Advancements in Artificial Lift Equipment and Practices for Slim Hole Completions

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INTRODUCTION

Slim hole completions have become quite common within the past six or seven years, in both oil and gas wells. To some companies, this type of completion has become a standard practice while to others for various reasons such as lack of application, the more restricted casing diameters or questioned overall economies, it has not achieved such a status. Regardless of the ultimate degree of acceptance, the development of slim hole completion techniques and the related artificial lift equipment present another example of the petroleum industry's willingness to pursue new avenues for greater oil and gas recovery and expanded profits.

This slim hole discussion will be confined to sucker rod and subsurface hydraulic lift designs applicable in casing diameters of 4 - 1/2 in. o. d. or smaller. Sucker rod designs will be confined to 2 - 7/8 in. o. d. and 2 - 3/8 in. o. d. casing. Subsurface hydraulic designs will include 4 - 1/2 in. o. d. casing. In part, this will be a review of lift designs, available for many years, related to new developments. Casing diameters will be classified on outside diameter. Tubing will be classified on nominal diameter.

SLIM HOLE SUCKER ROD PUMPING SYSTEMS

New lift design requirements here have been confined to application within 2 - 3/8 in. and 2 - 7/8 in. casing. Where two or more small diameter casing strings are cemented within one bore hole serving two or more zones, the single zone lifting system can be considered as applicable to all zones.

One of the most common approaches, which requires no specially designed equipment, is the utilization of standard insert pumps in the 2-3/8 in. or 2-7/8 in. casing in conjunction with appropriately designed sucker rod strings. This ar-

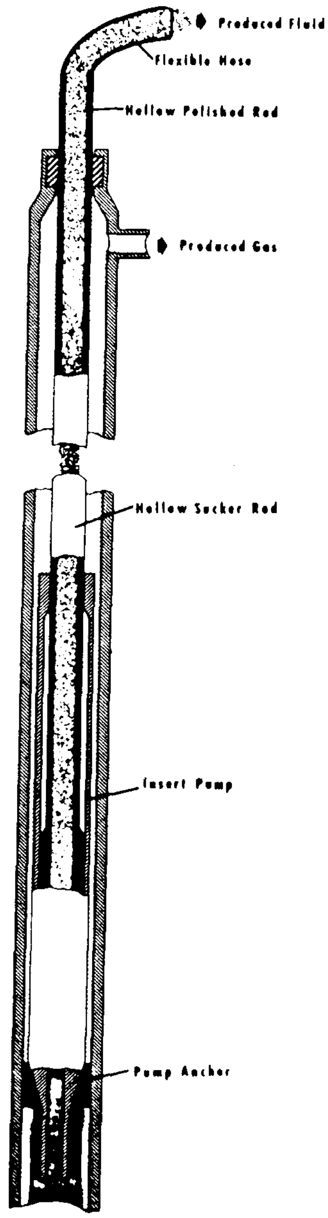

Fig. 1
Hollow Rod Installation With Production Up Hollow Rod and Gas Vented Through Casing Annulus

rangement would be considered a miniaturized casing pump. Either a pump seating assembly sealing in a seating nipple run in on the casing, or alternately an insert pump anchor, would serve as the casing packoff.

The major advantages of this miniature casing pump lift system are:

(1) Elimination of a tubing string for greater economy.
(2) The downhole pump displacement of insert pumps in the 2-3/8 in. or 2-7/8 in. casing.
(3) Use of large diameter sucker rods compatible with load requirements.
(4) Fluid lubrication between rods and casing.

The disadvantages are:

(1) Inability to vent formation gas.
(2) Reduced chemical treating abilities.
(3) Potential sticking of pump or rods in casing due to sand, gyp or paraffin accumulations.
(4) Potential casing wear and corrosion.

The slim hole lift system utilizing hollow sucker rods has become a common application in slim hole completed wells. This type system is largely responsible for numerous sucker rod and sucker tubing connection designs. Early experience dictated the need for special joint connections to withstand load characteristics peculiar to the hollow rod pumping system when pumping fluid up the hollow rod string.

In the most commonly applied system, a 2 in. or 2-1/2 in. insert pump is run on the hollow rod string and is landed on an insert pump anchor having no packoff element. Produced fluid is pumped up the hollow rod string, and produced gas is vented up the casing annulus. At the surface, produced fluid is discharged through a hollow polished rod with a flexible hose connection. This flexible hose arrangement is shown in Fig. 1.

