EFFECTIVE LOADS FROM SANDIA DOWNHOLE DYNAMOMETER TESTING

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ABSTRACT

The Electronic Downhole Load Cells DHLC, was used during the mid-1990s to acquire downhole dynamometer data. This unique DHLC was mounted at a desired location in the rod string (usually between two rod tapers). Dynamometer data was collected while the well operated. SANDIA coordinated collecting DHLC data on six (6) different types of wells. The petroleum industry provided the wells and SANDIA collected, de-coded and presented the data. NABLA and others concurrently acquired the surface Dynamometer measurements. DownDYN software developed by SANDIA was used to display and export the collected data.

The dynamometer data acquired at each rod taper for each well will be displayed. The DownDYN software is no longer supported by current Windows Operating system. This valuable information will be lost, if the DownDYN software is not modernized. Downhole Load Cell data measured at the pump resolved the display of the downhole pump loads. This paper will discuss the true/effective load argument for display of downhole dynamometer data.

Introduction

The Electronic Downhole Load Cells (DHLC) is used to measure rod loading and other parameters. The DHLC tools were developed by Glen Albert Engineering[1]. Albert Engineering (AE) manufactured and provided the DHLC tools as a service to industry. The tools used to acquire the sets of field tests were upgraded by AE under contract to Sandia National Laboratories to provide a fairly complete and high quality measurement of downhole sucker rod pumping dynamics. The DHLC is unique because it can be mounted at a particular location in the rod string (usually between two rod tapers) and the dynamometer data can then be collected while the well is operating. In 1996 SANDIA coordinated collecting data using the DHLC for different types of well conditions. The petroleum industry provided wells and paid for the installation cost to run the DHLC. SANDIA and Albert Engineering collected, de-coded and presented the data. NABLA and others provided the surface Dynamometer measurements at the same time as the DHLC collected data in the well.

Downhole Dynamometer Database Program - DownDyn

The Downhole Dynamometer Database contains data acquired during tests made on six (6) different wells using both a surface dynamometer and a number of different downhole dynamometer load cells. This collected data is contained in data files managed by a program called DownDyn. The DownDyn program allows the user to: 1) select a well's data file, 2) select specific information from the file, 3) plotting data or 4) exporting the information. **Fig. 1** shows the primary DownDyn screen being used to select well_5a available in the database, an acquisition test conducted on 07/31/96, and selection data acquired from Tool2 Above the pump at 4993 feet. Following are the available wells stored in the database:

RMOTC	May, 1995	(well_1)
Fiberglass ‘	Oct, 1995	(well_2)
Rotaflex	Feb, 1996	(well_3)
Speed Change	Mar, 1996	(well_4)
Gas Separator (a)	Jul, 1996	(well_5a)
Gas Separator (b)	Jul, 1996	(well_5b)
Tension Pump	Dec, 1996	(well_6)

Once a particular well's dataset is selected there are many types of plots of data that can be produced. The two primary display types are to plot load versus position to create a dynagraph or plot of measured data versus time. **Fig. 2** is an example plot of downhole showing motion of the rod string for data acquired on 08/04/96 10:00:00 AM from Tool #2 positioned above the pump at a depth of 4995 feet. The rod velocity and position data were determined by integrating the acceleration data acquired by the tool. For a time dependent graph, one or more of the following variables can be plotted on the y -axis: axial acceleration, velocity, position, lateral acceleration #1, lateral acceleration #2, load #1, load #2, load #3, pressure, and temperature. As plotted and exported time is in units of seconds, acceleration is in units of inches/second squared, velocity is in units of inches/second, position is in units of inches, load is in units of pounds of force (lbf), pressure is in units of pounds per square inch and lateral acceleration is in usits of g (32.2 ft/sec squared).. For some tools ran is a well all of this data may not be available, for example a tool ran below the pump would not have usable acceleration data if the tubing were anchored and there were no tubing movement.

The downhole dynamometer records data are over a time interval longer than one stroke. When plotting a downhole dynagraph, the data plotted is a section of the data beginning at the plot start time lasting for the time interval of one stroke. For a time dependent plot, the length of this window is determined by the plot duration. The sampling speed and the spampling time duration of a particular test is shown when a test is selected for analysis.

There are five downhole dynamometer tools. Data is not available from every tool for every test. The tool selection box gives information as to the depth of each tool. The description file for each well gives a complete description of the rod string design and locations of the tool. In the Appendix is a partial 1 page out of 4 pages showing an example of the well description file for well_5a.

The DHLC tools were housed in a 1.75 OD by 13.5 long pump barrel extension. With the end fittings (3/4 API sucker rod pins exposed), the shoulder-to-shoulder length is 20.375 inches. The lower end fitting has been modified to allow a pressure transducer inside the housing to measure fluid pressure outside the DHLC. The DHLC tool has been pull tested to 39,640 lbs ultimate tensile strength, with failure occurring in the barrel threads. In practice, 25,000 lbs is considered as the operational limit on the DHLC to allow some margin of safety during the pulling operation.

Reason to Participate in DHLC Project

Amerada Hess participated in the Sandia DHLC project and provided SSAU 4115 well to SANDIA for the purpose to run the DHLC. The test was identified as "Downhole Dynamometer Testing Gassy Well w/separator on Amerada Hess Corporation SSAU 4115 well". In this study a series of test were made by installing the DHLC at each of the rod tapers, just above the pump and just below the pump intake. On August 04, 1996 data was collected on Amerada Hess Well SSAU 4115 using the DHLC. The particular dynagraph referenced throughout this paper comes from the test on 08/04/96 at 10:00:00 AM from DHLC #2 approximately 2 feet above the pump at a depth of 4993 feet. The collected data is displayed in both True and Effective load for the dynamometer cards as shown in **Fig. 3**.

Fig. 3 displays the same dynamometer trace for the effective load and the true load for a 0.75-inch diameter rod at the pump depth. The DHLC had exposed end fittings of a 3/4 API sucker rod pin, therefore using the ¾ rod to determine the true load is reasonable. The height of the pump card is the fluid load, Fo, of 1833 pounds applied to the rods by the pump is same for true or effective load. The true load is dependent on the diameter of the rod carrying the load, the larger the diameter the more negative the displayed true load. The effective load is equal to the force applied to the rods by the pump and remains the same independent of the rod diameter.

