A REVIEW OF THE NON-DIMENSIONAL PUMPING PARAMETERS AND THEIR USE IN SUCKER ROD STRING DESIGN

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ABSTRACT

During recent sucker rod pumping problem solving schools presented at the SouthWestern Petroleum Short Course, it has become apparent that few engineers and operators know about the non-dimensional pumping parameters developed by Sucker Rod Pumping Research Inc. and provided to the industry in API RP 11L for rod string designs.

This paper will discuss the background and physical meaning of the two main parameters Fo/Skr and No/No', show the nomograph of their inter-relationship, and provide recommended limits which are typically not provided in modern rod string computer programs. These limits may assist in reducing sucker rod system failures. The relationship of these design parameters to the dynamic motion of the sucker rod pumping system and the formation of undertravel or overtravel dynamometer cards will be provided. Additionally, a comparison of sucker rod string design recommendations, resulting sucker rod system failure frequencies per year and a discussion of operating practices will be provided.

BACKGROUND

A group of sucker rod pumping equipment manufacturers and petroleum company users undertook an in depth study of the complex problems associated with a more appropriate design of sucker rod strings than just using static loads as originally described by Mills[1]. In 1954, a non-profit organization was created called Sucker Rod Pumping Research, Incorporated, to control and direct this effort. The Midwest Research Institute in Kansas City was retained to develop the model and equations necessary to complete this work. The design calculations and analog computer model developed from this work was provided to the American Petroleum Institute during the research phase of this project and before the Sucker Rod Pumping Research organization disbanded. The recommended practices developed by this group were eventually published as API RP 11L[2]. These correlations and design practices have been and still are used as the basis for many sucker rod string design programs for conventional pumping units and steel sucker rods.

While there were some process descriptions in the API RP 11L standard, many people developed internal processes and procedures to design sucker rod strings using the API or modified API procedures. Gipson and Swaim provided many workshops and schools, both internal to their employer and external to the industry, as well as developing the "Beam Pump Design Chain[3]" that provided documentation on the practical aspects of designing the sucker rod lift system using RP 11L. This document provided recommendations on the limits of the operating and non-dimensional parameters in this standard as well as formed the basis for many operating companies design process.

As the industry continued to develop and use alternative producing equipment (non-conventional and non-API pumping units along with non-steel sucker rod strings) the industry developed proprietary programs to allow appropriate design. The advent of the Wave Equation[4] and the continued increases in power of personal computer provided many engineers and operators, as well as service company personnel, the ability to easily and quickly design sucker rod strings and do multiple operating parameter studies to determine the effect of pumping speed, stroke length, and pump plunger size on the design loads and equipment sizing. However, the primary parameters and non-dimensional operating parameters developed by the Sucker Rod Pumping Research, Incorporated, still have some validity on optimizing the performance of the rod string.

A few problems were discovered by the authors on what these parameters were and how they should be used during a few past sucker rod troubleshooting schools presented at the Southwestern Petroleum Short Course. Many attendees, both operators and engineers, did not know the fundamentals nor knew about the major non-dimensional operating parameters Fo/Skr and N/No'. Thus, this paper was developed to provide a summary along with a understanding of how these parameters may effect the sucker rod operating conditions. Additionally, design philosophies on limiting the non-dimensional parameters to potentially impact field failures will be discussed.

NON-DIMENSIONAL OPERATING or PUMPING PARAMETERS and DYNAMOMETER CARD PRINCIPLES

There are many symbols, nomenclature and definitions that were developed and used in API RP 11L for the manual design of sucker rod strings. Many of these also are used by modern day, "sophisticated" computer design programs. Some of the basic terms and the unit of measure include the following:

- CBE: Counterbalance Effect, measured at the polished rod at the 90^{o} crank angle, in pounds.
- Er: Elastic constant of the sucker rod string, in inches per pound foot
- Et: Elastic constant of the tubing string, in inches per pound foot
- Fc: Frequency factor, or a constant of proportionality which depends on the sucker rod string design
- Fo: Static fluid load on the gross plunger area, in pounds
- F1: Fluid load on the gross plunger area plus the maximum upstroke dynamic effects, in pounds
- F2: Dynamic effects on the downstroke, in pounds
- Fo/Skr: Dimensionless sucker rod stretch load
- kr: Spring constant of the total sucker rod string, and represents the load in pounds required to stretch the total sucker rod string one inch
- kt: Spring constant of the unanchored portion of the tubing string, and represents the load in pounds required to stretch the unanchored portion of the tubing one inch
- MPRL: Minimum polished rod load, in pounds
- N: Pumping speed, in strokes per minute (SPM)
- No: Natural frequency of the non-tapered sucker rod string, in SPM
- No': Natural frequency of a tapered sucker rod string, in SPM.
- N/No: Dimensionless pumping speed factor for a non-tapered sucker rod string
- N/No': Dimensionless pumping speed factor for a tapered sucker rod string
- PPRL: Peak polished rod load, in pounds
- PRHP: Polished rod horse power
- PT: Peak torque at the polished rod, in inch-pounds
- S: Polished rod stroke length, in inches
- Skr: Total load necessary to stretch the entire sucker rod string length a distance equal to the polished rod stroke length, in pounds
- Sp: Resulting downhole effective pump stroke, in inches
- SV: Standing valve or standing valve load, in pounds = Wrf
- TV: Traveling valve or traveling valve load, in pounds = Wrf + Fo
- W: Total weight of the sucker rod string in air, in pounds
- Wrf: Total weight of the sucker rod string in produced fluid, in pounds

The inter-relationship of these loads and the development of a surface dynamometer cards for a "zero" speed condition and for a speed greater than zero are shown in Figure 1. For the "zero" speed basic surface dynamometer card shown by the dashed line, where N=0:

Peak Polished Rod Load, PPRL = Wrf + Fo
Minimum Polished Rod Load, MPRL = Wrf

As the pumping speed increases greater than 0, N>0, then the dynamic effect F1 result in an increase in the PPRL on the upstroke and the dynamic effect F2 on the downstroke results in a decrease in the MPRL. When N>0 the PPRL at the surface is greater than Wrf + Fo due to the dynamic effects of stretching the rods sufficiently to apply Fo at pump. The MPRL is less than the weight of rods in fluid due to the dynamic effects on the down stroke due to transferring the Fo carried by the traveling valve onto the standing valve.

When the industry and the Midwest Research Institute developed the rod string design for multiple production rates (up to 1500 bpd), for any depth (from 2000 to 12,000 ft.), using various size pump plungers, surface stroke lengths and pumping speeds, etc., many representative surface dynamometer cards were developed to show the resulting rod string operating loads and stroke length. API Bull 11L2 provides a catalog of these various cards[5]. This reference contains many pages of analog surface dynamometer cards representative of most possible pumping conditions.