The major advantages of this hollow rod lift system are:

(1) Venting of gas for maximum pump efficiency.
(2) The sucker rod string serves also as a tubing string.
(3) The downhole pump displacement of insert pumps in the 2-3/8 in. and 2-7/8 in. casing
(4) Pump suction can be chemically treated.
(5) Fluid and sand confined to hollow rod string. This also means increased fluid velocity and sand carrying abilities.

The major disadvantages are:

(1) Limited volume or depth capabilities due to available tubular strength
(2) Potential casing wear partially due to lack of lubrication between rod and casing strings.
(3) Fishing must be performed within the casing.

An alternate to the above system is the use of a crossover at the pump which permits venting the gas up the hollow rod string and producing the fluid up the annulus. This approach provides fluid lubrication between rod and casing strings and in some cases would permit greater fluid production, as a result of improved flow characteristics in the annulus.

A lift system which should be related here is one using a small vent string clamped to and cemented with the casing string. A take off collar above the well perforations would connect and open the side string to the casing. With this system, solid sucker rods could be used for greater production and load capabilities. Gas venting capabilities at lower formation pressures and high gas volumes would be increased, compared to hollow rods, due to the larger vent area. Chemical treating, like the hollow rod system, would be down the gas vent channel and both could be plastic coated internally.

A third common slim hole lift system often applied where smaller fluid volumes are involved is one using 1-1/4 in. or 1-1/2 in. nominal tubing inside 2-3/8 in. or 2-7/8 in. o. d. casing. This system is simply a miniature of the standard lift designs applied in larger tubing-casing combinations.

Slim hole rod pumps have been designed by several pump manufacturers to match the smaller tubing sizes. Due to the reduced clearances involved, stationary barrel, bottom anchor insert pumps are most generally recommended for this application. Pump bores in these slim hole pumps range from 3/4 in. to 1-1/2 in. (tubing pump), but the most commonly used sizes are 1 in. bore in 1-1/4 in. tubing and 1-1/6 in or 1-1/4 in. bore in 1-1/2 in. tubing.

The need for a smaller diameter sucker rod for the 1-1/4 in. tubing size brought about the development of 1/2 in. sucker rods with 1 in. o. d. slim couplings. A 5/8 in. sucker rod with 1-1/4 in. o. d. slim couplings is used in the 1-1/2 in. tubing size.

The major advantages of this miniature lift system are:

(1) Gas can be vented for maximum efficiency.
(2) Well can be chemically treated, down the casing annulus.
(3) Wear is confined to tubing and rod string and is minimized by fluid lubrication between the two.
(4) Solids, corrosion and paraffin confined within tubing string, and tubing can be pulled, if necessary to to retrieve fish.

The major disadvantages are the depth and volume limitations.

Useful Accessory Items

Numerous items of accessory equipment have been developed to either eliminate or minimize some of the problems which can be encountered in slim hole pumping. Some of these should be mentioned as they have notably contributed to a more successful or flexible application.

Ratio Compound Pump Design-Considering the already limited capacity of the pumps used in many slim hole applications, reduction in pump efficiency due to gassy production may make the application impractical. In a system which permits venting produced gas, the effectiveness of gas separation before entering the pump suction is related to fluid velocity in the well bore and, therefore, reduction of casing diameter means reduction in separating capabilities. In the casing pump applications which require a packer, no separation is possible and all gas must be produced through the pump. For these reasons, a pump designed to handle gassy production more efficiently is often required for slim hole applications.

One such pump design advancement, known as the Ratio Compound Pump, has been developed for 1-1/4 in. and 1-1/2 in. nominal tubing sizes and for 2-3/8 in. and 2-7/8 in. casing sizes. Fig. 2 presents a schematic illustration of this design.

