Performance of Special Sucker Rod (AlphaRod® CS) After 5 Years of Field Experiences Worldwide.

Abstract

After many years of satisfactory results gotten with conventional steels sucker rods, application has been restricted to neutral or benign environments. As this environment gets more aggressive, standard materials reach their limits.

In this scenario, this new special sucker rod (AlphaRod® CS) was created to deliver superior performance on benign environments and at the same time overcome more demanding requirements offering a solution to fatigue and corrosion-fatigue problems, one of the major and unpredictable causes of premature failures in O&G industry.

Since its development, more than five years of field trials and in excess of 200 installations worldwide are summarized in this paper in order to validate its performance at field conditions vs the improvement found on laboratory tests. With proven field performance evidence, deep failure analysis and worldwide data comparison allowed us to understand and detect patterns that defines with more precision the product application range in terms of corrosion content and/or stress levels.

According to laboratory test results, the product has shown an outstanding performance giving 2 to 3 times more resistance than conventional sucker rod steels. In the same vein, field experiences showed an important improvement in terms of run time.

In particular, unconventional reservoirs producer wells push the limits from a loading and harshness point of view on existing ALS in a fashion that creates problems with reliability. This new special sucker rod (AlphaRod® CS) improves sucker rod string reliability in those conditions and helps reduce downtime and OPEX to operators.

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TENARIS SUCKER RODS

Contents

Introduction

Under corrosive environments, fatigue limit of the steel is dramatically reduced in correspondence with the environmental conditions (pressure, temperature, CO_2 and H_2S concentration, bacterial activity, chlorides contents, pH and injection water chemical composition), mechanical conditions (stress level, frequency and load spectrum) and metallurgical conditions (steel cleanliness, chemical composition, residual elements, microstructure and grain size).

Since the launch of the AlphaRod® there has been a strong interest. Operators understand the technical superiority of the fine grain martensitic structure and its connection to the wide spread problems of the corrosion fatigue mechanism.

The current study was executed considering the performance of 244 wells under test protocol in Argentina, Romania, USA and Canada. The success criteria was measured in terms of Run Life compared with Standard Rod depending on the region (D, HS 4138, KD).

With this study, we aim to understand AlphaRod® CS performance using specific KPIs based on the comparison with standard sucker rod commonly used worldwide. In addition, stablish an application range considering stress and corrosion levels as main parameters.

Development

a. General Considerations

Results from more than 244 installation in wells worlwide were consolidated and analyzed applying specific KPIs. AlphaRod® has acumulated additional 150 oilfied installations via different distribution channels with a wide range of applications and several operators. This latter group has not been included in this analysis due to the lack of access to data.

Operators run AlphaRod® in many combinations:

- AlphaRod® alone
- AlphaRod® taper combined with other grade taper (High Strength or API)
- AlphaRod® taper with FiberGlass taper

For simplicity, the net Run Life comparison (#days) was calculated within the protocol time period. Therefore, the majority of the data points were still active and counting days by the time of this analysis.

As general criteria, when a failure to the AlphaRod® string or taper occurred the following procedure was followed:

1- Change taper/string (most of the cases).
2- Continue with the same taper/string. In both cases the run life counter started from "zero" again. The resulting RL was calculated as an average of previous RL.

For the most part, it was attempted to replicate the operational conditions before and after the AlphaRod® installation. However, being in the highest interest of the operator, there may be some cases where certain application conditions were modified, either in the interest of well productivity, or overall performance in the system.

The loading range was typified for the analysis in a qualitative way. A three tier level system was used to provide insight to a set of complex and varied well conditions faced. Of course, being AlphaRod® a non-API High Strength grade, the range levels were set in the upper half of the loading scale as shown below:

Load Level	Low	Med	High
% Goodman of AlphaRod® CS SF 0.9	0-60	61-80	>81

The above table does not become a statement of Tenaris' application guidelines for different corrosive environments. The goal of this approach for Goodman analysis was to normalize all loadings to 0.9 SF for ease of comparison.

