# QRod

## Help and User Guide



Echometer Company
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## File Menu

### New

This command resets all values to the example design data.

### Open

This command allows the user to recall a data file that was
previously saved in a folder.

### Save

This command allows the user to save a data set for a specific
well design in a folder.

### Print Report

This command prints all input parameters, calculated design results, and graphs.

### Exit

This command terminates execution of the program. All files are closed and  information
entered during the session is not saved.

## Save Command

A data file may be saved to disk for later processing. The user specifies the location and
the name of the file:

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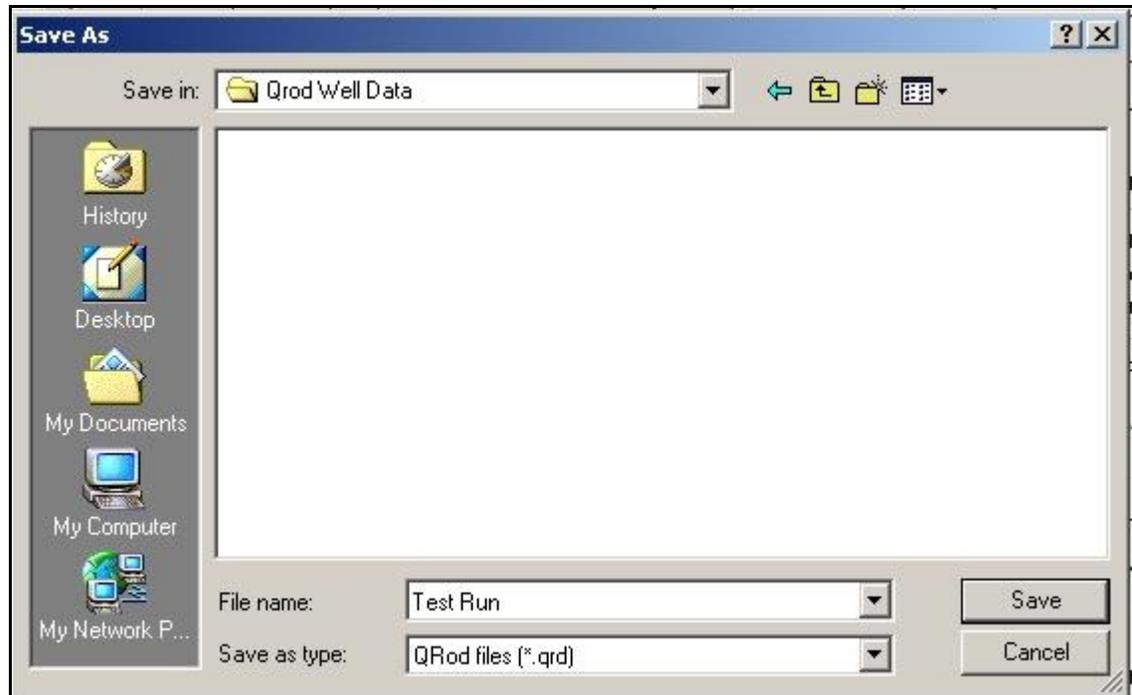
## Open Command

This command allows the user to recall a data set that was previously saved.



## Tools Menu
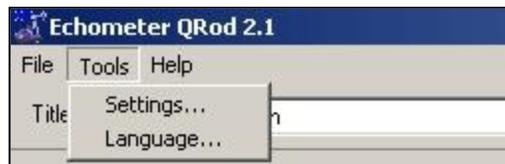


Is used to select certain default settings and the language used by QRod.

### Settings

This command brings up a window, which allows the users to set a number of parameters to desired or default values.

**Target Rate Increment**: the amount that QRod uses to change the Target Rate when seeking the SPM that will yield the desired rate.

