SHALE OIL PRODUCTION CHALLENGES IN BEAM PUMPING BEING SOLVED WITH PREMIUM SUCKER ROD DESIGNS

Rodrigo Ruiz, Gustavo Alvarez and Jim Few
Tenaris

The production of the shale oil well at start up can produce high fluid rates with a high energy causing it flow naturally. After this stage, a high rate artificial lift systems such as ESP or Gas lift is required. But because of the rapid depletion of the stimulated zone during the first year (between 60 – 80% in Eagle Ford), the most flexible form of artificial lift available is used, the beam pumping.

Because the pump depth could reach between 4000 up to 12000 ft., the beam pumping system is limited in flow rate. A big surface pumping unit and high strength rod are necessary. Other complex challenges to overcome are the combination of crooked or highly deviated well bore, high GOR, propant or sand flow back and the presence of H2S. Small tubing completions in shale wells, with 2 3/8" tubing installations, pushes the system to provide high fluid velocity with effective solids transportation in low rates and more inexpensive equipment but with sucker rod diameter restriction to 7/8" slimhole couplings.

Optimizing artificial lift equipment selection, sizing, and design will ensure longevity of the equipment and continued production. A premium sucker rod connection has a design that allows the use of 7/8" and ¾" strings tapers with KD material to work in corrosive environments with regular size pumping units and lighter strings with guides when necessary in wells where 1" and high strength rods should be the conventional alternative.

This paper explains the experiences of more than 70 strings installed and the benefits achieved for a major operator working in the Eagle Ford formation.

BEAM PUMPING IN SHALE OIL WELLS

Eagle Ford Shale (EFS) is a hydrocarbon producing formation of significant importance due to its capability of producing both gas and more oil than other traditional shale plays. During the last three years of development, oil production growth exponentially, reaching 688,429 barrels of oil per day (BOPD, see fig. 1)[9].

Typically, liquid production of Eagle Ford Shale wells declines very fast, 60% to 80% within first year. As a consequence it is very usual to notice three different stages of production. During the first or initial stage, wells are able to flow naturally to the surface high volumes of liquids. While liquid rates and pressure decline in the first months, a second stage of production is noticed because of the wells are not capable to produce the liquids to surface efficiently, and a transitional high rate Artificial Lift method like ESP or Gas Lift is run into well to produce the liquids. However, after the first year, liquid production usually drops below 350 bbls/d what makes wells with ESP and/or Gas Lift inefficient. As a consequence, a more flexible Artificial Lift system like Beam Pumping is commonly installed in wells in this third stage. Beam Pumping is the most capable lifting method to handle different well conditions in a cost-effective manner (see fig. 2)[6].

Due to the simple operation of rod pumping, with more efficiency than other types of Artificial Lift, beam pumping systems can operate in a wide range of production rates and depths. Pumping systems have a high salvage value, because of surface units and gearboxes can last more than 30 years, if it is not loaded over 100% of rating. For this reason the presence of beam pumping is still strong among operators in shale assets.

ARTIFICIAL LIFT CHALLENGES IN SHALE OIL

Over the last years, the number of oil shale wells has increased and as a result, Artificial Lift Systems have been pushed to the limits by the more demanding conditions required like: deeper wells, deviated geometries, corrosive environments and higher production rates. Therefore, the analysis performed while designing a Beam Pumping installation for shale wells is a complex combination between costs evaluation and the expected run life of the Artificial Lift System as a whole.

A typical Beam Pumping installation for oil shale wells is:

- Tubing size 2 3/8” or 2 7/8”.
- Pump plunger diameter: up to 1 ¾”
- Rod Strings: 86 (1” SH-7/8-3/4) or 76 (7/8 SH-3/4)
- Rod steel grades: D or D Special (due to H_2S presence)
- Pump Depth: 7,000-10,000 ft
- Additional loads due to wells deviation and use of rods guided

Considering the well conditions mentioned above, rod loading in Shale wells could reach high loads such us 180% on the API grade D SF1 Goodman rating. Therefore, overloaded API rod string designs and some additional challenges have been overcome in many Shale oil wells by implementing premium connection rods technology, as it is discuss next:

A. Allowable rod string Size

Tubing ID limits the size of rod to be run through it. For instance:

- Tubing 2 3/8” 4.7#/ft: maximum rod string to run is API 76 with 7/8” rod Slimhole couplings
- Tubing 2 7/8” 6.5#/ft: maximum rod string to run is API 86 with 1” rods Slimhole couplings

From the sample of wells analyzed, 20% of the wells were completed with 2 3/8” Tubing. In those cases, 76 strings were the only alternative, and so far ten of them reach one year without failures. Due to changes in new development project objectives, the operator decided to use 2 7/8” in new wells but still using 76 strings in some of them to reduce loads over the pumping unit.