Due to there is no universal standard to qualify the harshness of the environment for sucker rods in oil producing wells, based on fluid composition we stablished a general criteria expressed in terms of H_2S, CO_2, and bacteria content. Also, understanding the influence of chlorides as corrosion mechanism accelerator, this was incorporated in the ambient classification. The following table shows the reference values for each parameter:

Corrosion Level				
		Low	Medium	High
Accelerator	*Cl^+ [ppm]*	0-5000	5001-20000	>20000
AGENTS	*$PPCO_2$ [psi]*	0-20	21-100	>100
	PPH_2S[psi]	0	0-2	>2
	*Bacteria [CFU^+]**	0-3	4-6	>6

**Colony Forming Unit*

Additionally, the following considerations were considered to scoring each case:

1. High levels of Cl^+ are not enough to qualify a corrosion level in the absence of an agent (CO_2, H_2S, Bacteria).
2. The presence of one agent is enough to qualify corrosion level.
3. More than two agents on the same level increase severity.
4. Above medium load level (as per previous Goodman classification), corrosion level increases the severity.

b. Field performance by region

1. USA

With more than 200 installations considered in this analysis for the USA (+450 estimated total strings including distributors)[1], it has become the leading region worldwide in utilization of the AlphaRod® CS. A wide application range with a diverse set of goals: string weight reduction, increase reliability or runlife in aggressive environments and up to increase of production in wells with unrealized potential.

Although it was not possible the execution of fully controlled test protocols, several clear variables were put under scrutiny: rod loading, wellbore conditions, previous rod string/grade reliability metrics or simply production increase. Often expectations of previous Run Life increase was specific and measured. In some others just a baseline of double up was agreed as a reasonable goal.

In this specific aspect of value proposition and expectations, it is important to note that most of the operators in the USA went straight to the toughest application conditions to test Alpha to the fullest. Therefore, we find very high percentage of the installations located in high loading range and high corrosion level environments.

The performance of AlphaRod® CS was being mainly compared by the operators in the USA against previous installations of D, KD and HS4138. There was, of course, a slight predominance of KD rods towards the Permian and Eagle Ford regions, and HS4138 towards the Bakken.

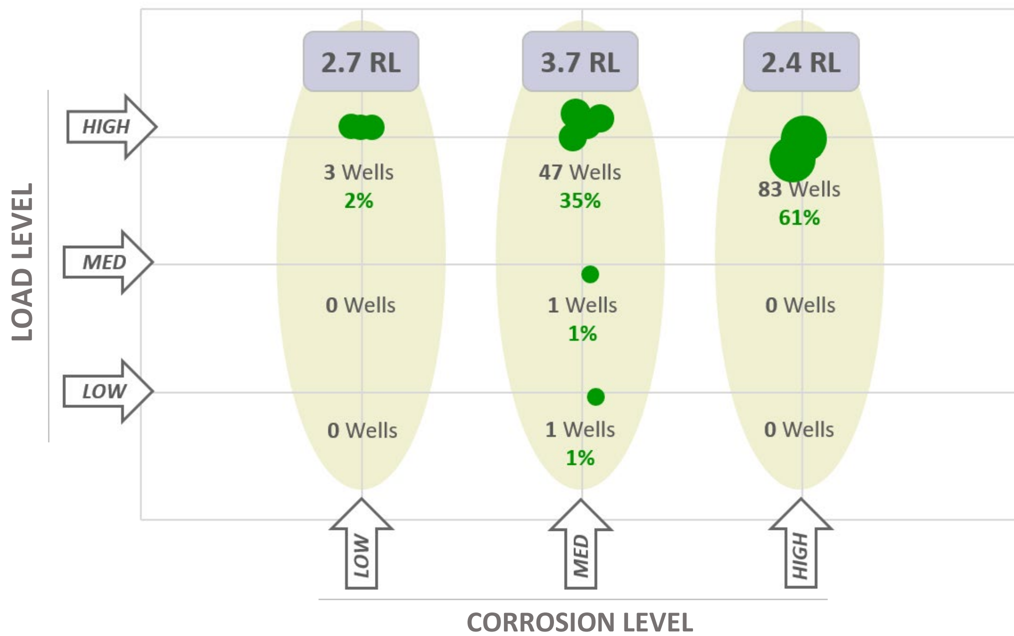
[1] Tenaris also has a wide distribution network in the USA via other companies. We have estimated the installation base through those to be approximately 150+ wells. However, data sharing in those cases is not effective. The one objective affirmation we can make regarding those installations is that we have only received 3 cases of failed rods.

