Problems Involved In Pumping Deep Wells

By Barney O. Carlson

Shell Oil Company, Midland Area Production Dept.
Hobbs, New Mexico

Introduction

A basic objective of any oil producing company is to recover the maximum amount of oil from a reservoir with a minimum cost. Many of the deep reservoirs in the West Texas-New Mexico area of production will require deep artificial lifts. The installation of any method of deep pumping is costly and operating expenses are high. Consequently, oil operators are making every effort to reduce costs in order to obtain reasonable profits from deep pumping wells. Lower operating costs will result in higher recovery percentages of one of our most important natural resources, crude oil.

The artificial lift of fluid from deep depths does not differ greatly in principles from that of pumping relatively shallow wells. Problems caused by corrosion, abrasion, or normal wear can exist in any lift installation; however, the problems inherent with any method of pumping are usually amplified with depth. A particular problem might be four times as troublesome with a 10,000-foot lift as it is with a 5,000-foot lift. This is to say that pumping from deep depths is expensive. Since there is only a small margin for error, it is essential that close control be exercised with deep-lift installations, and the costly problems involved in deep-well pumping deserve consideration and study. The percentage of total pumping wells which require deep lifts is relatively small, but it should be remembered that the number will increase and that even deeper pumping will be required in the future.

Definition of Deep Pumping Wells

The primary purpose of this presentation is to discuss the problems encountered in artificially lifting fluid from oil producers which have deep working fluid levels. For this purpose, a deep pumping well shall be defined as any well in which the fluid lift is from 7,000 feet or deeper. This classification does not include all deep wells since many are in reservoirs with active water drives which will not require fluid lifts from depths as great as 7,000 feet.

It is estimated that ten percent or more of the wells currently requiring artificial lift in the West Texas-New Mexico area of production are deep pumpers or will be prior to depletion. Also, with the deeper drilling which is now in progress, it is only logical to assume that the number of deep pumpers will increase.

Lift Methods

There are currently three methods in use in this area to lift production from deep pumping wells. These are rod pumping, hydraulic pumping, and gas lift. Rod pumping is the most employed method of artificial lift, and the development of long-stroke pumping units and high-strength sucker rods has made practical the lift of deep wells with rod equipment. Hydraulic pumping has been used for deep fluid lifts for several years. Gas lift is an old production method which is in general use for shallow, high-rate lifts, and during recent years there have been applications of this method to deep-well artificial lift.

The power transmitting medium is different for each of the several lift methods. Sucker rods transmit energy to a bottom-hole pump with rod pumping, and lease oil under pressure is the power-transmitting medium with a hydraulic system. Gas lift utilizes the energy released from compressed gas. The over-all efficiency of any of the lift methods is low.

Practical experience indicates that the mechanical or positive displacement methods, rod and hydraulic pumping, have efficiencies which are generally higher than those experienced with gas lift. Over-all efficiencies must be considered in selecting prime mover horsepower, but it should be stressed that the over-all lift efficiency is not necessarily directly proportional to lifting costs.

There are no set standards or policies within the industry concerning applications of lift methods. It is generally true, however, that there are some pumping conditions, surface and subsurface, which make one particular method of lift the most attractive. There is a constant search for better methods or improvements in equipment or operation of present methods. That a best lift method for deep wells has not been found is evidenced by current selection practices. In one relatively small field in New Mexico the three lift methods being discussed have been installed to lift production from the same reservoir. From this observation it might be concluded that operators have much to learn about deepwell pumping since it is improbable that the three methods will give the same results.

Lift Method Selection

The selection of equipment to lift production from deep wells efficiently is a problem that is becoming increasingly important as it becomes necessary to deplete by artificial lift a large number of deep reservoirs. Therefore, the first problem encountered in deep-well pumping is the selection of a pumping method which will give the desired lift with the lowest capital expenditure and operating expense.

Some of the factors which are considered in selecting a deep-well pumping method are past artificial life experience, new developments, surface and sub-surface conditions, and past and predicted well performance. Information from field personnel regarding the deep well can be of great assistance in this study. Well producing characteristics and test production data should be accurately reported. Swabbing tests are not an absolute indication of a well's productive capacity, but they are representative, and such information as swabbing rate, water cut, working fluid level or drawdown should be reported. In the case of a test pumping installation, all pertinent well production data should be precisely reported since considerable money is expended to get representative test pumping data. The important consideration is that an engineer needs more information than the bare fact that a well needs pumping to select the most economical deep-lift method. With accurate test data and the basic reservoir and well data which are availble, it will be possible to study the problem and make a sound recommendation.