Note in this design the top valve that would close on the beginning of the downstroke due to the fluid load above it. The intermediate traveling valve on the bottom of the plunger is consequently free to open immediately due to the low pressure area created above the plunger as the plunger travels downward. The higher pressure in the fluid area below the plunger will cause the oil and gas or froth to freely transfer from the pump chamber to the annular area above the plunger. With the pump chamber scavenged, the

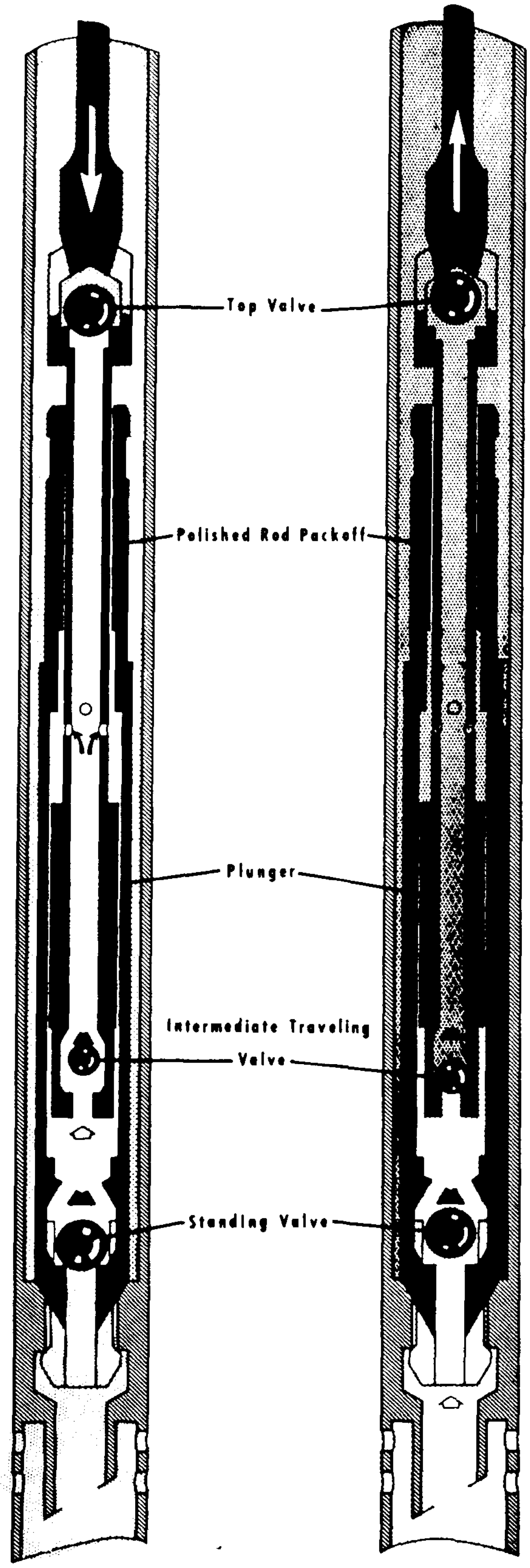

Fig. 2
Ratio Compound Schematic - Up and Down Stroke

standing valve will open immediately during the upstroke to permit a full stroke refill of the pump chamber

Increased efficiency, therefore, is brought about by elimination of gas locking conditions by the compounding action of the two valve-controlled chambers, the speedy and efficient transfer of fluids from the pump chamber to the discharge chamber on the downstroke, and the extended fill up period into a pre-scavenged pump chamber during the upstroke.

Top Seal Assembly - As previously mentioned, the close clearance involved between pump OD and the ID of 1-1/4 in. or 1-1/2 in. nominal tubing makes the use of stationary barrel bottom anchored slim hole pumps advisable. This type of pump is known to have better suction characteristics than a traveling barrel pump and can be safely operated at greater depths than a top anchored pump. However, in the stationary barrel bottom anchor design, the long annulus between the stationary barrel and the tubing forms a natural sand trap.

Top seal assemblies have been developed for larger tubing sizes which effect a sand-tight seal between the top of the pump and the tubing to avoid this sanding-in problem. Recognizing a definite need in slim hole pumping for a top seal assembly to seal in 1-1/4 in. and 1-1/2 in. tubing, the manufacturer developed a top seal assembly as shown in Fig. 3. Unlike the larger assemblies which utilize a rubber packoff sealing off against the tubing ID, the slim hole top seal is effected by a metal ring on the pump assembly, seating in a top seal nipple in the tubing string.

Insert Pump Anchor — The use of an insert pump anchor run in with the pump eliminates the need for using a seating shoe, with restricted ID, in the casing string. This approach leaves a full casing ID to work in or below, plus giving the flexibility to set the pump at any depth desired.