One of the advantages of knowing and using the major speed, N/No', and load, Fo/Skr, non-dimensional pumping parameters, is that a "suite" of typical surface analog dynamometer cards can be displayed that describe a wide range of operating conditions. This suite of cards showing the effect of non-dimensional speed changes ranging from 0.1 to 0.5 and non-dimensional load changes ranging from 0.1 to 0.6 is shown in Figure 2. In Figure 2 as pumping speed increases going up the N/No' axis, for a given load factor, the dynamometer card shape changes with increased area and decreased MPRL. Similarly, for Fo/Skr, as the non-dimensional load increases for a given speed factor, the dynamometer card area and the PPRL increases. Card area represents the PRHP, work done at the surface, and the area is important since it shows as these dimensionless parameters increase the work done at the surface increases. Each surface card is a plot of the polished rod loads at the various positions during a complete upstroke and downstroke cycle versus the polished rod position.

Modern predictive software using well conditions as input can also be used to displayed surface dynamometer card shapes that describe a wide range of operating conditions. Figure 3 shows the QRod[6] predicted surface dynamometer cards for both the anchored tubing and the unanchored tubing cases. Notice that the kr slope, the spring constant of the total sucker rod string, is seen in the initial slope at the beginning of the upstroke on the surface dynamometer card for anchored tubing as the F1 force is being applied at the surface over a certain portion of the upstroke. Notice that the kt slope, the spring constant of the unanchored portion of the tubing string, is shown at the beginning of the upstroke in the pump card as fluid load is transferred from the tubing back onto the rods where the tubing compresses and moves relative to the rods. A predictive program solves for the surface/pump dynamometer cards using a damped wave equation model over the time for one cycle. The solution of the wave equation requires input of the polished rod position as a function of time and description of pump loading as a function of pump position. The resulting pump card is a plot of the fluid load the pump applies to rod string as a function of the downhole pump stroke length. On the upstroke the fluid load, Fo, is due to the differential pressure acting on the gross cross-sectional area of the plunger [Ap] and Fo can be calculated as: Fo = (Pdis - Pintk) * Ap. The differential pressure, (Pdis - Pintk), is difference between the discharge pressure (pressure at the pump discharge into the tubing), [Pdis], and the pump intake pressure, [Pintk]. On the downstroke the differential pressure across the plunger is near zero and the pump card sets on the zero load line. The predicted surface dynamometer cards are very similar to the analog API RP surface dynamometer cards when the predictions are done using the same operational conditions.

Figure 4 shows these two card traces along with the major rod string loads, the inter-relationship between the development of these loads and some of the design operating parameters. This surface dynamometer data was collected using a dynamometer system mounted at the polished rod of the well to acquire both load and position through out one complete cycle. The surface dynamometer card is labeled to show, the F2 load subtracted from the Wrf (or SV load) to obtain the MPRL. The TV measured load is the combination of the Wrf plus the Fo load. The addition of dynamic effects on the upstroke or the F1 load is added to the Wrf to obtain the PPRL. The Fo from the pump card should be near the Fo from Fluid Level line, when the pump intake pressure is determined by acquiring a fluid level. Fo Max line represents the load on the plunger with no help from the reservoir pressure, assuming that the pump intake pressure is zero. Fo from the pump card should be compared to the Fo Max line, if Fo is not close to the Max line then the pump intake pressure may be too high with the well not being produced near its maximum rate. Finally, the Sp of 155.9 inches is shown in the pump card versus the surface stroke of 168 inches along with the Fo load. The diagnostic wave equation uses the measured surface dynamometer data as input and uses a model for the damped rod string to calculate the loads and position applied to the rods at the pump depth (or at any depth between the pump depth and the surface). The diagnostic wave equation model takes all of these various surface conditions and conditions along the rod string into account to determine what is happening at the downhole pump. Diagnostic and predictive software display surface dynamometer cards for the purposes of designing and diagnosing the sucker rod pumping systems. The primary use of the pump dynamometer card is to identify and analyze downhole problems and the primary purpose of the surface dynamometer card is to identify and analyze surface problems. Thus, in order to properly troubleshoot a sucker rod pumping installation, both surface and pump types of dynamometer cards are important to obtain and analyze.

OVERTRAVEL
Overtravel is caused by the dynamic motion of the beam pump system adding momentum to the rod string, resulting in the pump stroke length increasing over static conditions. Figure 5-7 are predicted for a 5000 foot deep well, with a 2 inch diameter pump, anchored tubing, 76 API Designation rod string, 100 inch surface stroke, 50 psi pump intake pressure, water tubing fluid gradient, and the strokes per minute, SPM, from near 0 through 10.7.

Figure 5 is the predicted dynamometer cards at pumping speed of approximately N=0 SPM, when at 0 SPM there is no overtravel. The fluid load, Fo, applied to the rods by the differential pressure acting across the pump plunger is equal to 6,896 lbs. The predicted, MPRL, minimum polished rod load of 8,278 lbs is equal to the weight of the rods in fluid, Wrf. The predicted, PPRL, peak polished rod load is 15,196 lbs. At near zero SPM the MPRL is approximately equal to the weight of rods in fluid, Wrf, and the PPRL is approximately equal to the weight of the rods in fluid plus the fluid load. Fo/Skr for these well conditions is calculated to be 27.1%. The pump stroke, Sp, is 72.8 inches, which is 27.1%, Fo/Skr, less than the 100 in. surface stroke, S. These 27.1 inches of lost surface stroke is due to the rods stretching 27.1 inches in order to pickup the 6896 lbs fluid load applied to the rods by the pump. The rod string has a 254 lb/in spring constant, kr, based on the lengths and diameter of the rods that make up the rod string taper. kr means that the rods will stretch 1" when 254 lbs of fluid load is applied to the rod string. Fo/Skr represents the decimal fraction of the surface stroke lost to rod stretch required to pickup the fluid load.

As the pumping speed increases to speeds greater than 0 SPM then dynamic effects generally result in an increase in the PPRL on the upstroke and a decrease in the MPRL on the downstroke. The PPRL is greater than Wrf by a dynamic surface force, F1, required to apply Fo force at pump. The MPRL is less than the weight of rods in fluid due to a dynamic surface force, F2, transferring the Fo carried by the traveling valve to the standing valve.

Figure 6 shows the dynamometer cards predicted at a pumping speed of N=5 SPM. The change in the PPRL and MPRL is predicted with the same conditions as previously described, but only increasing the speed to 5 SPM. This increased SPM results is a F1 load of 8700 lbs above the weight of rods in fluid to increase in the PPRL to 16,988 lbs. The dynamic F2 force of 1775 lbs reduces the MPRL below the weight of rods in fluid to 6,513 lbs. Plus, the pump stroke increases from a static stroke of 72.8 inches to 74.6 inches, due to 1.7 inches of overtravel.