After a lift method has been selected, the engineer must design a particular installation from the available equipment. A factor which must be considered in the final equipment selection is the experience and ability of field personnel since it is the production foreman and pumper who must operate a system or installation. It is usually economical to install equipment which will require a minimum of pumper attendance.

General Deep-Well Pumping Problems

Equipment Operation and Maintenance

There are a few general problems which must be overcome to gain desired results with any of the lift methods. Probably the most important of these is to get field personnel completely familiar with the method and equipment in use. The pumper must know how to operate, maintain, and regulate installation properly. It is he who must utilize the equipment to lift oil from a well, and it is he who can get the most from the installation. There should be no question unanswered as to routine operation and maintenance. The pumper should also be capable of analyzing operational difficulties, and he should know equipment limitations.

Lifting Rate Control

Another problem which enters into the operation of any pumping equipment is pumping rate. It is desirable that the rate of equipment operation be within safe limits and that the lift rate be within the well's productive capacity with any artificial lift installation, but these factors are of special importance for deep-well pumping. When rate of displacement with positive displacement equipment exceeds the rate of well production, an overpumped condition of fluid pound and low volumetric efficiency results. Over-pumping adds excessive wear to rod or hydraulic pumping equipment and will increase lifting costs for any of the methods. A severe fluid pound will part a string of highly stressed sucker rods and will reduce the useful life of a bottom-hole production unit or pump. The injection of more gas than needed in a gas-lift well increases lifting costs, and in some cases there may be a decrease in production. The importance of correcting the costly practice of operating with a fluid pound and low volumetric efficiency cannot be overemphasized.

Management sometimes unknowingly is responsible for an over-pumped condition because of the emphasis given to getting maximum production from any well. With deep-well pumping, it is probable that the cost of lifting the small increase in daily production gained by an over-pumped condition exceeds the value of the additional oil.

Problems Experienced With Mechanical Lift Methods

The discussion of specific deep-well pumping problems will concern the mechanical or positive displacement lift methods because of the writer's limited experience with gas lift. Also, a majority of the problems discussed will be those experienced with rod pumping, which is not meant to infer that problems associated with other lift methods are less severe or occur less frequently.

Lifting Cost Control

The costly problem associated with mechanical lift methods is mechanical failure of surface and subsurface equipment. Lifting costs consist of certain fixed costs, such as overhead and taxes, and direct operating expense. With rod pumping or any pumping method, it is the direct operating expense that must be studied and controlled. These costs consist of materials, surface and subsurface maintenance, and lease labor. The primary consideration here will be the problems experienced with lift equipment operation and maintenance and the control of such problems.

Initial Decline in Production

The first problem that an operator might encounter with a deep-lift pumping installation is a rather constant decline in production for no apparent reason. For example, during the first month of operation the production rate may have dropped from 240 to 200 barrels of fluid per day with the same equipment and a constant rate of operation. It is very probable that the decrease in production is caused by a decline in the working fluid level and nothing more.

In most cases fluid levels are high when pumping installations are first completed. However, there is an initial drawdown of fluid level in any well. If the well in question has poor reservoir communication, it is possible that this decline in working bottom-hole pressure and level will occur over a rather lengthy period of time. A similar condition can exist in a well that has good reservoir communication if the reservoir mechanism is a solution gas drive and the reservoir pressure is dropping rapidly, but for this example the initial, rapid drawdown is followed with a slower decline during remaining well life.

As working fluid level drops, the fluid load on the pump increases which means that the stretch in the rods on the upstroke increases. The result is a decrease in plunger stroke and production. With deep pump submergence, pump efficiency will be high since the pressure which forces fluid thru flow restrictions and into the pump is high. It might be stated that the pump is precharged. Also, with deep pump submergence there is less possibility that free gas will be present in the pump to decrease volumetric efficiency. As a pump submergence lessens, the pump volumetric efficiency is decreased. The efficiency may drop from more than 90 to less than 70 percent with a pump in good mechanical condition.

