Petroleum and Coal

Article **Open Access**

Performance Evaluation of Artificial Lift Systems for Heavy oil Wells in the Egyptian Eastern Desert

Mahmoud A. El Gharbawi[1], Ahmed A. Elgibaly[2], Adel M. Salem[2], Mohamed Abbas[3],

[1] *Dara Petroleum Company, Egypt*
[2] *Suez University, Egypt*
[3] *Trans Globe Energy Corporation, Egypt*

Received March 6, 2020; Accepted June 1, 2020

Abstract

This paper describes the execution of performance evaluation (PE) for artificial lift systems (ALS) of heavy oil wells in Egypt. The subject wells are located in Egyptian eastern desert (EED). Canadian-Egyptian joint venture is operating them. Progressive cavity pump (PCP) and reciprocating rod pump (RRP) have been chosen as ALS methods. With the objective of evaluating ALS in this area, both data analysis (DA) and PE have provided the more convenient ALS, the main failures per each ALS and best practices. Moreover, a new software has been developed to automate this analysis and share successful achievements.

Descriptive analytical approaches have been executed by using some key performance indicators (KPI), such as: failure index (FI) and recurrence index (RI). DA and PE have been applied to ALS, such as: RRP and PCP. Therefore, the definition for each ALS boundaries and the classification of failures have been performed. The study covered failures started on 2012 till the end of 2017 for average 100 wells with 622 failures. FI and RI reached 3.0 and 3.7, respectively, in 2014 due to manufacturer defects then drop to 1.0 and 1.7, respectively, at the end of 2017 after applying comprehensive decisions and procedures. The analysis showed that PCP has been more convenient than RRP in this area, and the dominant failure in RRP was rod string with 200 failures over the last six years, but the dominant failure in PCP was down hole pump (DHP) with 143 failures in the last six years.

Finally, a software developed to provide an increased visibility about individual well performance and, more broadly, about field through automating data analysis and sharing successful practices.

Keywords: *Progressive Cavity Pump System Failures; Reciprocating Rod Pump System Failures; Heavy oil problems; Key Performance Indicators; Egyptian Eastern Desert; Int-track software.*

1. Introduction

The subject wells are located in EED as shown in Fig. 1. RRP and PCP systems have been chosen as a preferred ALS. Most of the production is from sandy limestone and sandstone formations. API gravity of produced oil is from 18 to 21°. Water cut is about 75%, and it varies from field to another. Sand production is 10%. H_2S has started increasing in the fields, and it reaches 1000 PPM in some fields. All wells are onshore and vertical with average depth 5000 ft. Today the subject fields are in declining production, increasing water cut, and in a challenge of maintaining a sustainable oil production as shown in Fig. 2.

Many challenges face the artificial lift wells, and with the global meltdown in oil prices in 2014, cost reduction becomes a millstone for the companies' budget plan. Standing on this point, the objective of this paper is to evaluate the performance of ALS in EED, choose most convenient type, perform comprehensive analysis of ALS failures and provide best practices. Moreover, software has been developed to automate data analysis and build a library which could share successful achievements.

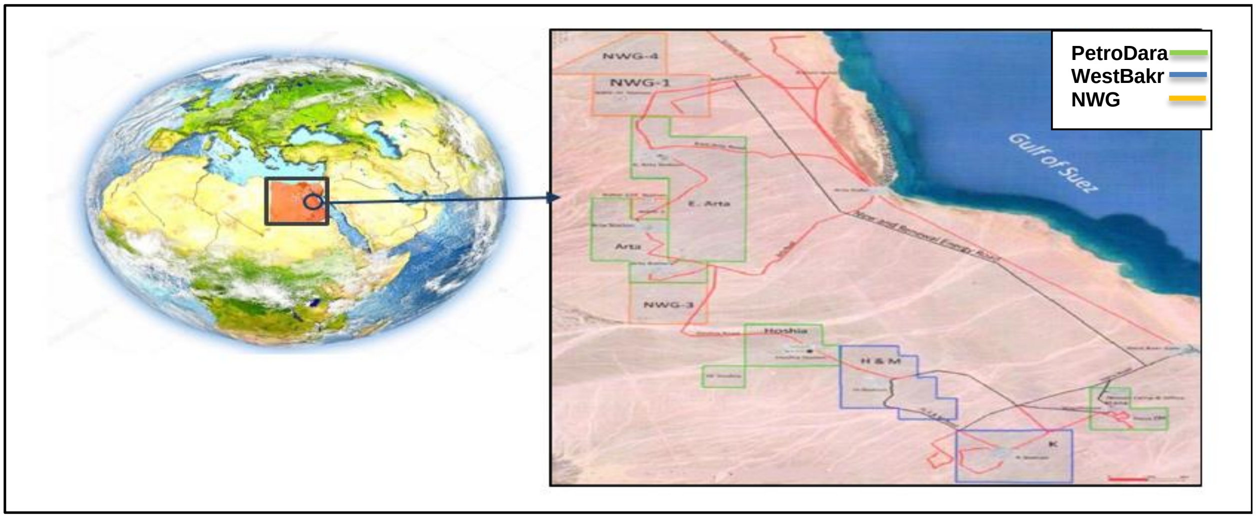


Fig. 1. Fields location at the Egyptian eastern desert

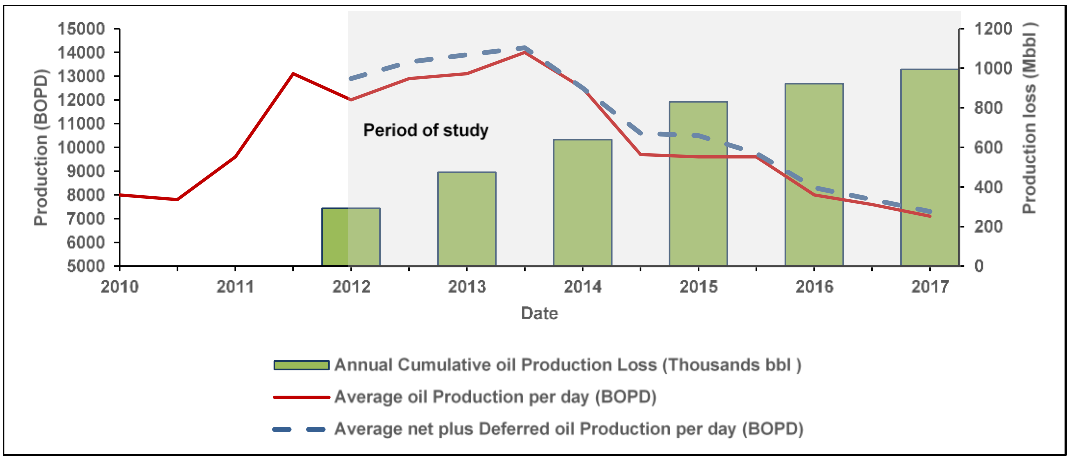


Fig. 2. Fields net oil and loss production in the period of study

2. Literature review

In this section, a short review on the previous works which described how ALS failures were investigated and what methodology was applied. In addition, valuable recommendations and guide lines were provided to avoid repeating these failures.

