Pumping Through Macaroni* (Hollow) Sucker Rods

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INTRODUCTION

The use of Macaroni tubing is not new; for many years oil producers have been successfully pumping fluids through and around this tubing. However, these applications have generally been limited to wells above 3,000 feet. This limitation, imposed because of the failure of the mechanical joint in reciprocating service, can be materially altered or entirely eliminated if we understand the problems and design accordingly. To do this, we must first determine the forces which are present in pumping with Macaroni sucker rods and evaluate their magnitude.

Some of the forces present are: dead weight of rods, dead weight of fluid, acceleration and deceleration, fluid friction and mechanical friction. All of these forces are present to some degree in a reciprocating rod string, and the sum of these forces constitute the polish rod load.

DERIVATION OF FORMULA

Since pumping with Macaroni (hollow) and solid rods are similar in fundamental respects, the formula for calculating maximum polish rod loads for solid rods as proposed by K. N. Mills can be altered to reflect loads when pumping through Macaroni sucker rods.[1] Mill's formula is

$$PL\ (Max.) = W_f + W_r\ (1 + \frac{N^2L}{70,500})$$

or

$$W_f + W_r\ (1 + C) \qquad (1)$$

where:

PL = polish rod loads - lbs.
Wf = weight of fluid, lbs., = (area of plunger - area of rods) x P.G. x Depth
Wr = weight of rods, lbs.
L = length of stroke, in.
N = number of strokes per minute
$C = \frac{N^2L}{70,500}$ (called acceleration factor)
P.G. = pressure gradient per foot or .433 x S.G.

This formula as it is constituted above is also applicable to pumping through the annulus (between the Macaroni sucker rods and tubing or casing.).

This formula does not accelerate the fluid in the annulus because the displacement of the pump is small in most instances when compared to the volume of the annulus and consequently does not move the oil any appreciable distance, and also because of the slow rate of stress transmission of the fluid. However, with Macaroni sucker rods being used both for rods and tubing, all the oil in the tubing is accelerated once the traveling valve closes on the up stroke; so the formula should be changed to read:

$$PL\ (Max.) = (W_f + W_r)\quad (1 + C) \qquad (2)$$

The factors in the formula all remain the same except W_f, which now becomes the weight of the volume of oil inside the Macaroni sucker rods (internal area of tubing x P.G. x depth). For this reason, the maximum polish rod load is not determined in any way by the size of the pump.

The minimum polish rod load for a solid sucker rod string is calculated by:

$$PL\ (Min.) = W_r\ (1 - C) - W_r\ \frac{62.5}{490} \qquad (3)$$

The last factor in this equation is the buoyancy of the rods. When the annulus is vented while producing through Macaroni sucker rods, the buoyancy factor is nearly zero. (Actually, the working oil level in the annulus will provide some buoyancy.) The equation then becomes:

$$PL\ (Min.) = W_r\ (1 - C) \qquad (4)$$

Three Different Conditions

When the rods start the down stroke, three different conditions can exist depending upon the size of the plunger and rods. First, if the plunger diameter and Macaroni sucker rod internal diameter are the same, the weight of the column of oil rests on the standing valve and the net weight of the oil on the rods is zero (Fig. 1). Second, where the internal diameter of the rods is greater than the outside diameter of the plunger, part of the column of oil (area of plunger x P.G. x D.) rests on the standing valve and the balance rests on the Macaroni sucker rods (Fig. 2). Since this balance of weight is moving downward, it should be decelerated the same as the rods. And third, where the outside diameter of the plunger is greater than the internal diameter of the rods, all of the weight of the oil in the rods and pump is supported by the pump standing valve (Fig. 3). However, a force, (area of plunger - internal area of rods) x P.G. x D resists downward

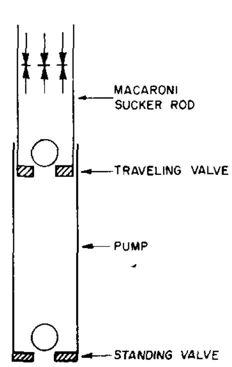

FIG. 1

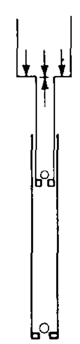

FIG. 2

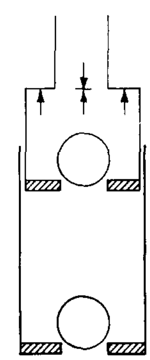

FIG. 3

*T. M. applied for U. S. Patent Office

movement of the rods. This force will displace fluid which must be accelerated upward by the weight of the rods.