Figure 7 shows the predicted loads on the API 76 rod string when loaded to 100% of the Allowable Modified Goodman stress range, when 100% loading condition is due to increasing the pumping speed to N=10.7 SPM. This increased SPM results is a F1 load of 11,378 lbs above the weight of rods in fluid to increase in the PPRL to 19,666 lbs. The dynamic F2 force of 4,100 lbs reduces the MPRL below the weight of rods in fluid to 4,188 lbs. Now at this speed the overtravel of the rod string has increased to 13.8 inches with an effective pump stroke of 87.1 inches.

Figures 5-7 may be used to analyze the theory behind pumping speed change using the resulting predicted dynamometer surface and pump cards. Note that the 0 spm case shows the surface card parallelogram similar to the Figure 1, where the API RP publication showed the dashed line representing a dynamometer card for N=0 SPM. A summary of the major design loads and some of the operating parameters are provided below the figures. The surface card PPRL increases and MPRL decreases as the pumping speed increases from N=0 to N=10.7 SPM. The effective bottomhole pump stroke length, Sp, increases from 73.2 to 87.1 in. completely due to plunger overtravel resulting from the increasing the N/No' ratio as shown by the suite of cards in Figure 2, while the static stretch remained constant for the Fo/Skr of 0.271 (for these predicted dynamometer cards the rod string, surface stroke, and fluid load on the pump did not change). The increased travel with increased speed compared to the zero speed case results in an overtravel condition. The output from the program shows the overtravel amount increases from 1.7 inches at N = 5 spm to 13.8 inches at N =10.7 SPM. Thus, in general some overtravel should be anticipated in all sucker rod pumping systems since the pumping units are operated at a speed greater than zero.

The natural undamped frequency, No, of a straight uniform diameter rod string is calculated by the equation:

$$No = 15\ V_S/L$$

Where: V_S = Velocity of sound in steel, 16,333 ft/sec, L = Length of Rod String, Feet

The natural undamped frequency, No, is equal to 48.9 SPM for the 5000 foot length rod string for these predicted example dynamometer cards. The natural frequency of the rod string should be adjusted for the impact of the taper, No', where No' = No x Fc according to the API RP 11L and Fc is equal to 1.093. The No' for a 5000 foot length 76

API rod string is 53.4 SPM. For the example SPMs of 0, 5, and 10.7 the associated N/No' dimensionless ratios are 0, 0.094, and 0.200. In Figure 8 the API RP 11L nomograph of Sp/S vs. N/No' is shown and the nomograph Sp/S ratio compare well with the Sp/S predicted using the wave equation.

OVERTRAVEL and UNDERTRAVEL DISCUSSION

Figure 9 provides an example diagnostic measured surface card and predicted pump card having a high N/No' due to relatively fast pumping speeds. This example is classified as an overtravel condition where the downhole Sp is longer than the surface stroke. The 13.74 fast SPM causes increased dynamic effects which increase the card area and load range (the difference between PPRL minus MPRL). Also, these conditions cause the surface card shape and general axis to slope down from left to right. For the example provided, the Sp is approximately 10% more than the surface stroke length. The general shape of overtravel cards can be observed in a number of surface card conditions or problems. These include: parted rods, flowing wells, unseated pumps, gas locked pump, worn pumps, and from installing fiberglass rods downhole.

Figure 10 provides diagnostic measured surface card and predicted pump card having conditions related to undertravel. Undertravel occurs when the downhole Sp is less than the surface stroke length (usually due to high Fo/Skr ratios). The general surface dynamometer card axis slopes up from left to right. The undertravel condition is due to rod stretch from the applied fluid load, downhole friction, or other reasons. For this example, the downhole static stretch is approximately 40.0 inches, effectively shortening the downhole Sp. The general shape of undertravel cards can be observed in a number of other surface card conditions or problems. These include: stuck pumps, plunger is too large for the rod string, sand or scale problems, too tight stuffing box packing, and/or paraffin/asphaltene problems.

In summary, is overtravel good or bad? Overtravel could be considered good since pump displacement is increased due to the increased downhole plunger stroke length. However, it could be considered bad since failures tend to increase with increased pumping speed. As with most things in the oil field, there probably is an optimum pumping speed and related N/No' in the range of 5 to 10 spm where there is some overtravel but not too much overtravel to result in an increased failure rate.

NON-DIMENSIONAL OPERATING PARAMETER USE IN DESIGN

The sucker rod computer programs should provide output results that include the primary design and operating parameters. These include PPRL, MPRL, SV load, TV load, PT at the polished rod, and PRHP. However, a recent paper comparing a number of computer programs used for design found that not all programs provided these necessary design loads and not the major non-dimensional operating parameters of N/No' and Fo/Skr.[7] Since publishing this paper, a number of companies have made positive changes to include these parameters, but, not all programs display all of the parameters.

Why is it essential to display these loads and non-dimensional parameters? Display of the non-dimensional operating parameters allows the comparison of the diagnostic measured dynamometer data to the predicted dynamometer data in a case by case basis. Comparing diagnostic to predicted dynamometer data highlights where there are differences and allows the user to try to determine what is causing the differences. Additionally, it is easier and less costly to adjust the computer program input data and try changes in the design to determine what should be done to optimize the well versus making field and well changes.

An example of where these non-dimensional pumping parameters have been used is shown graphically in Figure 11 and 12. Figure 11 shows contour lines that were used by the sucker rod design program of Company J. When a rod string was designed by Company J, the design software would alert the designer that his design was acceptable or if outside the red line, then the design program would not allow the rod string design to be displayed. Company J belief was by adhering to these design limits led to a long lived sucker rod strings. Sucker rod designs by Company J using this technique tended toward slower in SPM and longer in stroke length. Another operating Company H had the sucker rod design philosophy of keeping the dimensionless parameters with-in the bounds of 0.2 to 0.35 N/No' and 0.2 to 0.5 Fo/Skr. With respect to N/No' and Fo/Skr the permissible sucker rod designs by Company J and H methodologies were exclusive of each other. Company J would not accept rod designs by Company H, nor would Company H accept rod designs by Company J. But both companies's believed that their proprietary sucker rod design practices led to long operational life. Company H bounding of N/No' was based on recommendations from Howell and Hogwood[8], that to obtain the best efficiency from motors, N/No' should be greater than 0.20. However, the N/No' should not exceed 0.35 since it becomes more difficult to counter balance the pumping unit. Company H minimum and maximum for Fo/Skr was to balance the cost of the pumping equipment versus the cost of operating failures.