Case-1

A great contribution for failure analysis of artificial lift wells was developed by Monroy [1] and Rubiano [2]. They developed a failure analysis methodology for La Cira-Infantas oil field in the Middle Magdalena valley in Colombia. Their publication describes the implementation of a methodology for classification of artificial lift system failures.

This methodology was applied to different artificial lift systems, such as: RRP, PCP, Electrical submersible pumping Systems (ESP) and Electrical submersible progressive cavity pumping systems. The starting point was the definition or limitation of the boundaries of every system. Moreover, the root cause analysis (RCA) classification had been described to refine the action plans.

Included in this methodology, some KPIs: FI, indirect FI, pulling index, RI, average run life and average run time were used. These KPIs helped track performance improvement in the last two years and get excellent results by dropping failure index from .98 to .7 and recurrence index from 1.55 to 1.29.

Case-2

Another contribution to perform and evaluate the failure analysis of Artificial lift wells was developed by Rangel [3]. He had developed a failure analysis methodology for Huyapari field in the Orinoco Oil Belt in Venezuela, and it is operated by PETROPIAR, a joint venture company, where over 600 horizontal wells have been perforated and completed with PCP as the preferred artificial lift method to produce extra heavy oil. With the objective to identify and address the main causes of failure affecting PCPs run life and performance, RCA had currently been implemented and it gave outstanding results by involving both suppliers and customers in a continuous improvement and learning experience as shown in Fig. 3.

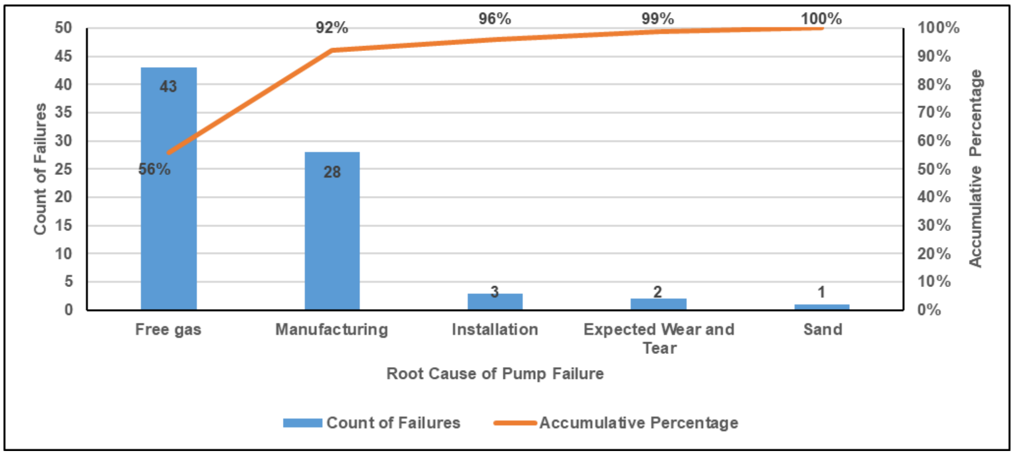


Fig. 3. Distribution of root causes in RCA process which published in [3]

Case-3

Another great contribution was developed by Husin [4] for evaluating beam pumping wells in Egypt. His work achieved two objectives. The first was analyzing the results of Agiba Petroleum Company beam pumping system problems and their data analysis and ending that analysis with design rules that were learned from that experience. The second objective was to establish an expert system program to diagnose and troubleshoot beam pumping problems. This analysis was done by identification and analysis of the problems encountered in Agiba fields in the last ten years.

3. Performance evaluation methodology

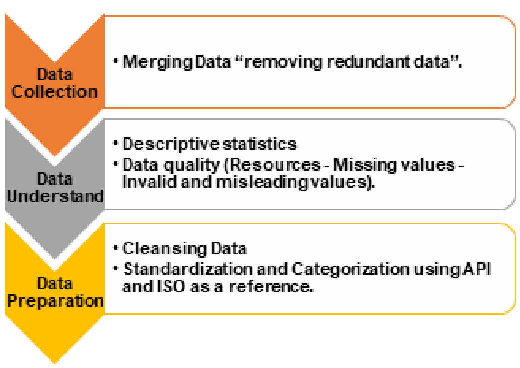


Fig.4. Preprocessing steps have been applied for data resources

PE methodology started by building structured data then followed by measuring the KPIs and analyzing failures per each ALS. The extensive analysis for each failure has provided useful recommendations and good practices for other companies in this area and others have the same conditions

Different data resources were collected which includes workover, production reports and failure, observation reports. Before analyzing the data, a preprocessing step was followed as shown in Fig. 4. After applying the preprocessing steps, a structured data was built for 100 wells covering 622 downhole failures for different ALS used in the subjected fields.

Analytical approach was applied for the data to achieve the objectives of the study. As the number of wells changed significantly, depending only on the number of failures gives a wrong evaluation of ALS performance if it is used alone. The used units to express failures frequency and recurrence rates were failure/active well/year and failure/failed well/year, respectively which were the standard ways to express failure rate in many publications, for example [5]. Fig. 5 shows KPIs (FI, RI) which were used to evaluate the performance of subject wells. Those general failure indexes were followed by failure classification to determine the most repetitive failure items in both ALS.

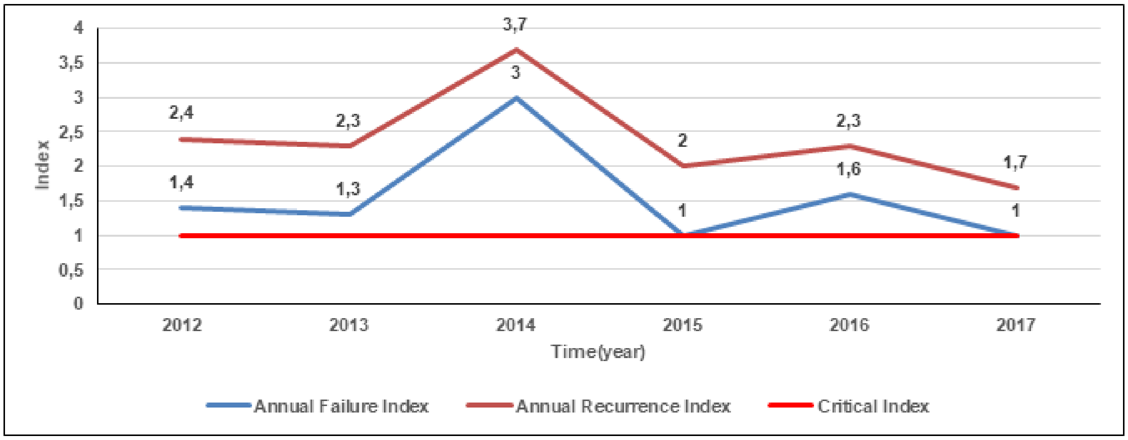


Fig. 5. KPI for the subject wells

4. Classification of ALS failures

The analysis covered both existing ALS (RRP, PCP) individually, and united upstream categorization for both ALS was used for the failures as following:

- Tubing system (TS) includes (Tubing hanger, Tubing, accessories (Tubing drain, No turn tool)).
- Rod string system (RS) includes (Polished Rods, Sucker Rods, accessories (shear joint, rod guide, rod couplings)).
- Down hole pump (DHP) includes (Pump; SR (rod valve, plunger, barrel), PCP (Rotor, Stator)).