**SPM Increment**: the amount that QRod uses to change the Stroke Rate when seeking a desired rate.



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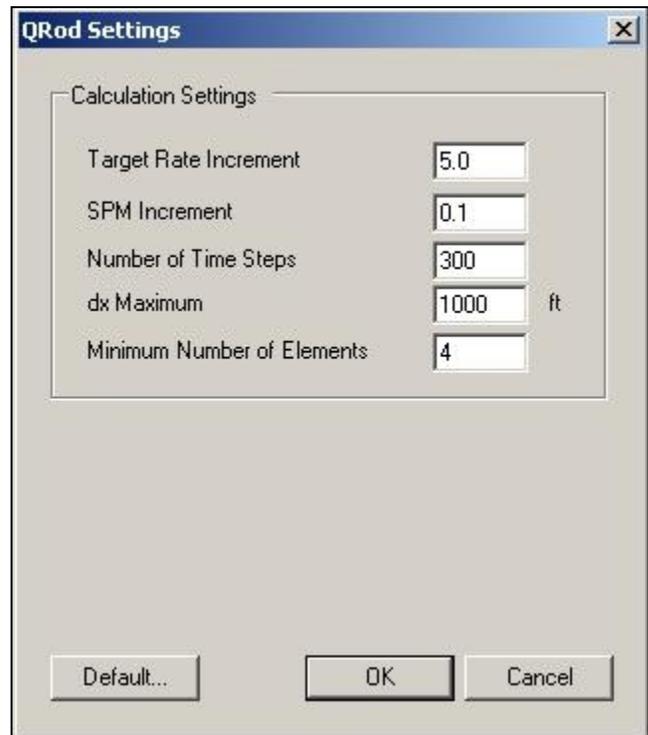
**Number of Time Steps**:
Is the number of time steps per pumping stroke. The parameter is allowed to range from 100 to 500. Increasing the number increases the accuracy of the approximations used in solving the differential equation at the expense of more computation time. Similarly decreasing the number increases the speed of the calculations at some expense in accuracy. The normal value of 150 has been shown to produce acceptable results with reasonable calculation time.

**dX Maximum**
For the purposes of solving the differential equation, the rod string is divided into discrete intervals of equal length. dX Maximum (Settings window) is the maximum length allowed in the program. Making dX Maximum a smaller value increases the accuracy of the calculations at the expense of more calculation time. The normal value for dX Maximum is 1000 ft. The minimum value allowed is 100 feet. See Minimum Number of Elements for more information.

**Minimum Number of Elements**: is the minimum number of discrete intervals that you wish the program to divide the rod string into for the purposes of calculation. The larger this number the more accurate the calculations will be at the expense of more calculation time. This parameter and dX Maximum together determine the actual interval length. The total length is divided by the Minimum Number of Elements to determine an interval length. If this interval length is greater than dX Maximum the total length is divided by dX Maximum to determine the number of elements to use in the calculations. Minimum Number of Elements is allowed values >= 3 and the default value of 3 is recommended.

## Language

Select the language to display the QRod screens, results, and graphs.

The current version of QRod gives the choice of English or Spanish.

After selecting the desired language the user must Exit and Restart QRod for the language change to become active.

## Help Menu

### Help with QRod

This command brings up detailed searchable help on how to use the QRod program.
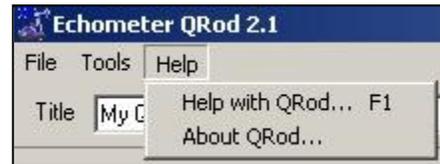
### Navigating the Main Screen

The left hand side of the main window is where the user inputs the primary data for the program. Less frequently changed parameters may be input in the Settings Screen.

### Title

The Title is a text string that appears as the first line of the report created by Print Report. The title should be 1 line of 80 characters or less.

## *Design Inputs*



## Unit Type Selection

This dropdown list allows the user to select the type of surface unit to use in the calculations. A Fourier series approximation for the motion of each of the beam unit types is used. Stroke Length scales the approximations. Conventional (CW rotation and CCW rotation), MarkII, and Air Balanced units are available.

**CWConv -** selects the conventional unit with clockwise rotation of the crank**.**

**CCWConv -** selects the conventional unit with counter-clockwise rotation of the crank.

**MarkII -** selects the MarkII unit with counter-clockwise rotation of the crank.

**AirBal** - selects the air-balanced unit with clockwise rotation of the crank.

## Pump Depth

The user enters the Depth, in feet, of the pump. You have the option of typing in a value or using the drop down list to select a value.

## Surface Stroke Length

The user enters the surface Stroke Length, in inches. You may select only standard API Stroke Lengths. Achieving the desired production rate will require manipulating Stroke Length,
Pump Diameter, and Stroke Rate.

