SUCKER ROD PUMP BARRELS INCLUDING THE TAPERED BARRELS FOR PRESSURE BALANCE ON THE UPSTROKE

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INTRODUCTION

Downhole sucker rod pumps are simple, linear, reciprocating hydraulic pressure pumps of oil well production, as well as water and condensate production from gas wells. This general class of pump is known for its ability to resist fluid-borne particulates, corrosion, high pressure, and varying oil/gas ratios. This is achieved by incorporating special metallurgies and pump designs, which make them relatively trouble-free and highly reliable in harsh downhole environments.

There are many sucker rod pump arrangements of standard parts which give us pumps for certain production characteristics, such as the top hold down insert pump for some particulate production problems that arise with bottom hold down pumps, or tubing pumps for higher production rates using the same size tubing. Despite the differences in their design and application, all downhole sucker rod pumps comprise of approximately 5 basic pump parts, namely, the standing valve, traveling valve, plunger, barrel and hold-down seal assembly. Each one of these components are essential to the operation of the pump, as well as the other parts which connect these 5 basic parts together. This paper will concentrate on the barrel, its materials, depth limitations, and optional configurations such as tapered inside diameters.

ALL BARRELS HAVE THE SAME TOLERANCE

History

Sucker rod pump barrel sizes, inside diameter tolerances, and threads were standardized by the American Petroleum Institute in API 11AX almost 100 years ago. There have been minor changes and sizes added since then, however, the inside diameters have had the same tolerance across the range of sizes from 1-1/16” inside diameter to 2-3/4” and larger, except for soft-packed barrels.

The original intent of API 11AX was to make these products standardized such that sucker rod pump parts from different manufacturers would fit together. Later, standardized materials were added, as well as quality requirements. All of these requirements are optional for manufacturers, but mandatory for those manufacturers who want their pump parts and assemblies recognized as complying with API 11AX.

BARREL MATERIALS

The selection of materials for sucker rod pump barrels is limited, due to the stringent pressure limitations imposed on them by the depths at which they are installed, and the nature of the reciprocating stresses that they endure throughout each day. At 10 strokes per minute, a sucker rod pump barrel, and other pump parts, go through about 14,000 stress cycles per day. This frequent and sustained exposure to high levels of stress means that sucker rod pump parts, including barrels, are prone to failure due to fatigue stress if they don't wear out first. The choice of barrel materials must be carefully considered to ensure that they can withstand these conditions and maintain optimal pump performance.

Popular barrel materials listed here in descending order of their minimum yield strengths, according to API 11AX, are 501 steel, low carbon steel, and brass, with yield strengths of 70,000 psi, 60,000 psi and 50,000 psi respectively.

Please note that stainless steel materials are not used in sucker rod pump barrels. There is a common misnomer used in this industry, where 501 steel is called "stainless steel", but it only has 4 to 6% chrome, whereas 3XX stainless steel has a minimum requirement of 18% chrome to achieve the passivity of stainless steel. 501 steel does have better corrosion resistance and higher strength than the common low alloy steel used in sucker rod pump barrels, and thus is a good choice in some applications where the corrosion resistance of brass is not needed, and a higher strength is desired. The 3XX stainless steels are not used for sucker rod pump barrels due to their low yield strength.

Another misunderstanding in the industry is that brass barrel material is low strength material. However, the brass material used in sucker rod pump barrels is a high strength brass (UNS C443XX inhibited admiralty brass) and is quite unlike common soft brass used in household applications. Admiralty brass has almost the strength of steel (83%) and is used successfully in some tough down hole applications. It offers high durability, resistance to corrosion, and is well-suited for harsh environments.

DEPTH LIMITATIONS

API 11AR has excellent charts for sucker rod pump depth limitations. These are calculated and organized by pump configuration, material, and barrel inside diameter. The calculations consider all the relevant failure modes and list the depth limitations based on the failure mode with the highest calculated stress.

Exceptions to the API 11AR charts exist but do not abound.

One of these exceptions is the use of 2" RWA pumps in the Drayton Valley, Alberta, Canada area using steel, chrome plated barrels at up to 5,000' depth, whereas the API 11AR recommendation is 3,732'.

Another is the use of 2-1/4” TH admiralty brass barrels with a nickel carbide coating. These are run below 8,000’ in the Bakken area, and the API 11AR recommendation is 6,062’.

Exceptions should be selected carefully, based on actual test values.

BARREL COATINGS FOR CORROSION AND ABRASION RESISTANCE

Currently, there are only two common barrel coatings used for sucker rod pump barrels; hard chrome plating and nickel carbide plating.