Failure frequency results from the Artificial Lift Energy Optimization Consortium, ALEOC, for 11 operators in the Permian Basin was obtained and provided by Texas Tech University[9]. These failure frequencies provide the number of sucker rod, pump and tubing failures per well per year and included data from over 25,000 producing wells. Figure 13 shows the failures frequencies per year along with the average and one standard deviation for the companies providing their failure data. Even though Company J and H had very different rod string design practices concerning permissible Fo/Skr and N/No' values, it is interesting to note that both companies had failure frequencies of approximately 0.4. The 0.4 failure frequency was the lowest of all the operating companies in the ALEOC study.

While there was a difference in approach to using the design and non-dimensional operating parameters, both of these companies at least had a design philosophy. However, probably equally or more importantly, both companies:

- Had an active program where production technicians
    - Acquired field data
    - Analyzed problems, and
    - Followed-up recommendations
- Practiced a "company" methodology to analyze, troubleshoot and optimize wells
- Tracked causes and condition of downhole failed equipment in an internal proprietary failure date base
- Determined root cause failure analysis and made appropriate repairs and changes to prevent future failures.

SUMMARY and CONCLUSIONS

1. The minimum rod string design results (PPRL, MPRL, SVL, TVL, PRHP, and PT) should be provided from the design program.
2. The two major non-dimensional pumping parameters (N/No' and Fo/Skr) should be provided from the rod string design program to determine where in the suite of cards, the design conditions are located.
3. While the differences in the design philosophy for using these parameters resulted in similar failure frequencies, they were useful to limit conditions that may increase failure rates. Both company J and H agreed that too much overtravel or too much undertravel will result in reduced rod string life.
4. Being a prudent operator analyzing, properly redesigning, repairing and optimizing wells should be conducted if low operating costs, optimum production and maximum well and field value are important.

ACKNOWLEDGEMENT

The authors appreciate their respective management for allowing this to be presented and published.

REFERENCES

1. Mills, K.N., "Factors Influencing Well Loads Combined in a New Formula," *Petroleum Engineering*, April 1939.
2. API RP 11L; "Recommended Practice for Design Calculations for Sucker Rod Pumping Systems," American Petroleum Institute, Washington, D.C., Fourth Edition, 1988.
3. Gipson, F.W. and Swaim, H.S., "Beam Pump Design Chain," Second Edition, 32nd Annual SouthWestern Petroleum Short Course, Texas Tech University, Lubbock, TX, April 1985.
4. Gibbs, S.G, "Predicting the Behavior of Sucker Rod Pumping Systems, *JPT*, SPE, 1963, pp 769-778.
5. API RP 11L2; "Catalog of Analog Computer Dynamometer Cards," American Petroleum Institute, Washington, D.C., 1969.
6. Jennings, J. W., "QRod a Practical Beam Pumping Design Program", SWPSC, Lubbock, TX, 1994
7. Hein, Jr., N.W. and Stevens, R., "A Current Comparison of Sucker Rod String Design Programs, 51st Annual SouthWestern Petroleum Short Course, Texas Tech University, Lubbock, April, 2004.
8. Howell, J.K and Hogwood, E.E., Electrical Oil Production – An Engineering Text, The Petroleum Publishing Company, 1962.
9. Heinze, L.R., Rahman, M.M., and Ge, Z., "Sucker-Rod Pumping Failures in the Permian Basin," SPE paper number 56661, SPE ATCE, Houston, TX., 3-6 Oct., 1999,

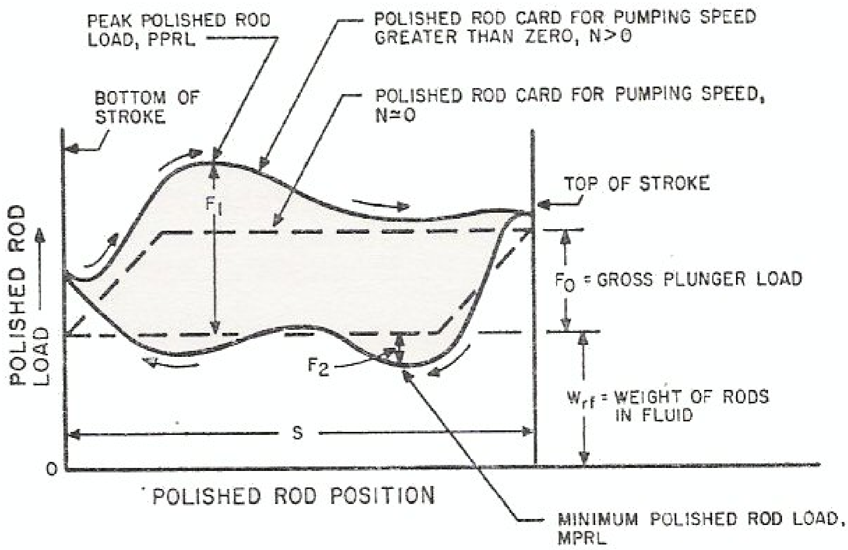


Figure 1. API RP 11L surface dynamometer sketches showing fundamental relationships from analog sucker rod string operating parameters and polished rod cards for pumping speed (N) $\simeq$ 0 and the dynamic effects on card shape when N > 0.

