ROD STRING DESIGN FOR MULTIPLE APPLICATIONS

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Abstract – This paper describes the derivation of rod string design for use over a range of production parameters. The concerns in achieving said design include: (a) reduction of tubing failures, (b) reduction of rod failures, (c) use of small pumping units and prime mover motors, (d) ease of adaptability to accomplish needed production change(s), (e) operation of system elements within rated capacities, and (f) optimization of system efficiencies. It can be demonstrated that, with proper planning and design, a single rod string design can be made to accomplish these objectives with accommodations to changes in production parameters being performed without entering the well bore.

OVERVIEW

Pioneer Natural Resources operates approximately 3,900 beam lift wells in the Permian Basin / West Texas area. Typical of similar wells in the area, there have been continuing failures of various components of the pumping system(s). The portion of the wells contained in this study group has experienced a 6.1-month mean-time-to-failure rate. Examinations of failures can be broadly grouped into three classifications:

(1) Pumping system equipment overloads, or
(2) Tubing failures due to rod buckling and wear, or
(3) Rod parts due to wear and corrosion/stress.

Considerable effort has been made to analyze the mechanism and mechanics of failure as each occurred. Focus was placed on wells in the Shackleford unit wherein wells are initially rigged at a seating nipple depth (SND) range of 6800' – 7200'. This initial SND is above well bore perforations to combat sand. A typical location is equipped with 2 3/8" tubing, and conventional geometry C228-212-86 pumping units. As situations permit, the SND is subsequently lowered to a level at or below perforations for operation. It is necessary to continue to use the same tubing and the same pumping units at the increased SND.

MORPHOLOGY OF DESIGN

Observations of the mechanics of failure reveal that:

(1) Many of the designs considered were subject to a considerable amount of buckling forces in the lower section of the rod string, causing tubing wear and increased operational costs.

(2) It is known that slower cycle rates can decrease the amount of rod buckling and tubing wear; however, slower cycle rates are not capable of producing the required production.

(3) While the use of molded rod guides is considered, and there have been a number of such applications made, it has been found that use of such rod guides:

   a. Can increase polish rod loading due to friction of the rod guides against the tubing. This increase can require additional horsepower requirements and can reduce pumping system efficiency.
   b. Can cause wipe-off of corrosion inhibitors and chemical treatments.
   c. Can induce drag of the well bore fluid due to turbulence.

Given the operational parameters, the purpose of the examination is to develop a pumping system methodology to accomplish certain goals:

1. Reduction / minimization of system element failures,
2. Application over a wide range of production parameters, particularly pump submergence,
3. Reduction of gear box loading,
4. Reduction of electrical consumption per production volume,
5. Adaptable to increasing SNDs using then-existing system elements.

Ideally, a pumping system methodology would be designed to accomplish the goals of the examination, with particular emphasis being placed on reduction of rod wear and tubing wear attributed to rod buckling forces. Ideally, such a methodology could be developed such that the system was adaptable over a wide range of parameters and changes could be made simply by changing motor sheaves sizes without re-entering the well to alter rod string components.

In addition to the reduction of failures, it is desirable to compare various designs according to production, polish rod loads, polish rod horsepower, motor size, electrical consumption per volume production, gear box loads, and rod stress loading.

During consideration of various designs, it became apparent that the use of K-grade sinker bars could be beneficial to combat rod-buckling forces. The incorporation of some number of 1 ½" sinker bars at the lower end of the rod string would provide needed weight to increase the amount of tension in the rod string. Additionally, it has been found that the larger sinker bar diameter (as compared to sucker rods) is beneficial in combating the effects of rod-tubing friction.

Additionally, the use of fiberglass sucker rods would lower string weights, polish rod loads, and gear box loading. With proper consideration, a fiberglass / steel / sinker bar combination offers mechanical improvements in downhole stroke length and increases system efficiency.

While limiting some operational effects, the use of steel rods (particularly 7/8" Grade D) above the fiberglass section offers several advantages:

1. Use of existing elements,
2. The above-fiberglass rod elements aid in widening the applicability of the design over a wide range of parameters.
3. Hot oiling treatments may be accomplished with fewer restrictions,
4. The steel element offers increased resistance to destruction in the event of incidental catastrophic failure, or in extraordinary attempts to defeat a shear device.(as might be encountered in unseating a stuck pump)

EXAMINATION OF DESIGNS

WELL A

This well is a typical well with a SND of approximately 7200'. The tubing is anchored. Since its completion date, this well was operated with all steel and steel with molded rod guide string design. Failure history reveals this well experienced 8 failures, both in rod breaks and tubing leaks due to wear, in the next 14 months.

Figure 1 represents the results of an examination of the then current system elements, an interim molded rod guide string design, and a steel/fiberglass/steel/sinker bar design. The fiberglass design was developed and installed for the following reasons:

1. Maintenance of acceptable production rates for this well. (8.8 SPM vs. 10 SPM for the other designs)
2. Reduction of polish rod loads and thus motor horsepower requirements.
3. Improved electrical usage per volume production.
4. Reduction of gear box loading, thus improving longevity of the pumping unit.

