Engineering Artificial Lift Equipment to Produce Gaseous Fluids

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INTRODUCTION

An engineering solution to a problem involves both technology and economics. The selection of artificial lift equipment on an engineering basis means selecting that equipment which will yield the greatest profit. Lift equipment selected on an engineering basis, then, should have the optimum combination of capacity, capital costs and operating costs. The lifting of gaseous liquids is a particularly difficult problem because is adversely affects all three of these facets.

At nearly all sessions of previous short courses there have been papers presented which discuss lifting gaseous liquids. However, these papers have discussed only the necessary arrangement and the selection of rod pumping equipment to handle such liquids. The intent of this paper is to discuss the suitability of the various artificial lift methods for producing gaseous liquids. The effect of these liquids on lift efficiencies has been included along with applicable operating arrangements and recommendations for obtaining acceptable equipment performance. Other lift methods which have been included are gas lift, hydraulic pumps and submersible centrifugal electric motor driven pumps.

RESERVOIR PERFORMANCE

A review of the theory of flow of gas and liquids from the reservoir into the well bore should provide a better understanding of the problem of gas interference with the various artificial lift systems.

An analysis of the reservoir performance indicates that the reservoir fluid (oil, water, or gas) which enters the well bore is dependent upon the amount of drawdown achieved in the bottomhole pressure. The amount of oil, water, or gas produced from a well cannot be controlled independently of each other; that is, unless some remedial work is performed. These fluids enter the well bore at a given rate with a given bottomhole pressure drawdown. They will maintain the same ratio regardless of the producing practices followed or which method of artificial lift is used. Lift equipment can only attempt to produce the fluid fill-in into the bore and has no control over which fluids are present.

The challenge then should be for each individual to use his ingenuity to devise methods which will permit the separation of liquids and gases at the bottom of the well bore. If successful, the gas can be vented to the surface and the liquids produced more efficiently by some type of artificial lift equipment. Separation is not always possible for each artificial lift method and certainly not always 100 per cent effective. Therefore, special subsurface arrangements and operating practices should be used to maintain the volumetric efficiency of the lift equipment as high as possible.

TYPES OF GASEOUS LIQUIDS

Gaseous liquids can be classified into the following categories:

Well Liquids With High GLR's

Free gas readily separates from the liquid phase but the volume of gas to be handled may exceed the capability of the separation equipment.

Gas Saturated Well Liquids

The amount of gas which needs to be handled by the pump depends on the pressure maintained on the well fluid at pump depth as well as the efficiency of the subsurface separation equipment.

Emulsified Well Liquids

Gas separation is rather slow with emulsified well liquids. Subsurface gas separation of this type fluid is not posible. Liquid must be produced in an emulsified state.

Gas separation devices can be used with the various types of artificial lift equipment to more efficiently produce the first two types of liquids listed above. For the last category, specially constructed pumps or excess displacement rate equipment are required to produce wells of this type.

PUMP SETTING DEPTH

The subject of optimum pump setting depth should be discussed before presenting an individual discussion of each of the different types of artificial lift equipment. The best pump setting depth is rather difficult to calculate in some fields and many times must be determined on the basis of trial and error. If it is desired to produce a well at its maximum rate, it will be necessary to set the lift equipment close to bottom so that maximum drawdown can be obtained. However, if the well has a producing capability considerably greater than the permissible allowable, the pump setting depth can be some distance above the formation. In either instance it is desirable to have a pumping fluid level at least 500 ft above the pump to insure the adequate flow of fluids into the pump suction.

Greater displacement efficiencies can be obtained from high capability wells if the lift equipment is set at a depth where the inlet pressure exceeds the bubble point of the produced fluid. Normally this practice is less costly with a hydraulic pumping installation than with a rod pumping installation. Centrifugal pumping equipment probably would not find application in a well which was being produced from a point where the producing bottomhole pressure was above the bubble point.

Lowering the pump setting depth of a hydraulic pump necessitates that only additional tubing be added for its placement. Little or no additional loads are imposed on the equipment since the operating pump pressure is primarily dependent upon the operating fluid level which remains unchanged. Tubing and rods both would need to be added to achieve a lower pump setting depth with a rod pump. The additional load of the extra sucker rods could necessitate the installation of larger surface equipment.

SUCKER ROD PUMPING

Gas problems are handled by the following two methods when using the rod pumping method of artificial lift.

(1) Application of gas separation devices to separate the gas from the liquid prior to pump entrance.

(2) Special design of subsurface pumps to most effectively handle the gas or gaseous liquids that reach the pump chamber and above all, prevent the pump from gas locking.

Gas Separation Devices

Most gas separation devices, usually referred as gas anchors, use the basic principle that gas lighter than oil and water and that gas will mo up and oil and water will move down in the pr scribed flow passages of the separation devic (Fig. 1). Sufficient downflow area should be pr vided to permit the liquid to flow downwards a lesser rate than the rise of the gas bubbl Bubble rise has been reported to be about fo to six in. per second depending on the ty liquid.

