

Design Calculations for Sucker Rod Pumping Systems (Conventional Units)

API TECHNICAL REPORT 11L
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Upstream Segment

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Foreword

This technical report is under the jurisdiction of the API Standards Subcommittee on Field Operating Equipment (API SC11). This technical report replaces Recommended Practice 11L, *Design Calculations for Sucker Rod Pumping Systems*, 4th Edition. This technical report shall become effective on the date printed on the cover but may be used voluntarily from the date of distribution.

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Design Calculations for Sucker Rod Pumping Systems (Conventional Units)

1 Introduction

1.1 In 1954, a group of users and manufacturers of sucker rod pumping equipment undertook a study in depth of the many complex problems associated with this means of lifting fluid from a well. To control and direct the effort, Sucker Rod Pumping Research, Incorporated, a non-profit organization was created. The services of Midwest Research Institute at Kansas City were retained to perform the work necessary to achieve the objectives of the organization.

1.2 The design calculations are based on correlations of the test data that were obtained during the research phase of the project. Sucker Rod Pumping Research, Inc., before its dissolution, released these correlated test results to the American Petroleum Institute for publication. This technical report for the design calculations of sucker rod pumping systems using conventional pumping units is based on these correlations.

1.3 Three discussions included in the final reports of test results by Midwest Research Institute have been published for permanent reference in API *Drilling and Production Practice* (1968). These discussions include the following topics:

- a) vibration characteristics of sucker-rod strings;
- b) physical characteristics of sucker rods;
- c) dimensional analysis of sucker-rod pumping systems.

1.4 A catalog of over 1100 dynamometer cards derived from the electronic analog computer for many combinations of the independent non-dimensional parameters F_o/Sk_r and N/N_o was included in the material released to API by Sucker Rod Pumping Research, Inc. This catalog has been printed as API 11L2, *Catalog of Analog Computer Dynamometer Cards*.

1.5 Two computer programs have been developed from the data in API 11L. One program developed tabular material calculated for depths of 2000 ft to 12,000 ft in increments of 500 ft and for production rates of 100 barrels/day to over 1500 barrels/day in varying increments. Rod and pump size combinations as listed in Table 4.1 were used, except for the elimination of rod no. 88 and rod no. 99. All API stroke lengths are covered. This material is printed as API 11L3, *Sucker Rod Pumping System Design Book*.

1.6 The other program developed a series of curves for selecting beam pumping units for depths of 1600 ft to 9900 ft and various rates of production and combinations of rod sizes, pump sizes, and speeds. Generally, the limiting factor on the curve is the peak torque rating of the unit. This material was printed as API 11L4, *Curves for Selecting Beam Pumping Units* (withdrawn from publication in 2008).

2 Validity of Calculations

2.1 In a majority of cases, it has been found that the values calculated by the following method have been in reasonably close agreement with measured values. Several groups conducting independent surveys have found this design method to give better results than other methods formerly used. However, since this method is based on the best interpretations of average values, the actual conditions found in individual cases may not always yield valid predictions of pumping system performance.

2.2 The designer must realize that there are a number of unusual conditions which may be present in a well that could cause misleading conclusions from these design calculations. Some of these unusual conditions are:

- a) slanted or crooked holes;
- b) very viscous fluid;
- c) excessive sand production;
- d) excessive gas production through the pump; and
- e) well flowing-off.

2.3 The research work was limited to simulated problems in which the tubing was assumed as being anchored at the pump. Therefore, the test results reflected only this condition. However, because of the many known cases in which tubing is unanchored, a formula is included which, experience indicates, will give a very close approximation of relative plunger travel with respect to the pump. This value is identified with the symbol S_p . Examination of the formula will reveal that the contraction of the tubing caused by the transfer of the fluid load from the standing valve to the traveling valve is subtracted from the calculated plunger stroke. It is realized that this formula is highly simplified and not mathematically correct, but it is close enough for practical application.

2.4 These design calculations may be used with confidence when applied to the broad category of average, normal pumping wells fitting the assumed conditions outlined in Annex A. Unusual, conditions not fitting the assumptions will cause deviations from calculated performance. The designer must recognize this fact even though he cannot calculate quantitative values for this deviation.

3 Symbols and Formulas

3.1 Symbols, with Units Where Applicable, Used in the Technical Report

3.1.1

CBE

counterweight required, lb

3.1.2

D

plunger diameter, in.