As an example, a shale oil well with production requirements of 245 bpd and a pump depth of 5400’ was analyzed. The tubing diameter was 2 3/8” and the pumping unit available was a 640 Mark II with a stroke length of 168”. This 76 guided design was loaded 90% of D premium connection Goodman with a service factor of 1 (170% G D API SF1). It has been running for one year without any rod failures.

As figure 7 shows, all the strings were working above the 100% API D @ SF 1. A 50% of them were above 120 and a 30% above 140%, reaching a maximum of 177% (92% of D MGD rating SF 1).

B. Corrosive Environment (Material Selection and Corrosion)

Conventional High Strength rods are usually required for high loads applications when API rods are overloaded. However, High Strength rods should not be used in corrosive environments. The high mechanical properties of these materials make them susceptible to premature failures due to, either H_2S or CO_2 corrosion. Therefore, a softer steel is needed like the premium connection rod made of KD steel. A direct effect of the microstructural features of the 4320 KD steel is a better toughness (see grade composition in table 1). Because of that, it leads to a better fatigue corrosion behavior and, therefore, it is expected to have a better performance of the KD sucker rods in slightly corrosive environments, allowing the operator to use a softer steel in extreme mechanical demands.

In this experience, more than the 80% of the premium connections sucker rod strings installed were 4320 KD grade. Among the sample of wells analyzed, H_2S concentration found in gaseous face was from 800 ppm up to 2100 ppm in some of the cases.

C. Well Geometry

Usually pumps are required to be set beyond the kick of point (KOP) increasing tubing-rod contact force. Taking into account a typical well deviation in Shale wells (see fig. 3), and in order to get an acceptable rod and tubing run life, molded guides are added in those sections where dogleg severity is high enough. In the group of wells studied 96% of the string is guided. This condition generates a considerable drag force increasing the maximum axial load in the pumping cycle, putting the API rod string above its fatigue resistance, as addressed in “High Loads and Pump Depth” next.

D. High Loads and Pump Depth

Pump depth distribution in figure 4 shows a tendency to set pumps deeper than 6,000’, where 39% of them are between 9,000’ and 12,000’. Based on our study, the maximum depth for a 1 3/4” pump was 11,049’, pumping 170 BPD (@80% Efficiency).

It is known, due to the depth and the shale well conditions the API connection design limits the Beam Pumping system, for details refer to "Premium Technology – Beyond the limits of Artificial Lift Systems- Field Experiences"[5], forcing the user to oversize their installation in every level of the system. Using those limits, an 86 type API D rod string and a 76 KD Premium rod string are compared for the same production requirements (Table 2).

There are several benefits of working with premium connection rods. API D rod strings would be working at 100% of Goodman ratio but, instead of that the 76 KD premium connections will be working at 80% of total capacity. A 76 premium connection rod design allows the use of a 2 3/8" tubing by running 7/8" slimhole couplings. In addition it is very important to highlight that these kinds premium rod designs provide a between 16% to 20% lighter rod strings.

Lighter strings working with pumping units from conventional developments projects work good for those fields were shale oil production share the same resources than conventional. If the design is accurate enough, there is still an opportunity to use regular pumping units. From our experience, more than an 80% of the pumping units were 640 in MII and C API conventional geometry.

An additional advantage of decreasing the string rod weight will be noticed in less power requirements, smaller prime movers and lower power consumption. This concept could be achieved nevertheless the pumping unit must always be working above 85% of gearbox rating to establish good efficiency ratios[10].

CONVENTIONAL VERSUS PREMIUM CONNECTION SUCKER RODS

Positioning In Flow Rate / Depth Graph

For string design proposes, the industry has adopted the Modified Goodman Diagram (MGD)[1], which limits the working loads on the string within the sucker rod fatigue safe area. Even though this method was originally designed to predict the rod body behavior, it can fairly be used for accurate rod connection designs mainly due to the modification it has had over the years based on field experience. Under the surrounding conditions in shale oil well installations, rod connections will be working on the edge of their mechanical limits when the combination of factors derivate in a loading equal or greater to 100% of MGD.

Figure 8 illustrates the hydraulic power limits (flow rate vs. pump depth) for several alternatives of sucker rods string designs working at the border of its operational capacity, 100% of MGD. For every case, a specific type was chosen; therefore each curve has a reference with his string type (76 or 86), grade and thread.