## Pump Diameter

The diameter of the pump plunger is units of inches. For 2 3/8 inch tubing, the largest tubing pump without using an on/off tool is 1.78 in and the largest API rod pump is 1.5 in. For 2 7/8 inch tubing, the largest tubing pump is 2 1/4 inches and the largest rod pump is 2 inches.

## Tubing Size

Tubing Size is the size of the tubing in the well. The tubing size is used only in the calculations for unanchored tubing. , If Anchored Tubing is selected the tubing size has

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no effect. As a practical matter, tubing size also determines the maximum size (Pump Diameter) that may be run. See Pump Diameter for more information.

## Anchored Tubing

If this box is checked, the calculations will be done assuming no movement of the tubing at the pump. If this box is not checked (Unanchored Tubing), calculations include the up and down movement of the tubing and the corresponding effect on the pump displacement. The tubing size may be changed in the Settings form using the drop down..

## *RODS*

This form allows selecting the make up of the rod string**.**

## Steel Rods Option

This option button selects all steel rods.

### Rod Number

The API rod number for the steel rod string is selected with this drop down list. The rod number is in 1/8 of an inch, so a 1" rod is called 8. An API rod number of 86 means, the rod string is composed of 8/8", 7/8", and 6/8" diameter rods. 76 rods have been selected by default. That is probably a good place to start for most wells. The percentage of each size is determined by the API method and depends on the pump diameter. This method will result in approximately equal stresses at the top of each rod section. This is referred to as a balanced design.

| mm => | 32 | 29 | 25 | 22 | 19 | 16 | |
| API Rod Number | 1 1/4" | 1 1/8" | 1" | 7/8" | 3/4" | 5/8" | |
|---|---|---|---|---|---|---|---|
| 55 | | | | | | ✔ | All 5/8" |
| 65 | | | | | ✔ | ✔ | Top 3/4" with 5/8" on bottom |
| 66 | | | | | ✔ | | All 3/4" |
| 75 | | | | ✔ | ✔ | ✔ | Top 7/8" with 3/4" in Middle and 5/8" on bottom |
| 76 | | | | ✔ | ✔ | | Top 7/8" with 3/4" on bottom |
| 77 | | | | ✔ | | | All 7/8" |
| 86 | | | ✔ | ✔ | ✔ | | Top 1" with 7/8" in Middle and 3/4" on bottom |
| 87 | | | ✔ | ✔ | | | Top 1" with 7/8" on bottom |
| 88 | | | ✔ | | | | All 1" |
| 97 | | ✔ | ✔ | ✔ | | | Top 1 1/8" with 1" in Middle and 7/8" on bottom |
| 98 | | ✔ | ✔ | | | | Top 1 1/8" with 1" on bottom |
| 99 | | ✔ | | | | | All 1 1/8" |
| 108 | ✔ | ✔ | ✔ | | | | Top 1 1/4" with 1 1/8" in Middle and 1" on bottom |
| 109 | ✔ | ✔ | | | | | Top 1 1/4" with 1 1/8" on bottom |

**Rod Grade**

The grade of the steel in the rods is selected in this box. This value is used to determine the Rod Loading of the top rod.

## Fiber Glass and Steel Option

This option button selects Fiberglass/Steel Combination rod strings (one Fiberglass size and one Steel size).



## Fiberglass Size

The size, in inches, of the Fiberglass rods is selected in this box.

## Fiberglass Percent (Fiberglass Option)

The percentage of the total rod string that is Fiberglass is selected in this box. The value must be between 40 and 90%.

## Steel Size (Fiberglass Option)

The size, in inches, of the steel rods below the Fiberglass section is selected in this box.

## *Default Settings*



## Total Sinker Bar Weight

Total sinker bar weight in lbs. If you have 300 feet of 1.5-inch sinker bars at the bottom of the well, then you would enter 1800 lbs.

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## Fluid Specific Gravity

Fluid Specific Gravity is the average specific gravity (fresh water = 1.0) of the fluid being produced in the tubing.

## Tubing Pressure

Tubing Pressure is the surface tubing pressure in psig.

## Casing Pressure

Casing Pressure is the surface casing pressure in psig. The casing pressure has to be less or equal to the pump intake pressure.