Fig. 6 shows PCP (TS, RS, and DHP) systems failures' ratios of total 209 failures occurred over the six years survey. The dominant failure system was DHP then RS. Fig. 7 shows RRP (TS, RS, and DHP) systems failures' ratios of total 413 failures occurred over the six years survey. RS was the dominant failure system then DHP.

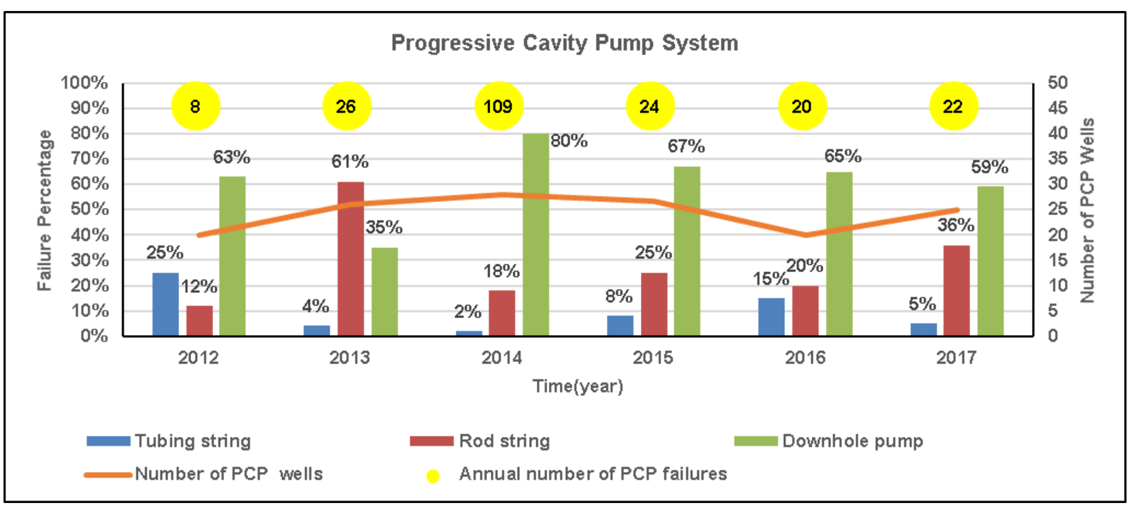


Fig. 6. PCP system failures' percentages over the years of study

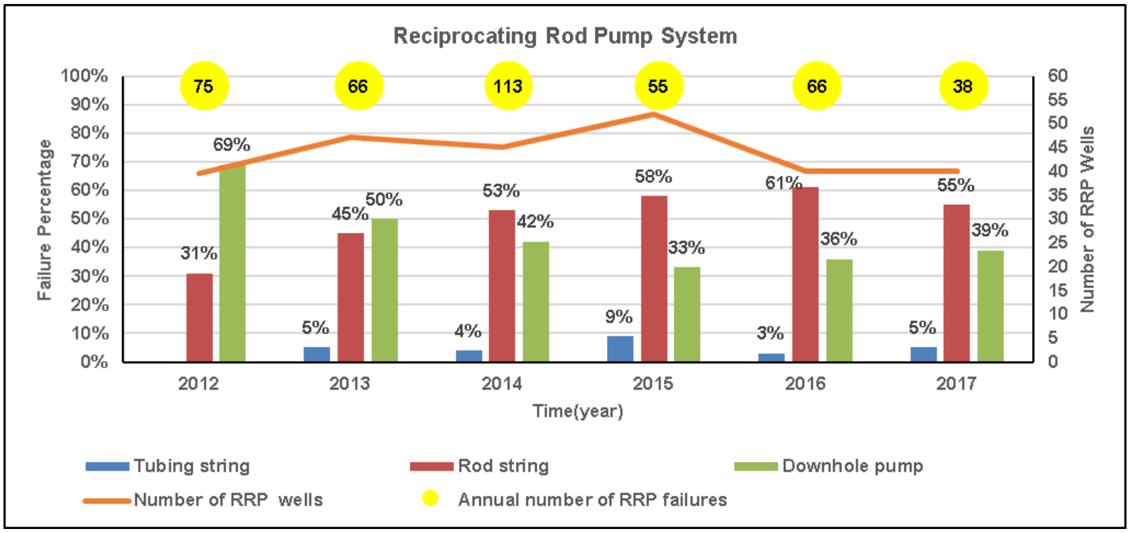


Fig. 7. RRP system failures' percentages over the years of study

In the following sections, each dominant ALS failure category has been analyzed in details to cover failure mechanisms, direct causes and remedial actions that were done and required.

PCP application

DHP was the dominant problem with 143 failures in the last six years. Fluid properties have changed on the mature state of the water flooding for some wells. On other hand, free gases and low productivity have been a feature of depletion of others. These varieties in production and fluid properties caused different problems for DHP as shown in Fig.8. In 2014, number of failures soared because of a manufacturer defect shipment of PCP. Part of a shipment had a debond failure which was related to a problem in cementing material, and other part had an incompatible elastomer.

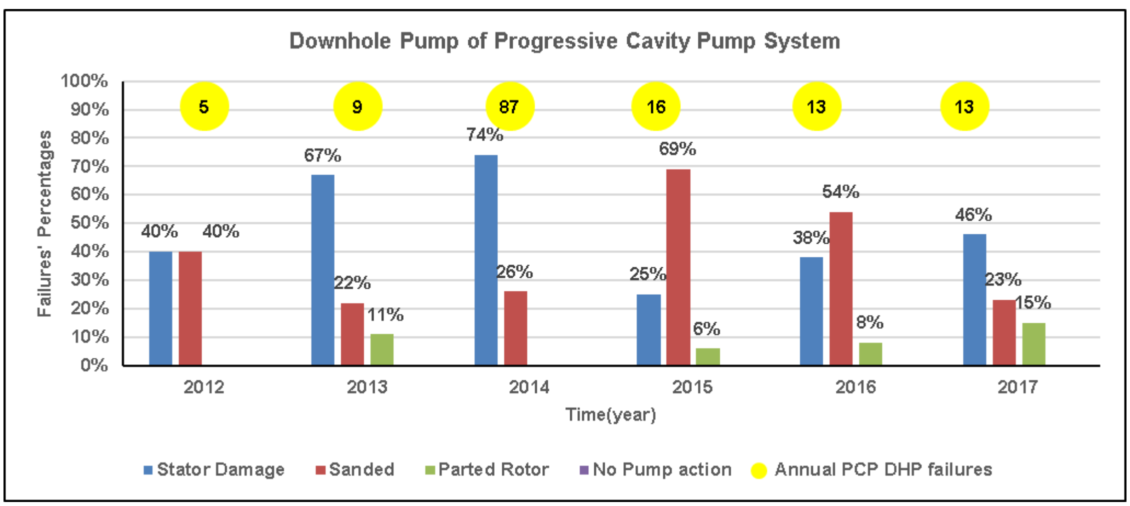
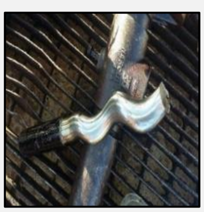