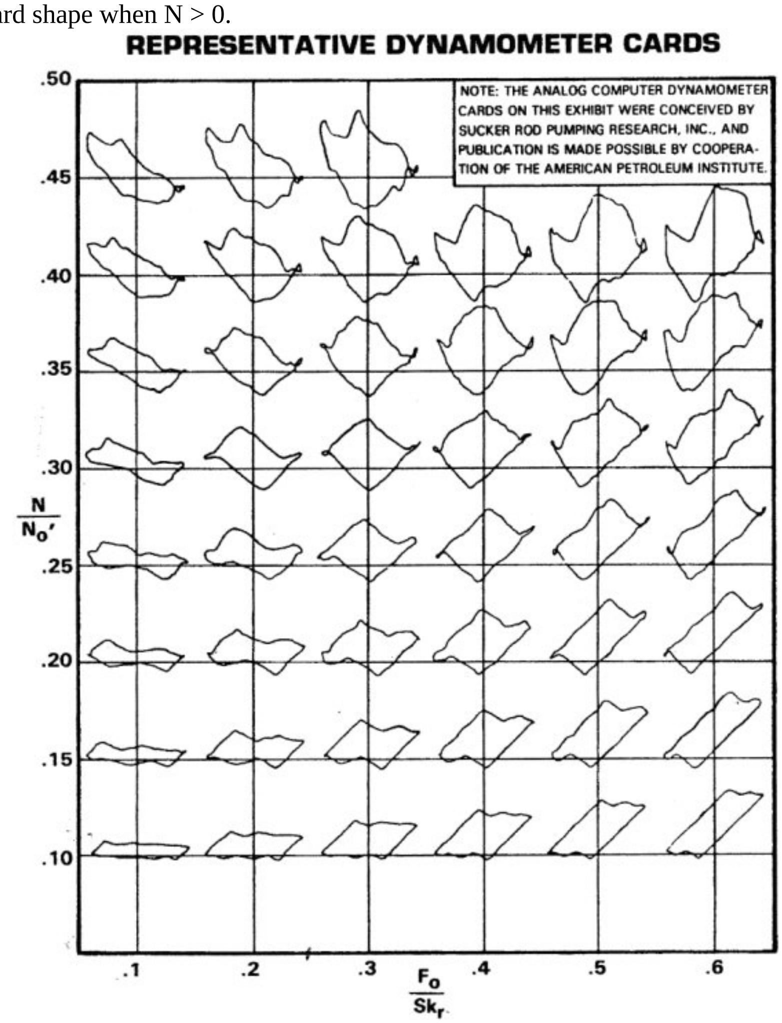


Figure 2. Suite of analog dynamometer cards from API Bull 11L2 showing non-dimensional pumping parameters and the effect on card shape. Ref. 5.

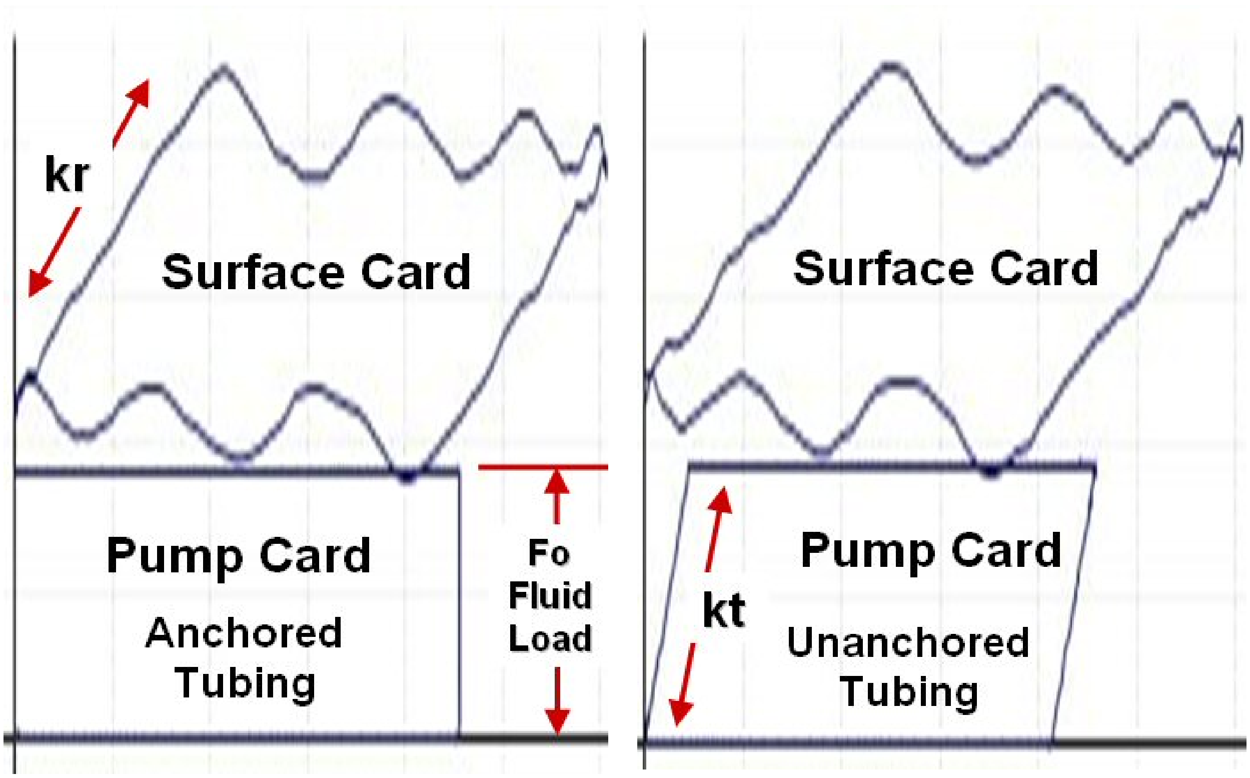


Figure 3. Example of Predicted Surface Dynamometer from Pump Conditions for Anchored and Unanchored Tubing.

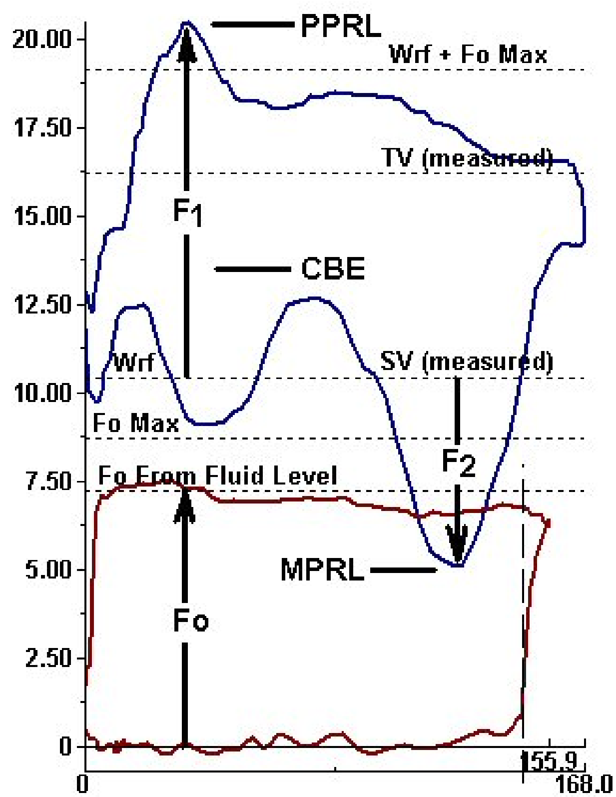


Figure 4. Surface dynamometer (upper trace) and downhole (lower trace) pump card loads showing relationship of the major sucker rod string loads and some operating parameters.