3.1.3

E_r

elastic constant—rods, in./lb-ft (Table 4.1, Column 4).

NOTE E_r represents the inches of elongation caused by the application of a load of 1 lb to a rod 1 ft in length

3.1.4

E_t

elastic constant—tubing, in./lb ft (see Table 4.2, Column 5)

NOTE E_t represents the inches of elongation caused by application of a load of 1 lb to a section of tubing 1 ft in length.

3.1.5

F_1

PPRL factor (see Figure 3.1)

3.1.6 F_2

MPRL factor (see Figure 3.1)

3.1.7 F_c

frequency factor (see Table 4.1, Column 5)

3.1.8 F_o

differential fluid load on full plunger area, lb (see Figure 3.1)

3.1.9 F_3

PRHP factor

3.1.10 G

specific gravity of produced fluid

3.1.11 H

net lift, ft

3.1.12 L

pump depth, ft

3.1.13 $MPRL$

minimum polished rod load, lb (see Figure 3.1)

3.1.14 N pumping speed, SPM **3.1.15** N_o natural frequency of straight rod string, SPM **3.1.16** N'_o natural frequency of tapered rod string, SPM **3.1.17** PD

pump displacement, barrels/day

3.1.18 $PPRL$

peak polished rod load, lb (see Figure 3.1)

3.1.19*PRHP*

polished rod horsepower

3.1.20*PT*

peak crank torque, lb-in.

3.1.21*S*

polished rod stroke, in. (see Figure 3.1)

3.1.22*Sk_r*

lb of load necessary to stretch the total rod string an amount equal to the polished rod stroke, S

3.1.23*S_p*

bottom hole pump stroke, in.

3.1.24*SPM*

strokes/minute

3.1.25*T*

crank torque, lb-in.

3.1.26*T_a*torque adjustment constant for values of W_{rf}/Sk_r other than 0.3**3.1.27***W*

total weight of rods in air, lb

3.1.28*W_r*

average unit weight of rods in air, lb/ft (see Table 4.1, Column 3)

3.1.29*W_{rf}*

total weight of rods in fluid, lb (see Figure 3.1)

3.1.30 $1/k_r$

elastic constant—total rod string, in./lb

NOTE k_r is the spring constant of the total rod string and represents the load in lb required to stretch the total rod string 1 in.

3.1.31 $1/k_t$

elastic constant—unanchored portion of tubing string, in./lb

NOTE k_t is the spring constant of the unanchored tubing and represents the load in pounds required to stretch the unanchored portion of the tubing, between the anchor and the pump, 1 in.

3.2 Formulas

An understanding of the formulas utilized for the solution of sucker rod pumping problems will be gained by referring to Figure 3.1. The variables F_0 , F_1 , F_2 , W_{rf} , and S are illustrated with this figure.