Performance, Run Life improvement

Results in the USA show that AlphaRod® CS operated in loading ranges around 90% Goodman (normalized to SF 0.9) in mild to aggressive fluid conditions. However, this has to be properly aligned with runlife expectations. As with any other steel component, the harsher the conditions, a reduction in allowable loading capacity should be incorporated in order to deliver longer runtimes.

The following chart shows the grouping of the installs in Loading vs Corrosion Level and the resulting runlife increase for each batch.

WELLS DISTRIBUTION | xRL Improvement



This performance is right on line with the expectations from the end users. Overall, above 2 times runlife improvement in all corrosion levels, and always operating at high loading ranges.

As corrosion increases to the Mid-level, we see the widest separation between Alpha and the compared rod grades. This is because at this level of loading and corrosion is where the previous installed rod grades suffer the most from corrosion fatigue mechanism and Alpha shines brighter. Thus, the RL multiplier is the highest.

Bakken RL performance

The majority of the installs of AlphaRod® CS in this region showed an application profile in heavy loaded and Mid-corrosive environment. The comparison or baseline found came mostly from replacements for HS-4138 previously furnished wells, it's a considerably outstanding performance, with over 3x the previous runlife.

Corrosion Level	# Wells	Average of x RL	Average % Goodman SF 0.9
Low	3	2.78	90
Med	29	3.61	96
High	7	2.64	91

Permian and EF

These two regions were combined in this analysis. They are characterized for being Mid to High harshness. Although loading is a bit lower than Bakken, the RL multiplier shows the stronger performance in Mid level corrosion ambient. In the majority of these installations, the previous rod grade in the wells was KD. Thus, the resulting applications of AlphaRod® CS ended up not only increasing runlife, but also operating at higher stress levels than the previous rod string. In some cases producing more and in other cases reducing the string design from 86 to 76. This latter one yielded additional value for the operators by helping reduction of the PPRL and even allowing the downsizing of the pumping unit.

Corrosion Level	# Wells	Average of x RL	Average % Goodman SF 0.9
Med	20	4.00	89
High	76	2.35	89

2. Argentina

Argentina takes the second place worldwide when it comes to AlphaRod® CS dispatched volumes. At the time of this study, more than 100 strings have been tested on the most productive and diverse oilfields. However, as mentioned for USA, in many of these cases data sharing is not effective.