The term gas anchor is used to denote any several types of gas separation devices. The g anchor does not serve to anchor or hold any pa of the subsurface equipment. Actually their so purpose is to help separate gas from well flui and direct free gas up the annulus for venting the wellhead rather than let it enter the subsu face pump.

(1) Classification of Gas Anchors

(a) Natural - The natural type gas anchor achieved by merely setting the pump be low the casing perforations. This no only gives good gas separation but al permits maximum drawdown of the bo tom-hole pressure.

(b) Packer Type - The packer type gas an chor requires the use of a packer in co junction with a crossover arrangemen Well fluids are directed up a macaro string or a skirted annulus to a lev somewhat above the pump inlet an spill over into the casing tubing annul above the packer. Fluid is fed from th annulus area to the inlet of the subsu face pump. This arrangement expose the produced fluid to a lower pressur than is present at the pump inlet. There fore, no additional gas should break ou of solution while the oil is passing through the pump.

(c) Stinger Type - The stinger type gas anchor is constructed by fastening a small diameter pipe (usually 1 or 1-1/4 in.) and about 12 to 15 ft long to the lower end of the pump below the standing valve. This tube extends into a cavity which is formed by a bull plugged joint of tubing affixed below the pump seating nipple. The top four to six ft of this joint of tubing is perforated to permit well fluids to enter the pump. This joint of perforated tubing is usually called a mud anchor. It does not actually anchor anything but serves as an integral part of the gas anchor and prevents setting the subsurface pump in mud or sand when setting a pump low in the well bore to obtain maximum drawdown.

The stinger type gas anchor uses the reverse flow principle to separate the gas from the oil. In addition to providing the reverse-flow principle, the mud anchor can be oversized to create agitation for the well fluids between the anchor and the casing wall.

The use of an oversized mud anchor will also provide a larger flow area inside the mud anchor and give a reduced downward velocity to well fluids prior to entering the stinger and feeding the pump inlet. An oversized mud anchor should not be used if there is the possibility of sand or mud fill-in which would make recovery difficult.

The following tabulation contains general specifications regarding the assembly of the neces-