Fig.8. DHP failed items' percentage ratios for PCP system

All failures were analyzed in details in Table 1 to cover failure mechanisms, direct causes and remedial actions that were done and required. Second, RS was the second dominant problem with 60 failures for the last six years. As obvious, broken polished rod was the major failure and most crucial item with 39 failure for the last years as shown in Fig.11.

All failures were analyzed in details to cover failure mechanisms, direct causes and remedial actions that were done and required as shown in Table 2.

Table 1. Failure analysis for DHP system in PCP application

Failure descriptor	Failure causes	Remedial actions done and required
Deboned Elastomer 	• Manufacturing defect • Gas decompression at the bond material • Poor transportation and storage	• Re-evaluate functional evaluation and design validation with Manufacturer. • Set PCP intake lower perforation interval. • Following vendors and standard publications [8].
Swollen Elastomer 	• Improper elastomer selection.	• Check the elastomer type and re-evaluate compatibility test for new well.
Torn 	• Foreign Debris	• Use slotted tag bar.
PCP Plugged  Pump Cavities full of sand	• Improper technical design. • Power supply shutdowns.	• Re-evaluate pump design by using lower pitch size – eccentricity ratio. In 2017, Average run life for one of repetitive PCP plugged wells was doubled after using low pitch size – eccentricity ratio as shown in Fig.9. • Follow operation procedures which recommends pull rotor out of stator while power supply maintenance. It had a useful effect on intervention cost saving as showed in Fig.10. • Plan to use check valve and a pressure actuator relief valve (PAR) technology [9]
Parted Rotor 	• Poor spacing • Improper clamp installation • Poor monitoring of running parameters	• Follow check list mentioned in several publications [8]. • Follow standard clamp installation procedures. • Install double clamp • Calculate Rotor spacing in the worst operation condition (highest differential pressure expected).

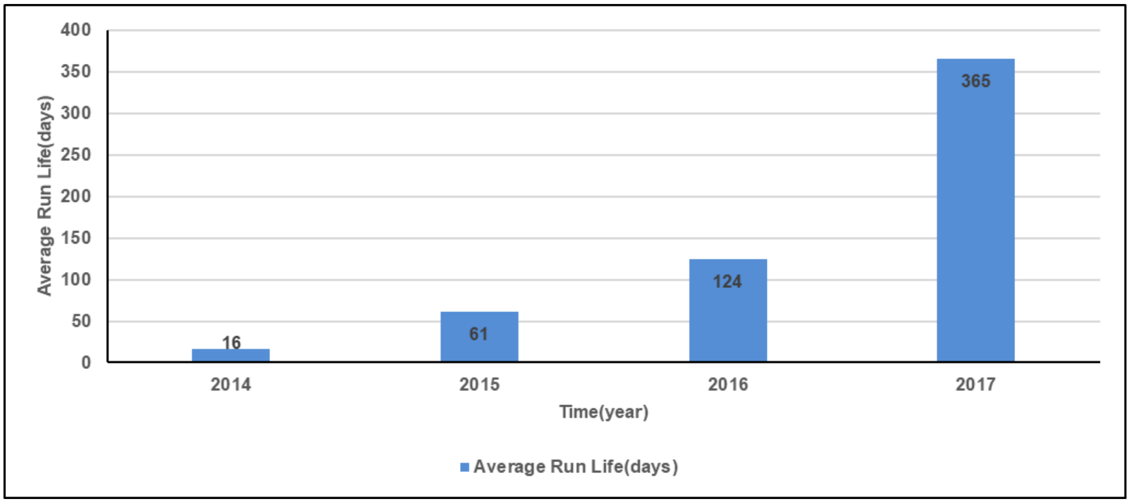


Fig. 9. Average run life improvement for one of EED well after using different Ps/e type