One such anchor is shown in Fig. 4. The entire setting, releasing and resetting operation of the assembly, is performed with vertical motion alone which removes the risk of unscrewing the rod string and the need for clutching the insert pump in the up position. The anchor tool can be used with or without the packoff as required.

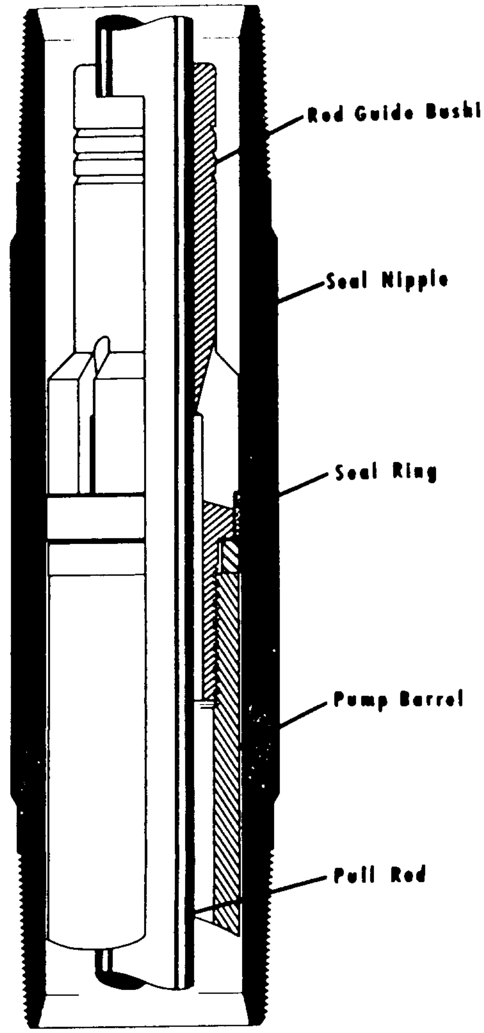

Fig. 3
Slim Hole Top Seal - Reference: 2-1/16" Tubing Size, 1-1/16" Pump Bore

SLIM HOLE HYDRAULIC PUMPING SYSTEMS

As in sucker rod pumping systems, several of the standard equipment arrangements for subsurface hydraulic pumping systems are readily adaptable to slim hole completions. For example, 2 in. and 2-1/2 in. hydraulic production units can be run as miniature conventional (or fixed type) casing pumps in 2-3/8 in. or 2-7/8 in. casing completions (See Fig. 5A). In 4-1/2 in. casing, the 2 in. or 2-1/2 in. production units can be run as a free type casing pump (Fig. 5C), gaining the advantage of being able to circulate the unit to the surface for servicing. In each of these casing pump installations, a packer is required and venting produced gas is impractical. A standard equipment arrangement which overcomes this problem in 4-1/2 in. casing is the conventional insert installation (Fig. 5B) using a 2 in. or 2-1/2 in. unit, run on 3/4 in. or 1-1/4 in. tubing inside of a 2-3/8 in. or 2-7/8 in. tubing string.

Slim Hole Application and Equipment

In recent years, however, major advances have come about to substantially expand free and conventional types of hydraulic installations for slim hole completions which noticeably increase available pump displacement and, equally important, bottom hole horsepower. The most significant of these is the development of both 1-1/4 in. and 1-1/2 in. hydraulic units (see specifications in Fig. 6) which are run as free pumps inside 1-1/4 in. and 1-1/2 in. nominal tubing sizes. This opened the doors for several new applications of artificial lift equipment in slim hole completions.

In 2-7/8 in. casing, either 1-1/4 in. or 1-1/2 in. tubing can be used with the appropriate bottom hole assembly to seal off the production unit, resulting in a miniature casing free installation (see Fig. 5C). Note that in this installation the production unit can be circulated in and out of the well for servicing. In operation, high pressure power oil is pumped down the tubing and the return fluids (spent power oil plus production) are returned up the casing annulus. In this application, all produced gas must be handled through the pump.