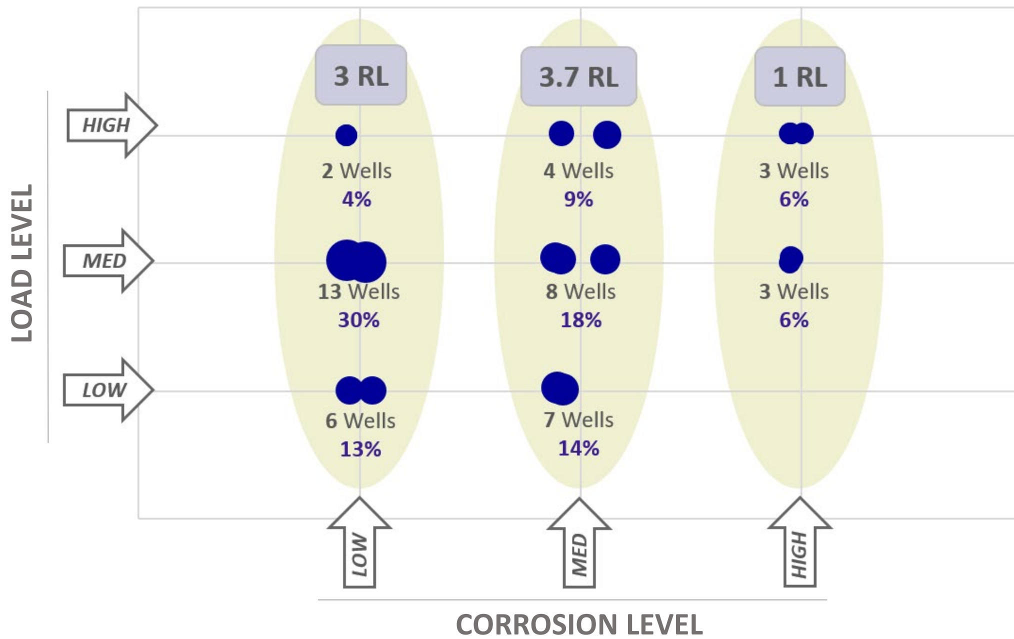
Taking that in consideration, there were more than 40 wells tested as part of protocols in which a careful and close follow up took place. The trials were carried on mainly at the south of the country, in “Cerro Dragon”, “El Trebol-Escalante” and “El Tordillo” fields to mention the major ones. The comparison was made vs D grade and HS4138.

Most of the selected wells belong to fields where secondary recovery techniques like water-flooding has been used for many years and the water-cut is 95% or higher. Another shared feature of these wells was the high sucker rod failure ratio (at least 2 failures per year).

As in most of the trials, the product was aimed to become a solution improving standard rod performance and offer an increased reliability in aggressive environments.

Compiled results from all tested regions, show that in general, relative RL obtained vs standard rod was satisfactory. On the following chart, results are exposed for each of the corrosion/loads levels combinations:

WELLS DISTRIBUTION | xRL Improvement



As expected, Run Life tends to grow as soon as corrosion level decreases. Particularly under high corrosion conditions, the results obtained were equivalent to the standard sucker rod setting probably the limit of AlphaRod® CS. Also, it might be considered that stress levels records shows the product was not at its highest demand scenario in terms of loads. Average % Goodman was around 70% (SF 0.9).

Considering premature and recurrent failures occurred in the presence of bacterial activity and CO2, chemical treatment might be applied if corrosion contents exceed medium values (respect to our data table).