By using the following formula all the conditions described above are satisfied.

$$PL\ (\text{Min.}) = W_r\ (1 - C) + (A_r - A_p) \times P.G. \times D \times (1 \pm C) \qquad (5)$$

Note: When the plunger diameter is larger than the internal diameter of the rods, "C" in the second portion of this equation is positive (+). It is negative (-) when the plunger diameter is smaller than the internal diameter of the rods.

A_r = internal area of rods, Sq. in.

A_p = area of plunger, Sq. in.

FLUID FRICTION

Another factor, however, should be considered—friction of the oil passing up through the Macaroni sucker rods. With conventional rods this is not considered as the friction up the annulus is relatively insignificant. It is also relatively insignificant for Macaroni sucker rods at average rates of production (100 B/D for 3/4 in. and 200 B/D for 1 in. Macaroni sucker rods), but at higher rates of production it becomes a factor. The following formula is suggested in these cases.

$$PL\ (\text{Min.}) = W_r\ (1 - C) + (A_r - A_p) \times P.G. \times D \times (1 \pm C) - F \qquad (6)$$

where:

$F = \triangle P \times D \times A$

where:

$\triangle P$ = $\triangle p$/1000 ft. of oil at 3.136 x BPD rate
D = depth in thousand feet
A = internal area of Macaroni sucker rods in sq. in.

Since oil is pumped only on the down stroke, the pressure drop per thousand feet must be calculated at twice the daily producing rate. Also, the speed of the polish rod is greater when at the halfway point of the down stroke. This is due to the angular velocity of the crank arm. The speed of the polish rod at this point is 1.568 times the average speed. Hence, the constant 3.136 comes from 2 x 1.568.

By multiplying 3.136 by barrels per day, the corrected maximum producing rate is found. The pressure drop per thousand feet is found from Fig. 4, using the corrected barrels per day rate.

MECHANICAL FRICTION

Mechanical friction is the force created by rods rubbing against the casing. With solid sucker rods it is ignored as all the rods are assumed to be in tension on both the upstroke and downstroke.

With Macaroni sucker rods it can also be assumed that the same reasoning applies with one exception — that exception occurs on the downstroke when the plunger diameter exceeds the internal diameter of the Macaroni sucker rods. When this condition exists, there is a force, represented by $(A_r - A_p) \times P.G. \times D \times (1 + C) - F$ in the minimum polish rod formula, which resists the downward movement of the rods. It is directly proportional to the plunger size.

This resistance to the fall of the rods could cause the lower portion of the rod string to bend out and contact the casing walls thereby creating mechanical friction.

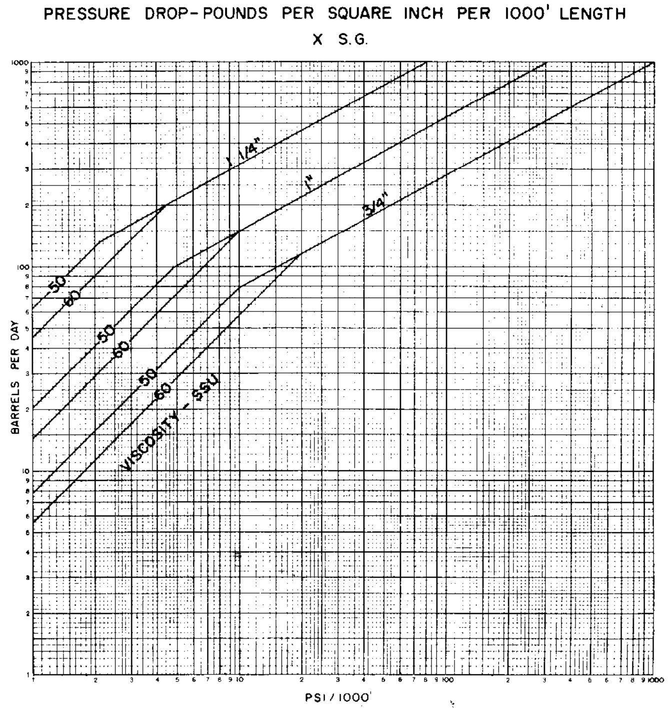

FIG. 4

Since it is impossible to calculate its magnitude at the present time, it is left out of the formula. Time and experience may give us the answer, and it is believed that rod guides or centralizers will minimize this force even when using large diameter plungers.

APPLICATION OF FORMULA

A modified Goodman's diagram has been prepared (Fig. 5) for continuous weld, J-55, and N-80 Macaroni rods. This diagram was devised in the same manner as the one proposed by A. A. Hardy for solid sucker rods.[2] It actually gives a four to one safety factor over the fatigue endurance limit as determined by the rotating beam test. The maximum range of stress in this diagram was set at approximately 37 per cent of minimum yield.

