal ESP unit in terms of design and materials and will also be used for creating a new version of Rosneft's uniform technical requirements, which will further increase the efficiency of oil production with the use of ESP.

15. Nasution, B. M., Yonathan, A., Abdillah, M., & Zhen, W. (2021). Pre-treatment experimental study of organic acid: An alternative means to overcome inorganic scale build-up problem in deep well. Paper presented at the *Society of Petroleum Engineers - SPE/IATMI Asia Pacific Oil and Gas Conference and Exhibition 2021, APOG 2021.*

Abstract: Organic acid has been widely applied for inorganic scale treatment in oil and gas industry including well stimulation and scale inhibitor. Thanks to its low corrosivity and slower reaction rate with rock, organic acid is considered to offer better performance comparing to strong acid - Hydrochloric Acid (HCl). Yet, proper treatment requires vigorous analysis and experiment in order to meet foremost expectations. Besides, mistreatment of scale could result in formation damage including clay precipitation. Pre-treatment experiments were performed on Zelda field at South East Sumatera block, that has faced with scale problem for ages. Water sample was taken from flowing Zelda A-08 well to be analyzed for mineral's saturation level. Scale was extracted from three sources including tubing, sand bailer, and Electrical Submersible Pump (ESP) of Zelda A-08. Those scale were treated in X-Ray Powder Diffraction (XRD) for mineral composition, and solubility test that utilized two types of acid system - formic acid (HCOOH) and hydrochloric acid (HCl) for comparison. Anti-swelling test and corrosion test were performed to examine the effectiveness of clay stabilizer and corrosion inhibitor. As for carbonate analysis, both formic acid 9% and HCl 15% have comparable solubility (98.17% vs 98% for tubing's scale, 91.86% vs 82.79% for ESP's scale, and 70.30% vs 68.07% for sand bailer's scale). Yet, longer reaction is carried out by formic acid 9% (1 hour) comparing to HCl 15% (18 minutes). For silicate analysis, HF-formic acid provided the higher solubility than HF-HCl (8.34% vs 5.67% for ESP's scale and 30.48% vs 25.68% for sand bailer's scale). On anti-swelling test, by reducing swelling tendency up to 62.6%, it proves that examined clay stabilizer works perfectly against swelling potential of clay, despite of high swelling tendency of sand bailer's scale (25.8%). On corrosion test, adding on corrosion inhibitor (pyridine-based) into solution results in regular HCl 15% has corrosion rate

26.279 g/m2.h which is much higher (300%) than HF-HCl (7.977 g/m2.h) and HF-formic acid (8.229 g/m2.h). Based on pretreatment test, formic acid 9% together with examined corrosion inhibitor and clay stabilizer, can be used as an alternative to regular HCl 15% for stimulation purpose where more areas will be covered that previously left unreachable by regular acid 15%. In addition, potentially more effective squeezed scale inhibitor using organic acid can also be achieved by performing further experiments. The method presented in this paper for pre-treatment experimental studies of organic acid can provide engineers with intensive guide to meet the best result of organic acid treatment.

16. Rassenfoss, S. (2022). If You Build a Better Sucker Rod, Will Buyers Be Willing To Change? *Journal of Petroleum Technology, 74*(11), 28-33.

Abstract: When the pump breaks down and the oil stops flowing, it's mostly likely due to a failed sucker rod. "The statistics are pretty strong. While you would think the rod pump or the progressing cavity pump is the component with the most problems, it is the rod string" that is most often to blame, said Lonnie Dunn, vice president for technology at Lifting Solutions. That's a critical fact for Dunn who works for the biggest maker of what are known as continuous sucker rods. Rather than connecting individual rods into a string long enough to run from the surface to the pump, a single long rod is run into the well like coiled tubing. While he was talking up coiled sucker rods at the SPE Artificial Lift Conference and Exhibition, a competitor at the conference, ChampionX, was announcing a first: a protective anodic coating for its continuous sucker rods that prevents corrosion and reduces the drag when a rod rubs against the surrounding tubing (SPE 209751). Unlike competitors that have relied on coatings that provide a physical barrier, ChampionX's defense relies on a powdered metal coating that short-circuits electrochemical reactions that can cause rapid corrosion. This is an emerging technology where the key components are long-proven. Continuous rod was patented nearly 50 years ago, and methods using anodic corrosion protection methods have been around even longer with uses ranging from protecting subsea risers to galvanized nails. Still both ideas are new in this slow-changing service sector, where there has been little change in the dimensions of the rods, and key design elements are usually based on API specifications. These companies are among a handful of innovators working to convince operators that a continuous rod is a better choice at a time when wells present more challenges, from

wellbores that curve by design or by accident to reservoirs producing increasingly corrosive fluids. It has been a slow change because "sucker rods have been around a long time and the product and servicing practices are well established whereas continuous rod, especially on the servicing side, represents a significant change," Dunn said. While there are advantages, from faster running times to reduced failures, when it comes to this long-established oilfield commodity, he suspects some customers assume "everything that can be done is done." Continuous rods eliminate the time required to make the hundreds of connections needed to make up a rod string. The risk of connection failures is reduced by replacing multiple rods with a long rod requiring connections only at the pumping unit on the surface and the pump downhole. To back up the promise of more-durable rods, the companies in this sector are adding corrosion-resistant coatings. "The general consensus is that the wells are going to get more and more corrosive, and the industry will be going after oil and gas in harsher conditions," said Alex Perri, product line director for ChampionX.