On occasion a pump is pulled because of a drop in production resulting from fluid level decline only to find that the pump is in good working order. There will be evidence of normal pump wear in any case. Only slightly worn valves, barrel, and plunger might be replaced to insure that the pump is as good as new. In the meantime, the well has been shut in and the bottom-hole pressure has been building up so that when the well is again pumped, a higher production rate is initially experienced. Therefore, it can be seen that the cycle explained could continue. The net result is excessive lifting costs.

The following are results of calculations which illustrate the cycle discussed. The example well is equipped with a tapered 1-inch, 7/8 inch, and 3/4 inch rod string and a 1-1/2 inch plunger insert pump set at 10,000 feet. Calculated production with a working fluid level near 3,000 feet and five 20-foot strokes per minute is 285 barrels of fluid per day. With a working fluid level at or near 6,300 feet, the calculated production has decreased to 240 barrels of fluid per day operating at the same speed. Finally, with a working fluid level near 9,600 feet, calculated production is only 200 barrels of fluid per day with five 20-foot strokes per minute. Pump volumetric efficiency was assumed to be approximately 90 percent with the working fluid near 3,000 feet, 80 percent with the fluid level near 6,300 feet, and 70 percent with the fluid level at 9,600 feet.

Surface Equipment Maintenance

Maintenance of both surface and subsurface equipment constitutes the major part of operating expense with deep-well installations. Daily maintenance of surface equipment is of primary concern to the pumper. If a pumping unit is properly sized for pumping conditions, there should be little difficulty or few failures with surface equipment. This is especially true of conventional crank-balanced beam pumping units. Experience indicates more maintenance is required for the hydraulic pumping jack or the air-balanced beam unit. Also, if the prime mover is properly sized, it should give little trouble.

It should go without saying that the pumper should diligently follow company policies or the manufacturer's recommendations for servicing equipment. The specified or equivalent lubricants should be used. This is not only important to insure maximum equipment life, but it will eliminate the question of improper lubrication in the event of equipment failure. There have been instances of a chassis lubricant being used in bearings on a pumping unit that were designed to run in a gear lubricant.

Electric motor operation does not present many problems. The operator should be sure that the motor has proper lightning, short circuit and overload protection. It is not uncommon for the motor control panel to be equipped with relay heaters which are rated too high for the motor installed. A rod break or any condition causing overload could then result in burned windings.

Gas engine operation should be within the maximum speeds recommended by the owner or the manufacturer. For best results, the engine load should be equal to or slightly less than recommended by the API. Multi-cylinder engine manifold vacuum is the best field indication of engine load. Crankcase lubricant changes and filter changes should be made according to company policies or manufacturer's recommendation for local conditions. The manufacturer' recommendation for total hours operation between oil changes can usually be considered a minimum. The engine should be maintained in good running condition because an engine operating poorly is probably overloaded and overloading causes excessive wear.

A cause of excessive engine and pumping unit wear is an improperly counter-balanced condition. On a deep lift, very large peak torques or reducer loading can result if the unbalanced condition is severe. For example, if only two-thirds the effective counterbalance needed was used on a 10-foot stroke beam pumping unit, the beak torque would be approximately 720,000 inch-pounds as compared with 360,000 inch-pounds with the correct counterbalance. This is for a 9,000-foot lift with a 1-1/2 inch plunger operating at nine strokes per minute. The example is an extreme case, but it does give an indication of that which is possible. The API rating of the speed reducer which probably would be in use on the example well is 456,000 inch-pounds peak torque capacity.

It is essential that pumping unit installation be level and properly aligned over the well if best results are to be obtained. This is especially true for big pumping jacks. If a beam unit is not properly aligned and level, bearing life will not be satisfactory. Also, it is possible for conditions to be such that there is not enough unit adjustment available to permit proper polished rod alignment in the tubing. Because of the high polished rod load, such a condition will mean short stuffing-box packing life.

The problems which can exist with surface equipment are usually relatively simple to correct. However, proper attention to these problems will reduce lifting costs which otherwise may be considerably in excess of normal costs

Subsurface Equipment Maintenance

A major part of the direct lifting expense is subsurface maintenance. Long-stroke beam and long-stroke hydraulic pumping units are in use for deepwell rod pumping to lower peak rod stresses, reduce rod fatigue, and increase pump efficiency. This makes possible lower lifting costs and deeper lifts. The initial investment is considerably higher than that which would be necessary for a shorter stroke installation. Since additional capital was invested to gain additional stroke length, it is only resonable to expect the pumper to utilize the longest stroke for as long as possible. Limitations on sheave sizes and prime mover minimum speed will make it necessary to reduce stroke length prior to and during the "stripper" stage of production in order to prevent severe over-pumping. For the deepest lifts, rod stresses are still high, and any unusual condition is likely to cause rod failure.