Maximum and minimum stresses may be calculated by dividing the polish rod loads by the area of metal in the body of the Macaroni sucker rods. The calculated minimum stress is plotted in Fig. 5 on the minimum stress line. The calculated maximum stress is plotted vertically above this point. The maximum stress line just above the maximum stress point is labeled with the grade of

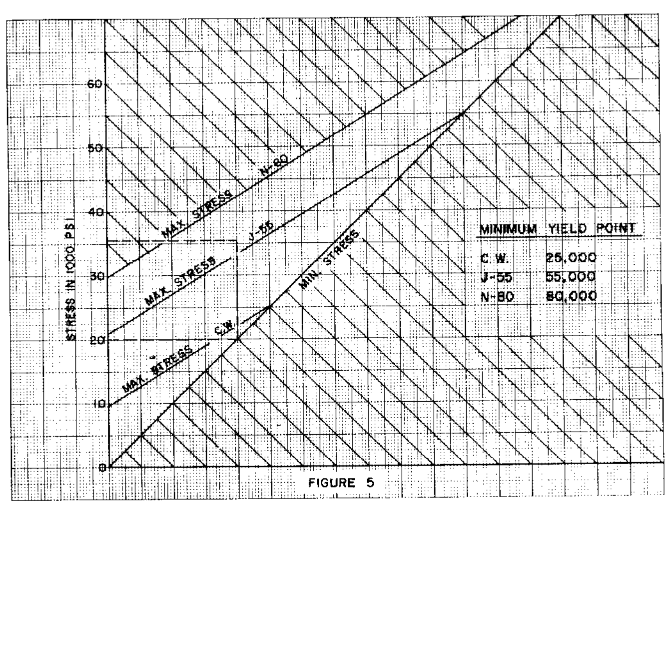

FIGURE 5

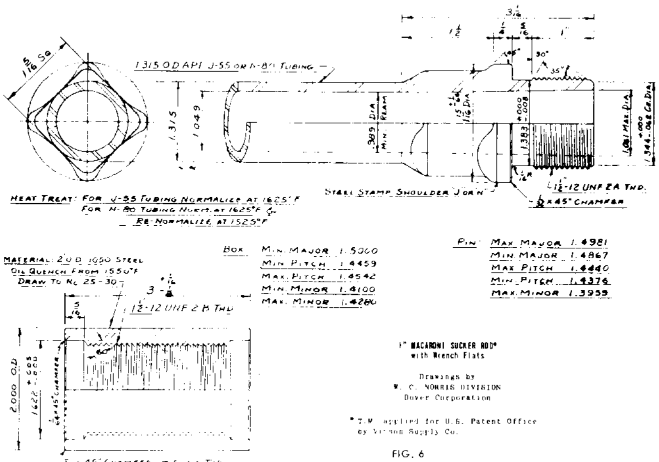

FIG. 6

steel required to successfully fulfill the requirements of this pumping problem.

Rods in a pumping well are generally subjected to bending. This bending can create high stresses which cause premature failure of the mechanical joint. Mechanical joints (Fig. 6) for Macaroni tubing are in production now. These are similar to a sucker rod joint where the stresses of bending and load are passed through a shoulder rather than through the last fully engaged thread. This joint was designed to be stronger than the tubing, and consequently, the full area of metal in the tubing can be used to figure stresses.

This joint is now available in 3/4 in. and 1 in. pipe size in grades of steel of continuous weld, J-55 and N-80; 1-1/4 in. pipe size will probably be available in the future. Since API line pipe or API tubing joints are not supported by a shoulder as are Macaroni sucker rods, the metal under the last effective thread is subject to high bending stresses. Therefore, the area of metal used for calculating stresses should be decreased when using this type of joint.

Rod Stretch

The amount of Macaroni rod stretch is dependent upon the change in load on the string. This change in load is proportional to plunger size, specific gravity of the fluid, and pump depth. Rod stretch can be expressed by the following formula:

For 3/4 in. Macaroni sucker rods

$$S_r = .537 \left(\frac{D}{1000} \right)^2 \times A_p \times S.G. \qquad (7)$$

For 1 in. Macaroni sucker rods

$$S_r = .363 \left(\frac{D}{1000} \right)^2 \times A_p \times S.G. \qquad (8)$$

Where:

S_r = rod stretch, in.

A_p = area of plunger, sq. in.