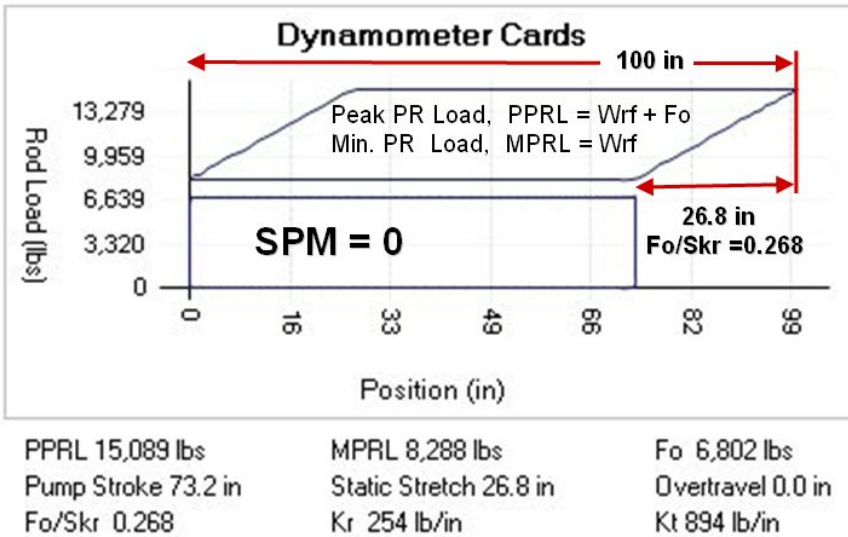


Figure 5. Example well surface and pump cards and loads with N = 0 spm

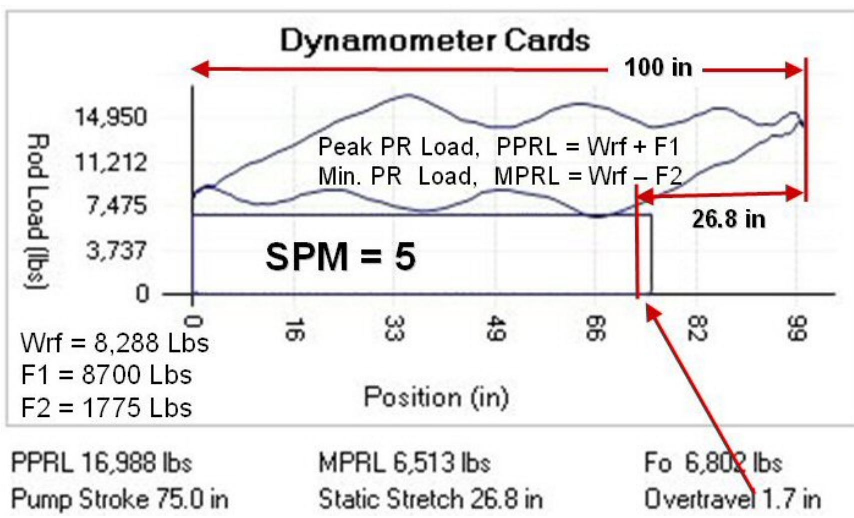


Figure 6. Example well surface and pump cards and loads with N = 5 spm.

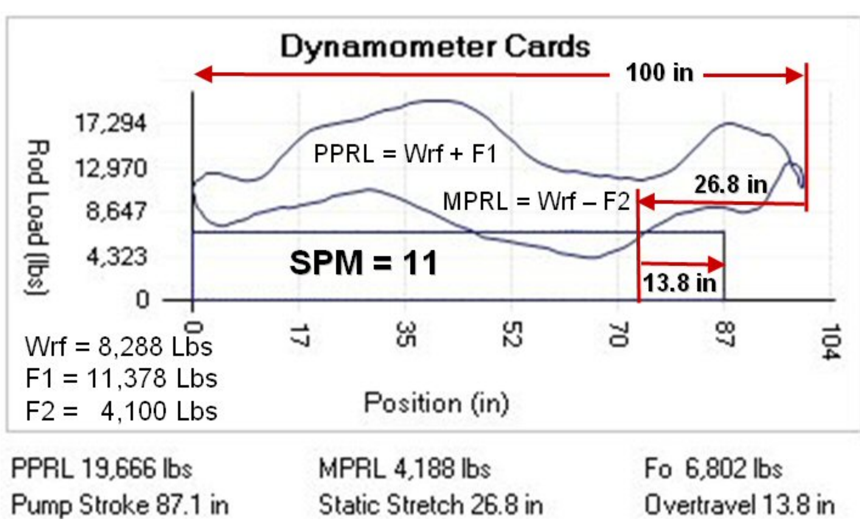


Figure 7. Example well surface and pump cards and loads with N = 10.7 spm.

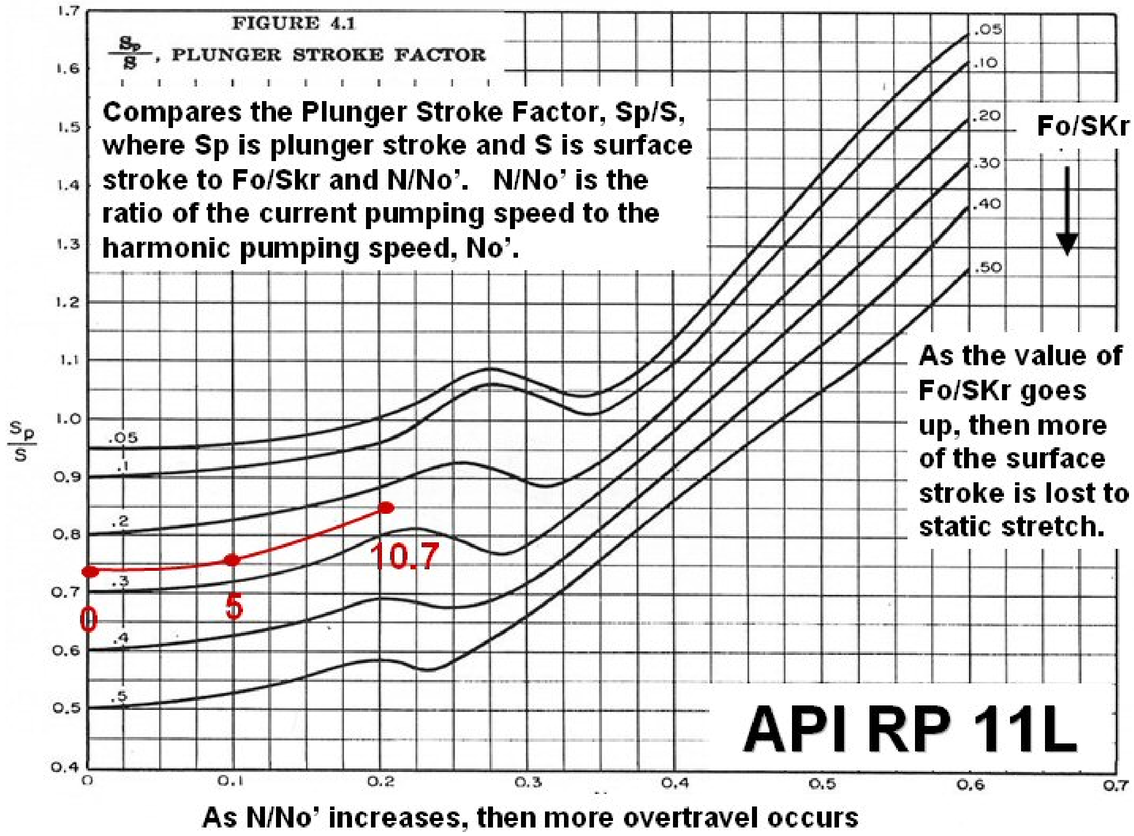
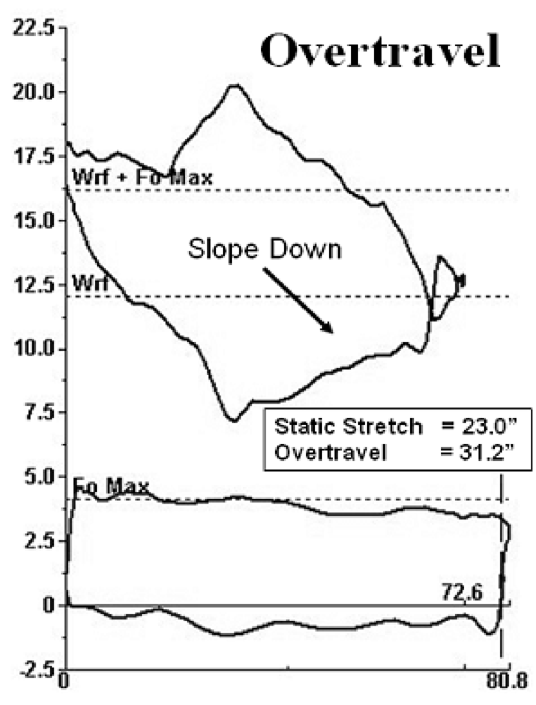


