CONVENTIONAL BEAM PUMPING PRODUCTION CHART ANALYSIS

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INTRODUCTION

Secondary recovery projects continue to place greater demand on existing sucker rod pumping systems. Increased water injection, water breakthrough, and water encroachment have placed greater requirements on individual sucker rod pumping systems than was anticipated originally.

Four major limitations exist in a sucker rod pumping system. These limitations are as follows:

1. *Gear reducer torque limits* are usually reached prematurely because the unit is being operated in the longest stroke.[1]
2. *Rod stress* normally requires the use of an API Class C or D rod. Recently two new sucker rods were designed for stress ratings of 40,000 to 50,000 psi. The new rods should raise the maximum allowable stress for a sucker rod pumping system.
3. *Critical speeds* are often greater than anticipated.[1] In the great majority of cases, some other design parameter will limit the design before critical speed is approached.[1]
4. *Polished rod stroke length* is limited to pumping unit manufacturing design, but the best stroke length available should be used.

The majority of secondary recovery producing wells are equipped with conventional beam units. Proper utilization of these existing units can result in improvement in the loading efficiency of these units coupled with an increase in fluid production capability. Substantial savings can result through delayed or unnecessary investment for larger units.

The conventional beam pumping-production charts were constructed for use as a guide in designing sucker rod pumping systems and for review of existing systems.

GENERAL EXPLANATION OF CHARTS

The conventional beam pumping production chart is a family of curves illustrating the relationship of production (BFPD) by various pump diameters to the number of strokes per minute. Standard torque ratings, stress allowables, and critical speed have been superimposed on the charts to illustrate specific sucker rod system design limitations. Figures 1A through 1H are a set of conventional beam pumping production charts for 5000-ft pump depth. (All figures are presented at the end of the paper). The charts have been constructed by using the following assumed operating conditions:

1. Constant polished rod stroke length (for each chart)
2. Standard tapered rod string
3. Fluid level equal to pump depth
4. Anchored tubing
5. Specific gravity of the fluid equals 1.00.

Design calculations were made by the API RP 11L[2,3] (Sucker Rod System Design) and API RP 11BR[4] (Modified Goodman Stress Diagram) method. Sucker rod system design computations were made by Mobil's computer program (M6036).

The API RP 11L sucker rod design calculation does not consider the following factors:

1. Pump friction
2. Friction between rods and tubing (vertical and/or slanted or crooked holes)
3. Rod coupling - piston effect
4. Very viscous fluids
5. Paraffin and scale
6. Excessive sand production
7. Corrosion
8. Impact loading (fluid pound or gas interference)
9. Use of sinker bars

10. Use of the high-slip motor (35-45% slippage)
11. Excessive tightening of the stuffing box (shallow wells)
12. Fluid friction
13. Wells attempting to flow.

PRODUCTION CURVES

Figures 1A through 1H illustrate fluid production (100% efficiency) by various pump diameters plotted against strokes per minute. Rod string dynamic effects, with an increase in speed (SPM), prevent the individual fluid production curves from being defined as a straight-line function. In addition, the individual fluid production curves cannot be defined as parallel lines; therefore, the curves can be defined as a family of similar curves.

GEAR REDUCER TORQUE LIMITATION

Figure 2 relates fluid production by pump diameters to various polished rod stroke lengths coupled with a constant gear reducer torque. Figure 2 also shows how the fluid production capabilities increase as the polished rod stroke length decreases.

Figures 1A through 1H illustrate the fluid production curves with the superimposed gear reducer torques. The calculated gear reducer torques placed on the curves correspond to the standard API gear reducer torque ratings.

Figures 1A through 1H also illustrate how maximum fluid production may be obtained for a particular conventional beam pumping unit by decreasing the unit's polished rod stroke length.