To understand the problems involved more clearly, it is best to dispel the idea that deep pumping is slow pumping. For example, the average polished rod velocity with a 30-foot stroke hydraulic pumping unit operating at six strokes per minute is approximately the same as that of a 64-inch stroke unit operating at 34 strokes per minute or a 74-inch stroke unit operating at 29 strokes per minute. The rate of operation given for the short-stroke units would not be practical.

Sucker rod failure can be a costly problem. This failure cannot be eliminated in deep pumping, but it can be controlled. The cause of rod failures is overstressing. Since sucker rod stresses are high in a deep pumping well, there are many factors which can concontribue to conditions in a well to cause excessixe rod failures. Some of the factors which might add load to the already highly loaded rod string are crooked hole conditions, excessive pump friction, a sticking pump, paraffin in tubing, corkscrewed tubing, and excessive operating speeds. With the exception of a crooked hole, these conditions can be corrected. If left uncorrected, one of the factors, such as a sticking pump, might add sufficient load to cause rod stresses to exceed safe values with failure resulting.

There are factors which will reduce the safe operating stress of a given rod string. Improper rod handling which results in bent rods, nicked rods, or hammer-marked couplings will cause stress raisers or stress concentrations. When one of these conditions exists the stress of the concentration will probably exceed the same (endurance limit) stress and the rod will fail in fatigue. If a rod is bent, the work load will tend to straighten the rod which adds a bending stress to the already highly stressed rod. Coupling makeup is also important in a deep, rod pumper. A pin will not fail in fatigue if the makeup load exceeds the load to which the coupling is to be subjected since there will be no stress variation in the pin. Excessive makeup can start a fracture which will result in pin failure. Therefore, it is important that rods be handled carefully and that connections be cleaned and made up properly.

Corrosion is a problem in some wells. Pitting of rods can cause stress raisers and subsequent corrosion fatigue failure of the rods. When such a condition is present in a well, treatment using chemical corrosion inhibitors is normally employed. If such treatment does not control failures, it is necessary to reduce rod stresses.

Sucker rods are designed to operate in tension. Being a slender column, a rod string will buckle and bend under compressive loading. Compressive loading or the higher variation in tensile loading as caused by a gas or fluid pound will greatly reduce rod life. Consequently, a well should not be pumped with a fluid pound. When a rod string parts, it is very probable that a few of the smaller rods below the part will be damaged as a result of the string being dropped in the tubing. If the bent or corkscrewed rods are not replaced, it is possible that bending stresses cold cause future failures.

Another costly item in deep-well pumping is bottom-hole pump maintenance. Pumps must operate at relatively high velocities with a very high differential pressure across the plunger. These normal operating conditions in a deep pumping well reduce useful pump life considerably below that which can be expected with a shallow lift. Therefore, as would be expected, the bottom-hole production unit or pump repair frequency increases with depth of lift. Added to the increased frequency is the higher cost per job to repair the longer and more expensive pumps employed for deep-well lifts and the higher cost to pull and rerun a pump. The development and utilization of better bottom-hole production units is needed to decrease the repair frequency.

The pump repair frequency is sometimes increased by conditions which are subject to field control. As previously discussed, over-pumping will reduce subsurface equipment life. A severely corrosive well condition will increase the pump repair frequency, but this condition is subject to control by using chemical corrosion inhibitors. Sand, shale, or other foreign material in produced fluid creates a troublesome problem which is difficult to control. Such foreign material can cause excessive wear, sticking plungers, or stuck pumps. A critical examination of the well conditions and pump failures might indicate a solution which will increase the length of pump runs.

Tubing anchors are in general use with rod pumpings. A properly installed anchor will increase effective plunger travel and decrease tubing fatigue. Operators are using mechanical and hydraulic anchors for various reasons. For most installations, it is desirable that the tubing be in tension to the pump in order to avoid a corkscrewed tubing condition. This undesirable condition will result if an anchor works up the hole. A check should be made for this condition when tubing is pulled. In the event that a hydraulic anchor is in use, a drain collar might prove to be valuable. Hydraulic anchors should be reconditioned when pulled to avoid leakage. In the event that a tubing anchor is set in casing above the cemented section, it should be remembered that the string will be subjected to a working stress for which it was not designed.