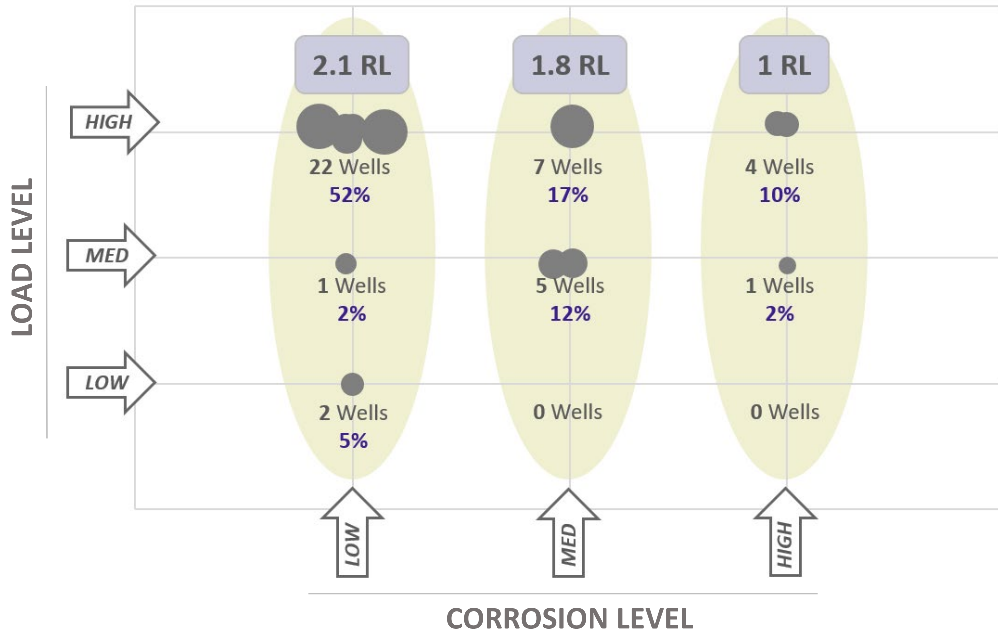
3. Canada

Canada has almost 50 installations of AlphaRod® CS. Given the business model Tenaris has in Canada via distributors, sometimes the collection of performance data is not ideal. We have collected data for 42 installs. Typical installations may not show as deep as the US Bakken or Permian, but still the loading averages in the top-mid bottom-high regions.

A strong particularity of most of the installs in Canada (60%) is that they are in Low corrosiveness environment. The goal in mind by the operators was to increase runlife against D and HS4138 rods in high load applications. The result is an outstanding RL multiplier of 2x.

Relative RL obtained vs standard rod for each of the corrosion levels was:

WELLS DISTRIBUTION | xRL Improvement



Special note to the High Corrosion Level RL multiplier: although being a small population, by the time of this analysis those wells were still operating, thus days are still accumulating and the RL multiplier increasing.

4. Romania

The oilfields in Romania have been produced for more than 100 years, which caused their depletion. Therefore, the majority of ALS currently used is represented by the Sucker Rods Pumping Systems.

The deployment of AlphaRod® CS started back in 2017, when a trial test protocol was agreed with a local oil operator, with the aim of increasing the sucker rods reliability by reducing the number of interventions generated by sucker rods failures. Initially, the testing protocol contained 18 wells from different regions of Romania, each one with specific features, which allowed AlphaRod® CS to be tested under several conditions. The predominant Tenaris rod grade in these tested wells was DA 4330 material, which was originally selected as a solution for mid to high level corrosive environments in Romania.

The data qualified and analyzed showed a trend for AlphaRod CS to exceed the runlife of D4330 in Low-to-Medium loads, combined with Low-to-Medium corrosion. The remainder data set was not qualified successfully due to size of the population and inconsistencies in operational parameters evaluated. This specially affected the performance evaluation in high corrosion level tests.

All in all, the Romanian AlphaRod CS testing was decided to be extended and revamped to have a more significant well population for analysis and results with more clear trends that help on making decisions.

5. Global AlphaRod® CS Results Integration

Applying the same criteria and grouping all regions data, the global integration of the results tend to be mimic that of the USA experience.

In general, AlphaRod® CS delivered an increased Run Life compared to standard steel rods under medium and low corrosion. Compiling results, and making a recap of the regions, relative RL obtained vs standard rod for each of the corrosion levels was:

Run Life Improvement			
REGION	CORROSION LEVEL		
	LOW	MEDIUM	HIGH
USA	2.7	3.7	2.4
ARGENTINA	3	3.7	1
CANADA	2.1	1.8	1
WAVG* WORLWIDE	**2.8**	**3.3**	**2.3**

*WAVG: Weighted average.

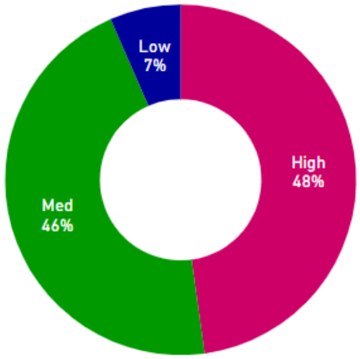
According to this table, results for low and medium corrosion levels were quite similar for all of the regions. With an overcome performance, in average, AlphaRod® CS almost duplicated previous Run Life for this environment.