## Pump Intake Pressure

Pump Intake Pressure is the fluid pressure just below the Standing Valve of the pump in psig. There are two options for determining the pump intake pressure:
1. User entered into the Pump Intake Pressure field
2. Calculated from PI and Reservoir Pressure for the Target Rate.

The Pump Intake Pressure cannot be less that the Casing pressure when calculated from PI and Reservoir Pressure

## Damping Factor

Damping Factor is a parameter that determines the magnitude of the friction losses between the pump and the surface. It is used in the equation describing the motion of the sucker rods. The Damping Factor will normally range between .05 (very low friction) to .5 (very high friction). The normal value is .1 to .15. The instantaneous friction is proportional to the product of the Damping Factor and the instantaneous velocity of the rods.

## Unit Efficiency

Unit Efficiency is the mechanical efficiency of the surface unit. The normal value is 95%

## Pump Efficiency

Pump Efficiency is the ratio of surface production rate to pump displacement rate expressed as a percent. This parameter accounts for the slippage of the pump as well as the shrinkage of the produced fluid as it is brought to the surface. The normal value is 95%.

## *Calculate from SPM or Target Rate*



## Stroke Rate

This allows the user to select the desire stroke rate. The minimum value is 1/2 stroke per minute.

## Target Rate

The value entered into this box is the total surface liquid production rate, in STB/D, that you are designing toward. When pressing the calculate button QRod determines the Stroke Rate required to get the Target Liquid Rate if possible.

If this item is checked the program will iterate to determine the Stroke Rate required to obtain the Target Liquid Rate within 1%. If the calculation does not converge the user must adjust Stroke Length, Pump Diameter, and/or Stroke Rate.

## Auto-Increment

These buttons are to the right and left of SPM and Target Rate. When this button is clicked the SPM or Target Rate is incremented by the amount specified in the settings screen, recalculation is done automatically and the entire screen is refreshed.

## Calculate

This button forces a recalculation of the problem with all settings that are specified.

## Results

```
Results
Rate (100% Pump eff.)           191   bbl/day
Rate (95 % Pump eff.)           182   bbl/day
Rod Taper, %              34.0, 66.0
Top Rod Loading                74.6   %
Min API Unit Rating       320-173-100
Min NEMA D Motor Size          16.8   hp
Polished Rod Power              9.0   hp
TVLoad                       12,000   lbs
SVLoad                        8,100   lbs
```

The **Results** section of the main screen presents the principal design output parameters and operational characteristics. The design result calculations are updated each time a parameter is changed and the Auto-Increment or the Calculate button is clicked. The results should always represent the solution for the data presented.

The calculated pump rate, rod taper design, top rod loading, polished rod loads, peak torque, unit size and motor size are shown. These are important results for a rod string design. For the example default data at 8.6 SPM we get a rate of 182 BPD. This is for a 76 rod string composed of 34.0% of 7/8 inch, and 66.0% of ¾ inch rods. The loading of the top rod is 74.6% of the allowable for grade "D" rods meaning that the rods are not over loaded. The loading is calculated using the modified Goodman diagram method. QRod uses a service factor of 1.0.

The PPRL (peak polish rod load) is 12,200 lb. And the MPRL is 5500 lb as shown below the Dynamometer Card Graph. This means that the beam rating of the unit should be at least 17,300 lb. The calculated peak torque for a balanced unit is 309 K in-lb and is shown below the Net Gear Box Torque plot. This value determines the minimum gearbox rating for the unit. The program displays the minimum API unit size that satisfies all the design requirements. Notice that there may not be a standard unit with the combination of gearbox, beam rating and stroke recommended by the program. The values displayed are simply the minimum required for each parameter.

The minimum motor size is determined from polished rod horsepower, the calculated cyclic load factor, and the mechanical efficiency of the surface unit. This is a minimum value. The actual motor used should be the next largest standard size.

### Rate

Two values of Pump Rates are displayed 1) the pump displacement for 100% efficiency and no slippage and 2) the pump displacement for the user-specified pump efficiency. The Pump Rate is the production rate, in barrels per day, for the calculated plunger stroke length, stroke rate and pump size. The pump efficiency is used to determine the rate that is produced to the surface.