ROD STRESS LIMITS — API CLASS C AND D RODS

The allowable sucker rod stress is determined by using the modified Goodman stress diagram technique. The modified Goodman stress diagram may be defined by the following equation:

S_a = $(T/4 + M\,S_{min})$ SF, or
S_a = $(0.25T + 0.5625\,S_{min})$ SF

Where:

S_a = Max. allowable stress, psi
M = Slope of S curve = 0.5625
S_{min} = Min. stress, psi (calculated or measured)
SF = Service factor
T = Min. tensile strength, psi

Mobil's computer program M6036 calculated the API Class C and D rod stress allowable with the following data:

SF = 1.00 (assumed value for both rods)
T = 90,000 psi for API Class C rod
T ≐ 110,000 psi for API Class D rod
S_{min} = Calculated min. beam load/by the area of the top rod (same for both rods)

Figure 3 illustrates the comparison of API Class C and D rod stress allowable curves and peak calculated stress curves by pump diameter versus strokes per minute. The allowable stress decreases as the speed (SPM) increases, with a corresponding increase in peak calculated rod stress.

The API Class C and D rod stress limit curves superimposed on the production curves (Figs. 1A through 1H) represent the point where the rod stress allowable equals the peak calculated stress per pump diameter.

CRITICAL SPEED INFLUENCE

Critical speed is defined as the speed (SPM) at which the minimum load on the polished rod approaches zero.[1] In practical applications, the critical speed is the speed at which the carrier bar is about to leave the polished rod clamp.[1]

The polished rod stroke length and the pump setting depth affect the critical speed. Figures 1A through 1H illustrate that as the polished rod stroke length increases the critical speed decreases. The critical speed increases as the pump setting depth increases. Normally, the increase in rod weight accounts for the increase in the critical speed with an increase in pump setting depth.[1]

Reviewing Figs. 1A through 1H, the effect on critical speed by varying the pump diameter appears to be minimal.

In most cases, critical speed would be a design limitation for shallow, high volume producing wells. Normally, sinker bars are mounted above the pump to assist in increasing the apparent critical speed.

EXAMPLE PROBLEM

A conventional 456,000 in-lb beam pumping unit is operating at 10 SPM with a 120-in. polished rod stroke length. Other operating conditions are as follows:

1. 1-in., 7/8-in., 3/4-in. standard rod taper (Class C rods)
2. Pump depth and fluid level equal 5000 ft.
3. The 2-7/8-in. tubing is anchored.
4. A 1-3/4-in. pump plunger is being used.

5. The specific gravity of the fluid is 1.00.

The current calculated daily fluid production is 312 BFPD at 80% efficiency.

Referring to Figs. 1A through 1H, how could this pumping unit be operated to provide a calculated daily fluid production of 380 BFPD at 80% efficiency?

The production charts reflect production (BFPD) at 100% efficiency. Therefore, the production at 100% efficiency would be 475 BFPD (380 BFPD/0.80).

Referring to Fig 1G, it is found that the 456,000 in-lb pumping unit can be operated with a 106-in polished rod stroke length at 11 SPM with a 2-in. pump to provide the required 475 BFPD at 100% efficiency or 380 BFPD at 80% efficiency. In addition, the change from a 1-3/4-in. pump to a 2-in. pump will require a change in the standard rod taper for the Class C rods as follows:

	Required Rod Footage	
Rod	1-3/4″ Pump	2″ Pump
1″	1280′	1435′
7/8″	1450′	1625′
3/4″	2270′	1940′

Figure 1G indicates the new operation will not exceed the limiting factor of critical speed.

SUMMARY

Each sucker rod pumping system should be utilized to its full capacity before changing to a larger pumping unit. Charts such as described in this paper help operating personnel to optimize producing capacity for each well.