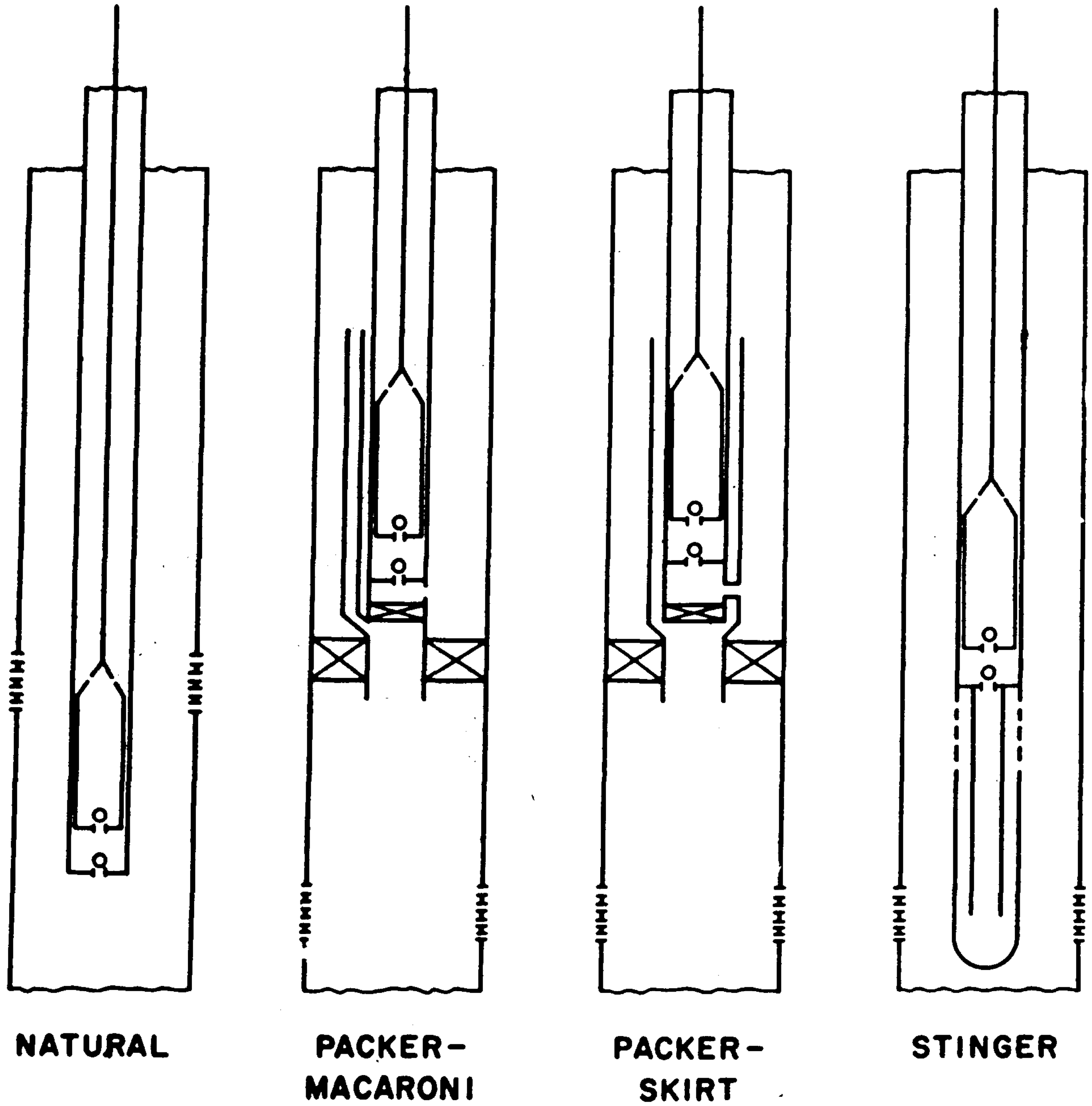


FIGURE I
TYPES OF GAS ANCHORS

sary components of a stinger type gas anchor (Fig. 2).

Stinger length - 12 to 15 ft. It should extend 5 to 10 ft. It should extend 5 to 10 ft below the bottom of the perforations in the mud anchor or the perforated nipple.

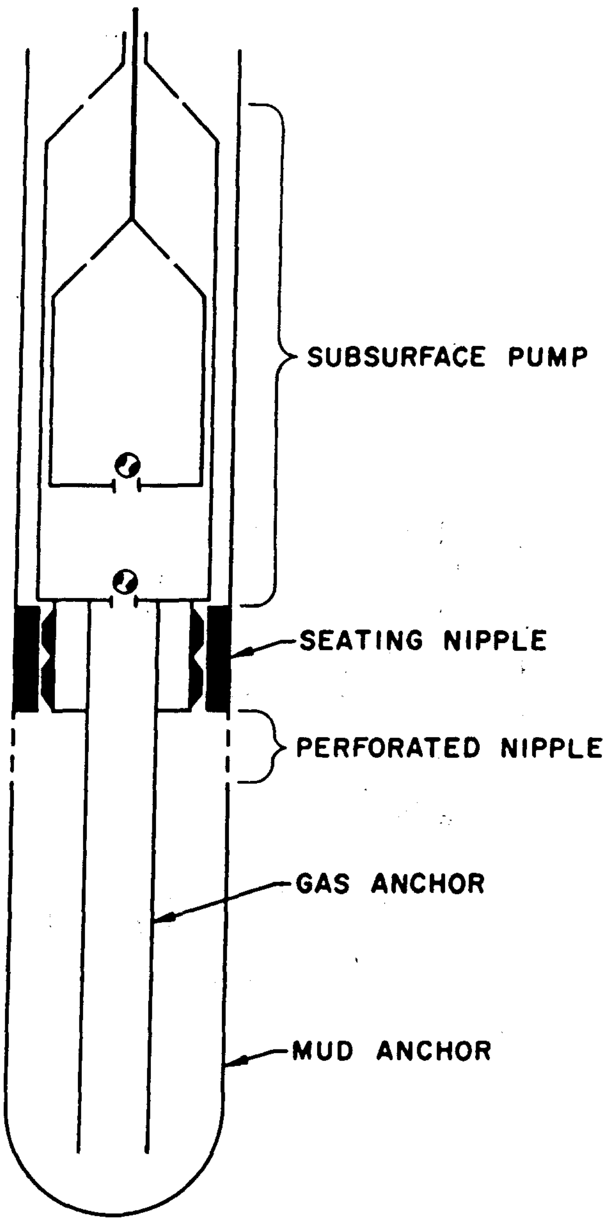


FIGURE 2
STINGER TYPE GAS ANCHOR

Stinger I. D. - As large as the pump bore is possible. However, not so large that the downward flow velocity exceeds the rate of rise of the gas bubbles as the liquid moves down the annulus between the stinger and the mud anchor. Aceptable combinations are 1-1/4 in. stinger inside 2-1/2 in. mud anchor and 1 in. stingers inside 2 in. mud anchors.

Mud anchor length - Full joint with top 4 to 6 ft perforated nipple between the mud anchor and the pump seating nipple.