## Rod Taper, %

The values appearing in this space are the percentages of each size rods in the string from the top down. The total length of each size rod is the total depth times the percentage for that section.

## Top Rod Loading

The rod loading is the ratio of the maximum stress in the top rod divided by the allowable stress expressed as a percentage. The modified Goodman Diagram is used to determine the allowable stress.

## Min Unit Size

The value that appears in this space is the minimum surface unit that will satisfy the requirements of Peak Torque, Peak Polish Rod Load, and Stroke length. Note that a standard unit may not exist with the calculated designation. In that case simply use the smallest size that is available and satisfies all the conditions.

## Min Motor Size

The value that appears in this space is the minimum size NEMA D electric motor for driving the unit. The size of the motor is determined from the cyclic load factor and polish rod horsepower. The actual motor used should be the next largest standard size.

## Polished Rod Horsepower

The polished rod horsepower corresponds to the area of the surface Dynamometer Card. The minimum motor size is determined from polished rod horsepower, the calculated cyclic load factor, and the mechanical efficiency of the surface unit. This number is a minimum value. The actual motor used should be the next largest standard size.

## TVLOAD and SVLOAD

The SVLOAD is the Weight of the Rods Buoyed in Fluid (Wrf). The TVLOAD is the Weight of the Rods Buoyed in Fluid (Wrf) plus the Fluid Load (Fo). The Fluid load (Fo) is the force caused by differential pressure acting on the pump plunger.

## Displaying Graphs on Main Screen

Clicking the Calculate Button causes result graphs to be displayed on the right hand side of the main screen. Following are the three types of Graphs

## *Dynamometer Cards*
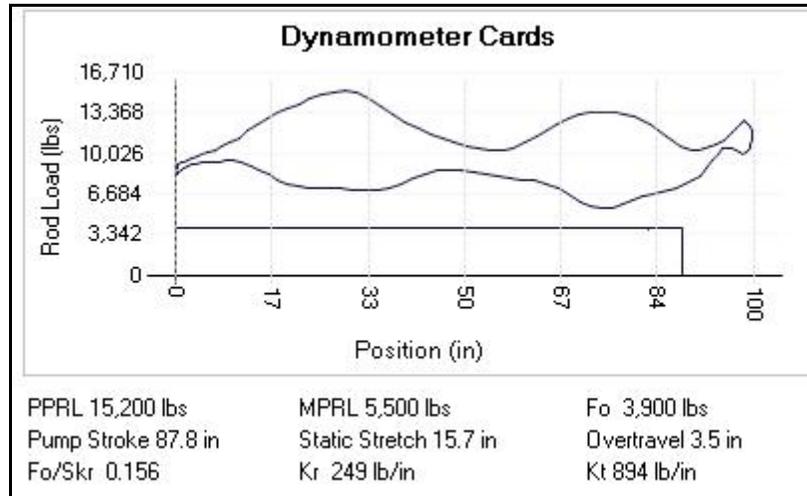


The surface and downhole dynamometer cards are displayed. Since the graph is refreshed each time the program recalculates, it is very informative to observe the effect of changing pump speed as the Auto-Increment Buttons are clicked.

### PPRL & MPRL

The peak polish rod load (PPRL), in pounds, is presented in this space. It is the maximum load calculated during the pumping cycle. The Beam Rating of the Unit is determined from this value. The minimum polish rod load (MPRL), in pounds, is presented in this space. It is the minimum load calculated during the pumping cycle.

### Fo

Fo is the fluid load. Fo can be calculated as: Fo = (Pdis - Pintk) * Ap. It is caused by the differential pressure acting on the cross-sectional area of the plunger [Ap]. The differential pressure, (Pdis - Pintk), is difference between the discharge pressure (pressure at the bottom of the tubing), [Pdis], and the pump intake pressure, [Pintk].

### Other Parameters

Kr is the composite coefficient of rod stretch in units of lbs/in. It is the amount of pounds force required to stretch the rod string by 1 inch. Kt is the coefficient of tubing stretch in units of lbs/in. It is the amount of pounds force required to stretch the tubing string by one inch. When the tubing is unanchored the pump card "leans over to the right" with the slope of Kt. Rod and tubing stretch, and over travel are accounted for in determining the Pump Stroke Length. The non-dimensional factor Fo/SKr is the decimal fraction of the surface stroke length lost to the static stretch caused by picking up the fluid load with the rod string.