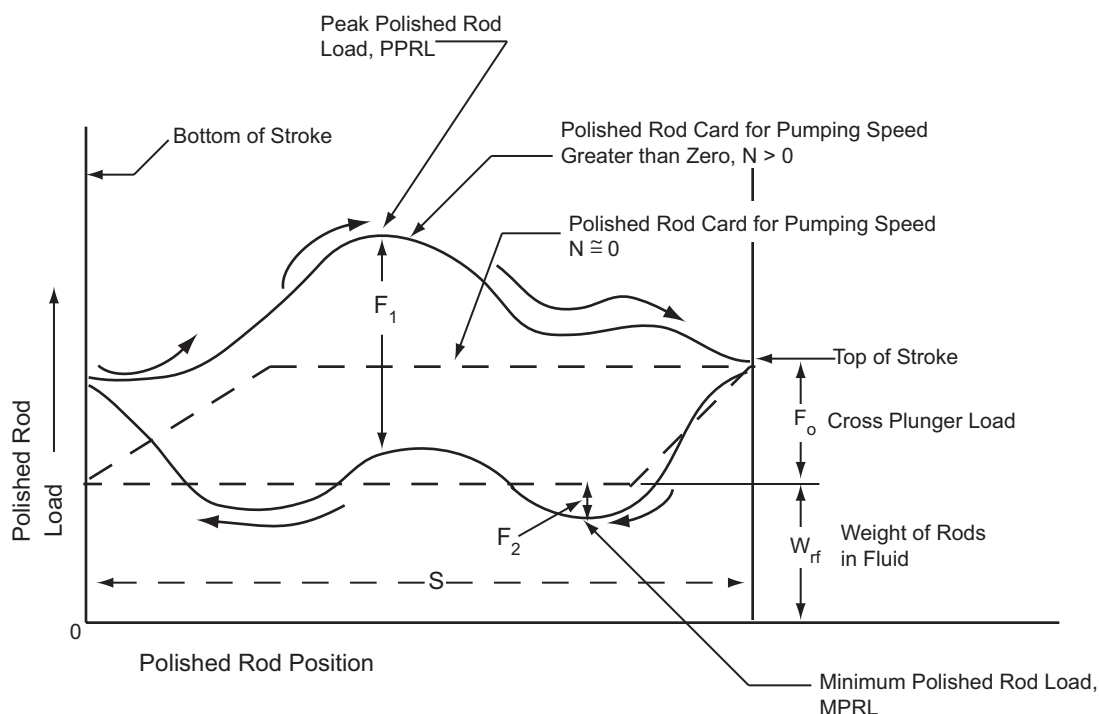


Figure 3.1—Basic Dynagraph Card

a) At pumping speed, $N \approx 0$

$$\begin{aligned} \text{peak polished rod load,} & \quad PPRL = W_{rf} + F_0 \\ \text{minimum polished rod load,} & \quad MPRL = W_{rf} \end{aligned}$$

b) For pumping speed, $N > 0$

$$\begin{aligned} \text{peak polished rod load,} & \quad PPRL = W_{rf} + F_1 \\ \text{minimum polished rod load,} & \quad MPRL = W_{rf} - F_2 \end{aligned}$$

3.2.1 The problem is generalized by using parameters of variables that are non-dimensional.

a) The independent non-dimensional variables are:

$$N/N_o \text{ (Dimensionally } = SPM/SPM = 1), \text{ and}$$

$$F_o/S_{kr} \text{ (Dimensionally } = \frac{\text{lb}}{\text{in.} \times \text{lb/in.}} = 1)$$

where

N is *SPM*
 N_o is *SPM* at natural frequency of rod string
 S is surface stroke
 k_r is spring constant of rod string

b) The dependent non-dimensional variables are:

peak polished rod load, *PPRL*: F_1/Sk_r
 minimum polished rod load, *MPRL*: F_2/Sk_r
 peak torque, *PT*: $2TS^2k_r$
 polished rod horsepower, *PRHP*: F_3/Sk_r
 plunger stroke, S_p : S_p/S

3.2.2 In the research project the sucker rod pumping system was simulated by an electronic analog computer. Computer runs were made for many combinations of N/N_o and F_o/Sk_r with the dependent non-dimensional variables being measured on each test. Test results were correlated by plotting the families of curves shown in Figures 4.1 through 4.5. From these curves, values for the various non-dimensional variables may be determined for substitution in the following design calculation formulas:

plunger stroke,

$$S_p = [(S_p/S) \times S] - [F_o \times 1/k_t]$$

NOTE When tubing is anchored, the value of $1/k_t$ equals zero, therefore the formula for S_p with anchored tubing becomes $(S_p/S) \times S$.

pump displacement,

$$PD = 0.1166 \times S_p \times N \times D^2$$

peak polished rod load,

$$PPRL = W_{rf} + [(F_1/Sk_r) \times Sk_r]$$

minimum polished rod load,

$$MPRL = W_{rf} - [(F_2/Sk_r) \times Sk_r]$$

peak torque,

$$PT = (2T/S^2k_r) \times Sk_r \times S/2 \times T_a$$

polished rod horsepower,

$$PRHP = (F_3/Sk_r) \times Sk_r \times S \times N \times 2.53 \times 10^{-6}$$

counterweight required,

$$CBE = 1.06 (W_{rf} + 1/2 F_o)$$

4 Design Procedure

4.1 The final solution to this design problem is reached through trial and error methods. Generally, three steps are required in designing an installation.

- A preliminary selection of components for the installation must be made.
- The operating characteristics of the preliminary selection are calculated by use of the formulas, tables, and figures presented herein.
- The calculated pump displacement and loads are compared with the volumes, load ratings, stresses, and other limitations of the preliminary selection.