Special Design of Subsurface Pumps

Two specially designed subsurface rod pumps can be used to produce gaseous liquids - a high compression ratio pump and a two-stage pump. By applying greater compression to the fluid these two pump styles tend to overcome the problem of gas locking. (A pump is gas locked when it becomes filled with gas and subsequent pump strokes merely compress and expand the gas without displacing it from the pump).

A high compression ratio pump has a low clearance volume and is usually operated at a long slow stroke. Low clearance volume is achieved by assembling the pump so the traveling valve and the standing valve are located very close together when the pump is collapsed. This can best be done with a stationary barrel, traveling plunger pump which has the traveling valve installed in a blind cage on the lower end of the pump plunger. This arrangement permits close-spaced pump valves, the maximum sized opening standing valve, and permits the liquid to enter the pump chamber with a minimum of agitation and pressure drop.

The flow of gas saturated liquid into the pump should be done with the minimum of disturbance to prevent gas from breaking out of solution.

API Standard 11 AX which covers standardization of subsurface pumps has the standing valve and traveling valve located within one to two in. of each other. This dimension could be further reduced to a fraction of an inch if desired for special application in difficult wells. Well servicing crews should be requested to space the polished rod at the surface so the subsurface pump will be closely spaced (pump valves close together) at the bottom of the downstroke.

A reduced clearance volume and an increased compression ratio can be obtained with a tubing pump by using a fixed standing valve rather than a retrievable standing valve. The need for a standing valve puller would be eliminated and the traveling valve can be placed in a blind cage on the bottom end of the pump plunger. Pulling costs for repairing the pump would be more expensive and this additional expense would have to be evaluated against improved pumping performance. Unfortunately there are no precise rules regarding the provisions which should be made when trying to effectively produce gaseous liquids. A small production increase due to improved lift efficiency can pay out a rather sizeable gas handling installation expense in a rather short time.

The two-stage pump (Fig. 3) is a specially designed pump recommended for installation in wells which produce gaseous liquids. In those operations familiar to the writer, this pump has performed more effectively in low volume wells (50-60 bbls per day or less) which produce emulsified liquids or gas saturated liquids. The two-stage pump is a multi-valved pump which has primary and secondary displacement chambers. Fluid enters the large primary chamber on the upstroke and is discharged into the smaller secondary chamber on the downstroke. Because of the larger primary chamber volume the secondary chamber is charged with fluid at a pressure considerably above pump suction pressure. The fluid is then discharged from the secondary chamber into the tubing on the subsequent upstroke. Since final compres ion is achieved on the upstroke, the pump needs to be close-spaced on the upstroke. In addition, a pump should be selected whose length will permit the maximum compression ratio to be obtained. If during the downstroke the well fluids which are being displaced from the primary chamber are in excess of the capacity of the secondary chamber, these well fluids simply bypass the secondary annulus chamber and continue up through the standing-traveling valve into the tubing string. The installation of an over-displacement size pump would probably be required to produce desired fluid rates at low pump efficiencies for those wells which produce emulsified liquids in excess of some 50-60 bbls per day.