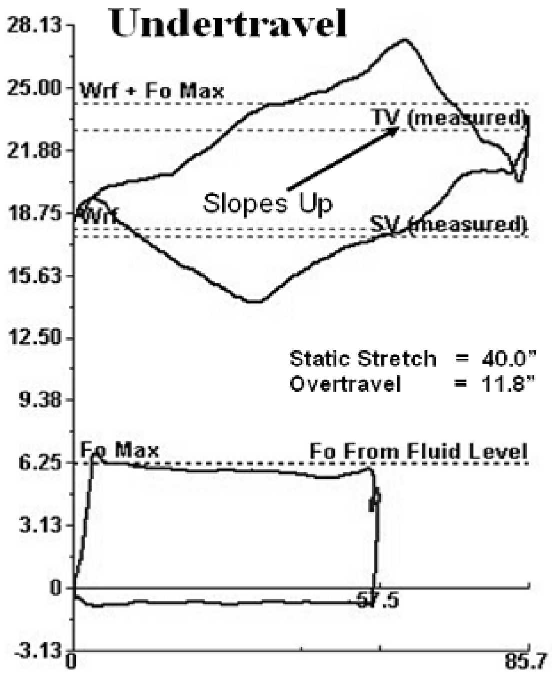
Figure 8. API RP 11L Sp/S vs. N/No'



Overtravel Plunger stroke is usually longer than surface stroke. Surface card slopes downward from left to right. Example: The 80.8" plunger stroke is *more* than the 72.6" polished rod stroke. The surface stroke is reduced by 23" of rod stretch required to lift the fluid load. The 13.74 SPM adds momentum to the rods increasing stroke by 31.2" inches. Overtravel cards include: parted rods, flowing wells, unseated pumps, gas locks, worn pumps, fiberglass rod strings or pumping at a very fast SPM.

76 Rod String + 250' Wt. Bars
1.25 " Diameter Plunger
7054 Pump Depth

Figure 9. Overtravel surface and pump cards and loads with discussion of overtravel.



Undertravel Surface card slopes upward from left to right. The pump plunger moves ***less*** than the plunger stroke. Undertravel is due to rod stretch from fluid load, downhole friction or other reasons. Undertravel cards include: stuck pumps, ***plunger is too large for the rod string***, sand or scale problems, too tight stuffing box and/or paraffin.

Example

86 Rod String + 150 WT Bars
1.5 " Diameter Plunger
9317 Pump Depth
6.69 SPM

Figure 10. Undertravel surface and pump cards and loads with discussion of undertravel.

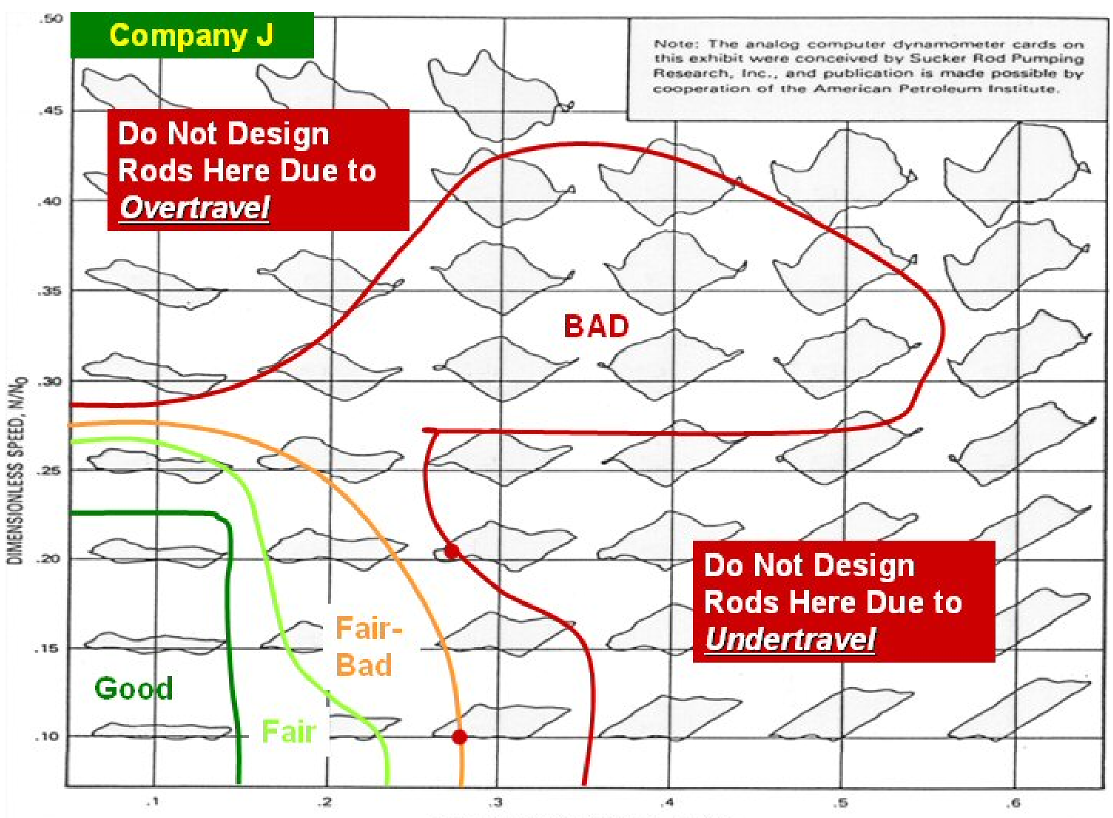


Figure 11. Company J Rod String Design Limits bounds for N/No' and Fo/Skr.