Hard chrome plating is solely applied to the inside diameter of the sucker rod pump barrel. It is an excellent choice for particulate production in non-corrosive to mildly corrosive downhole environments. It is essential to note that it is easily susceptible to hydrochloric acid, which will dissolve chrome plating at a rate proportional to the strength of the acid. Some other acid combinations commonly used downhole are safe for use with chrome plating, but only if they do not contain hydrochloric acid. To ensure the compatibility of hard chrome plating with specific acid combinations, testing is advised. Hard chrome plating has successfully been applied to low carbon steel, 501 steel and brass barrel materials. It is a popular plating option for sucker rod pumps operating in high particulate production wells.

Nickel carbide plating is an intriguing option due to its high corrosion resistance, and success in particulate production. This plating is applied to all surfaces of the sucker rod pump barrel; inside diameter, outside diameter, and threads, providing comprehensive protection against wear and corrosion. Unlike hard chrome plating, it is resistant to hydrochloric acid as well as other acids used downhole, and is applied to low carbon steel, 501 steel and brass materials.

Both hard chrome plating and nickel carbide plating on low carbon steel or 501 steel have a “failure” mode that is unique compared to other types of materials used in down hole sucker rod pumps. This “failure” mode is not a fault of the base material or the plating material. It is simply a natural way for these material combinations to react to each other. The “failure” mode is galvanic corrosion between the steel or 501 steel and the plating, with the steel or 501 steel being the sacrificial anode, and thus going away to protect the nickel in the nickel carbide plating or the chrome in the chrome plating. Of course, there must be a breach of the nickel carbide plating or chrome plating to allow corrosive fluids to reach the plating boundary. This breach can be due to abrasive wear, unusually large solids, or in the case of chrome plating, the effects of Hydrochloric acid. These “failures” are dramatic looking because the galvanic corrosion will cause a hole in the barrel, and subsequent washing out of the edges of the hole. Unless this happens within a short time after installation, it is not a manufacturing problem with the barrel, but rather a normal mode of the barrel reaching the end of its life, and other changes could possibly be made to the pump and well configurations to extend the barrel life.

BARREL SURFACE TREATMENTS FOR ABRASION RESISTANCE

A surface treatment differs from plating in that it alters the very nature of the sucker rod pump barrel material on the inside surface, and to a slight depth below the inside surface. Unlike plating, which is added to the surface, surface treatments, become an integral part of the wearing surface on the inside of a barrel.

The surface treatments commonly used to harden the inside surface of sucker rod pump barrels are collectively referred to as "case hardened", and come in the form of carburized, carbonitrided, induction case hardened, nitrided or boronized. Carburized, carbonitrided, and induction case hardened, and nitride treatments are not as popular as chrome or nickel carbide plating since they are not as hard. The first three are additionally not as popular because they are hardened steels which are vulnerable to quick attack from hydrogen sulfide as hydrogen embrittlement, leading to a dramatic failure. However, all of these are used successfully in abrasive conditions without severe corrosion. Boronizing has been tried unsuccessfully by several sucker rod pump companies over the years due to inconsistent inside diameter sizes and is recently being tried by another. Boronized surfaces are as hard or harder than chrome plated surfaces but offer less corrosion resistance than nickel carbide plating.

TAPERED BARRELS

History

Standard API barrels have straight bores, of the same diameter from one end to the other, with a small +.002"/-.000" tolerance for metal plungers. Tapers in these barrels always mean that the manufacturer rejects the barrel.

Barrels that were intentionally tapered were introduced more than 20 years ago with the intention of preventing gas locking and eliminating fluid and gas pound. This was accomplished by back filling the compression chamber near the top of the upstroke of the pump, or by spacing the pump plunger higher than normal to reach into the tapered barrel.

The tapered part of the barrel is typically accomplished by the attachment of a tapered barrel section on top of a normal RH barrel. A normal RH pump extension is then added above the tapered section to complete the assembly. The resulting pump looks like a normal RH pump with the insertion of the tapered section between the top of the barrel and the bottom of the top extension.

Considerations

- Taper barrel wall thickness: Since material must be removed to accomplish a taper in the barrel, the wall thickness must remain sufficiently strong enough to support the pressure changes on each stroke of the pump.