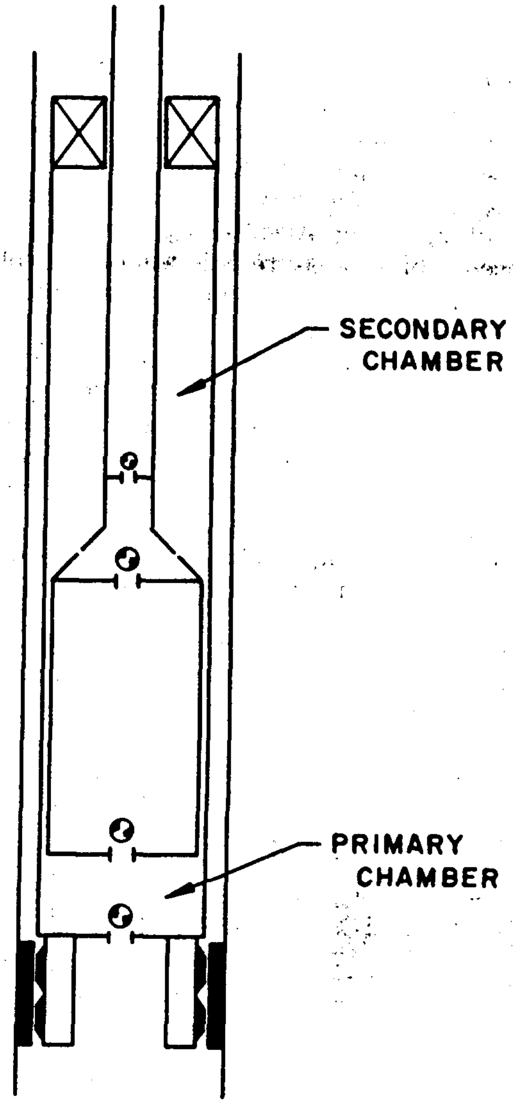


FIGURE 3
TWO-STAGE PUMP

GAS LIFT

The second most popular method of artifical lift is gas lift (Fig. 4). Gaseous liquids even present problems with this method of artificial lift. Since this is not a displacement type artificial lift method, the presence of gas would seem to have little effect on the ability of this lift method to produce gaseous liquids. This is an erroneous opinion. With the intermittent gas lift method of artificial lift, a head of fluid is accumulated above the operating valve inside the tubing string. The pressure required to lift this head of fluid is determined by the hydrostatic head it creates above the operating valve. Therefore, gaseous liquids would not be expected to have an effect on this lift method since the lighter gradient liquid would merely fill the tubing to a greater height in order to obtain an equivalent head pressure.

This single factor is true. However, there are other reasons gaseous liquids are a problem with intermittent gas lift. First, the continuous percolation of gas through liquids contained in tubing string above the operating valve increases the length of time it takes to bleed down the tubing pressure so as to efficiently lift a slug of fluid from the tubing string. Also, lifting fluid against an increased tubing pressure will reduce the volume of the starting slug and thus the amount of fluid produced at the surface.

A second and probably more important reason that gaseous liquids are a problem with intermittent gas lift is the fact that gas lift gas can more easily break through a slug of gaseous liquid and cause high fall-back losses and low fluid recovery rates at the surface.

The effect gaseous liquids have on the continuous flow method of gas lifting is somewhat different than has been discussed with the intermittent lift method. With continuous flow, additional energy is added to the flow column by the injection of gas through a gas lift valve to reduce the fluid gradient in the tubing to the point where the flowing bottomhole pressure can produce well fluids to the surface. The amount the well fluid gradient can be reduced depends on the amount of gas it initially contains.

A column of salt water which contains no gas could have a fluid gradient of from 0.45 to 0.50 psi per ft. As gas is injected into this fluid column, the gradient may be reduced to as low as 0.11 to 0.15 psi per ft. The amount of reduction would depend on the amount of gas injected. For example, for a producing rate of 600 BWPD in 2-1/2 in. tubing, 0.475 gradient fluid could be reduced to 0.15 psi per ft by injecting 250 cu ft of gas per bbl of produced fluid or to as low as 0.11 psi per ft by injecting 500 cu ft of gas per bbl of produced fluid. The above is based on an injection point of 4000 ft.

However, if well fluids already contain a considerable amount of gas and the well will not flow, the fluid gradient can be reduced only a limited amount by additional gas injection. For example, a well producing 400 BFPD in 2-1/2 in. tubing, 50 per cent water, with a GLR of 250:1 would have a gradient of 0.15 psi per ft. An injection rate of 750 cu ft of gas per bbl would be required to obtain a minimum gradient of 0.10 for such a well. The flowing gradient would be reduced from 0.15 psi per ft to only 0.10 psi per ft with the addition of 500 cu ft of gas per bbl of produced fluid. Oftentimes this small reduction is not sufficient to cause the well to flow with continuous flow gas lift at the desired producing rate. Another kind of artificial lift equipment should be considered for wells of this type.

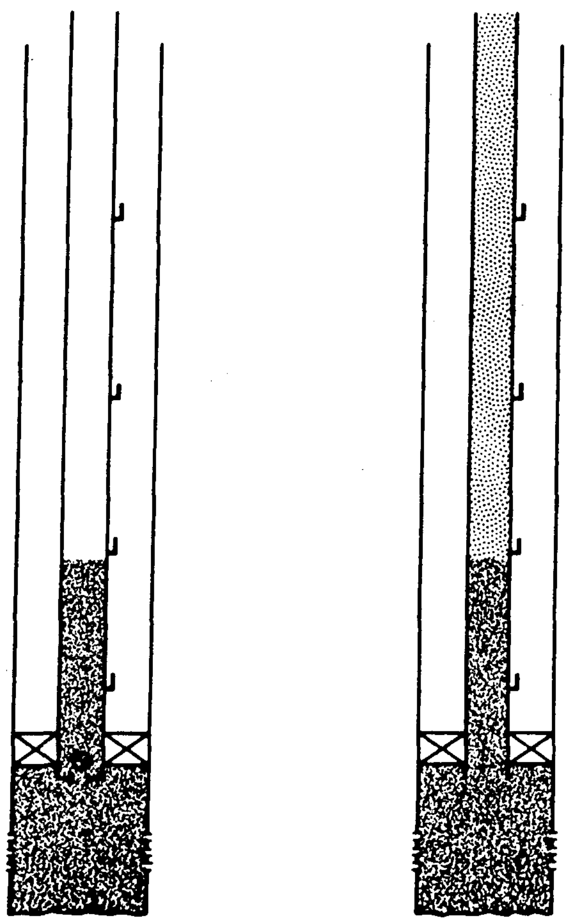


FIGURE 4
GAS LIFT

HYDRAULIC PUMPING

Hydaulic pumping is the third type of artificial lift to be considered for producing gaseous well fluids. Although hydraulic pumps are also a displacement type artificial lift system, optimum pump valve clearance is more easily obtained with hydraulic pumps than with rod pumps. Hydraulic pumps are constructed with a positive stroke length and by design have a minimum amount of clearance between the pump valves. Thus, most hydraulic pumps develop high compression ratios which keep gas moving through the pump. Of course, even with a hydraulic pump,