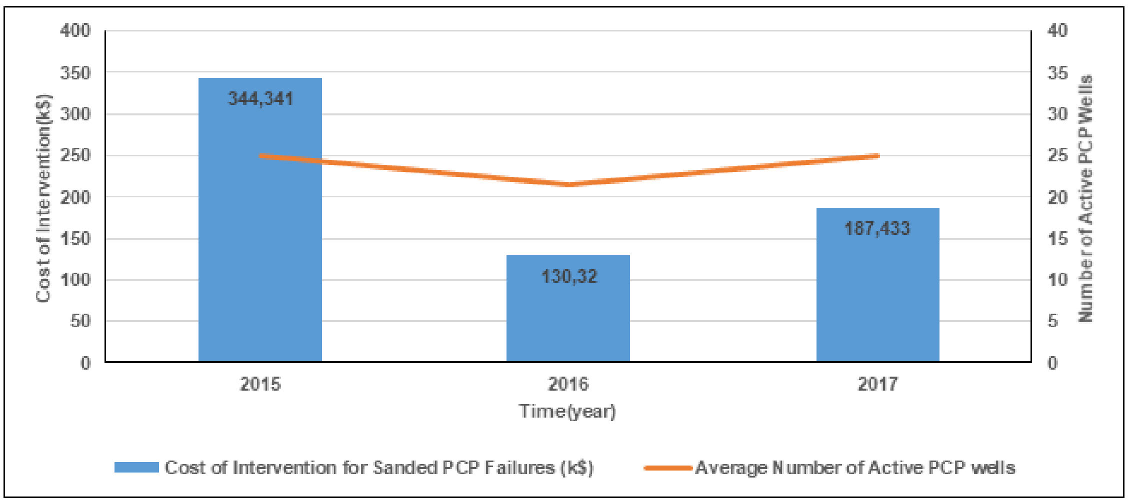


Fig.10. Operation precautions effect on cost saving

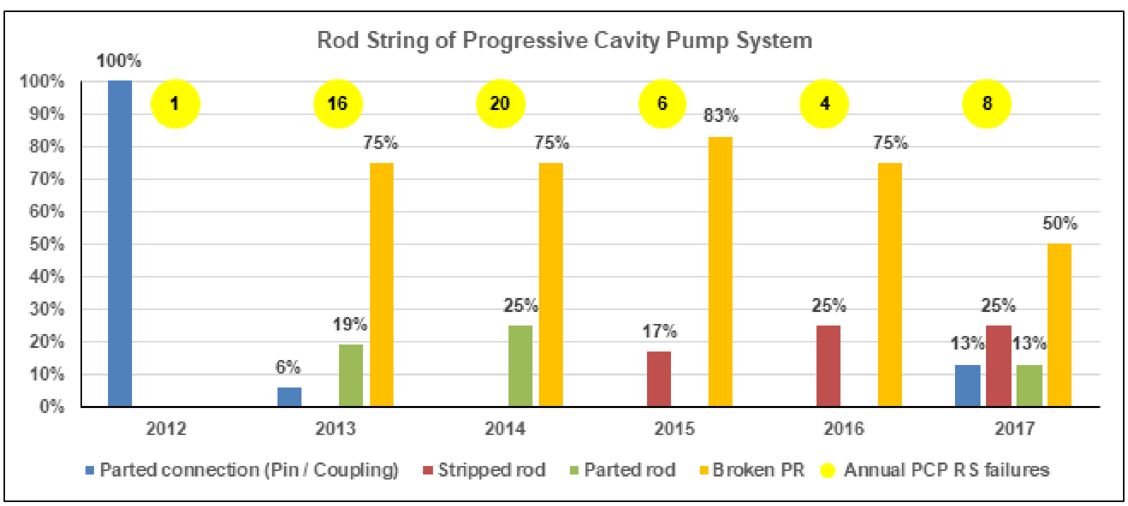


Fig. 11. Rod string failed items' percentages for PCP system

Table 2. Failure analysis for RS system in PCP application

Failure descriptor	Failure causes	Remedial actions done and required
Broken polished rod 	• Unleveled drive head unit. • Polished rod surface damage. • Poor transportation and storage	• Confirm drive head flange leveling before running the well. • Resize the internal diameter of the bottom brass of stuffing box. The larger clearance gave a margin of drive head leveling as shown in Fig.12. • Follow vendors and standard publications for handling and transportation sucker rods [10].
Rod thread's galling, and unscrewed. 	• Contaminated thread, hard stabbing and improper makeup • Weather Condition	• Following vendors and standard publications for handling, transportation and installation of sucker rods [10].
SR parted body 	• Over torque limit control program. • Corrosive medium in erosive condition	• Adjust torque control limit at 1.5 of designed or operating torque. • Upgrade sucker rods (SR) grade
Parted SR pin and coupling 	• Improper make up torque. • Rerun warmed coupling	• Follow vendors and standard publications for handling, transportation and installation of sucker rods [10].

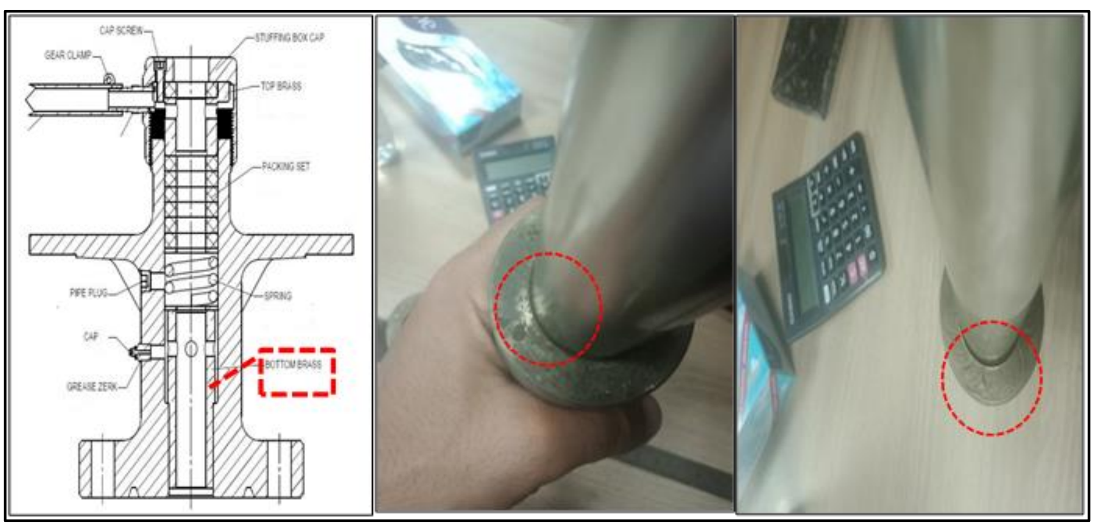


Fig. 12. Redressed bottom brass internal diameter of stuffing box

RRP application

RS was the dominant problem with 206 failures for the last six years. Broken polished rod was the most crucial failure with 103 failures over the years as shown in Fig. 13. Moreover, rods parted body was the second dominant failure that soared in the recent years in parallel with increasing W.C and H_2S.

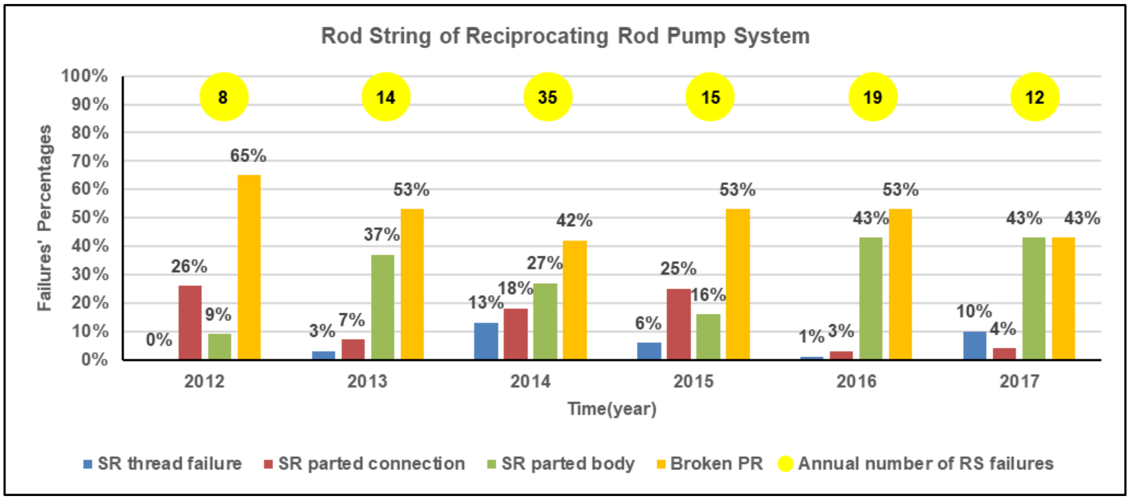


Fig.13. Rod string failed items' percentages for RRP system

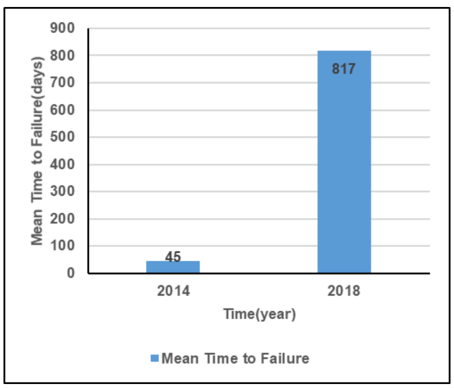


Fig. 14. Polished rod associated downtime improvement for one of critical wells

All failures were analyzed in details in Table 3 to cover failure mechanisms, direct causes and remedial actions. Second, DHP was the second dominant failure which drop significantly as shown in Fig. 15. All failures were analyzed in details to cover failure mechanisms, direct causes and remedial actions that were done and required as shown Table 4.