Percentage rod loadings are improved and compressive forces in the ¾" Grade D rod section are not found in this design. As to reduction of failures, as of fourth quarter 1998, there has been no failure since installation of the fiberglass rod string in the subsequent five months.

This design is applicable over a range of pump submergence levels and speed variations, as the conditions require. Additional discussion is found in "Application over a Range of Production Parameters".

WELL B

This well is a typical well with a SND of approximately 6975'. The tubing is anchored. Since its completion date, this well was operated with a balanced 76 steel string design. Failure history reveals this well experienced 8 failures, in rod breaks and tubing leaks due to wear all within the ¾" rod area, in the next 12 months.

Figure 2 represents the results of an examination of the balanced 76 steel rod design, and a steel/fiberglass/steel/sinker bar design. The fiberglass design was developed and installed for the following reasons:

1. Maintenance of acceptable production rates for this well.
2. Lowering of polish rod load.
3. Improved electrical usage per volume production.
4. Reduction of gear box loading, thus improving longevity of the pumping unit.

Percentage rod loadings are vastly improved and compressive forces in the ¾" Grade D rod section are not found in this design. As to reduction of failures, as of fourth quarter 1998, there has been no failure since installation of the fiberglass rod string in the subsequent 12 months.

APPLICATION OVER A RANGE OF PRODUCTION PARAMETERS

During consideration of the methodology, considerable attention was placed on design of a pumping system that could be adaptable for various ranges of pump submergence and production goals. This adaptability should be accomplished without re-entering the well bore to make additions to the rod string design, and should be accomplished with little more than changing motor sheave sizes to control cycle rates.

There are those occasions where a slower cycle rate is preferred to allow for naturally occurring gas/fluid separation that would occur at slower pumping rates. Additionally, improved pump fillage can be done at slower pumping rates, should such be necessary. Alternately, there are those occasions when it is desirable to increase the cycle rate when operating with a larger value of pump submergence. Figure 3 demonstrates a portion of the ranges available for Wells A and B available with a change in motor sheave, and without a change to the composition of the rod string elements.

Many of the wells in this group are initially produced from depths above the upper perforations because of difficulties that would be encountered from sand fouled pumps should the well be produced from below the perforations. Over some period of time, the opportunity presents itself to lower the pump depth to take advantage of additional production potential. To easily accommodate these changes, the rod string design methodology should incorporate the reuse of as many of the rod string design elements that are already in use at the well prior to the deepening.

WELL C

Well C refers to a well typical of those that would be candidates for deepening. Prior to lowering, the well was produced at 6969' using a 7/8" D steel/ ¾" D steel/ 1 1/2" K sinker bar rod design. In lowering the pump depth to 8636', it was possible to achieve the desired goals while utilizing all of the existing rod string components, and minimizing the purchase of additional components to those needed to increase the depth.

Figure 4 demonstrates the various performance parameters as compared to a balanced 76 steel taper. In comparison of the two designs, there are several items of particular significance:

1. The percentage rod loading in the 76 steel taper is well beyond manufacturer's ratings.
2. The ¾" portion of the 76 steel taper is subject to considerable amount of buckling forces.
3. The amount of counterbalance effect necessary for proper operation of the 76 steel taper would be difficult to achieve.

Comparing the results of the examination to the goals of the methodology, the steel/fiberglass/steel/sinker bar design provides:

1. Acceptable production rates for this well,
2. Good polish rod loads and motor horsepower requirements,
3. Good electrical usage per volume production,
4. Good gear box loading

This well has operated for three months as of the production of this report with no failures.

WELL D

To demonstrate the deepening of a well that already utilizes the methodology, Well D is presented. The then-existing well design consisted of 7/8" D/ 1" FSR/ 7/8" D/ 1½" K sinker bars, the totals of the elements on hand being displayed in Figure 5. The accompanying chart reveals that it was only necessary to add fiberglass rods and sinker bars to those elements already on hand.

Similar to Well C above, the necessary counterbalance effect would be difficult to achieve without application of the methodology.

Comparing the chosen design to a balanced 76 steel taper:

1. Production is increased to an acceptable level,
2. Good polish rod loads and polish rod horsepower requirements,
3. Good electrical usage per volume production,
4. Good gear box loading.

This design was installed three months prior to the production of this report and has operated with no failures.

SUMMARY

While recognizing that each well has its own personality, there are some general guidelines to the design considerations.

1. Generally, 1500' of 7/8" D steel is used between the polish rod and the fiberglass section; however, this amount may be adjusted as conditions warrant. It has been found that, in hot oiling operations, the temperature of the treatment fluid has normalized to well bore temperature at this level.
2. Approximately 35% of the rod string length is fiberglass
3. The balance of the footage is used between the fiberglass section and the sinker bar section. The use of 7/8" D or ¾" D is determined by weight limitations and/ or needs.
4. The number of sinker bars for each design is determined by considering the amount of side loading that is anticipated and then using 70% of that value.