In 4-1/2 in. casing, these 1-1/4 in. and 1-1/2 in. units offer the advantages of the free pump system without the limitations of a casing packer, in several alternate arrangements. Two concentric free systems (See Fig. 5D) are possible. One involves the use of 2-1/2 in. tubing with either a 1-1/2 in. or 1-1/4 in. concentric tubing string. The other uses 2 in. tubing with a 1-1/4 in. concentric tubing string. In both cases, the high pressure power oil is pumped down the smaller tubing string to pump in and operate the production unit, and the return fluids return up the annular space between the concentric tubing strings. The casing annulus is open for gas venting and chemical treating.

In the concentric arrangement of the 1-1/4 in. string inside the 2 in. string, close tolerances led to a unique bottom hole assembly approach to house and seal off the production unit. The 1-1/4 in. bottom hole assembly, less the top packoff sleeve, is run in with and as part of, the 2 in. tubing. The top packoff sleeve is run in and located with the 1-1/4 in. string to complete the bottom hole assembly.

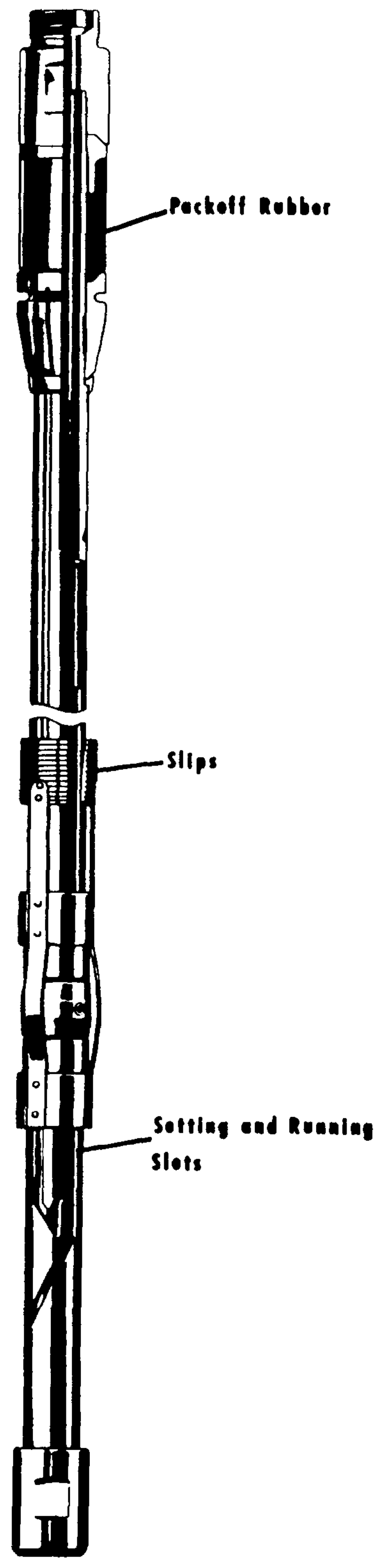

Fig. 4 - Insert Pump Anchor

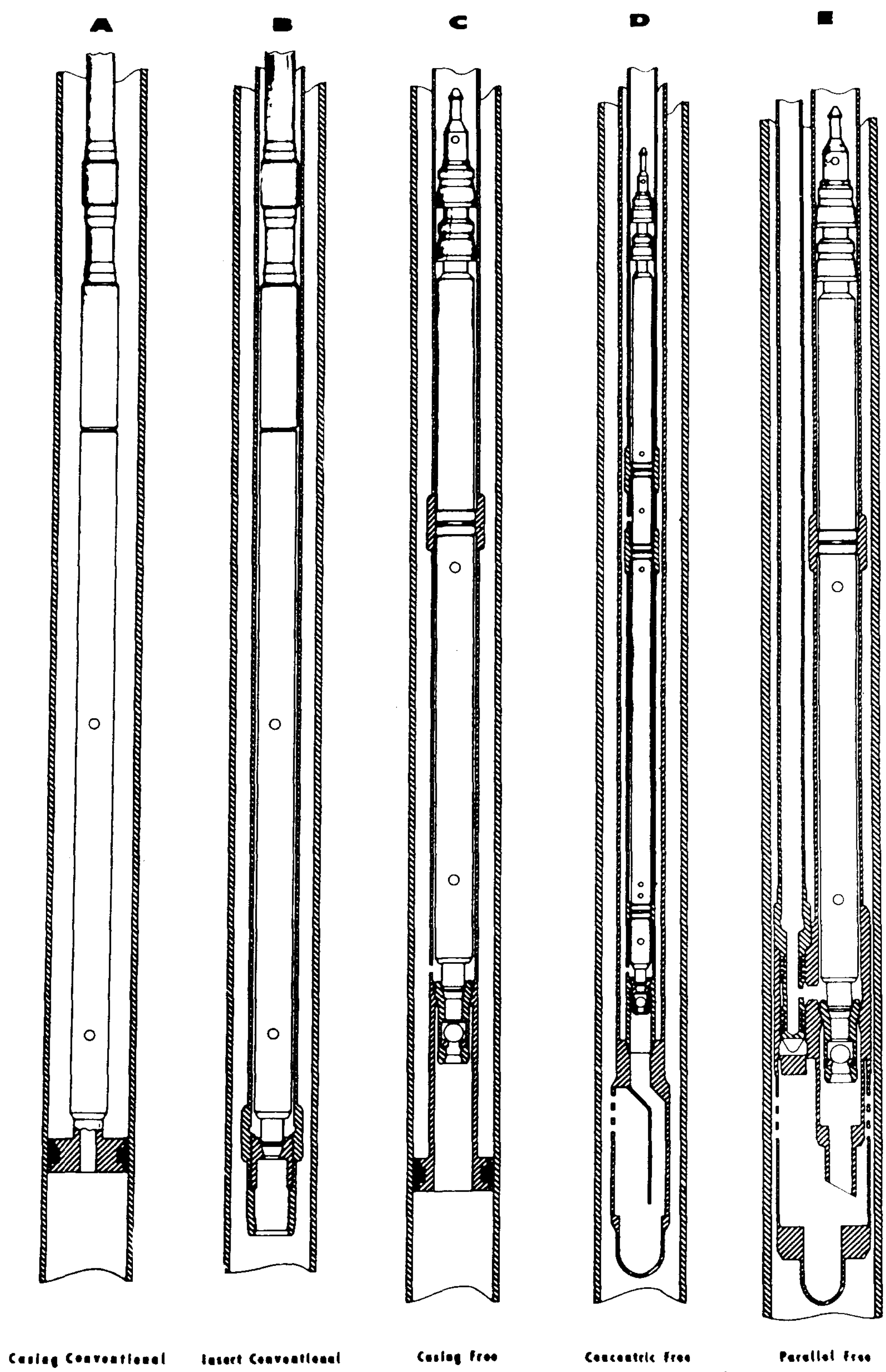

Fig. 5
Single Zone Hydraulic Completion Types

Figure 6

OILMASTER SLIM LINE

PRODUCTION UNIT SPECIFICATIONS

TUBING SIZE O. D. INCHES	ASSEMBLY NUMBER	BORE		AREA RATIO P/E	BAL. PRESS. PSI/ 1000'	STROKE INCHES	RATED SPEED SPM	DISPLACEMENT B/D			