Table 3. Failure analysis for RS system in RRP application

Failure descriptor	Failure causes	Remedial actions done and required
Broken polished rod 	• Misalignment pump jack • Unleveled carrier bar • Surface damage	• Check list has been built to cover all items included in publications [11-12] to prevent polished rod failure. A useful effect on wells mean time to failure (MTTF) as in Fig.14. • Follow vendors and standard publications for handling, transportation and installation of sucker rods [10].

Failure descriptor	Failure causes	Remedial actions done and required
SR parted body 	• Rod string buckling • Corrosive medium	• Re-design both rod sting and DHP with adjust pump jack running parameters as in publication [13].
SR parted pin and coupling 	• Improper makeup torque • Rod string buckling	• Follow vendors and standard publications for handling, transportation and installation of sucker rods. • Re-design rod sting, DHP with adjusting pump jack running parameters as in publication [13].
Rod thread galling, stripped and unscrewed	• Contaminated thread and hard stabbing • Improper makeup torque. • Weather condition	• Follow vendors and standard publications for handling, transportation and installation of sucker rods.

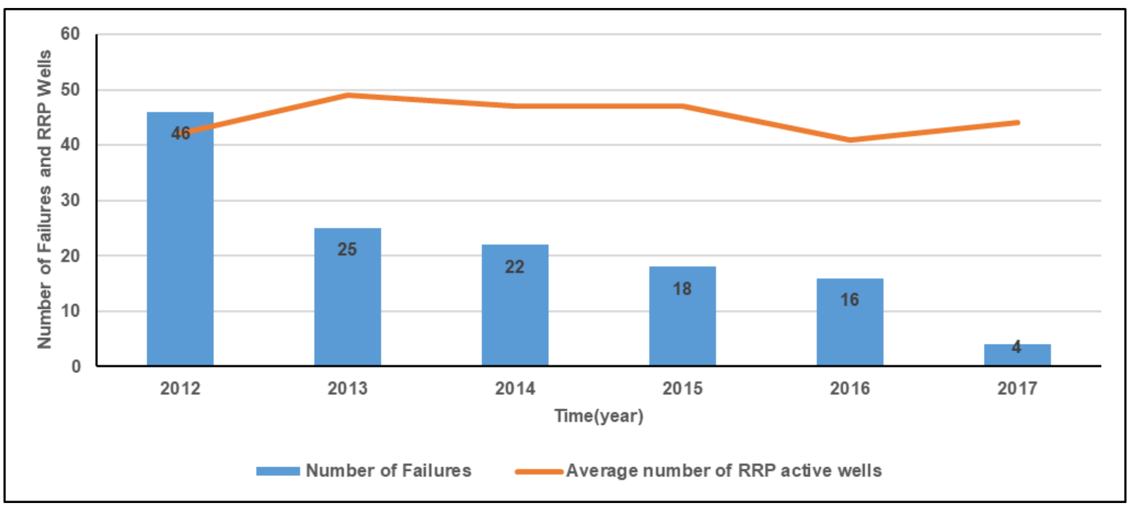
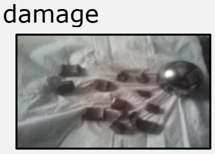


Fig. 15. Number of DHP failures for RRP wells

Table 4. Failure analysis for DHP in RRP application

Failure descriptor	Failure causes	Remedial actions done and required
Ball valves leak and damage 	• Manufacturing defect	• Follow [14] in assuring ball and seat hardness certificate.
Damaged barrel 	• Corrosive medium	• Upgrade barrel material as per publication [15].

5. Data analysis results

As a result of applying all mentioned recommendations and procedures in area of study, a significant improvement in both ALS systems performance has been achieved as shown Fig. 16. However, PCP failure index approved that PCP is the most convenient ALS in this area in case of all recommendations and good practices were considered. Moreover, elastomer selection and preventive sand plugging procedures were the turn key in PCP success after fixing manufacturer defect related problem. On other hand, in RRP system, broken polished rod was a major problem and by applying the related recommendation, its figure drop slightly. Regarding DHP in RRP system, upgrading material in both ball valves and barrels had a significant effect as shown in Table 5.