- Plating issues: Plating is used frequently in sucker rod pump barrels to increase the wear resistance and corrosion resistance. However, some plating processes such as hard chrome plating, require a consistent clearance between the barrel and the tooling in the plating bath. Other types of plating like nickel carbide depend only on a chemical bath reaction and are not affected by a taper.
- Wear: Abrasive wear can be more pronounced with a tapered barrel due to the increase in the volume of slippage. Some types of abrasive particles can cause more damage than others due to their sharpness or hardness.
- Barrel honing issues: Barrel hones are not made for honing a taper in barrels, only for producing straight barrels. Therefore, programming changes have to be made or other tooling changes to create a consistent rate of taper increase throughout the tapered barrel. Also, finish honing after plating by removing material is difficult due to the need to precisely match the taper during honing.

Amount of Taper in the Barrel

The amount of taper per foot affects the slippage rate past the plunger during the upstroke when part or all the plunger is in the taper. Most of the additional slippage happens when all the length of the plunger is in the taper. For greater taper values the resulting slippage is higher.

Several production variables affect the rate of slippage in the taper: viscosity of the fluid mixture, quantity of gas present with the fluid, and the type and quantity of particulates. Also, the manufacturer's choice made for the amount of taper, and the accompanying sucker rod pump choices made by the end user all affect the effectiveness of the tapered barrel.

Several tapers and viscosities were investigated for this paper, using the Patterson Slippage Equation from the 2007 Southwestern Petroleum Short Course[1]. The various outputs are shown in Figures 1 and 2. Also shown in Figure 3 are the effects of the different, calculated slippage values on the volume of the lower, standard barrel. As the plunger progresses up through the taper the volume of slippage increases. The total sequentially slipped volume is shown as its equivalent volume of the lower, standard barrel. This shows how much of the lower barrel is "back filled" by the slippage during the upstroke.

Pressure Changes

One of the great advantages of a tapered barrel pump is that the compression chamber pressure is balanced above and below the plunger during the upstroke. Since the pressure is balanced before the start of the downstroke there are several beneficial results:

- The traveling valve opens immediately because it doesn't need to build pressure in the compression chamber. Thus, upward force on the bottom of the plunger is eliminated, which helps to:
    - Reduce sucker rod compression on the downstroke.

    - Raise the minimum polished rod load, extending sucker rod life.
    - Extend sucker rod pump life, especially of the valve rod.
    - Reduce bowing of the sucker rods on the downstroke which reduces sucker rod and tubing wear.

Materials

Most standard sucker rod pump barrel materials and coatings are available for tapered barrels:

- Steel: boronized or nickel carbide plated
- Brass: nickel carbide plated

Boronizing is appropriate for tapered barrels due to the larger clearances for the plunger. Any small deviations in the tapered barrel inside diameter are inconsequential.

Testing/Operations

One challenge of the tapered barrel is inspection for reuse of the barrel. Standard API Barrels once pulled out of the hole are thoroughly cleaned then a dial gauge is used on the inside diameter of the barrel to measure wear. If gauged wear area reflects 0.005" more than the nominal inside diameter the barrel should be considered for replacement. Any sand cuts, grooves, or signs of corrosion also indicates replacement is required. With a tapered barrel, appropriate equipment to accurately ensure the barrel is not worn will need to be developed. Further studies are required on equipment/testing procedures to provide reliable data to pump shops to help with determining severity of wear on barrels and criteria for recommendation on replacement of product.

SUMMARY

In this paper, topics covered included discussions around design, materials, calculations, surface treatments and platings of barrels in downhole sucker rod pumps. Further information was provided around misconceptions on certain barrel materials, and additional uses and limitations. Benefits of tapered barrel pumps and how they have proven their advantages over the last two decades. The accompanying figures provide calculation results that can help explain the effects and advantages of increased slippage in tapered barrel pumps, while also considering various tapers and fluid properties.