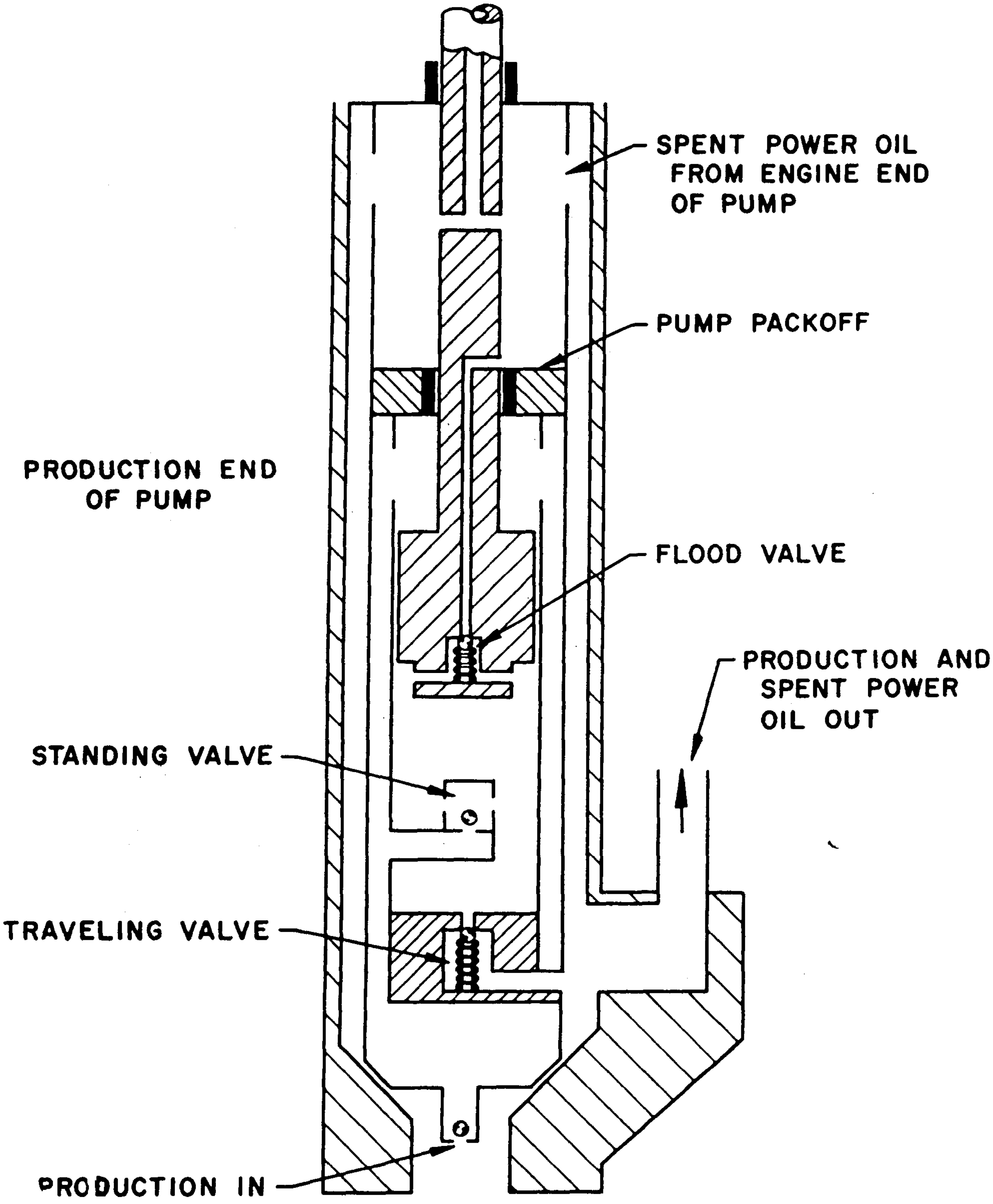