D = depth to pump, ft.

Overtravel

The amount of overtravel due to acceleration can be calculated from Coberly's formula.[3]

$$OT = 1.55 \times \left(\frac{D}{1000} \right)^2 \times C \qquad (9)$$

OT = over travel, in.
D = depth to pump, ft.
C = acceleration factor

DISCUSSION OF MACARONI SUCKER RODS

In analyzing the application of Macaroni sucker rods to oil field pumping problems, the following advantages and disadvantages have been listed for your convenience.

Advantages

1. Since Macaroni rods serve both as tubing and rods, they are less expensive than the conventional combination of tubing and solid rods.
2. They are versatile in that they could be used for tubing, sucker rods (pumping either through the rods or annulus), and in the case of the shouldered Macaroni joint, could be used as drill pipe.
3. Inhibitors can be injected into a well, whereas on some types of completions this is not possible.
4. Paraffin, sand and BS are all pumped up the inside of the rods, thereby reducing the danger of sticking a pump (due to this material settling on a packer).
5. It is not necessary to strip tubing and rods from a well at the same time if the pump hold down is stuck.
6. Since rod stretch is a function of the area of metal in the rod, Macaroni sucker rods have less stretch than 1/2 in. and 5/8 in. solid rods. The following table shows that wells equipped with Macaroni sucker rods would produce more oil under the same conditions due to the differences in rod stretch.

4000' well, 1-1/4" plunger, 44" stroke, 10 SPM

	1/2" Solid Rods 1-1/4" Tubing	5/8" Solid Rods 1-1/2" Tubing	3/4" Macaroni Rods	1" Macaroni Rods
Rod Stretch	18"	11"	9"	6"
Tubing Stretch	5"	4"	--	--
Total Stretch	23"	15"	9"	6"
Overtravel	2"	2"	2"	2"
BPD*	42	56	67	73

* at 100 per cent efficiency

7. The maximum polish rod load is less than with conventional rods when large diameter plungers are used.
8. The maximum polish rod load is less than with conventional rods when pumping up the annulus, due to buoyancy.
9. A maximum size of 2 in. insert pump can be employed with Macaroni sucker rods whereas a 1 in. insert pump is the largest that can be used with 1-1/4 in. tubing, and 1-1/4 in. insert pump with 1-1/2 in. tubing.
10. The use of Macaroni sucker rods permits the venting of a lower zone in dual completions.
11. A simple spear type of fishing tool can be used for recovering the rods in case of a rod failure. With conventional rods, the clearance between the coupling and pipe has to be ample for an overshot type fishing tool.
12. The rods do not have to be pulled to scrape paraffin.
13. The clearance between the casing and Macaroni sucker rod coupling allows more area for venting gas than do other conventional types of slim hole completions.

Clearance area between casing and coupling, sq. in.

	3/4" Macaroni	1" Macaroni	1-1/4" N. U.	1-1/2" Thinwall
2" casing	1.05			
2-1/2" casing	2.60	1.54	1.37	1.40

14. Tubing stretch is entirely eliminated in slim hole completions and can be eliminated by using a weighted bar hold down if tubing is used.

Disadvantages

1. In wells where paraffin is a problem, it may be necessary to scrape the internal walls of the rods more often than with tubing. This condition is partially offset by the fact that the rods do not have to be pulled when scraping is required. Also, a thin application of plastic to the internal walls would prevent the accumulation of paraffin.
2. Mechanical wear of both the Macaroni rods and casing will be greater than with conventional completions due to the previously mentioned resisting force — and due to a higher coefficient of friction — resulting from less lubrication between the rods and casing. The use of plastic or nylon centralizers should alleviate this condition.
3. The maximum polish rod load is higher than one-half inch solid rods when using small diameter plungers.
4. The pumping of large volumes of fluid inside the hollow rods is not practical. However, due to the buoyancy, annulus pumping should prove quite feasible and economical.

CONCLUSION

The above formulae are acknowledged to be only approximations of polish rod maximum and minimum loads. Such factors as working fluid level in the annulus, semi-flowing wells, paraffin buildup in the rods, mechanical friction, and watercut oils affect the calculations. The only way to determine the polish rod load is to measure it with a dynamometer.

However, it is expected that the above formulae will approximate well loads, or will serve as a starting point for a more accurate method. Macaroni sucker rods hold promise of becoming a more valuable tool in the economical production of petroleum. The intelligent design and selection of rod strings and pumps can prove very beneficial and satisfactory for a producer.

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3. C. J. Coberly, "Estimating Plunger Travel", API Production Bulletin 207, 1931.