17. Van Spankeren, M. H., & Hernandez, M. A. (2021). Autonomous Corrosion and Scale Management in Electric Submersible Pump Wells. Paper presented at the *Society of Petroleum Engineers - Abu Dhabi International Petroleum Exhibition and Conference, ADIP 2021*.

Abstract: Producers find a considerable amount of their operating expense (OPEX) comes from managing risks associated with corrosion and scale. Monitoring and chemical adjustment workflows are typically manual, and performed at low frequencies, leading to delays in event detection. As a result, the potential for negative events such as production shutdowns and well failures increase. This project's scope integrates chemistry domain experience with edge analytics, machine learning models, and intelligent equipment, to transform manual processes into an autonomous solution. The goal is to optimize operations, reduce well failures and workover costs, and maximize production. This solution is currently deployed in an oilfield, that has been historically challenged with a high number of electric submersible pump (ESP) failures due to corrosion and scale that resulted in significant production losses and unforeseen workover costs. The designed digital architecture supports autonomous management of scale and corrosion through remote monitoring and automated chemical injection. Real-time data is acquired from connected equipment, processed in an edge device running artificial intelligence, and autonomously sent to chemical pumps. Data from sensors, connected devices, and models are visualized in cloud applications, or integrated into existing client systems for end user analysis and full visibility of the entire process. The results show highly accurate models, precise chemical injection, and a reduction of well failures.

18. Wei, D., Zeng, J., & Yong, Q. (2021). High-Performance Bio-Based Polyurethane Antismudge Coatings Using Castor Oil-Based Hyperbranched Polyol as Superior Cross-Linkers. *ACS Applied Polymer Materials, 3*(7), 3612-3622.

Abstract: Bio-based antismudge coating, as a substitute for the petroleum-based one, has excellent liquid repellency and self-cleaning ability, which is of great value to keep a coated surface free of contaminants. In this study, we report a facile strategy to fabricate high-performance biobased hyperbranched polyurethane antismudge coatings. More specifically, a castor oil-based hyperbranched polyol was employed as a coating precursor, a hexamethylene diisocyanate trimer was used as the curing agent, and a mono-hydroxyl-terminated poly(dimethysiloxane) (PDMS-OH) was introduced as a low-surface-tension lubricant through covalent bonding. Consequently, a highly transparent smooth coating was obtained after the coating solution was completely cured. The coating loaded with 0.5 wt % PDMS-OH exhibited superb liquid repellency and self-cleaning ability, as attested by liquids such as water, hexadecane, peanut oil, pump oil, salt solution, strong acid, and strong alkali solutions that could slide off the coated surfaces cleanly. In addition, even after 1000 writing and erasing cycles, the coating still retained its ability to contract ink traces and the contracted ink could be easily removed with tissue paper. Apart from antigraffiti and antifingerprint performance, the coating applied on tin plate surfaces showed an adhesion grade of 5B and a pencil hardness of 3H and displayed superior corrosion resistance. Furthermore, this mechanically robust coating could withstand 1000 abrasion cycles without sacrificing its ink contraction ability. Therefore, this biobased antismudge coating should provide an alternative avenue for developing green and sustainable functional coatings.

19. Zhang, J., & Wan, J. (2021). Application of the cable laying coiled tubing in electric submersible pump. Paper presented at the *2021 3rd International Conference on Intelligent*

Control, Measurement and Signal Processing and Intelligent Oil Field, ICMSP 2021, 293-296.

Abstract: In order to realize the power supply of downhole units without submersible cable, an electric submersible pump (ESP) production technology based on cable coiled tubing was proposed to improve the long-term stability of oilfield production system. The system uses a cable core embedded in the coiled tubing as the power supply line for the downhole submersible motor and power line carrier technology to transmit downhole data to the surface in real time, enabling simultaneous downhole power supply and surface monitoring without the need for additional cables. It has been shown that the wireline coiled tubing can be used in oil Wells at 85°C for a long period of time, and can transmit data up to 2, 000 meters downhole with a bit error rate of no more than 10-4 in downhole and other harsh conditions, while the downhole equipment can obtain the rated voltage. Using coiled tubing as the power supply line and communication channel, compared with the traditional ESP system, it can save the downhole space and put more powerful ESP in, thus increasing the production head. The cable core protected by the tubing can also work in the well for a long time to avoid corrosion by the well fluid and ensure the power supply quality of the downhole unit.