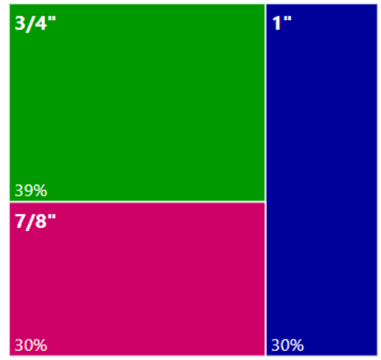
Entering severe conditions, with more presence of corrosion agents and accelerators, corrosion-fatigue mechanism experienced a higher probability of occurrence, with majority of failures registered at the body. For these cases, we consider other solutions to increase corrosion resistance dramatically would have to come from ongoing R&D programs.

c. Failure Events

Analysis of failure events where RLx<1 shows a trend concentrating more than a 90% of them on medium and high corrosion levels, having some higher occurrence on the latter one. Also, the dominance of failures on the ¾" taper are related to harmful operative conditions that caused steel exposure, like buckling and wear issues due to sub-optimal guiding strategy to mention the most important ones.

Failures by Corrosion Level *Failures by Rod Diameter*

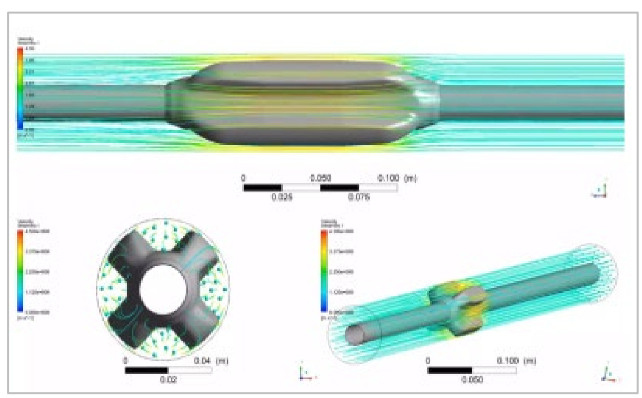




These findings are in line with the data analyzed in the previous chapters. In the section below, we drill down into the most common failure mechanisms and what Tenaris did to improve the product and prevent reoccurrence.

Failure mechanism	***Solution***	***Details***
Corrosion Assisted Fatigue due to erosion washout	Tenflow™ Guide	• Hidrodynamic design allows turbulence reduction at the end of a guide. • Enhanced vane design decreases drag forces, minimizing PRL. • Highest EWV without compromising hydrodynamic performance. • Reduces rod failures related to corrosion-erosion due to turbulence generated by a guide.

Guide bottom edge failure



TKE – Turbulence Kinetic Energy

Failure mechanism	***Solution***	***Details***
Corrosion Assisted Fatigue	Corrosion Inhibition Program Redesign	• AlphaRod® CS had already replaced KD rods in this well. • The operator tried to operate with a weak corrosion inhibition program.