								PER SPM		RATED SPEED	
		ENGINE INCHES	PUMP INCHES					ENGINE	PUMP	ENGINE	PUMP
1-1/4" NOM.	FB121008	1.030	0800	.60	262	18	75	2.23	1.34	167	101
1.660" O. D.	FB121010	1.030	1.030	1.00	433	18	75	2.23	2.23	167	167
1-1/2" NOM.	FB151210	1.250	1.030	.68	293	24	65	4.37	2.97	284	193
1.900" O.D.	FB151212	1.250	1.250	1.00	433	24	65	4.37	4.37	284	284

Also in 4-1/2 in. casing, a parallel free arrangement (Fig. 5E) is possible using 1-1/2 in. power oil tubing along with a 1 in. independently landed side string. This leaves the annulus open for gas venting and treating.

Note Fig. 6 showing specifications and capacities of these 1-1/4 in. and 1-1/2 in. units. These units offer sizeable pump end displacement from depth; capacity of the 1-1/2 in. unit is equivalent to the maximums obtainable only a few years ago with equally depth-rated 2 in. units. Higher capacities were made possible in all nominal tubing sizes by the development of a new production unit design called "cavity balancing". In this design, fluid passages previously housed within the production units were transferred outside of the unit by using the annular area between the unit and its bottom hole assembly (often called "cavity"). This permitted larger bores in both the engine and pump end of the unit, resulting in greater displacement, and horsepower capacities.