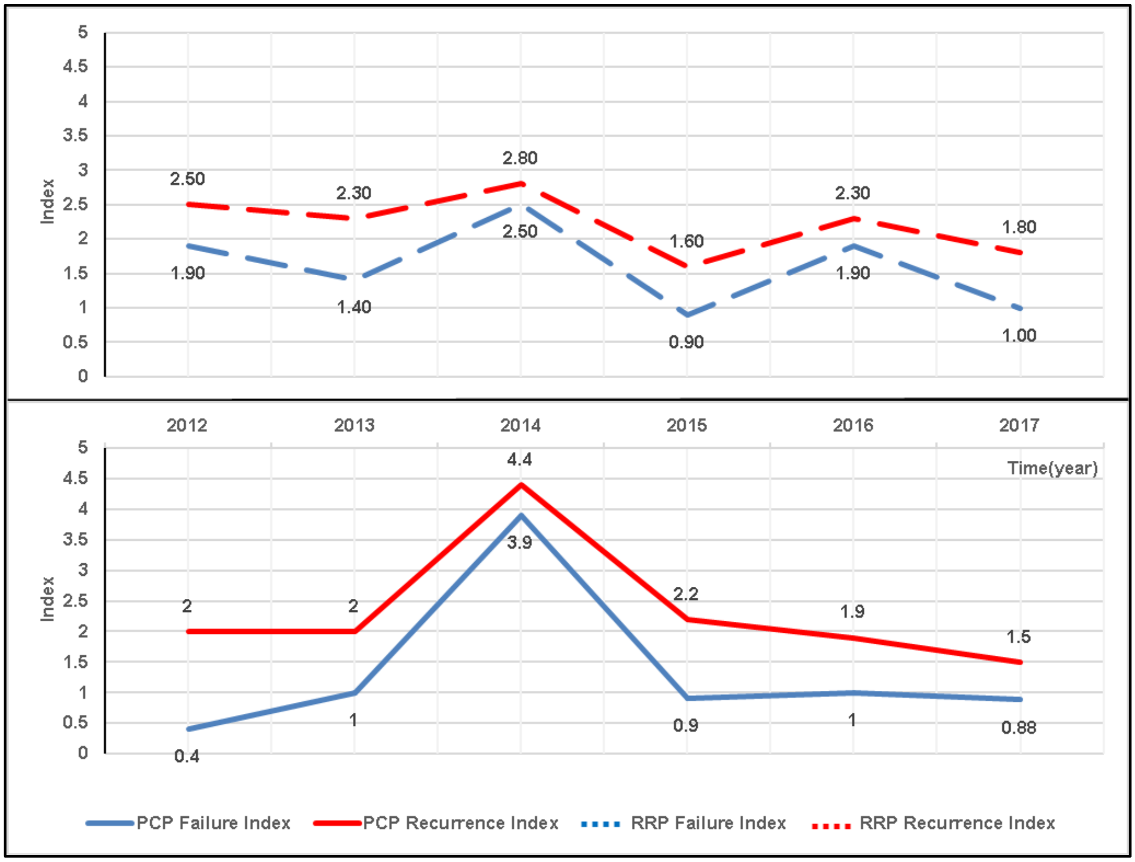


Fig. 16. Failure index improvement of PCP and RRP system

Table 5 ALS failure summary

RRP system	2012	2013	2014	2015	2016	2017
Active RRP wells	39	47	45	52	40	40
FI // RI	1.9 // 2.5	1.4 // 2.3	2.5 // 2.8	0.9 // 1.6	1.9 // 2.3	1 // 1.8
TS	0	3	5	5	2	2
RS	23	30	60	32	40	21
DHP	52	33	47	18	24	15
PCP system	2012	2013	2014	2015	2-16	2017
Active PCP wells	20	26	28	27	20	25
FI // RI	0.4 //0.2	1 // 2	3.9 // 4.4	0.9 // 2.2	1 // 1.9	0.88 // 1.5
TS	2	1	2	2	3	1
RS	1	16	20	6	4	8
DHP	5	9	87	16	13	13

6. Open source integration service

Simple open source integration service has been developed, named **Integrated track** (Tarek). The service was an efficient tool to the operator for automating the evaluation of artificial lift oil wells by using combinations of failure tracking, KPIs and archive. In addition, this objective was completed by providing a library of regional good practices. Software provides answers to numerous questions that evaluate ALS oil wells. The following are partial list of typical questions that can be answered by using the service

- What is the FI and RI for the operator's company per year?
- What is the MTTF for the running wells per year?
- What are the most critical wells per year (Critical describes a well whose MTTF is less than one year)?
- Is the ALS selection right or wrong?
- What is the failures' history for a well over the years?
- What are the roots causes for the failures over the years?
- Best practices to avoid most of ALS failures.

6.1. System formulation

The Integrated Track "Int-Track" service is an operated online web service build by a programming language (**PHP**) that operated by a different web browser, for example, Internet Explorer and Google Chrome.

The Int-Track open source service has been designed to be as simple as possible to use. The graphical user interface follows all the Windows conventions. A next figure shows a sample flow chart is designated to clarify a program methodology and how it works with different multidisciplinary activity as shown in Fig. 17.

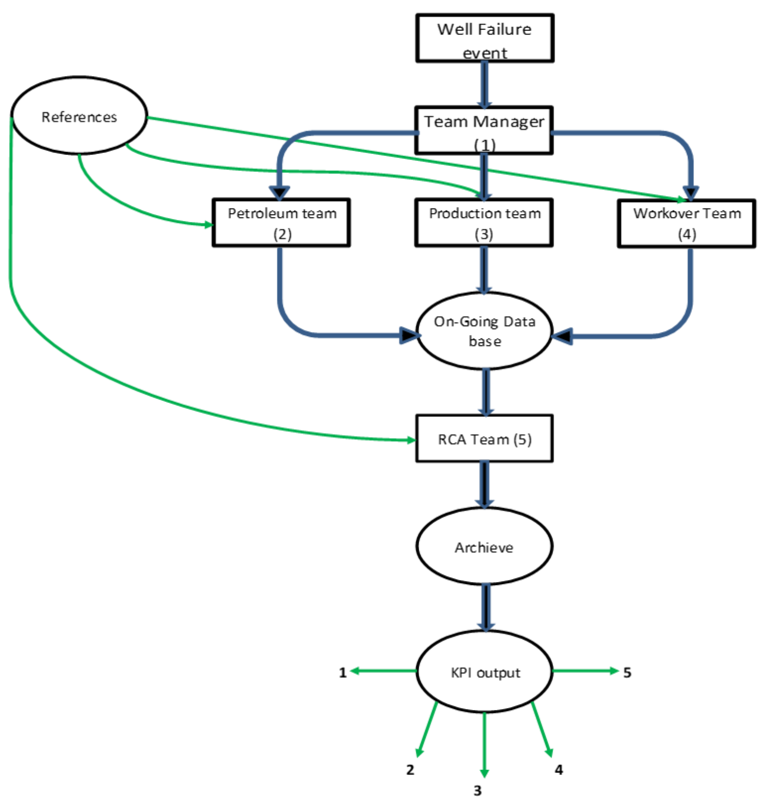


Fig. 17. Int-track open source service methodology

6.2. System validation

The program has been tested by Canadian joint venture company as shown in Fig.18 which presents program screens during adding new failure, tracking failure and diagnosing a problem. In addition, the testing results are available in the site [6]. The service has been an efficient multidisciplinary tool that guide companies' teams to solve problems by comprehensive analyzing figures and convenient regional good practices. As a result, Code and database, which are the core of the program, are available for use and upgradation as shown in [7].

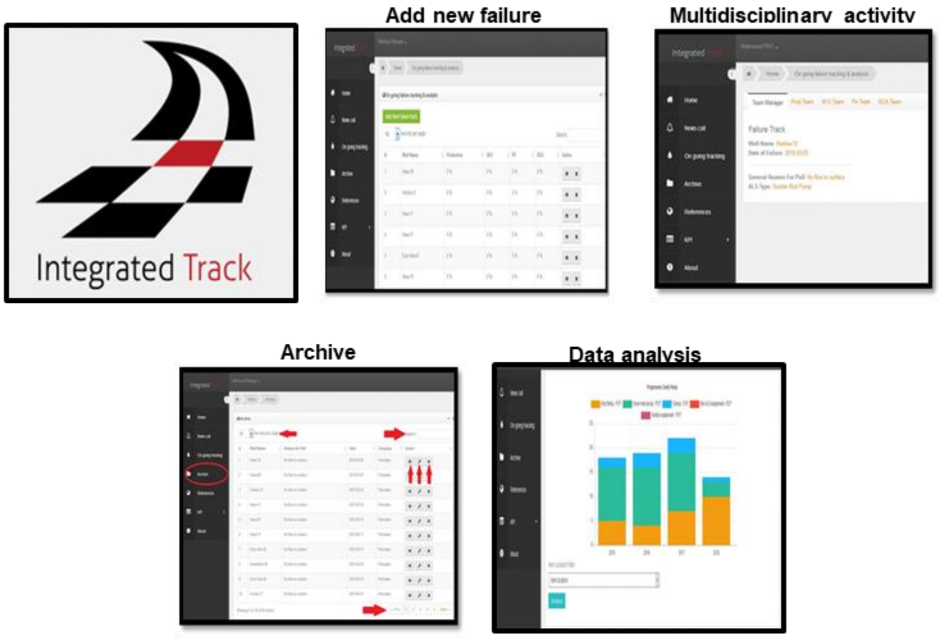


Fig. 18. Integrated Track open source service

7. Conclusions

From the various key performance indicators, failure index and recurrence index have been effective tool to determine the convenient ALS system. PCP is a strong ALS competitor, and it will be one of the best ALS choices for oil companies in EED. Functional evaluation, design validation and updated compatibility tests were critical barriers to avoid premature failure of PCP elastomer.