20. Bestgen, D., George, J., Mullins, K., Beans, G., & Penkala, J. (2020). Novel approach to extend electrical submersible pump run times in the williston basin. Paper presented at the *Proceedings - SPE Annual Technical Conference and Exhibition, 2020-October*.

Abstract: Williston Basin oil-producing wells utilizing Electrical Submersible Pump (ESP) lift undergo severe challenges with respect to scale and corrosion due to high TDS brines (250,000 - 320,000 mg/L) and high shear and high temperature operating conditions (275ºF-325ºF at the ESP). Corrosion most commonly attacks the ESP, lower tubing, andannular space locations where the cable armor contacts the metal. Scale is primarily calcium carbonate due to ~20,000 mg/L of calcium in the brine and is commonly seen around the ESP where temperatures are highest. The severity of these conditions canlimit ESP run times to 3-4 months until failure. Challenges for suitable protection from scale and corrosion include using specialty chemicals that provide temperature stability (325°F for the ESP environment and -40°F for winter temperatures at the surface), capillary qualification (the preferred delivery method), high TDS brine compatibility, and custom performance needs to address the various corrosion mechanisms. To this end, two strategies were developed combining uniquely qualified chemistries with specialized application. A new high temperature/high TDS scale/corrosion inhibitor was developed for delivery down the capillary (Menendez et al. 2019). A corrosion inhibitor was then identified formitigating cable armor-tubing corrosion suitable for application as a preconditioning batch treatment during ESP installation. Using ESP run time as a metric and comparing treatments with a conventional scale/corrosion inhibitor combination, it was found that the new combination product provided a 73% increase in run time (230 v. 132 days). When the pre-conditioning corrosion inhibitor treatment was done in conjunction with the new combination product, the run time showed a 100% increase (264 v. 132 days). These findings are discussed in conjunction with improved practices for ESP management under severe corrosion and scale challenges. It is important to consider that any extension in ESP run time gained through mechanical or chemical means offers improved well production, lower operating expense, and improved profitability to the producer.

21. Knyazeva, Z. V., Yudin, P. E., Petrov, S. S., & Maksimuk, A. V. (2020). Using Metal-Sprayed Coatings to Protect Submersible Electric Pump Motors from the Impact of Complicating Factors in Oil Wells. *Russian Journal of Non-Ferrous Metals, 61*(5), 592-599.

Abstract: This paper presents an overview of the results of the application of metal-sprayed coatings to protect the outer surface of electric submersible pumps (ESP) from the effects of complicating factors in oil wells. The metal-sprayed coating is applied using hot spraying, and the choice of the method is based on the chemical composition, the materials that are used, and the properties of the finished coating. The most common coatings on the Russian market include monel and austenitic stainless-steel alloys applied by arc metallization or high velocity spraying. Traditional coatings obtained by thermal spraying are characterized by an insufficiently high level of physical, mechanical, and chemical properties. Studies of the abnormal cases of submersible electric motors (SEMs) have shown that the most significant disadvantages of the applied coatings include insufficient resistance to mechanical shock, as well as abrasive wear; higher electrochemical potential in relation to the base metal; violations of the application technology;

and significant coating porosity. One of the main reasons for the observed disadvantages is a limited number of traditionally used methods and materials. To solve the problem of using protective SEM coatings and significantly increase their properties, service life, and economic efficiency, it is necessary to use modern scientific achievements in the development of coatings to protect metal surfaces from wear and corrosion, namely, to expand the number of coating methods and materials, work out a methodology for assessing the quality of coatings, and develop a methodology for assessing the economic efficiency of protective coatings. Solving these problems will allow us to make a reasonable technical and economic choice of a specific SEM coating for specific operating conditions.

22. Ramachandran, S., Liu, Z., & Tsague, T. (2020). Corrosion inhibition treatment to extend electrical submersible pump run times. Paper presented at the *International Petroleum Technology Conference 2020, IPTC 2020.*

Abstract: Cable failure and corrosion are two important modes of failure for electrical submersible pumps (ESP) especially for ESP working in high temperature, high shear, and saline environments with carbon dioxide (Lea et al. 1994). About 5 % of pump failures are attributed due to corrosion (Chandran et al. 2017). High total dissolved solids (TDS) in the well fluid create conductive and corrosive conditions that can "lead to tubular and structural pitting, scattered pitting and crevice corrosion as often is seen in pulled equipment" (Kalu-Ulu, AlBori 2019). In Algeria, the majority of problems with ESP systems relate to salt deposition, corrosion, and the quality of dilution water (Brahmi, 2018). Electrical failures are among the main source of failure in high TDS, H_2S environments. (Roth et al. 2018). In this manuscript, the development and implementation of corrosion inhibitor treatments to prevent two forms of corrosion issues. One form of corrosion is inside of production tubulars under high temperature, high shear saline environments with carbon dioxide. The other form of corrosion issues is outside of production tubulars on external tubing walls and ESP cables armours under high temperature high pressure and possibly oxygen contaminated CO_2 environment.

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