Coinciding with the introduction of these slim hole hydraulic units, accessory subsurface and surface equipment was also introduced. As an example: Fig. 7 shows the slim line wellhead control. This assembly serves multiple functions in the wellhead hook-up:

(1) Controls the flow of fluid to pump in and operate the production unit or to surface it by reversing the fluid flow.
(2) Catches and holds the production unit when it is surfaced.
(3) Suspends the 1-1/4 in. or 1-1/2 in. nominal concentric tubing string.

Another notable accessory item introduced to the industry initially with the slim line hydraulic equipment was the new Teflon coated pump retrieving cups. The Teflon coating over rubber offers not only a much lower coefficient of friction and longer wear life, but also adds bursting strength normally acquired by wire reinforcing the rubber cups.

Reverse Flow Conventional Unit

This unit, designed especially for 2-7/8 in. casing completions, reverses the normal flow pattern used in the conventional hydraulic (fixed) casing completions. As shown in Fig. 8, high pressure power oil is pumped down the annular area to operate the hydraulic unit. Return fluid, power oil plus production, returns up the concentric macaroni string to the surface. This confines the production and any sand, paraffin or corrosion properties to the macaroni string, thereby preventing potential stuck tubing or casing damage, and permitting the use of soluble paraffin plugs under severe paraffin conditions. Higher fluid velocity in the macaroni string minimizes sand accumulation.

CONCLUSION

What we know today as slim hole completions are , for the most part, here to stay. The continued efforts for improvements in completion practices and improving or developing new rod and hydraulic pumping equipment, both in basic design and expanded application, have already played a significant part in making this type of completion more practical, more productive, and more economical. The future holds promise for further developments.