Pitch size-eccentricity ratio was a crucial parameter in sand handling features of EED PCP system. Rig crew professionality is a corner stone for any company's failure control plan.

Carrier bar assembly at pump jack was crucial point for most premature rod string failure in EED RRP system. Upgrading DHP material in RRP system was a turn key feature that diminished failure rate significantly. Simple open source service program has been an efficient tool to evaluate performance, automate analysis and share regional good practices.

8. Recommendations

PCP application

- To follow ISO 15136-1 quality which includes functional, design validation and standard handling and storage procedures.
- To repeat compatibility test to cover new wells and other wells that have a radical change in its production fluid properties.
- To use slotted tag bar and other PCP accessories to increase DHP lifespan.
- To follow preventive sand plugging procedures to eliminate failures related to shut down.
- To follow API SR handling and care practices.

- To adjust and review all control limits (torque and well head pressure).

RRP application

- To confirm surface unit alignment and leveling according to a firm check list
- To repeat DHP material compatibility test to cover new wells and other wells that have a radical change in its production fluid properties.
- To follow API standard procedures including SR handling, care, installation procedures.
- To follow PCP quality validation for some SR requested item.

Abbreviations

PE	*Performance Evaluation*	*DHP*	*Down Hole Pump.*
ALS	*Artificial Lift System.*	*ESP*	*Electrical Submersible Pump.*
EED	*Egyptian Eastern Desert.*	*MTTF*	*Mean Time To Failure.*
PCP	*Progressive Cavity Pump.*	*RCA*	*Root Cause Analysis.*
RRP	*Reciprocating Rod Pump.*	*TS*	*Tubing System.*
DA	*Data Analysis.*	*RS*	*Rod String.*
KPIs	*Key Performance Indicators.*	*SR*	*Sucker Rod.*
FI	*Failure Index.*	*PAR*	*Pressure Actuator Relief*
RI	*Recurrence Index.*		

Acknowledgments

We would like to thank all co-workers who have contributed to this paper from Dara Petroleum Company, and TransGlobe Energy Corporation. A special thanks goes out to the joint ventures general managers Ehab Ragaee and Jeff Edelman. Also, a special thanks to Khaled Mounier and Bernie Dumanowski, joint ventures operation manager, and field team which includes Todd Crichton, Mohamed Abobakr, Ayman Allam and Ahmed Gamal for their strong continued support.

This paper reflects the views of its authors and does not necessarily reflect the views of Dara Petroleum Company and TransGlobe Energy Corporation.

References

[1] Monroy M, and Gutierrez J. Failure Index Reduction Strategy for Artificial Lift Systems in Cira Infantas Field. Paper presented at the SPE Latin America and Caribbean Artificial Lift Conference and Exhibition, Salvador, Bahia, Brazil, 27–28 May 2015. SPE-173950-MS. https://doi:10.2118/173950-MS.

[2] Rubiano E, and Martin JL. Run Life Improvement by Implementation of Artificial Lift Systems Failure Classification and Root Cause Failure Classification. Paper presented at the SPE Latin America and Caribbean Artificial Lift Conference and Exhibition, Salvador, Bahia, Brazil, 27–28 May 2015. SPE-173913-MS. https://doi:10.2118/173913-MS.

[3] Rangel SV, and Delgado AS. Successful Application of Root Cause Analysis on Progressive Cavity Pumps Failures in Orinoco Oil Belt. Paper presented at the SPE Latin America and Caribbean Heavy and Extra Heavy Oil Conference, Lima, Peru, 19-20 October 2016. SPE-181142-MS. https://doi:10.2118/181142-MS.

[4] Husin M. 2013. Performance Analysis of Beam Pumping Systems. MS Thesis. Cairo University. Cairo (May 2013).

[5] ISO 14224, Petroleum, Petrochemical and Natural Gas Industries Collection and Exchange of Reliability and Maintenance Data for Equipment. 2016. London: ISO.

[6] Tarek. arabiacode.com. Integrated track, http://arabiacode.com/int-track/admins/users/login, (username: Demo@gmail.com, password: 123456).(accessed 01 Jan 2020).

[7] Gharbawi, M. drive.google.com. Integrated track https://drive.google.com/drive/folders/1Q75egUZuBzXT01A4T2tkS01LtNV6GdLq?usp=sharing.

[8] ISO 15136-1, Petroleum and Natural Gas Industries - Progressing Cavity Pump Systems for Artificial Lift - Part 1: Pumps. 2009. Switzerland: ISO.

[9] Hicks R. New Technology Reduces Flushbys and Extends PCP Run Life in Australia. Paper presented at the SPE Middle East Artificial Lift Conference and Exhibition, Manama, Kingdom of Bahrain, 30 November-1 December 2016. SPE-184223-MS. https://doi:10.2118/184223-MS.

[10] API 11BR, Recommended Practice of Care and Handling of Sucker Rod, fourth edition. 2000. Washington, D.C:API.

[11] Harbison-Fischer. Polished Rod Failure Prevention. 7th Annual Sucker Rod PumpingWorkshop presented 27-30 September 2011. Oklahoma City, Oklahoma.
[12] WeatherFord. 2017. Polished Rod Application Guide. Internal report, WeatherFord Artificial Lift Systems. Oklahoma.
[13] Eritici C. 2016. Compressive Forces Causing Rod Buckling in Sucker Rod Pumps. MS Thesis, Texas University, Austin (May 2016).
[14] API 11AX, Specification for Subsurface Sucker Rod Pumps and Fittings, Eleventh edition. 2001. Washington, D.C: API.
[15] Don-Nan. 2016. From Failure To Success: A Metallurgical Story on Sucker Rod Pump Barrels. Internal Report, Don-Nan Pump Company, Midland, Texas. https://www.don-nan.com/papers.

To whom correspondence should be addressed: Mahmoud A. El Gharbawi, Dara Petroleum Company, E-mail: mahmoud.gharbawi@gmail.com