The area beneath each curve delimits the safe working zone (service factors not included). In this case, and because of the nature of the string installed, 76 strings in API D, high strength, D premium connection and KD premium connection rods are exposed; and just to compare, an 86 API D was also included.

As the chart shows, every well was over the safe area of 76 API D, and in several cases, over 86 API D. For the case of those 76 KD string were all working over API D grade and in four cases above 86 API D. This find demonstrates the overlapping between sucker rods, the API D being replacing for premium connection sucker rods with 4320 KD steel.

In those cases where the depth or rate forced the operator to choose an 86 design, it is proved that premium connection sucker rods design works with excellent results reaching levels of high strength sucker rods but using 4320 KD steel, with an extra cover under mild corrosion risks.

The experience in beam pumping operations shows that there are several tendencies of development orientated to find a solution for border conditions. Considering this additional value to the existing installations and looking for the cost effective solution that gives the operations the best run life and therefore an increase of profits.

CONCLUSIONS

When conventional rod pumping designs with API connection are pushed to the limit, it is commonly known that the weakest point of the string will be found on the sucker rod connection. Some of the reasons for this behavior are:

the connection has a non-uniform stress distribution along the thread profile resulting on very high stress concentration, a tendency to back off and the high risk of being easily over/under torqued.

Steel premium connection sucker rods prove to be the best solution to reduce connection failures in demanding applications. This design decreases the stress and improves its distribution all along the thread profile due to its geometrical characteristics of a tapered trapezium thread profile; flank-to-flank contact and diametrical interference[4] (see fig. 9). These improvements allow to increase the MGD working area of a regular Grade D rod while duplicating its capacity over the standard high strength rods, which is close to 200% of Grade D rods (see fig. 6).

Goals Achieved

1) The use of 4320 KD steel sucker rods with premium connections at the same level as high strength rods, set a new limit in ALS for this grade of steel beyond conventional boundaries with outstanding results in mild corrosive environments.

2) A reduction between 15 to 20% in weight is obtained by the use of premium connection rod strings design type 76. In those cases where the operator uses 86 strings, the optimization of the system efficiency could be achieved while the gearbox rate is above 85%.

    a. Due to the weight reduction that this technology offers, shale oil wells are able to be produced with the same pumping units size as for conventional projects.

3) Due to the reduction of rod size needed in this application, the operators using this technology are able to produce through 2-3/8 tubing with 76 rod strings where a 2-7/8 tubing with 86 rod string would be normally needed.

4) Operation parameters reached with premium connection rods showing a reliable operation in extreme conditions such as:

    - Maximum pump setting depth:11025 ft
    - Maximum production rate: 360 bpd
    - Minimum tubing size: 2-3/8
    - H2S concentration (in gaseous face): 2100 ppm H2S.

REFERENCES

1) API RP 11BR, "Recommended Practice for Care and Handling of Sucker Rods", USA. April, 2008.
2) API Spec 11B, "Specification for Sucker Rods" API, USA. 27th ed., May, 2010.
3) Tenaris Sucker Rods General Catalog. Tenaris. http://www.tenaris.com/en/MediaAndPublications/BrochuresAndCatalogs/SuckerRods.aspx.
4) SPE 120627. "New Sucker-Rod Connection Designed for High-Load Applications". Francisco Diaz Telli, Daniel Muse, Ezequiel Fernandez and Matias Pereyra, Tenaris and Rita Toscano, Simytec. 2009
5) Fernandez Ezequiel. Tenaris. "Premium Technology – Beyond the limits of Artificial Lift Systems- Field Experiences". Southwestern Petroleum Short Course. Lubbock, TX. 2012.
6) World Oil Webcast, "Artificial Lift and the Shale Revolution: BlueRodTM Premium Connection Rod Solution for Shale Challenges" Jim Few. Tenaris Rods. November 2013.
7) SPE 27990 "New and Expected Developments in Artificial Lift" Lea, Amoco and Winkler, 1994.
8) SPE 110234. "Overview of Beam Pump Operations". L. Rowlan, Echometer company; J. F. Lea, PLTech and J. N. McCoy, Echometer Company.
9) Railroad Commission of Texas. http://www.rrc.state.tx.us/eagleford/#gas
10) "Power Efficiency of Sucker Rod Pumping" Gabor Tackacs, PhD. University of Miskolc.