Where: **True Load = Effective Load – Buoyancy Force** **(1)**

One of the objectives for Amerada Hess, AHC, to participate in the DHLC project was to resolve the display of the downhole pump card. Analysis of the actual DHLC measured pump card would be used to verify the accuracy of the effective downhole pump card calculated from the AHC internally developed diagnostic wave equation program.

Effective versus True Load

In 1963 Sam Gibbs[2] published the wave equation without the gravity term, as stated in the paper leaving out buoyancy had no impact on the wave equation calculated dynamic pump loads. The paper further states the solution of the wave equation without the gravity term results in the pump card being plotted below the zero load line by the missing fluid buoyancy force. The buoyancy force as defined long ago by Archimedes is equal to the weight of the volume of fluid displaced by an object; this object is well_5a's entire rod string. **Fig. 4** shows the effective SANDIA pump card shifted below the zero load line by the 1226 pound Archimedes buoyancy force acting on the SSAU 4115 well's entire rod string volume.

In 1993, J. F. Lea[3] published SPE paper 25416 to explain that the effective forces and not the true forces that determine whether a sucker rod will buckle. The true load represents the actual axial force felt by the molecules in the internal structure of the steel rods and is negative due to being shifted below the zero load line by the buoyancy force. Negative true loads will not cause the sucker rods to buckle because when the rod is deflected, there is a restoring force from the pressure exerted by the surrounding fluid on the rod body.. However, the effective force is the force that determines if the rod will buckle, when the effective load becomes negative the rods can/will buckle.

In Lea's paper the concept of true and effective loads relationship is defined as:

True Load = Effective Load – PoAo (2)

Where:

Po = external pressure at the depth of the DHLC
Ao = cross sectional area of the sucker rod at the depth of the DHLC.

PoAo = Buoyancy Force…………………….(3)

Eq. 3 is only true for the entire rod string, if the rod string is vertical (not in a deviated well) and the rod string is a constant diameter from top to bottom of the rod string. If a tapered rod string is in the well and the bottom rod is a 1.5 inch diameter weight, then **Eq. 3** will calculate a very large buoyance force due to the assumption that the entire rod string is 1.5 inches in diameter.

Display by the DownDyn. Software of the DHLC downhole pump cards has changed over time. The original data was presented as effective load. The second revised display of data was presented in terms of true load, but every rod diameter in the taper was treated as the size of the 0.75 inch diameter of 3/4 API pin connections on the DHLC. The last true load presentation showed the downhole dynamometer pump cards with large negative loads when true loads were calculated based on actual rod diameters. When 1.5 inch diameter weight bars were used to calculate the rod area, then the very large negative true loads resulted in additional confusion. To correct the confusion in 1998 SANDIA modified the DownDyn program to display effective loads by default and only display true load if the user enters a specific rod diameter. **Fig. 5** compares the effective load to the true load at the same depth based on a rod area of a ¾ inch rod, a 1.5 inch rod and the rod string with Archimedes buoyancy removed. There is only one effect load, but there can be many (infinite number) true loads at the same pump depending on the rod area used in the calculation of the **PoAo** buoyancy force.

Effective load is continuous at changes in rod string diameter and the use of effective load avoids the question as to whether the load reported applies to the rod diameter above or below the DHLC or to an unspecified nominal rod diameter. Effective load also allows the loads measured by the DHLC below the pump and above the pump to be reported without impact due to rod area. All data exported by the final DownDyn program are in terms of effective loads. In addition to displaying effective load, the revised DownDyn program provides true load as an option (click Plot True Load under Load Options) **Fig. 6**. To use this option, the user must input the specific rod diameter for the true load to be calculated. **Eq. 2**.

Reference Loads Line for Diagnosing the Pump Card

The fluid load, Fo, the pump plunger applies to the bottom of the rod string fluid is directly related to difference in pressure above minus the pressure below the plunger multiplied by the plunger area. The zero load line is a reference line that aids in the diagnostic analysis of the pump card shape. This zero load reference load line can be calculated independently from the pump card shape. The effective load pump card calculated using the diagnostic wave equation from the measured surface dynamometer card's load and position should result in the pump load on the down stroke setting very near the zero load line.

During the down stroke if the standing valve were closed and the traveling valve were open, then the reference load line of zero exists. The effective load pump card load during the down stroke sets on the Zero Load reference line and positioned on 0 load signifies that the pump plunger applies no load (Zero) to the rod string during the down stroke when the TV is open and the SV is closed. The assumption in the calculation of the Zero Load Line is that very little pressure drop occurs through the open traveling valve. When the effective pump card plots below the zero load line, then excessive friction or possibly pump friction could result in the rod string buckling during the down stroke.

Effective DHLC Loads During the Down Stroke

Examination of the 6 downhole effective pump cards extracted from the Downhole Dynamometer shows (3 out of 6) 50% have small negative effective loads during the downstroke. The sucker rod string behaves as long slender Euler column, where rod buckling can occur under even the very small negative effective loads. When the sucker rods buckle during the downstroke then excessive rod on tubing wear will result in holes in tubing and increased sucker rod failures. **Fig. 7-12** show the effective load DHLC pump cards. Even though the negative loads for the three wells is small (-58, -93 and -34 pounds), excessive rod on tubing wear is expected if weight bars are not ran in the wells. If any compressive load is applied to the rods by the pump, then the very long slender sucker rod column begins to buckle; and would buckle to failure if intermediate support were not provided by the tubing. Buckling to failure does not occur in sucker rod strings, because the mode of buckling increases to cause the critical buckling load of the long column to be greater due to intermediate support to the rods provided by the tubing. Bracing of the sucker rod string by the tubing prevents buckling to failure of the sucker rods. Bracing of the tubing (rod contact onto the tubing) increases the critical buckling load above any compressive force applied to the rod string. If the ¾ inch rods touch the tubing in 3 places due to bucking, then the compressive force on the rods is 200 lbs. The pump card does not usually show this negative load. This small negative load is difficult to identify. When the rods buckle then the tubing supports/absorbs the compressive load, this results in increased rod on tubing contact. When weight bars are ran, then the pump loads appear the same. But the hole in tubing goes away, why? Because the tubing has the same force acting on tubing from rods, but the weight bars large area of contact spread the force out over more area of contact and results in reduced rod-on-tubing wear.

Conclusions

The DownDYN software is no longer supported by current Microsoft Windows Operating systems. Windows XP or earlier operating systems are required to execute the DownDyn software. The DHLC data is not available from any other source. This valuable information will be lost, if the DownDYN software is not converted to execute under current and future Microsoft Windows Operating systems. Downhole Load Cell measured data has helped understand and resolve the display of the downhole pump loads. Industry needs to fund the rewriting of the DownDyn software so the DHLC data will be available into the future.