## *Pump Velocity*



Pump Velocity vs. Position
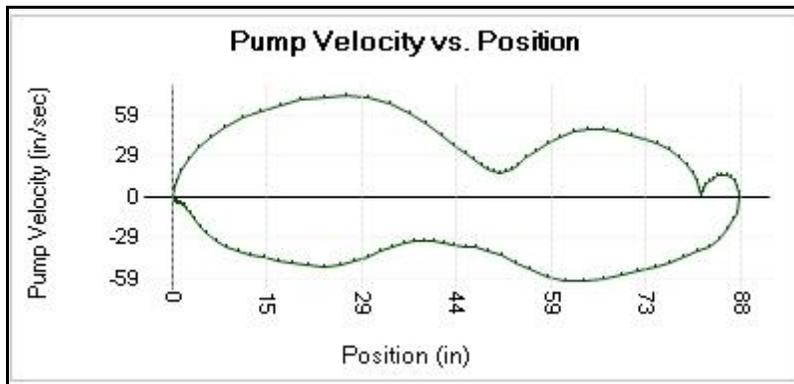
The center graph is the plot of the plunger velocity versus plunger position

## *In-Balance Net Gearbox Torque Curve*



Torque

| Peak Gear Box Torque | 309 | Kin-lbs |
| Counter Balance Moment | 629 | Kin-lbs |
| Counter Balance Effect | 13,300 | lbs |
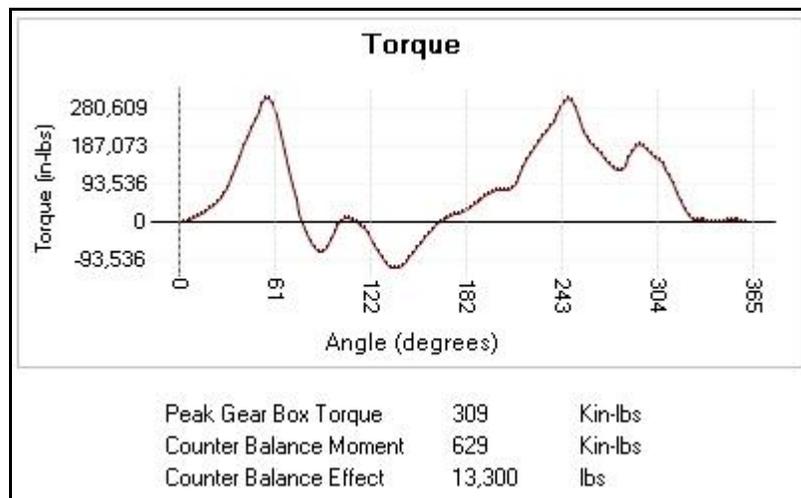
The **Torque** graph is the plot of the In-Balance Net Gearbox Torque on the gearbox versus crank angle. Crank angle is positive in the direction of rotation. For conventional units, crank angle is measured from the 12 o'clock position, for the air-balance and Mark II units it is measured from the 6 o'clock position.

### Peak Gear Box Torque

The Peak Gear Box Torque is the maximum torque on the output crank of the gearbox expressed in inch-pounds. It occurs either on the upstroke or the downstroke (on the upstroke while lifting the rods and on the downstroke while lifting the counter weights.) The program calculates the counter balance moment and the corresponding counter balance effect required so that these two torque values are equal.

## About QRod

Check the web for software Updates to the QRod program.

Comments from the author, Jim Jennings: QRod is a program that obtains a solution to the damped wave equation describing the motion of sucker rod pump strings. It uses an approximation for the motion of the surface unit as the surface boundary condition. The results obtained include loads, stresses, torques, power, and pump displacement. I have attempted to put in all the features needed to do the job accurately without adding bells and whistles which tend to add very little to the accuracy but much to the complexity for many problems. I hope you enjoy using the program and that it helps you do your job more efficiently.

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## Example Calculations

The following shows an example calculation using both steel and fiberglass rod installations.

## *Steel Rods Configuration*

Start off with:

Pump intake pressure of 50 psi, 144 inch surface stroke a 76 steel design with a pump size to 1 ½ inch. 1 ½ inch plunger diameter is the largest rod pump that can be run in 2 3/8 inch anchored tubing.