Aggressive corrosive environment – heavy corrosion attack

Conclusions and recommendations

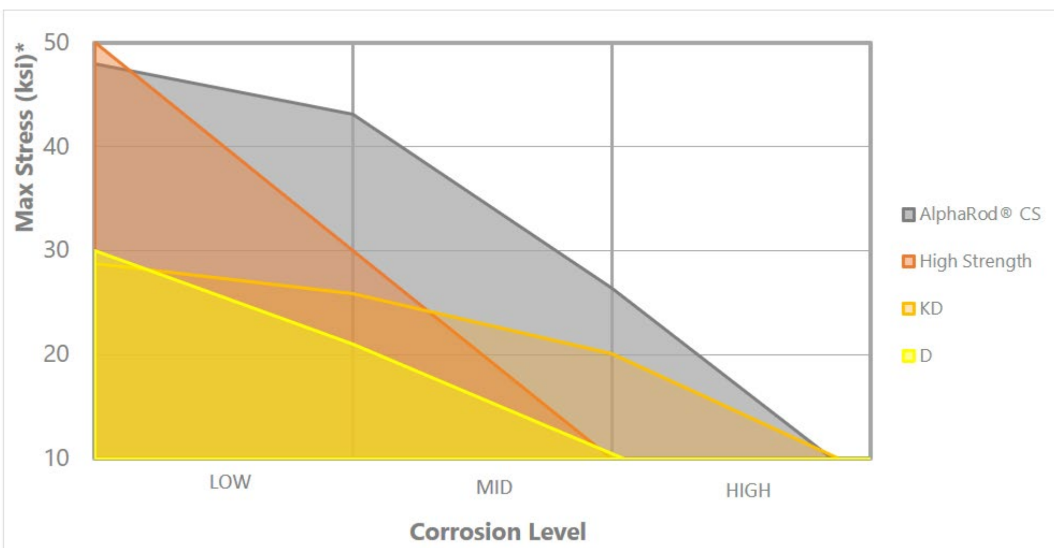
USA experience showed that we can push AlphaRod® CS up to 80% of High Strength Goodman. Regarding environment severity, the product was operated in harsher corrosion levels compared to other regions, and the results met the customers' expectations. In general, it has been demonstrated that AlphaRod® is capable of replacing D, KD and HS4138 rod grades in low, medium and high corrosive level wells. All this ultimately create value by increasing runlife and decreasing rod string overall weight, which maximizes well productivity and uptime.

In Argentina, there is proven evidence of the improvement given by this special rod when talking about low-to-medium corrosive environments. Some users have already adopted it as the new standard. However, the results in high corrosion were equivalent to the standard sucker rod and therefore did not improve rod reliability. For those cases, chemical treatment might be applied if corrosion contents exceed medium values (respect to our data table).

The Canadian experience has demonstrated that the value proposition from Alpha extends into harshness levels that not necessarily are Mid or High. In this case, the operators found Alpha increasing their runlife even in Low corrosiveness levels, boosting their OPEX savings as they prevented the frequent losses associated to remote location access and seasonal access. AlphaRod CS keeps growing dramatically in these applications and RL multipliers growing.

Regarding Romania, we are not able to make any conclusions and we will continue testing.

After the research done and conclusions exposed above, we recommend the following rod grade selection chart:



**Typical Max Stress Values*

The information contained on this graph is for a quick material selection. String design must be based on Goodman Diagram and Service Factor according well environment.

Annex

Application Profiles					
Parameters	USA		Canada	Argentina	Romania
	Bakken	**EF/Permian**	**Bakken**	**Cerro Dragón/El Trebol**	**Tasbuga/Barbuncesti**
Oil Production Scheme	UR	UR	UR	Conventional/ Secondary	Conventional/ Secondary
Depth [ft]	8.000-10.500	6.000-11.000	5500-6000	6.000-8.000	6.000-8.000
Production [bfpd]	150 - 300	200 - 420	250-400	230 - 350	150 - 280
Max Loads [lbs]	41.000	33.000	39,000	25.000	30.000
Previous Grade	HS4130	API D, KD, HS4138	T66, HD	API D/HS4138	API D 4330
Dominant Corrosion Level	Mid	Mid	Mild	Mid	Mid

References

[1]M. Bühler, F.R. Camara Guillet, E. Lopez, M. Pereyra, Tenaris. SPE-184899-MS. “Development of a Fatigue Corrosion Resistant Steel for Sucker Rods”.
[2] Tenaris Brochure. “The New Generation AlphaRod® Sucker Rods”, Version 02, April 2018.