…..Negative pump loads are confusing[4], because most people think that negative loads mean compressive force. When true pump card loads are displayed most people think the negative loads of the pump card will buckle the sucker rod string. PoAo does not equal the buoyancy force when the rod string is tapered or when the rod string is not vertical. Negative true loads do not exert a mechanical buckling force on the rod string, but negative effective loads do mean a compressive force is being applied to the rod string that can result in buckling of the slender rod string..

…..Much confusion in the oil industry has been generated by presenting pump cards with large negative.true loads. In some cases it has been documented that excessively long sections of sinker bar are ran at the bottom o rod string to over-come the negative compressive true loads displayed by some diagnostic software programs. Almost 20 years ago Robert Sosa[5] stated: "Example output from predictive and diagnostic programs available on the market show different negative loads on the downstroke. We have measured pump cards with the DHLC that shows very little negative loads. Why can't industry get together and consistently show the same type of pump card." Robert's comments still apply today. Pump card loads should be displayed as only effective loads.

References

1. Albert, G.: "Downhole Dynagraph Measurement" A Thesis for MS at University of Oklahoma, 1986.
2. Gibbs, S. G.: " Predicting Behavior Sucker Rod Systems," SPE 588, 1963
3. James F Lea :" Interpretation of Calculated Forces on Sucker Rods", SPE 24516, 1995
4. O. Lynn Rowlan, : "Effect of Fluid Buoyancy on Rod String Loads and Stresses" ", presented at 44th Annual Southwest Petroleum Short Course, at Texas Tech University, in Lubbock, Texas.
5. Sosa, Roberto L.: "Review of Downhole Dynamometer Testing", presented at 43rd Annual Southwest Petroleum Short Course, at Texas Tech University, in Lubbock, Texas.

Figure 1 – DownDyn – Downhole Dynamometer Database Software

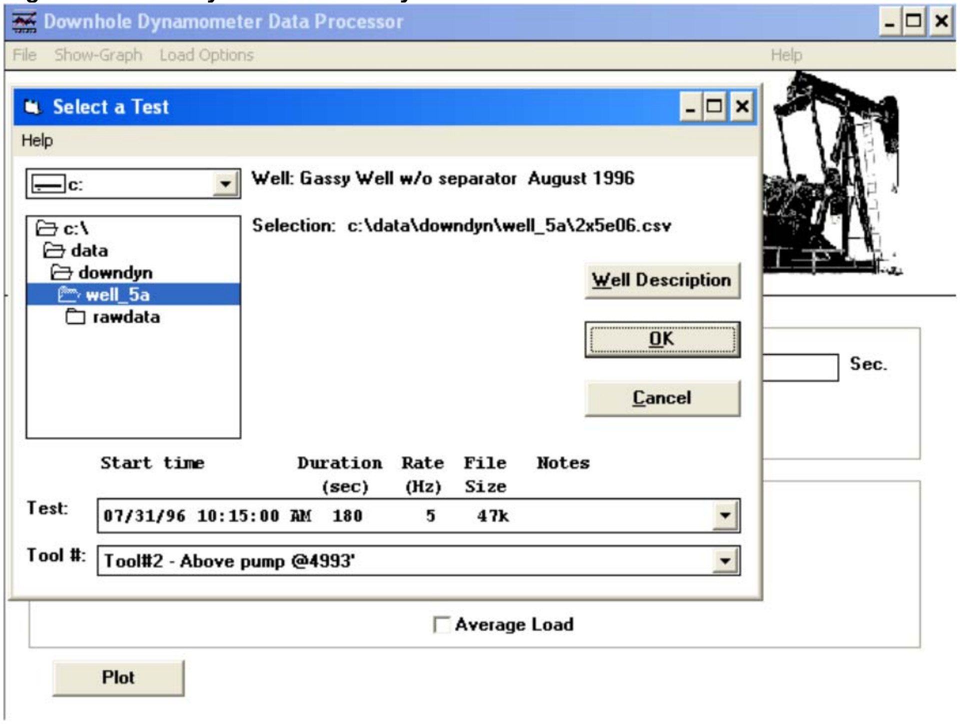


Figure 2 – DownDyn Plot of Downhole Motion of the Rod String

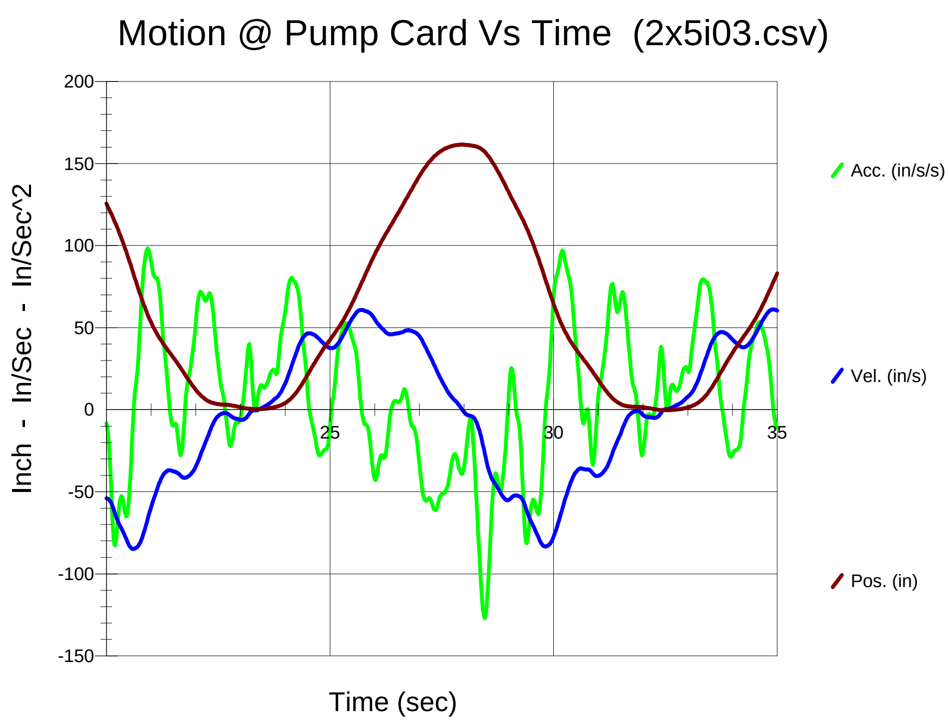


Figure 3 – True Vs. Effective Load from DHLC (205i03.csv) File (Red – 0.75 Dia. Rod