REFERENCES

1. Lewis, Kay W.: Methods for Improved Utilization of Beam Pumping Units, a paper presented at the nineteenth annual Southwestern Petroleum Short Course, Texas Tech University, Lubbock, Texas, Apr. 1972.
2. API Recommended Practice for Design Calculations for Sucker Rod Pumping Systems (Conventional Units), API RP 11L, First Edition, Mar. 1967.
3. API Recommended Practice for Design Calculations for Sucker Rod Pumping Systems (Conventional Units), Supplement 1, API RP 11L, First Edition, Jan. 1970.
4. API Recommended Practice for Care and Handling of Sucker Rods, API RP 11BR, Fifth Edition, Mar. 1969.

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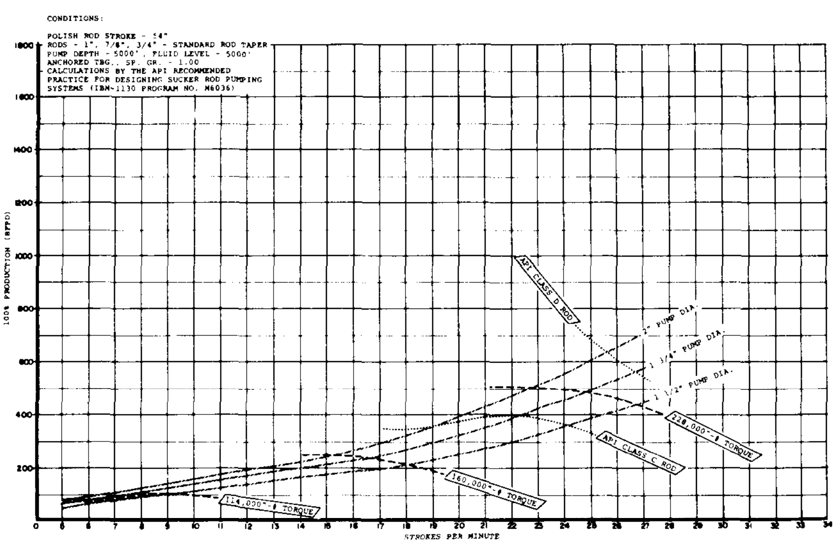