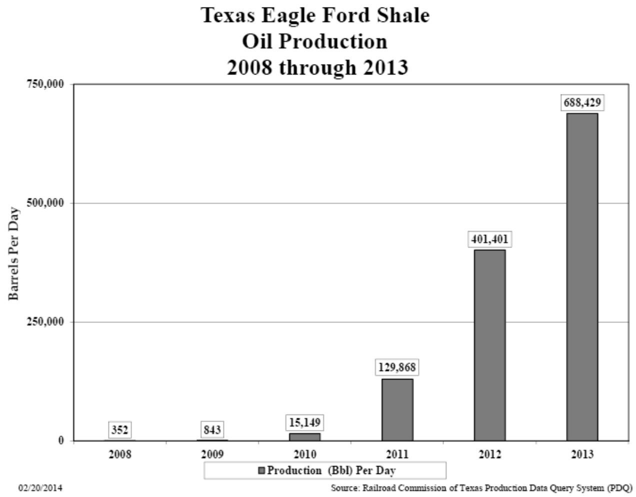

Figure 1 - Eagle Ford Oil Production -2008 to 2013-

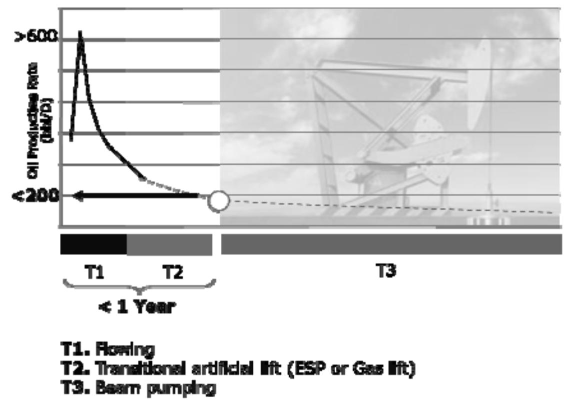

Figure 2 - Shale oil well depletion example

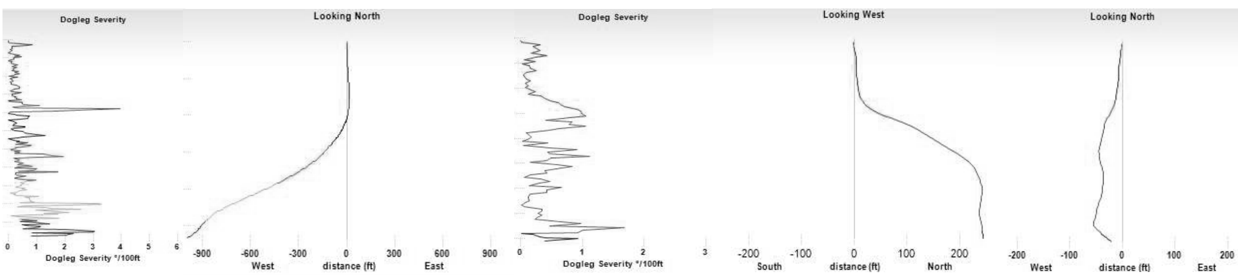

Figure 3 - Examples of well deviation in shale wells.

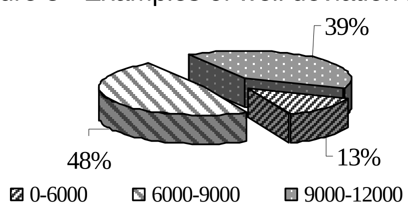

Figure 4 - Pump depth distribution [ft]

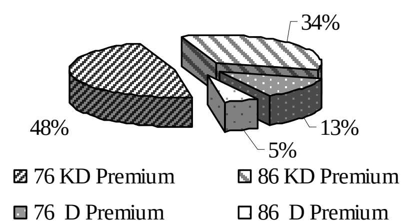

Figure 5 - String type and grade distribution.

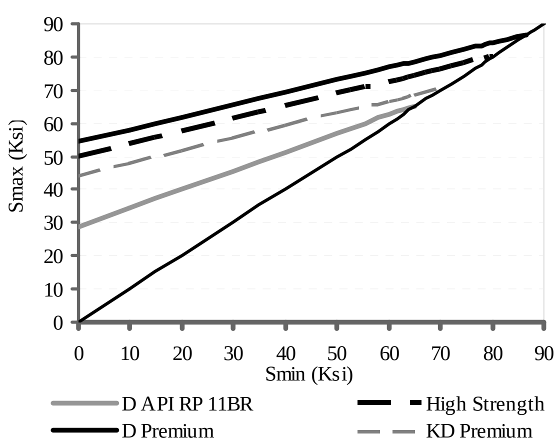

Figure 6 - Modified Goodman Diagram

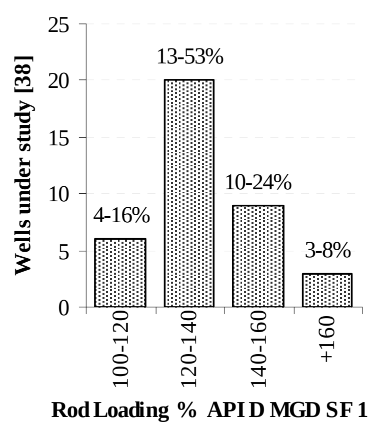

Figure 7 - Rod loading distribution of under study wells.