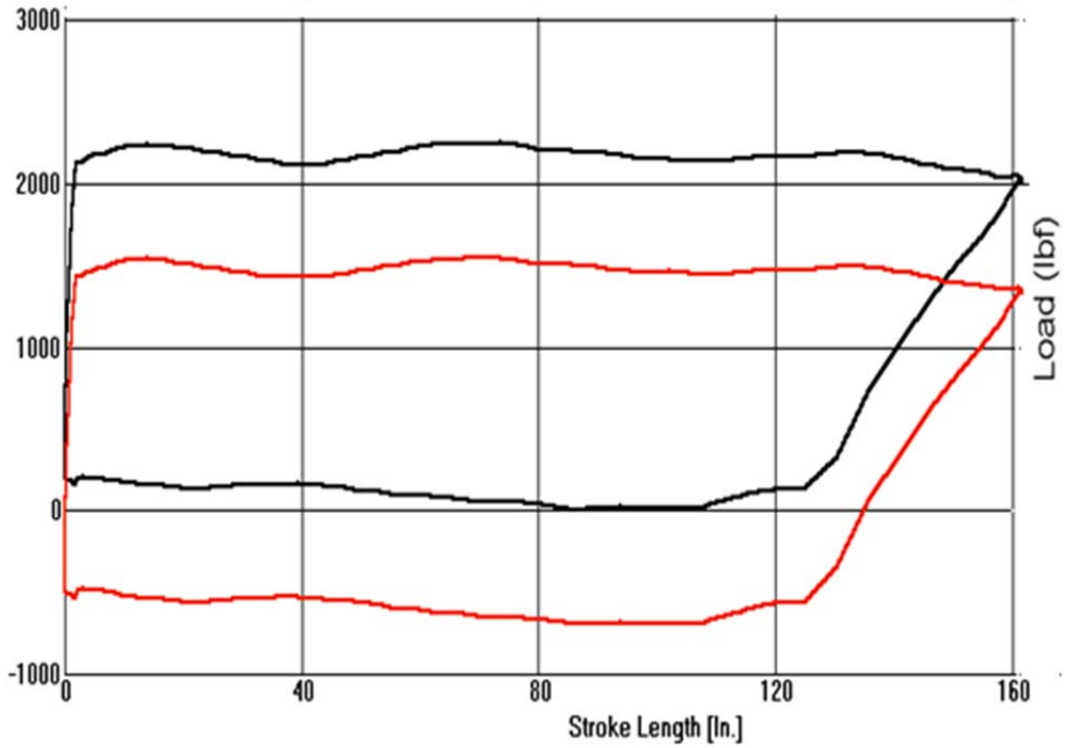


Figure 4 – Sandia Pump Card Shifted below the Zero Load Line by Archimedes Buoyancy

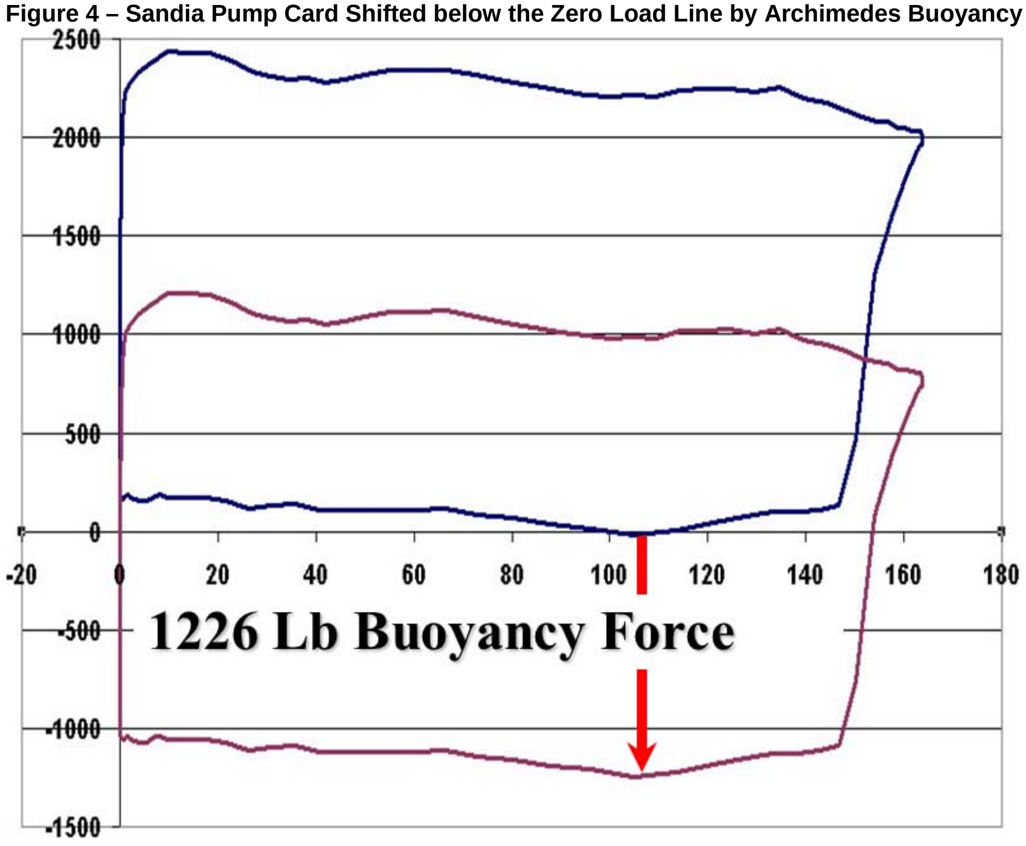


Figure 5 – Effective Load Comparison to Various True Loads a Same Depth in well_5a