FIG. 1A—DAILY FLUID PRODUCTION VS. SPM, 5000 FT PUMP DEPTH, 54-IN. STROKE

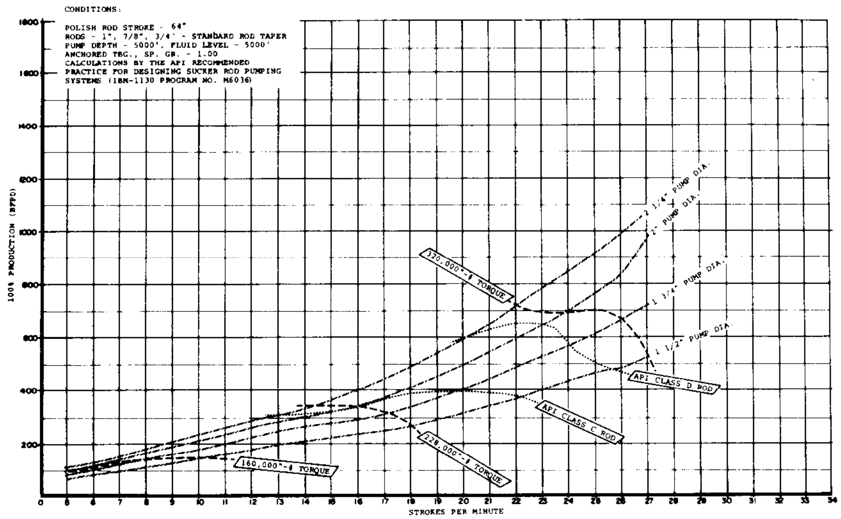


FIG. 1B—DAILY FLUID PRODUCTION VS. SPM, 5000 FT PUMP DEPTH, 64-IN. STROKE

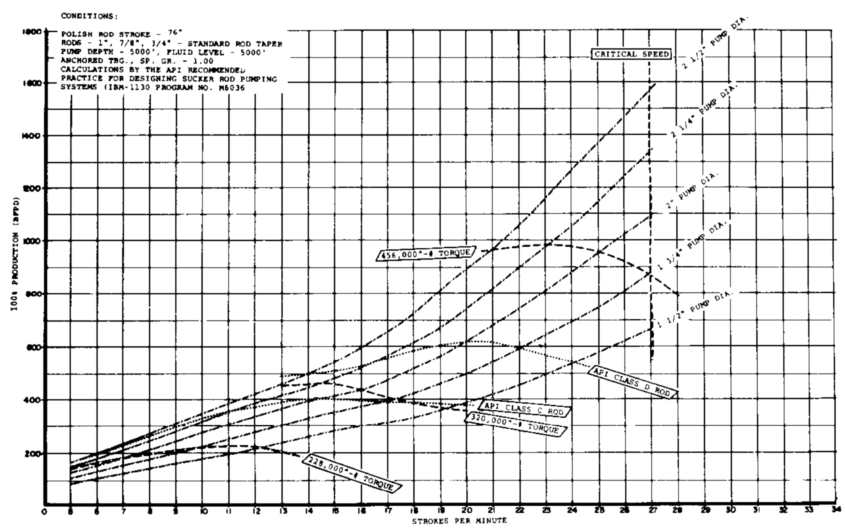


FIG. 1C—DAILY FLUID PRODUCTION VS. SPM, 5000 FT PUMP DEPTH, 76-IN. STROKE

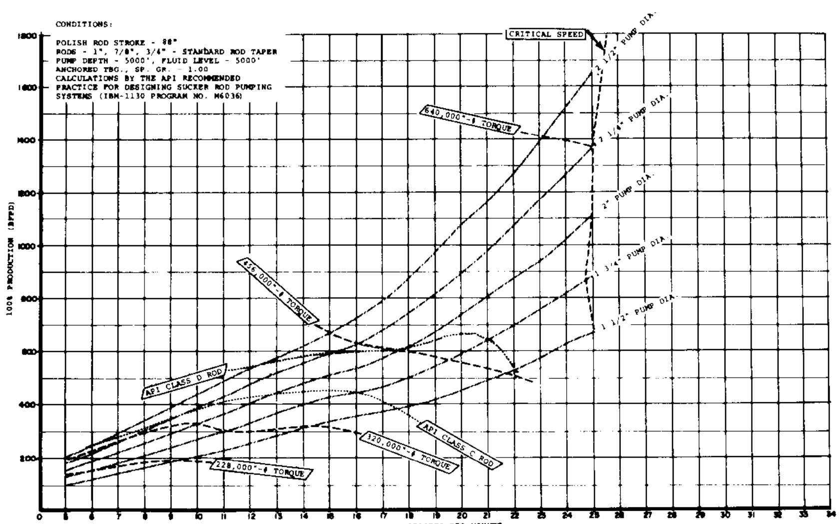