At 7000 foot with a SPM of 7.8 the pump displacement is 245 BPD depth with a 90% pump efficiency. The D grade rods are loaded to 99.8% of their Modified Goodman guide rating.



The well has potential to produce at a higher rate, so click on the **Target Rate** option to determine the SPM for **400 BPD** . This requires operating the unit at 12.2 SPM.

Several interesting things appear:

- First of all, the rod loading (123.8%) is higher than before. It exceeds the grade D capacity requiring installation of high strength rods.
- The motor power has increased from 34.0 hp by more than 100% to 80.4 hp.
- The minimum unit rating requires a 912 unit instead of 640.

**Results**

| | | |
|---|---|---|
| Rate (100% Pump eff.) | 444 | bbl/day |
| Rate (90 % Pump eff.) | 400 | bbl/day |
| Rod Taper, % | 34.0, 66.0 | |
| Top Rod Loading | 123.8 | % |
| Min API Unit Rating | 912-256-144 | |
| Min NEMA D Motor Size | 80.4 | hp |
| Polished Rod Power | 33.7 | hp |
| TVLoad | 16,700 | lbs |
| SVLoad | 11,300 | lbs |

**Calculate from SPM or Target Rate**

○ Stroke Rate  << | 12.2 | >>  SPM

◉ Target Rate  << | 400 | >>  bbl/day

[ Calculate ]

- The pump stroke is 138.7 inches, with 30.4 inches of static stretch and 25.1 inches of over travel.
- The fluid volume increased by 63%.

**Dynamometer Cards**



| | | |
|---|---|---|
| PPRL 23,900 lbs | MPRL 3,500 lbs | Fo 5,400 lbs |
| Pump Stroke 138.7 in | Static Stretch 30.4 in | Overtravel 25.1 in |
| Fo/Skr 0.211 | Kr 178 lb/in | Kt 639 lb/in |
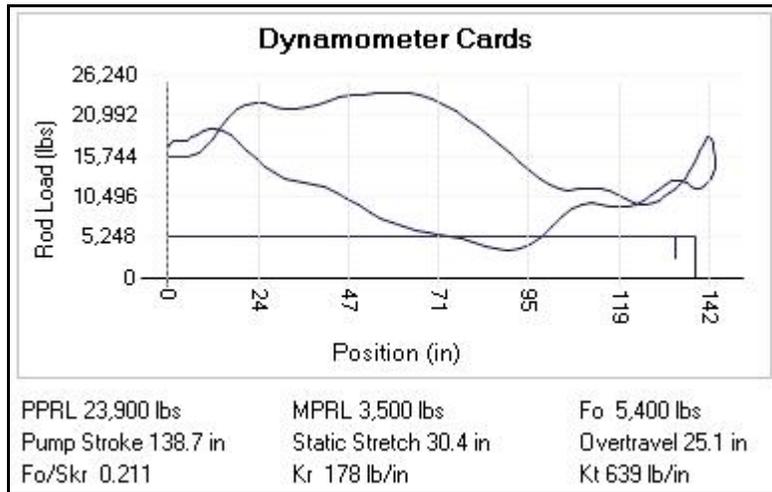
Additional hp is required to overcome the increased friction in the downhole system and overall inertia. Friction is proportional to the rod velocity that increased with the increased stroke rate.

## *Fiberglass Rods Configuration*

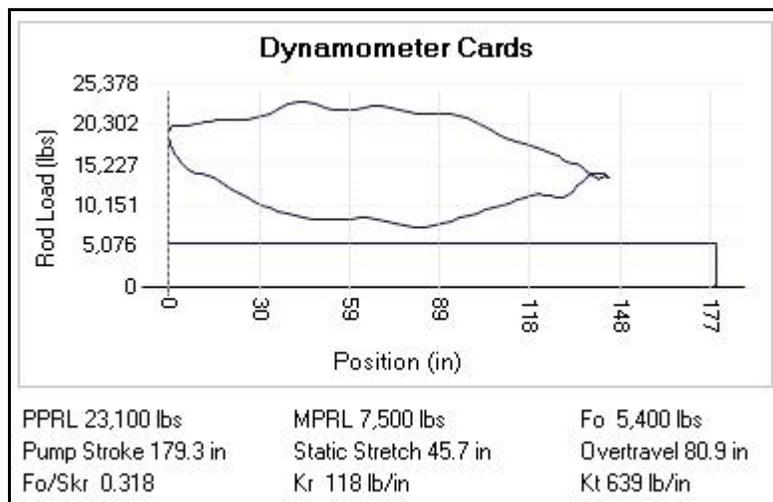Select the "Fiberglass and Steel Rods" option button in the Rods frame.