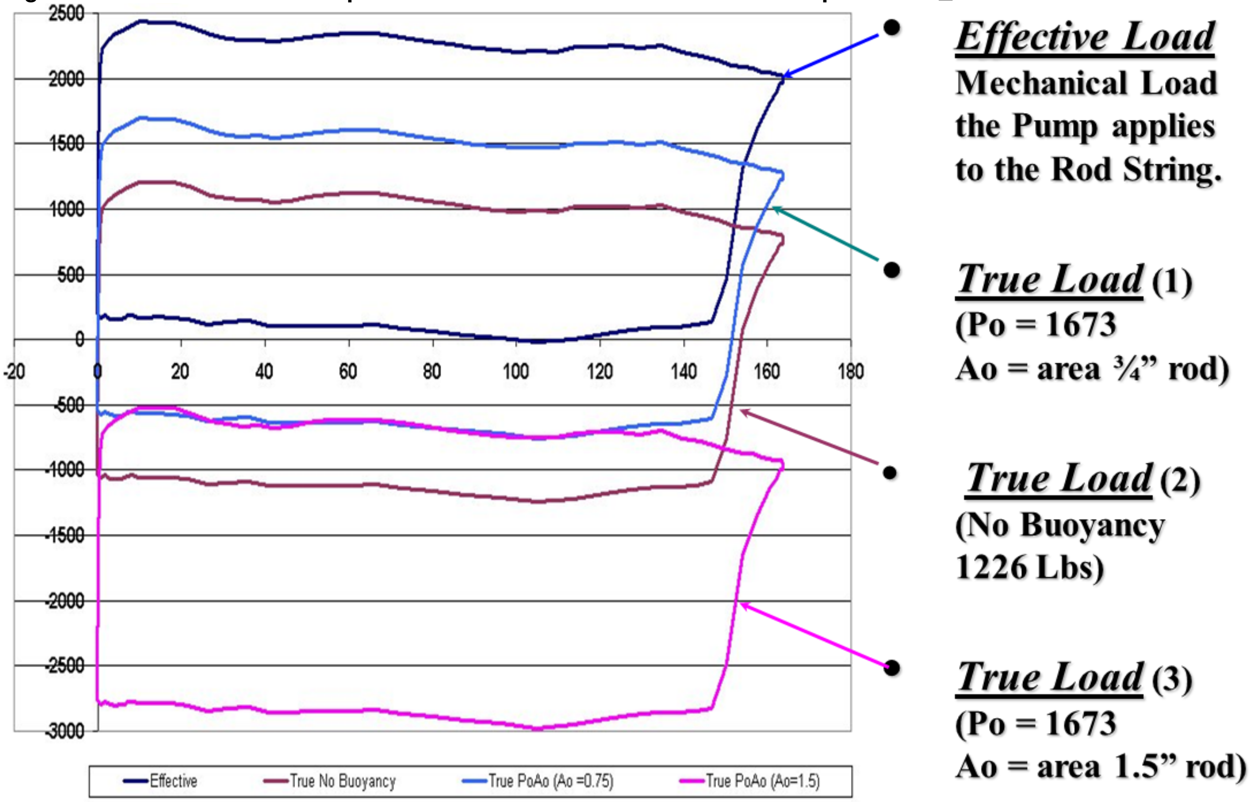


Figure 6 - 1 Effective Load VERSUS Input of Infinite Number of True Loads

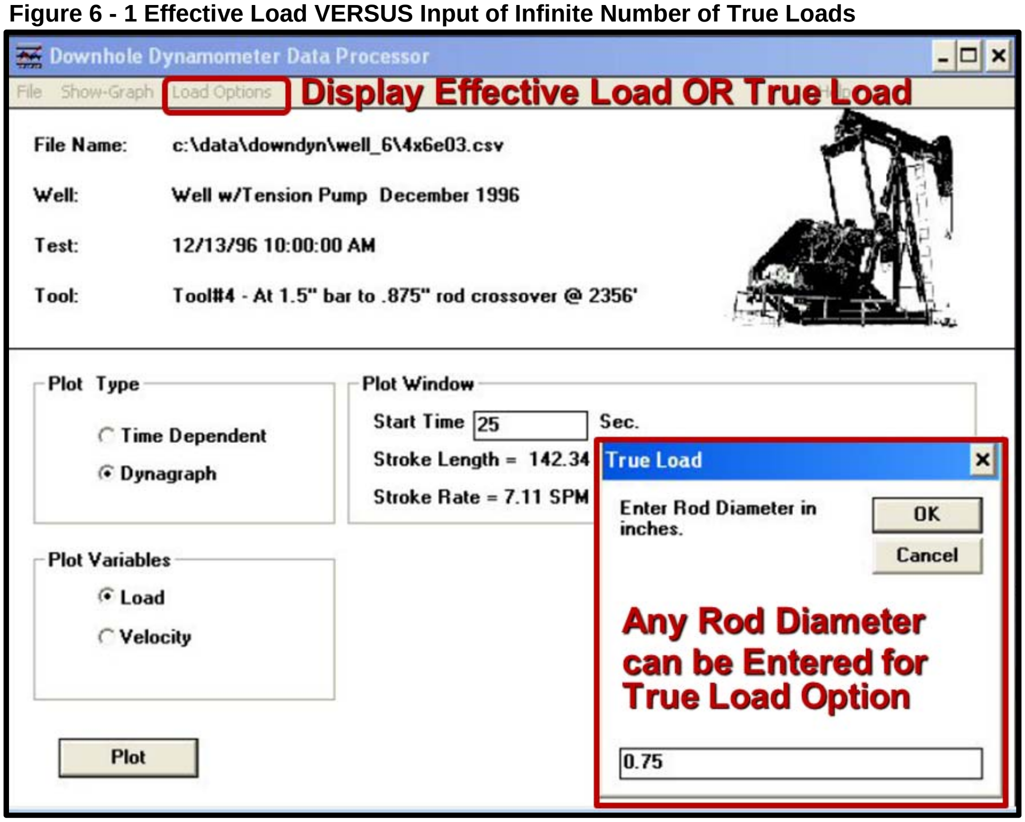


Figure 7 – Effective Load Surface and Pump Card Loads for Well_1

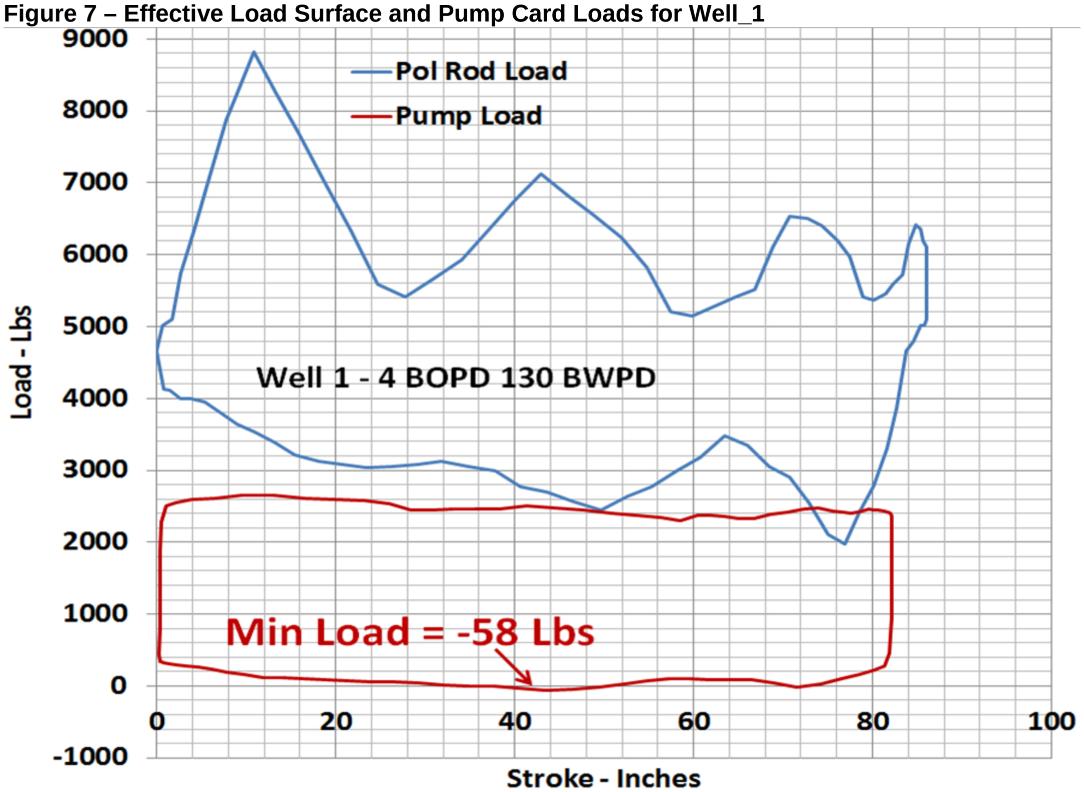


Figure 8 – Effective Load Surface and Pump Card Loads for Well_2

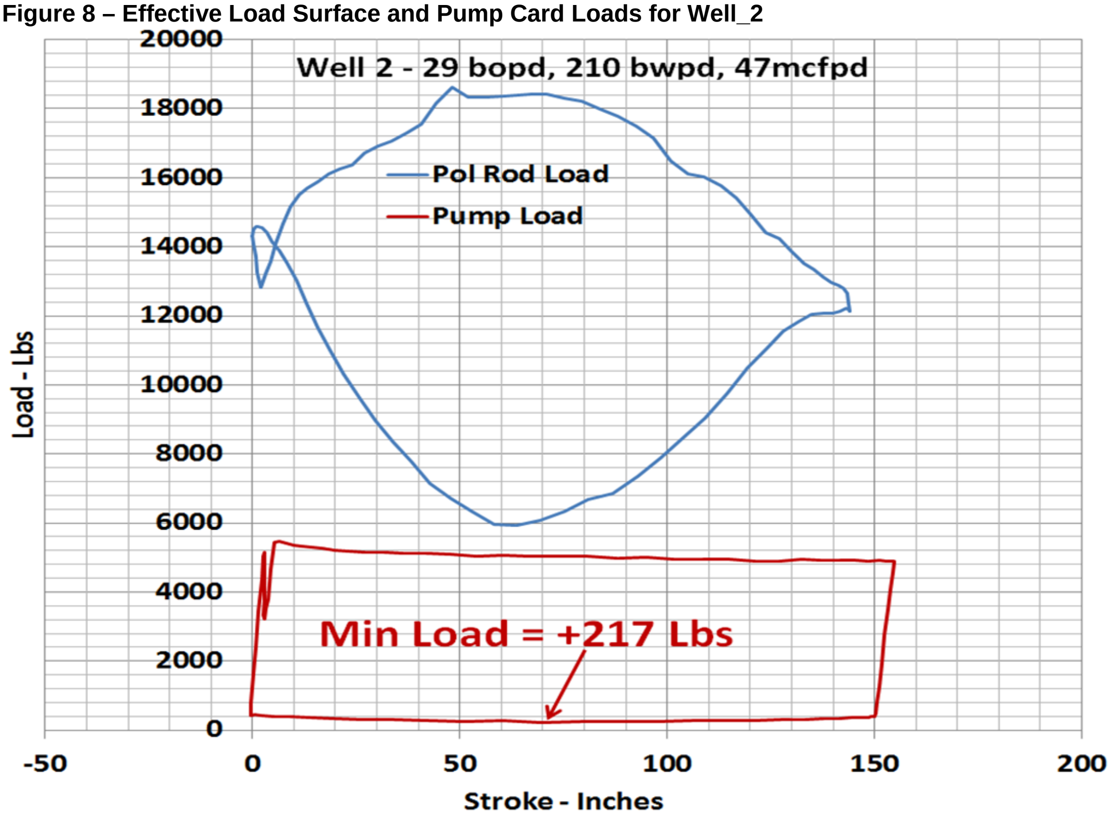


Figure 9 – Effective Load Surface and Pump Card Loads for Well_3

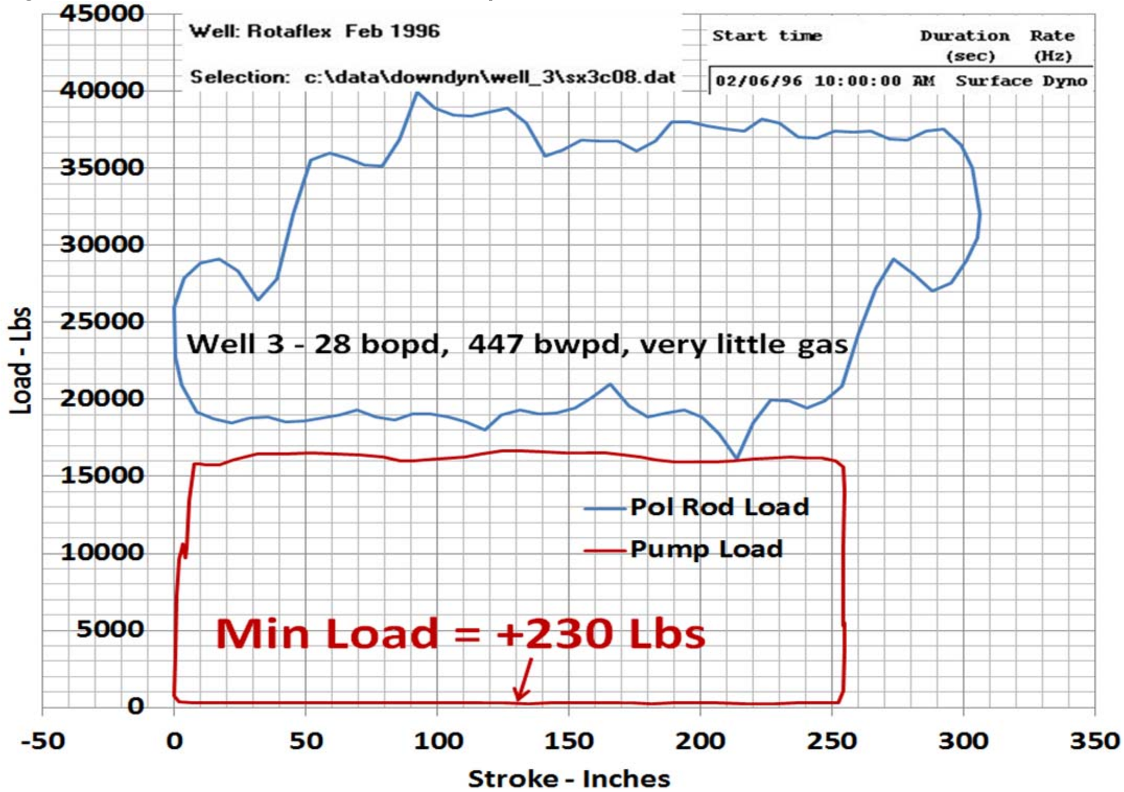


Figure 10 – Effective Load Surface and Pump Card Loads for Well_4

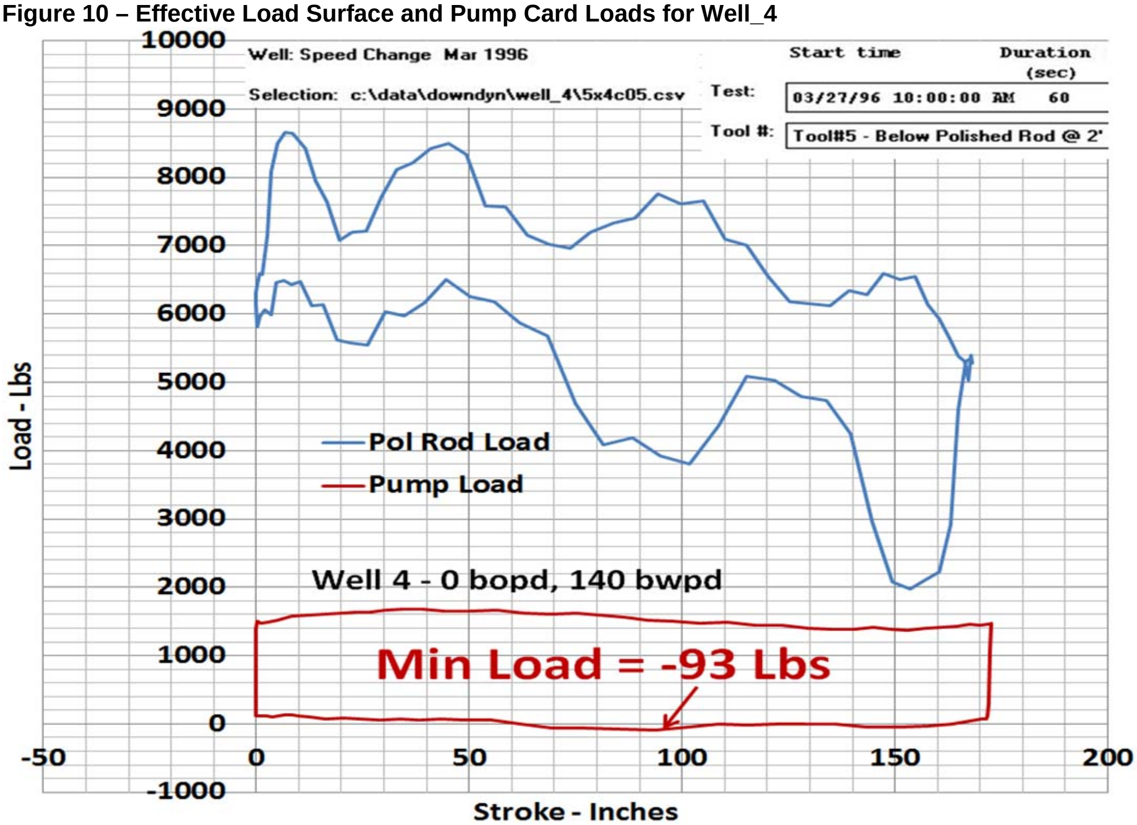