FIG. 1D—DAILY FLUID PRODUCTION VS. SPM, 5000 FT PUMP DEPTH, 88-IN. STROKE

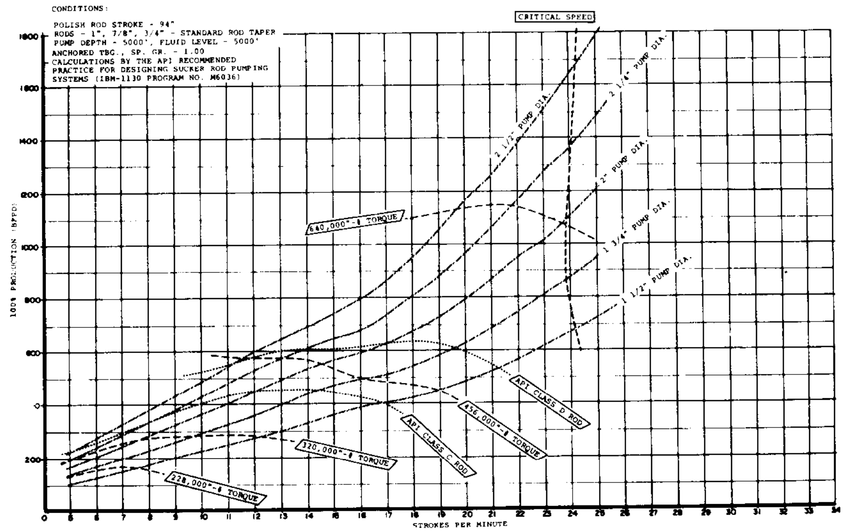


FIG. 1E—DAILY FLUID PRODUCTION VS. SPM, 5000 FT PUMP DEPTH, 94-IN. STROKE

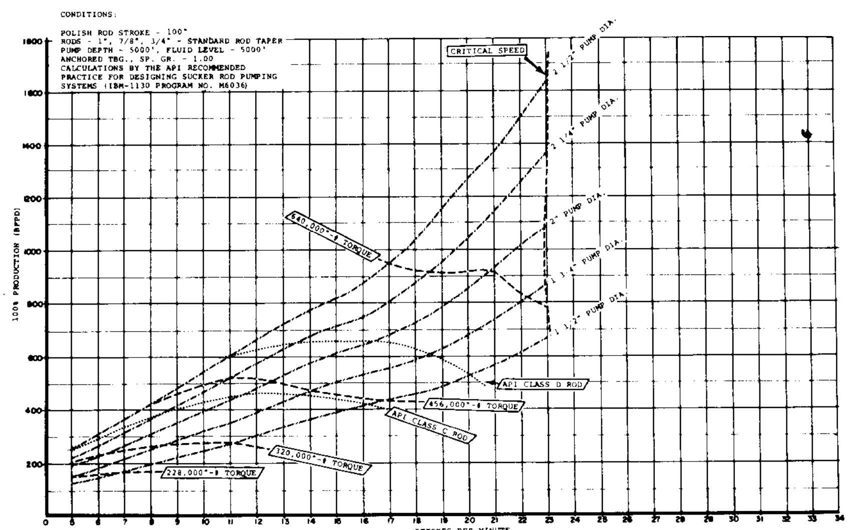


FIG. 1F—DAILY FLUID PRODUCTION VS. SPM, 5000 FT PUMP DEPTH, 100-IN. STROKE

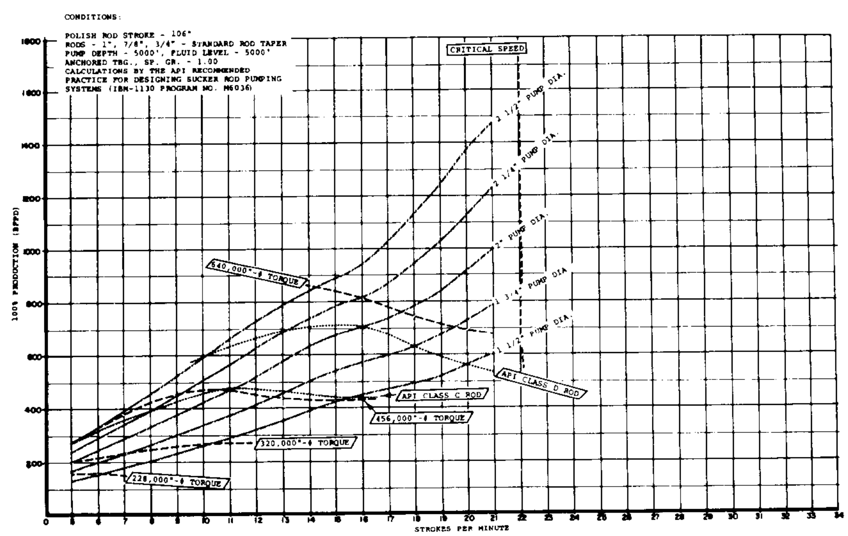