FIGURES

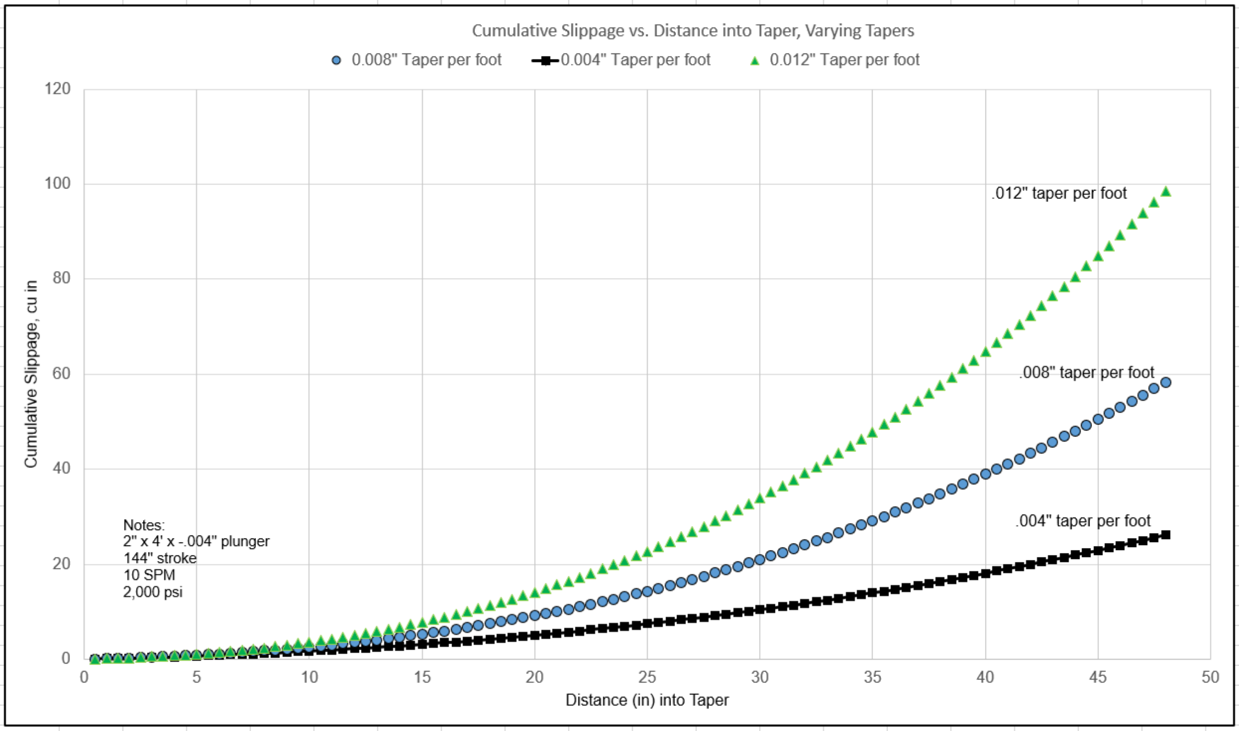

Figure 1

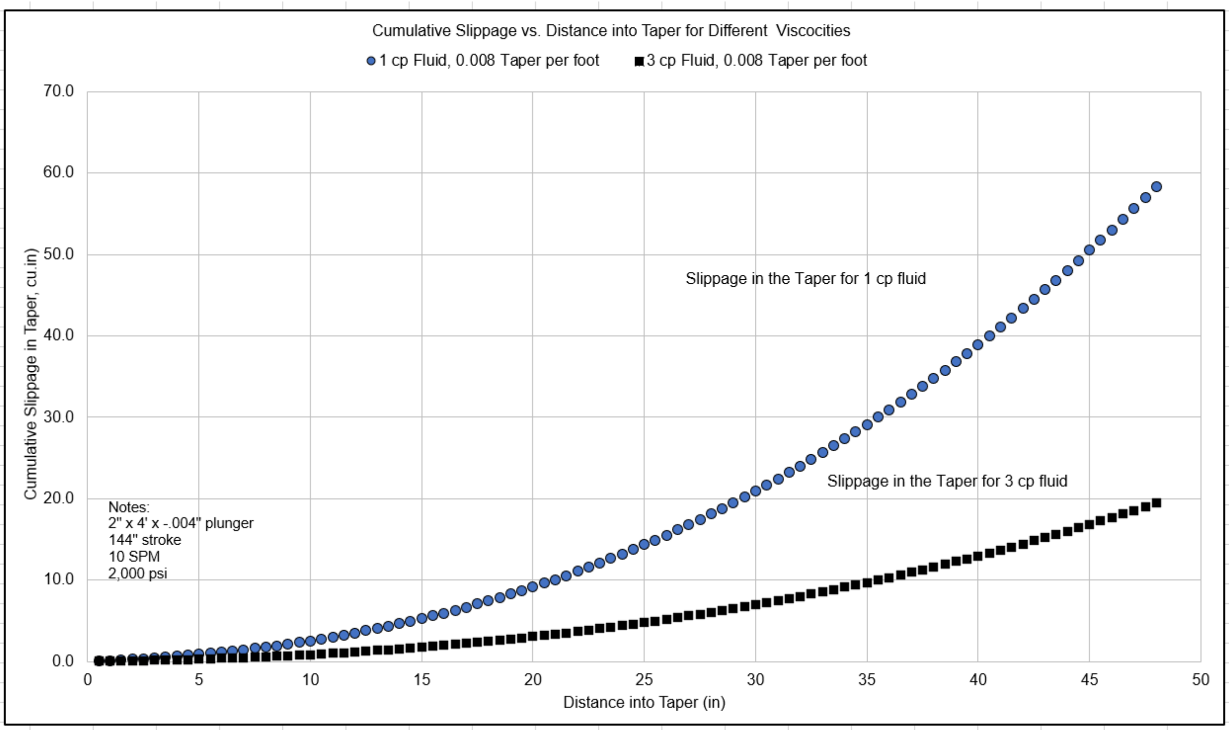

Figure 2

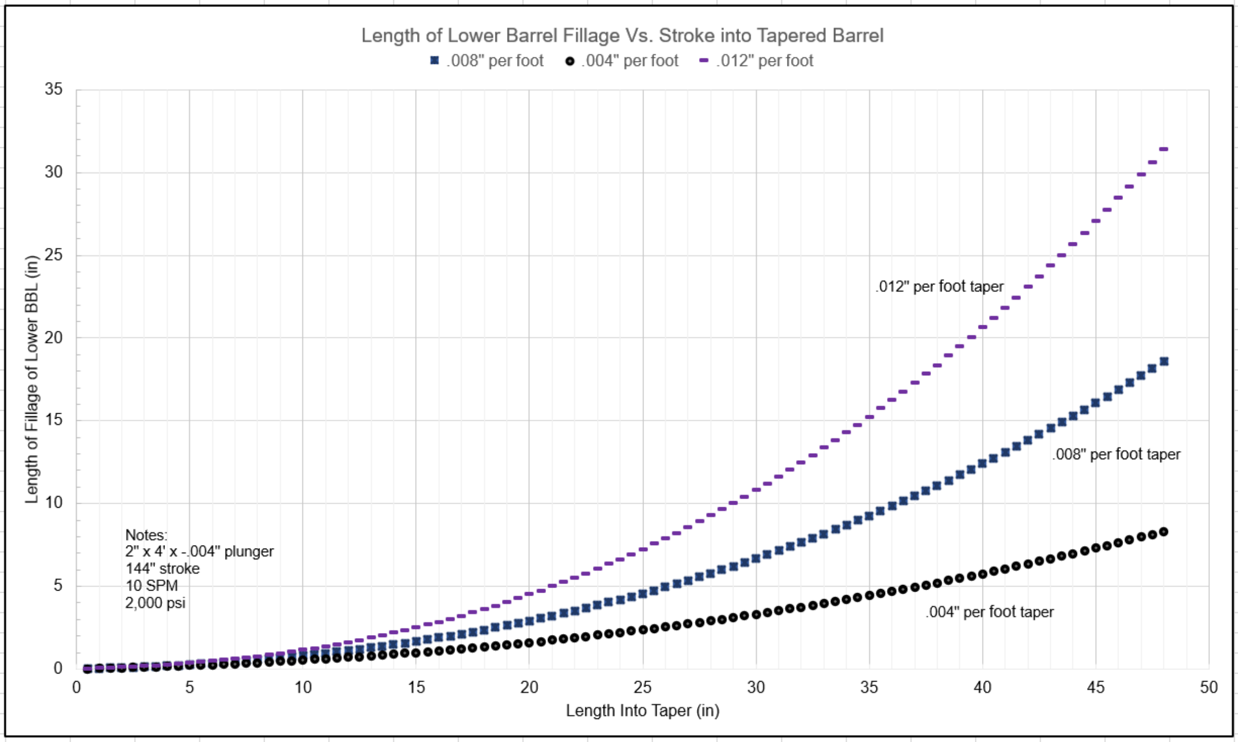
Length of Lower Barrel Fillage Vs. Stroke into Tapered Barrel
.008" per foot
.004" per foot
.012" per foot
Length of Fillage of Lower BBL (in)
Length Into Taper (in)
0
5
10
15
20
25
30
35
40
45
50
.012" per foot taper
.008" per foot taper
.004" per foot taper
Notes:
2" x 4' x -.004" plunger
144" stroke
10 SPM
2,000 psi

Figure 3

REFERENCES

1. John Patterson, Kyle Chambliss, Lynn Rowlan, Jim Curfew: “Progress Report #4 on “Fluid Slippage in Down-Hole Rod-Drawn Oil Well Pumps”, SWPSC, Lubbock, Texas (2007)