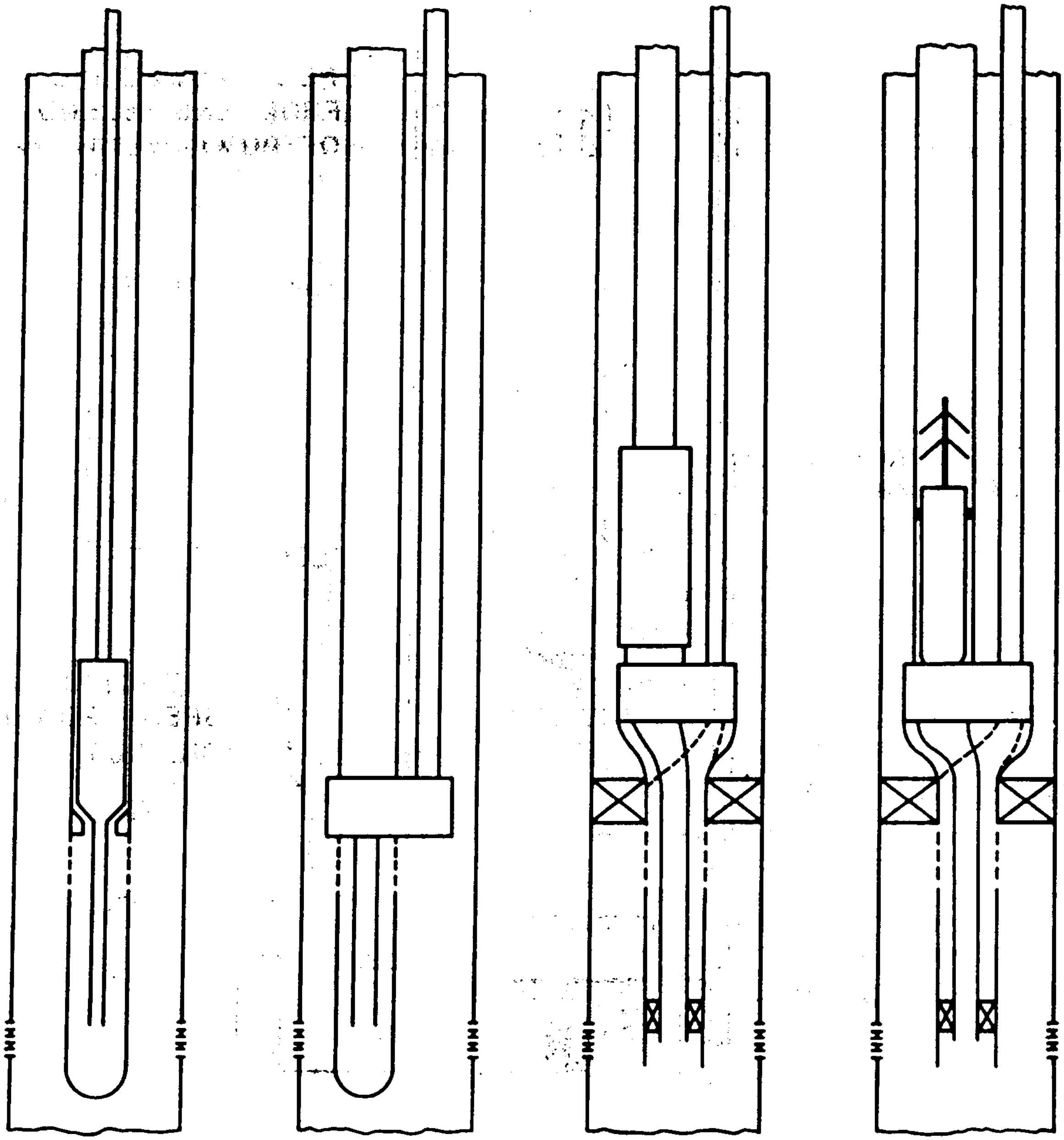