Figure 11 – Effective Load Surface and Pump Card Loads for Well_5a

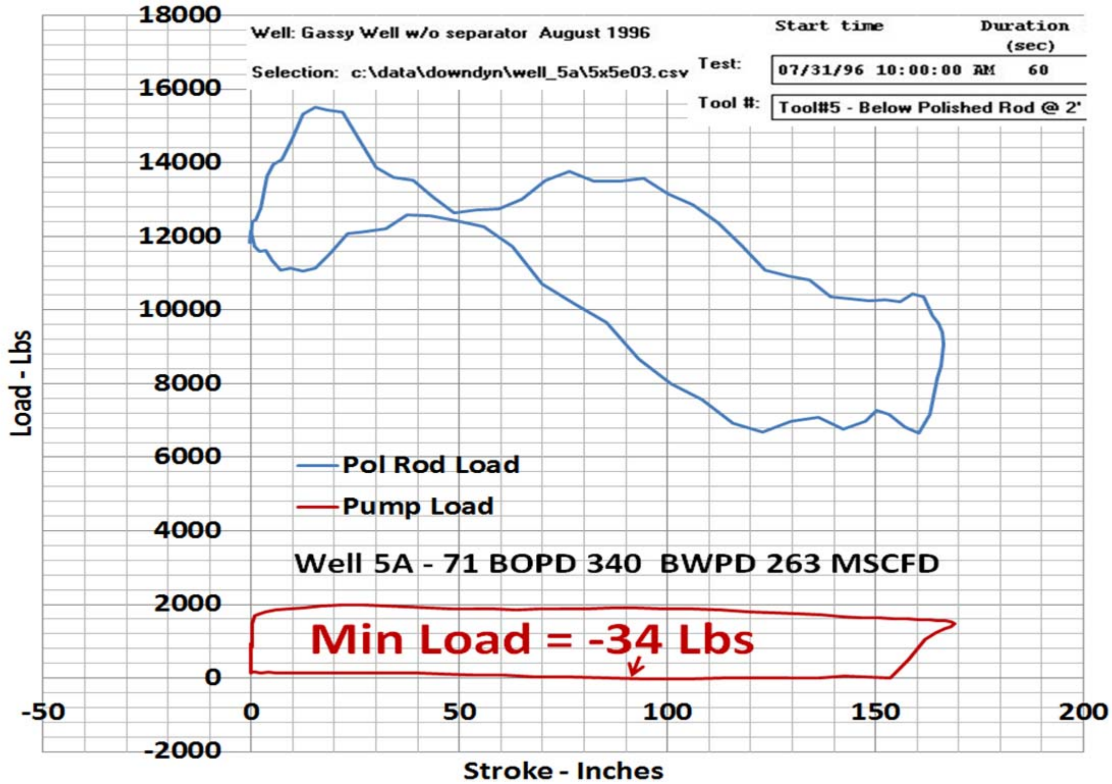
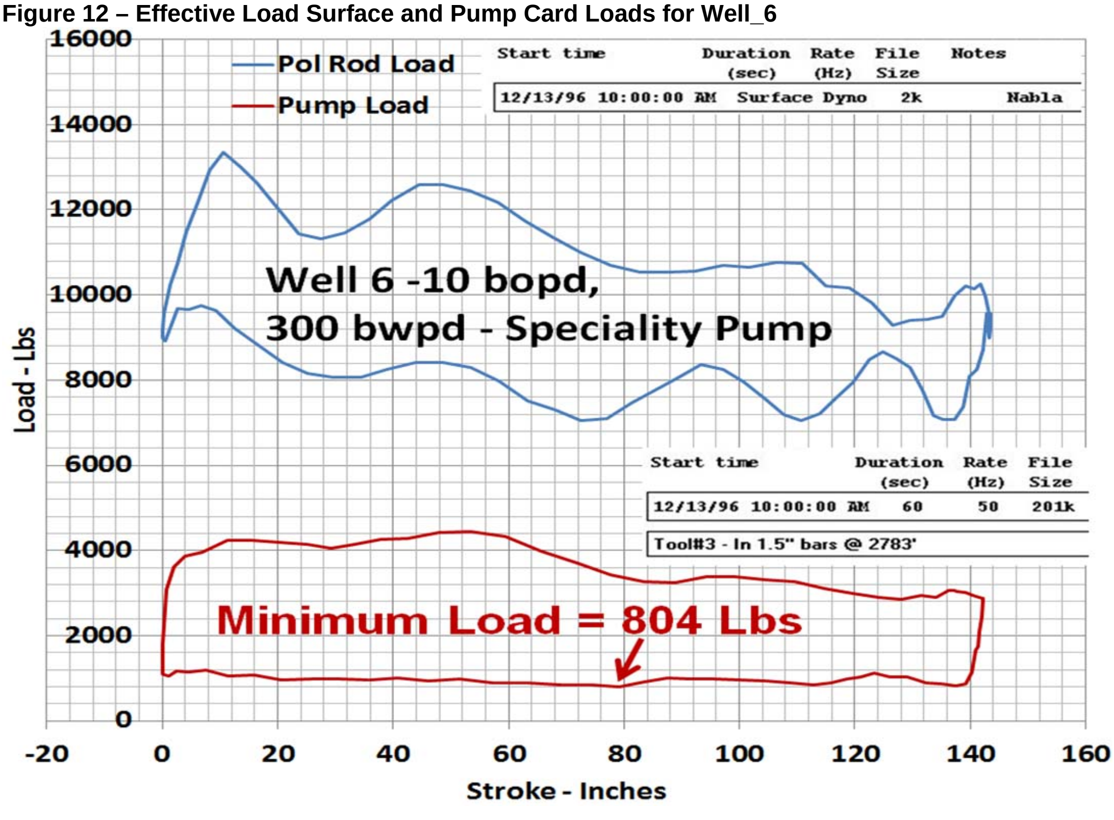


Figure 12 – Effective Load Surface and Pump Card Loads for Well_6



Appendix:

To return to Downhole Dynamometer Program: Minimize or close this window or select File & Exit from the menu. To word wrap: Select Edit & Word Wrap from the menu.
****
Well #5A
Test Number: 05a

Test Date: July/August, 1996

General Comments: Five Albert Engineering/Sandia National Laboratories (AE/SNL) downhole dynamometer tools were used in this test, including one placed below the pump. The