Select 1.2 inch for the Fiberglass size, 75% Fiberglass and 1.25 for the Steel rod size to start with. Click on the Calculate button to automatically determine the SPM for a target rate of 400 bbl/day.

The Dynamometer Cards graph shows a significant amount of over travel (144" @ Surface versus 179.3" @ Pump), that is the pump stroke is greater than the surface stroke length.



| | | |
|---|---|---|
| PPRL 23,100 lbs | MPRL 7,500 lbs | Fo 5,400 lbs |
| Pump Stroke 179.3 in | Static Stretch 45.7 in | Overtravel 80.9 in |
| Fo/Skr 0.318 | Kr 118 lb/in | Kt 639 lb/in |

The 400 bbl/day are produced with a lower 9.9 SPM because there is more over travel with the Fiberglass rods.  The Minimum NEMA D motor size that is required is now much less @ 51.7 hp. horsepower.

The loading on the Fiberglass rods and the glass/steel intersection is 61%.

The Min Fiberglass load is a relatively low 1,742 lb. Since Fiberglass needs to be loaded in tension at all times, this may not be a very safe design. Adding more steel at the bottom, will reduce the chances of getting compression loading in the Fiberglass and at the same time save some money since steel is cheaper than Fiberglass.

Highlight the 75 in the Percent Fiberglass box and type in 65:

**Results**

| | | |
|---|---|---|
| Rate (100% Pump eff.) | 444 | bbl/day |
| Rate (90 % Pump eff.) | 400 | bbl/day |
| Rod Taper, % | 75.0, 25.0 | |
| Top Rod Loading | 81.5 | % |
| Min API Unit Rating | 912-213-144 | |
| Min NEMA D Motor Size | 51.7 | hp |
| Polished Rod Power | 32.3 | hp |
| TVLoad | 16,200 | lbs |
| SVLoad | 10,800 | lbs |
| | | |
| Max Fiberglass Load | 12,608 | lbs |
| Min Fiberglass Load | 1,742 | lbs |
| Max Fiberglass Stress | 11,628 | psi |
| Min Fiberglass Stress | 1,607 | psi |
| Fiberglass Load | 61.1 | % |

**Calculate from SPM or Target Rate**

Stroke Rate  << 9.9 >> SPM

Target Rate  << 400 >> bbl/day

Calculate

**Rods**

- Steel Rods
- Fiberglass and Steel Rods

F-Glass Size   1.2  in      Steel Size   1.5  in

Percent Fiberglass  65

and click the Calculate button.

**Results**

| | | |
|---|---|---|
| Rate (100% Pump eff.) | 444 | bbl/day |
| Rate (90 % Pump eff.) | 400 | bbl/day |
| Rod Taper, % | 65.0, 35.0 | |
| Top Rod Loading | 95.2 | % |
| Min API Unit Rating | 912-305-144 | |
| Min NEMA D Motor Size | 59.8 | hp |
| Polished Rod Power | 35.8 | hp |
| TVLoad | 21,500 | lbs |
| SVLoad | 16,100 | lbs |
| | | |
| Max Fiberglass Load | 21,018 | lbs |
| Min Fiberglass Load | 5,714 | lbs |
| Max Fiberglass Stress | 19,384 | psi |
| Min Fiberglass Stress | 5,270 | psi |
| Fiberglass Load | 75.3 | % |

**Calculate from SPM or Target Rate**

Stroke Rate  << 9.1 >> SPM

Target Rate  << 400 >> bbl/day

Notice that the SPM has decreased to 9.1 SPM as a result of the additional over travel and the minimum Fiberglass Load is now 5714 thus insuring that the fiberglass section will be maintained in tension during the complete stroke..