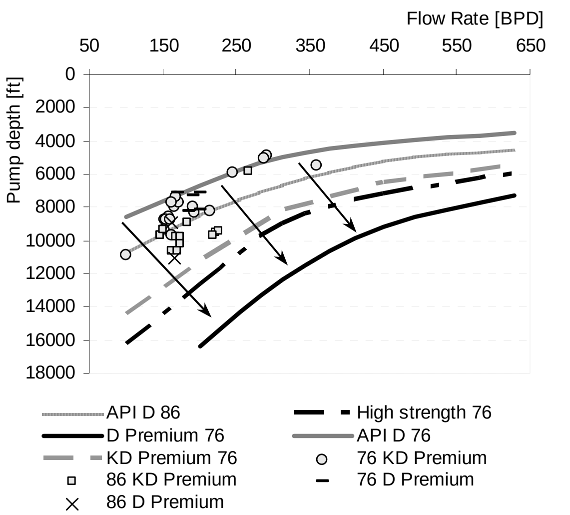

Figure 8 - Wells distribution along Beam Pumping Hydraulic Power Limit chart.

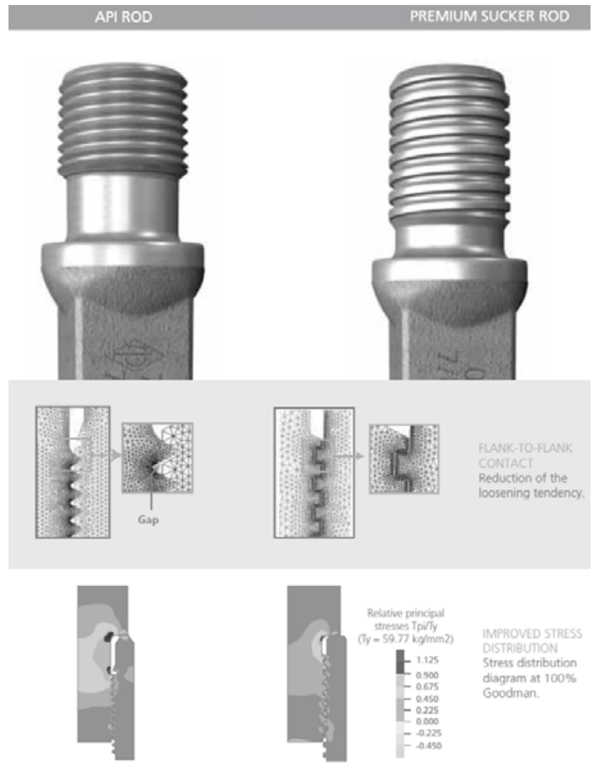

Figure 9 - Premium connection sucker rod features

Table 1 - 4320 KD Chemical composition.

Chemical Composition	KD 4320 Premium Connection
C	0.18-0.25
Mn	0.80-1.00
S	0.025 MAX
P	0.025 MAX
Si	0.15-0.35
Ni	1.15-1.50
Cr	0.70-0.90
Mo	0.20-0.30
V	0.03-0.07
Al	0.01-0.05
Cu	0.25 MAX
Mechanical Properties	
YS (KSI)	85 Min
UTS (KSI)	115-140
Heat Treatment	
Normalized	
Tempered	

Table 2 **-** Weight reduction achieved by using 76 KD premium type string against 86 API D. * the maximum level of reduction can be reached by unbalancing the loads for each taper, making longer the smallest.

	86 API D Rods	76 KD Premium	% Reduction
Tubing Diameter [Inch]	2 7/8”	2 7/8” - 2 3/8”	-
Sucker Rod String Diameter	1”- 7/8”- ¾” +SB (100% Goodman APID)	7/8”- ¾” +SB (80% Goodman KD)	-20%
Structure Load [%]	**81.7**	**72.8**	-11%
% Existing Gearbox Torque	**110.7**	**82.4**	**-28%**
String weight reduction	**-16 up to 20%***		