Within the study group, there have been three hundred, twenty (320) wells adapted to this methodology. The mean-time-to-failure rate has been extended to 14 months. There have been no failures in the fiberglass section of the rod string system after installation of this methodology. The above examples demonstrate that it is possible to design, install, and operate a rod string system with attention to minimization of buckling/ wear related failures, utilization of small pumping units, and optimization of system efficiencies.

PU Conv. 228-212-86

Taper			
1	(98) 7/8" D	(96) 7/8" D	(59) 7/8" D
2	(190) 3/4" D	(174) 3/4" D	(67) 1" FSR
3		(18) 7/8" D w/ mrg	(115) 3/4" D
4			(11) 11/2" K SB
	subs/pony	subs/ pony	subs/pony

BFPD		115	137	132
PRL		18129	19039	15631
PRhp		7.8	9.6	8.5
Reqd. motor		25	30	20
Kwh/BF		2.08	2.21	1.81
GB loading (M in-lbs.)		225	273	196
Stress loading (%)				
	Taper 1	83	92	67
	Taper 2	83	93	41
	Taper 3		32	68
	Taper 4			15

Figure 1 - Well A

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Taper		
1	(103) 7/8" D	(56) 7/8" D
2	(176) 3/4" D	(68) 1" FSR
3		(110) 3/4" D
4		(10) 1 1/2" K SB
	subs/ pony	subs/pony

BFPD		146	145
PRL		18941	16383
PRhp		8.3	8.2
Reqd. motor		20	20
Kwh/BF		1.60	1.51
GB loading (M in-lbs.)		255	206
Stress loading (%)			
	Taper 1	91	77
	Taper 2	91	47
	Taper 3		80
	Taper 4		17

Figure 2 - Well B

Well A

8 SPM

	100# PIP	500# PIP	1000# PIP
BFPD	107	110	113
PRL	15958	15242	14545
PRhp	7.6	7.0	6.2
Reqd. motor	20	20	15
Kwh/BF	1.94	1.79	1.63
GB loading (M in-lbs.)	197	197	182
Stress loading (%)			
Taper 1	71	64	57
Taper 2	42	38	34
Taper 3	71	65	58
Taper 4	15	14	12

10 SPM

	100# PIP	500# PIP	1000# PIP
BFPD	161	162	166
PRL	16798	16235	15483
PRhp	12.6	11.6	10.3
Reqd. motor	30	25	25
Kwh/BF	1.99	1.88	1.68
GB loading (M in-lbs.)	248	226	209
Stress loading (%)			
Taper 1	82	77	70
Taper 2	52	47	41
Taper 3	80	73	65
Taper 4	18	16	14

Well B

8 SPM

	100# PIP	500# PIP	1000# PIP
BFPD	138	145	150
PRL	17931	16383	15371
PRhp	8.8	8.2	7.2
Reqd. motor	20	20	20
Kwh/BF	1.65	1.5	1.34
GB loading (M in-lbs.)	208	207	194
Stress loading (%)			
Taper 1	85	77	68
Taper 2	50	47	41
Taper 3	86	80	69
Taper 4	20	17	15

10 SPM

	100# PIP	500# PIP	1000# PIP
BFPD	197	210	225
PRL	17442	17000	15915
PRhp	13.5	13.0	12.0
Reqd. motor	30	30	25
Kwh/BF	1.66	1.55	1.39
GB loading (M in-lbs.)	237	245	217
Stress loading (%)			
Taper 1	87	85	77
Taper 2	56	54	50
Taper 3	90	84	76
Taper 4	22	20	17

Figure 3 - Parameter Performance

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to lower SND from 6969'
Existing rod string elements
(94) 7/8" D
(175) 3/4" D
(9) 1 1/2" K SB
subs/pony
30 hp motor

Taper		
1	(124) 7/8" D	(33) 7/8" D
2	(221) 3/4" D	(74) 1" FSR
3		(192) 3/4" D
4		(9) 1 1/2" K SB
	subs/pony	subs/pony

BFPD	128	121
PRL	21678	17256
PRhp	10.9	9.9
Reqd. motor	20	15
Kwh/BF	2.09	1.86
GB loading (M in-lbs.)	147	97
Stress loading (%)		
Taper 1	104	74
Taper 2	105	48
Taper 3		89
Taper 4		17

Figure 4 - Well C

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to lower SND from 6738'
Existing rod string elements
(161) 7/8" D
(66) 1" FSR
(8)) 1 1/2" K SB
subs/pony
30 hp motor

Taper		
1	(112) 7/8" D	(29) 7/8" D
2	(242) 3/4" D	(120) 1" FSR
3		(132) 7/8" D
4		(12) 1 1/2" K SB
	subs/pony	subs/pony

BFPD	103	122
PRL	21457	18648
PRhp	8.9	10
Reqd. motor	30	30
Kwh/BF	2.50	2.06
GB loading (M in-lbs.)	250	198
Stress loading (%)		
Taper 1	102	84
Taper 2	103	56
Taper 3		62
Taper 4		18

Figure 5 - Well D