purpose of the test was to compare rod loading with and without the Echometer Decentralized Gas Separator. The position of tools 4 and 5 was different for the two phases of the test, so the test is numbered 05a for the first phase (without separator) and 05b for the second phase (with the separator).

Well Depth: 5278' (Plugged back to 5278')

Casing Record: 5.5" to 5090'

Tubing Record: 2.875" to 5060', seating nipple at 5060', tubing anchor at 4970', tubing set with 18,000# tension.

Rod String:

-Size-	-Description-	Length Ea.	Number	Cum.Depth@end
1.5"	Polished Rod	30'	1	0'
	Tool #5	2'	1	2'
1.0"	API Grade 'D' Steel	4'	1	6'
1.0"	API Grade 'D' Steel	2'	1	8'
1.0"	API Grade 'D' Steel	6'	1	12'
1.0"	API Grade 'D' Steel	25'	60	1512'
0.875"	API Grade 'D' Steel	25'	64	3112'
0.75"	API Grade 'D' Steel	25'	64	4712'
	Tool #4	2'	1	4714'
0.75"	API Grade 'D' Steel	25'	1	4739'
	Tool #3	2'	1	4741'
1.5"	Sinkerbars	25'	10	4991'
	Tool #2	2'	1	4993'
	Flexbar Stabilizer	4'	1	4997'
	Pump	24'		5060'
	Perforated stinger	70"	1	5066'
	Tool #1	2'	1	5068'

Note on Depths: Rod depths are relative to the bottom of the polished rod. Pump depths are relative to the stated seating nipple depth which is usually relative to the kelly bushing.