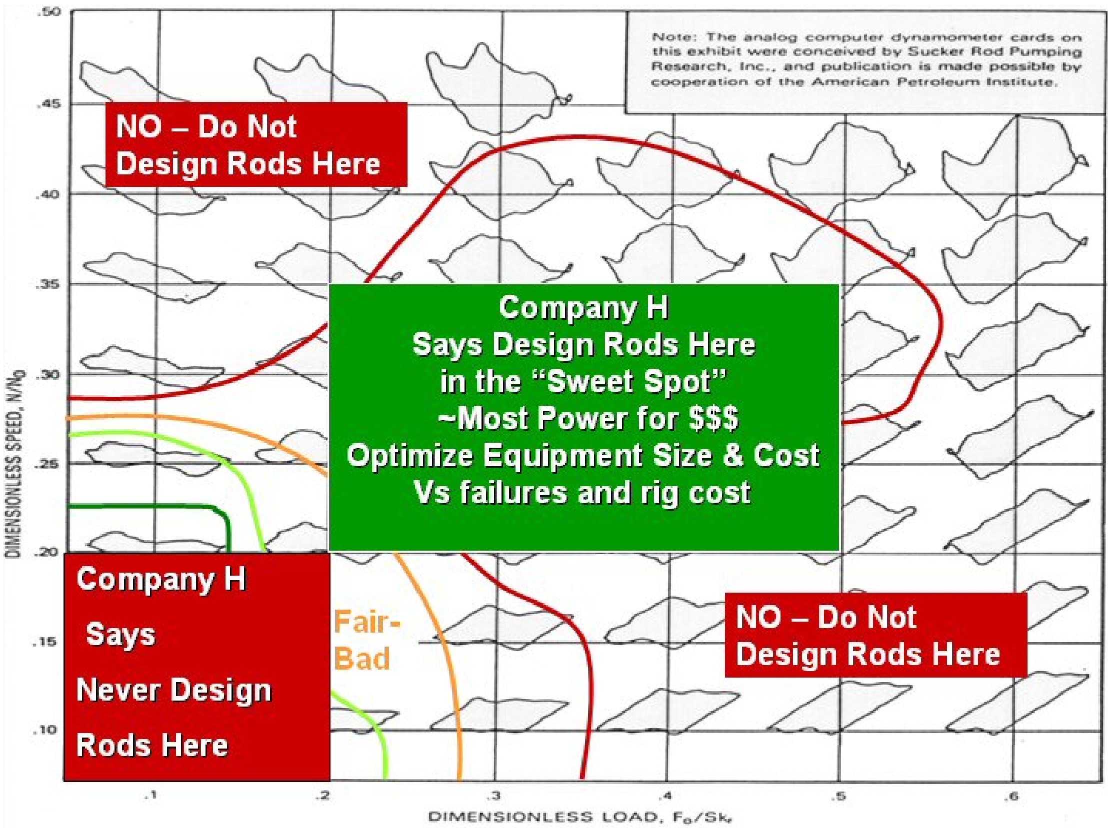


Figure 12. Comparison of two different companies recommended sucker rod non-dimensional operating parameter Company H; bound by 0.2 to 0.35 N/No' and 0.2 to 0.5 Fo/Skr

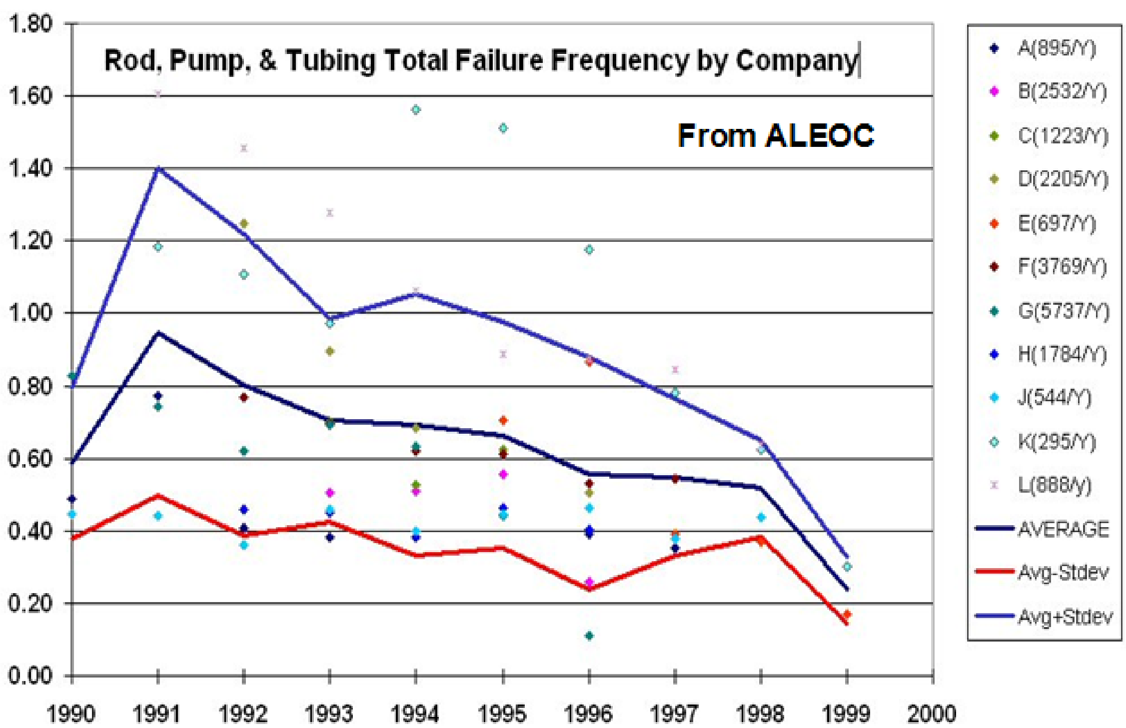


Figure 13. ALEOC total sucker rod equipment failure frequency vs. year data provided for the member companies which also show company H and J similar failure frequencies even though different rod string design philosophy. Ref. 9.