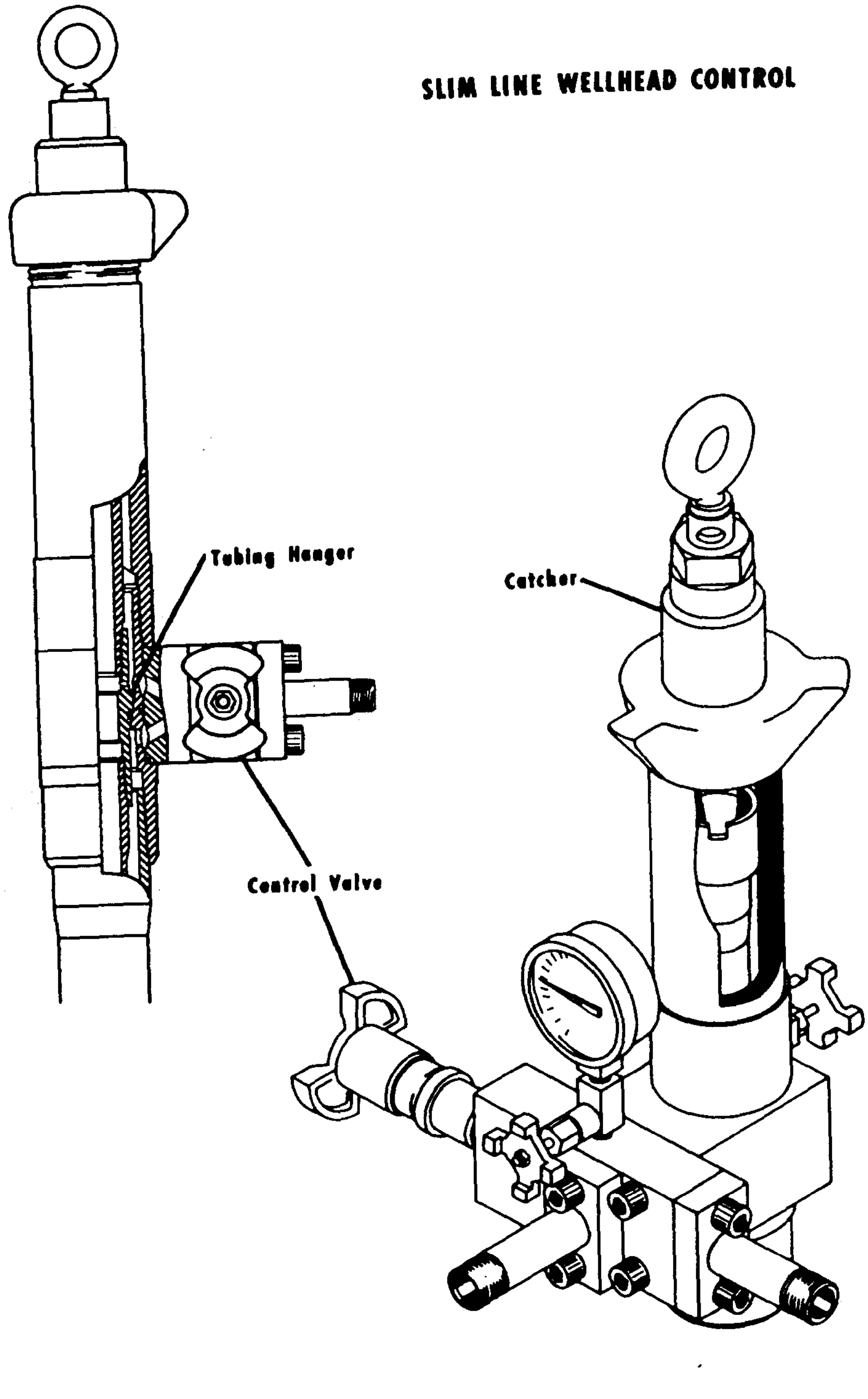

Fig. 7
Slim Line Wellhead Control

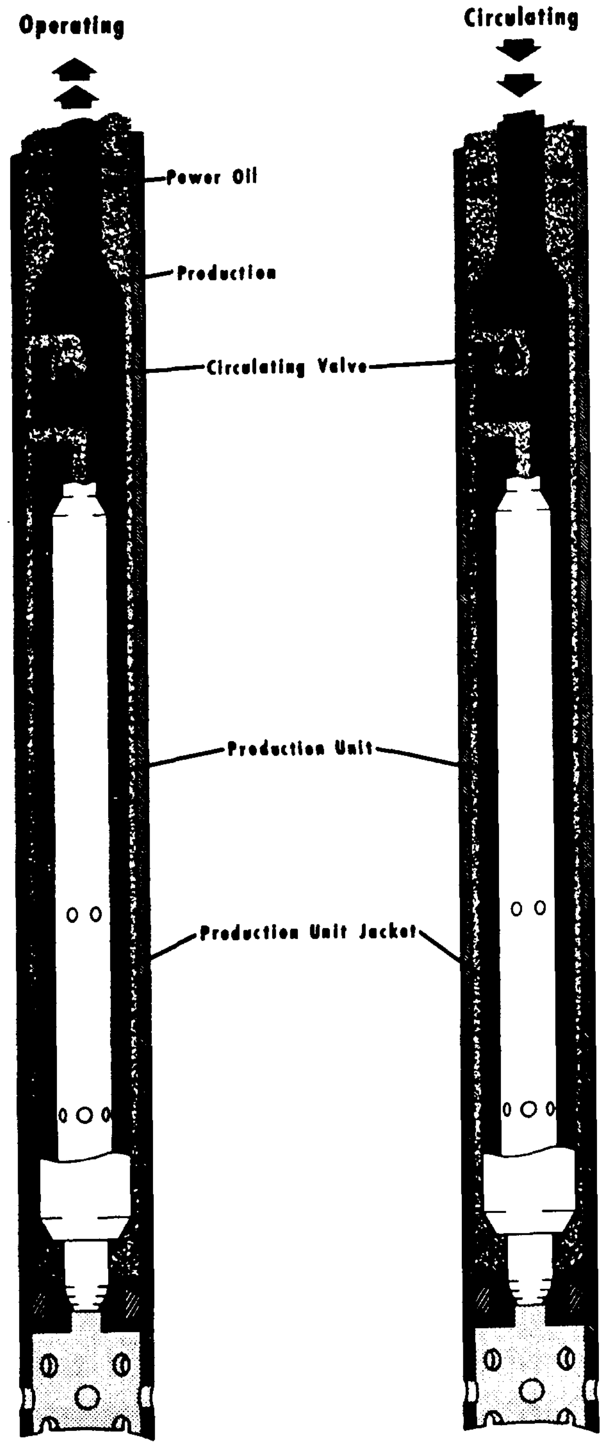

Fig. 8
Reverse Flow Schematic - Production and Reverse Flow On Conventional Shoe