FIGURE 5

FLOOD VALVE ON HYDRAULIC PUMP



CONVENTIONAL INSERT

FREE-TYPE PARALLEL

CONVENTIONAL CASING

FREE-TYPE CASING

FIGURE 6
HYDRAULIC PUMPING INSTALLATIONS

efficiency will be reduced if free gas enters the pump and occupies space which could otherwise be filled with liquids.

One manufacturer of subsurface hydraulic pumps has incorporated a flood valve in his pump to help eliminate the entry of free gas into the pump (Fig. 5). This flood valve works as follows: During the last inch of the upstroke travel of the pump plunger a port in the valve rod is exposed to clean spent power oil above the pump packoff. This port directs spent power oil down through the valve rod and out through the flood valve into the pump chamber. Therefore, the unfilled portion of the pump chamber is automatically filled with spent power oil before the downstroke begins. The flood valve not only helps eliminate free gas from the pump chamber but also eliminates detrimental fluid pounds. In addition, the flood valve provides clean power oil to lubricate the pump plunger.

Hydraulic pumps are better able to combat gas interference than rod pumps because of their close spaced valves, high compression ratios and special construction features. However, in addition to these advantages, a gas anchor may also be required to help obtain high volumetric efficiencies with these pumps. A stinger type gas anchor can be used in conjunction with a mud anchor for the conventional insert or free type parallel installation. Packered installations such as the free type or conventional casing installations may be effectively produced by setting the pump at a point where the subsurface pressure is above the bubble point of the well fluid. This can be done at minimum cost with the hydraulic pump. If packered installations cannot be operated in this manner, they can be equipped with a macaroni vent string if adequate clearance inside the casing string is available. Sufficient storage volume should be provided below the packer when equipping a well with a vent string to permit gas to collect above the pump inlet (Fig. 6).

SUBMERSIBLE CENTRIFUGAL PUMPING

The final lift method to be considered is the submersible centrifugal electric motor driven pump. This subsurface pump is also susceptible to gas interference, and its volumetric efficiency will be reduced when gas is present in the well fluids. However, lift equipment of this type is normally applied only to large volume producing wells which make a high percentage of water. Therefore, the possibility of a large amount of gas being present in the well fluids being produced with this lift method is considerably reduced.

Producing gaseous liquids with a centrifugal pump can result in a loss in volumetric efficiency the same as it does with other artificial lift systems. The magnitude of loss will depend on the amount of gas contained in the produced fluid. Gas separators are available to combat this problem and should be used if gas interference is anticipated. These separators form an integral part of the pump and are available in various sizes and lengths. They vary in operation from one having the reverse flow theory (Fig. 7) to a more sophisticated hydraulic-mechanical device which uses centrifugal force created by specially designed entrance ports to separate gas from the well fluid. A specially designed impeller represses this gas and discharges it into the casing annulus so it can be vented at the wellhead.

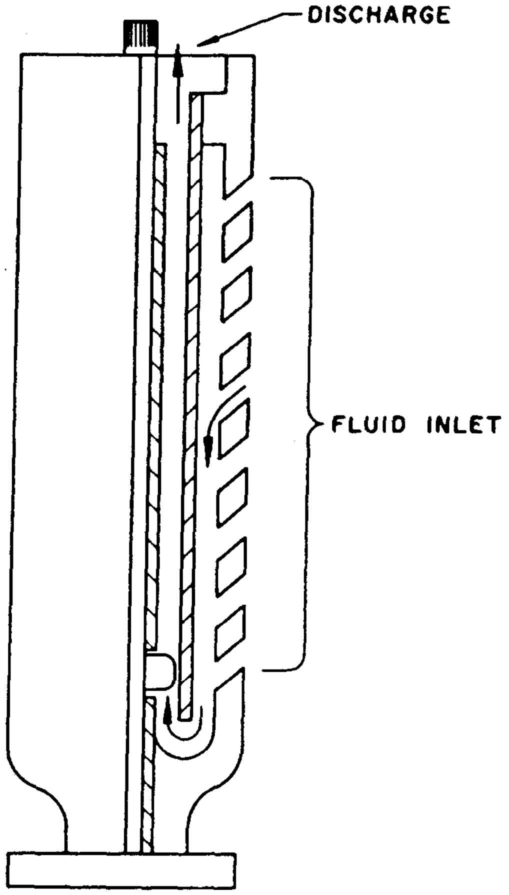


FIGURE 7
SUBMERSIBLE PUMP GAS SEPARATOR

SUMMARY

In summary, gaseous liquids can cause a reduction in displacement efficiency for each of the lift methods discussed. However, special equipment and field practices have been developed to combat this problem. This discussion has outlined the availability of subsurface separation equipment, specially constructed bottomhole pumps and recommended operating practices which should help reduce gas interference to a minimum for every type artificial lift method except gas lift. Therefore, to obtain improved efficiency, analyze the gas interference problem and engineer the selection of the necessary artificial lift equipment to efficiently produce the available well fluids.

REFERENCES

1. James N. McCoy, "Analyzing Well Performance," SPE Paper Number 337.
2. John R. Brennan and Harold Palmou "Down Well Gas Separation," Proceedin of Third Annual West Texas Oil Liftin Short Course, 1956.
3. John S. Page, "Pumping Gaseous Fluids a Means for Making Down Hole Separatio Proceedings of Fifth Annual West Texas O Lifting Short Course, 1958.
4. C. J. Merryman, "Gas Anchors Pay Di dends," Proceedings of Seventh Annu West Texas Oil Lifting Short Course, 196
5. J. E. Gallian, "Application of Insert Ro Pumps in Gaseous Wells", Proceedings o Eigth Annual West Texas Oil Lifting Sho Course, 1961.
6. L. E. Johnson, "Selection and Installation o Subsurface Pumps for Pumping Gaseou Wells", Proceedings of Ninth Annual We Texas Oil Lifting Short Course, 1962.