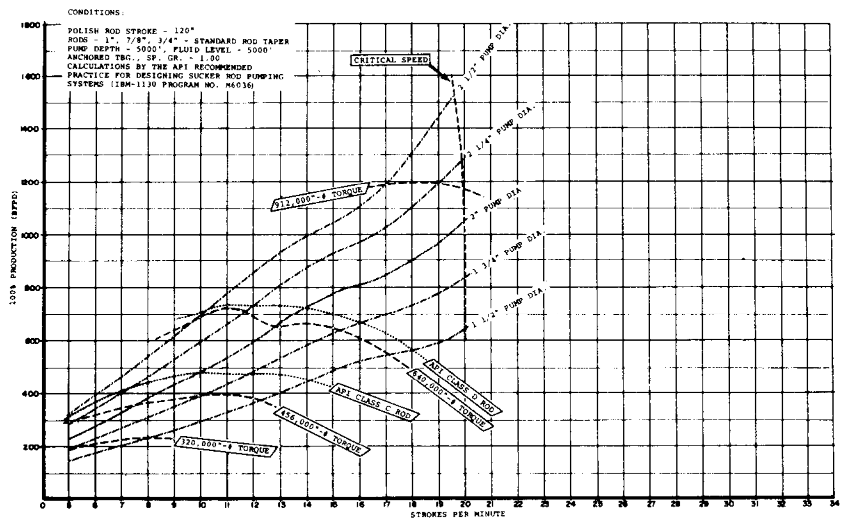


FIG. 1G—DAILY FLUID PRODUCTION VS. SPM, 5000 FT PUMP DEPTH, 106-IN. STROKE

FIG. 1H—DAILY FLUID PRODUCTION VS. SPM, 5000 FT PUMP DEPTH, 120-IN. STROKE



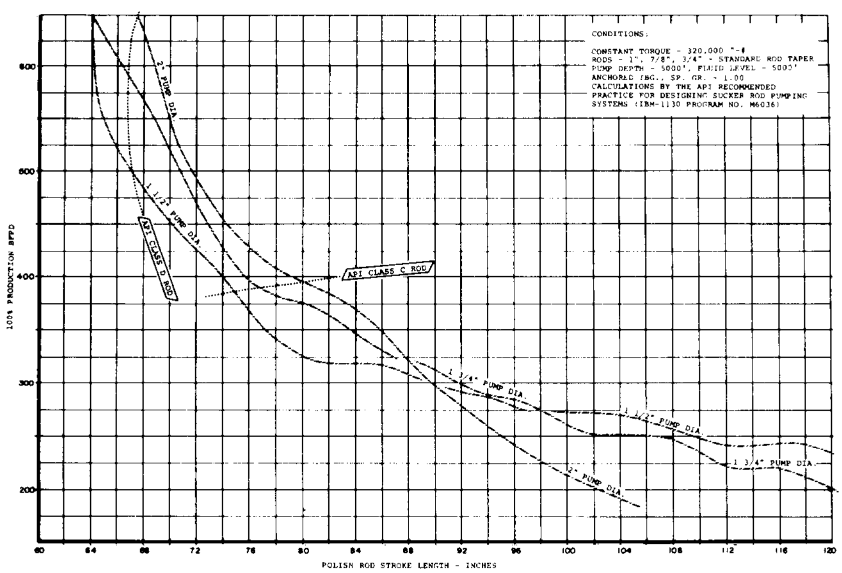


FIG. 2—DAILY FLUID PRODUCTION VS POLISHED ROD STROKE LENGTH FOR SAMPLE PROBLEM

FIG. 3—STRESS VS SPM FOR SAMPLE PROBLEM