A further difficulty with pump operation is seating equipment. A common practice is to provide a bottom lock and seal and a top seal and stabilizer. If properly spaced, this arrangement gives satisfactory operation. In the event of pump change, it is important that seal-cup spacing be the same as that initially used. This will reduce the possibility of an improper pump seat and fluid leakage past the pump.

Essential to satisfactory hydraulic production unit operation is clean power oil. Proper treating facilities should be provided, and power-oil tank bottoms should be kept clean of water and deposition. Operating pressures should be kept to a minimum by proper pump selection and by keeping lines clean of paraffin. A minimum of oil should be by-passed at the power-oil pump, because by-passed oil is wasted energy. An operating problem with hydraulic pumping which deserves mention here is maintenance of a pump with a free system. With this system, the production unit can be pumped to the surface. Because of the ease and speed with which a pump can be removed, it is probable that more "green" pumps are pulled. Replacement of a pump still in good condition adds unnecessary lifting costs.

When subsurface failures are frequent, a well study can be profitable. A useful tool for such studies is a dynamometer. The dynamometer card is a continuous recording of polished rod load during the pumping cycle. Card shape is influenced by many factors. An abnormal condition will be indicated on the card, and it is usually possible to determine the subsurface difficulty by careful analysis of the card. Cards recorded during normal operation are useful in the study. Also, fluid level surveys give data which are valuable for well studies.

Recent Developments

There have been recent developments in artificial lift equipment which appear to offer advantages as concerns the pumping of deep wells. Some are new ideas, while others are new applications of available equipment or old ideas.

Hydraulic Counterbalance

As has been discussed, permissible rod stresses limit deep-well rod pumping. Advancement has been made in the past several years by rod manufacturers in increasing the safe working stresses. A recent development now available for general use has made it possible to pump deeper without increasing rod stresses. This device is a hydraulic rod weight counterbalance in the well. The hydraulic tool is located in the tubing and rod string at a point which is approximately half way between surface and the pump. The tool plunger, which is made up in the rod string, works in a barrel which is a part of the tubing string. The top of the plunger is subjected to the low pressure in the casing, while the bottom of the plunger is working against tubing pressure. An upward or counterbalincing force results from the differential pressure across the plunger. The rod load above the tool is reduced by an amount equal to the effective counterbalance. The counterbalancing force can equal only a part of the rod load below the tool. Two deep pumping installations were put into operation in West Texas a few months ago with the down-hole hydraulic counterbalance. The operator has reported satisfactory results and that the reduction in polished rod load was as calculated.

Automatic Controls for Hydraulic Pumping

One operator is preparing to install a four-speed electric motor with automatic controls on a four-well hydraulic pumping installation. With a conventional single-speed electric motor there is relatively constant power oil output. In the event that all wells are not being pumped, some oil will be by-passed, and by-passed oil is wasted energy. The proposed system should eliminate this energy waste. In addition, with the automatic controls, any well can be pumped on the desired schedule without regard for the other wells. That is, the wells can be operated as if they were equipped with individual pumping units.

Ball Pumping System

A ball pumping system utilizing compressed gas as the source of energy is in the process of development. With this system, balls are intermittently released and pumped down a tubing string with gas. The balls enter the fluid column in the production string of tubing. Expanding gas forces the ball and fluid to the surface.

Plunger Lift

Plunger lift is not new, but its application to deep-well pumping is relatively new. The traveling plunger operates between the fluid and expanded formation and injected gas to force fluid to the surface. The purpose of the plunger is to reduce to a minimum slippage of gas past the fluid.

Summary

This discussion has, for the most part, concerned the mechanical lift methods because of the writer's limited experience with gas lift. Also, most of the problems discussed are those experienced with deep-well rod pumping; however, this is not an indication that the problems experienced with gas lift or hydraulic pumping are less severe or occur less frequently.

It is evident from current lift method selection practices and the high operating costs experienced with all methods that there is no lift method which is completely satisfactory or far in advance of the other two for deep-well pumping. Each operator has his own reasons for utilizing a particular method for a given lift, and one of the reasons might well be that the operator has experienced very unsatisfactory service with the other methods in another field or area. Regardless of the lift method selected, the equipment should be operated so as to lift fluid at the desired rate with a minimum cost. Finally, it is apparent that every effort should be made to improve the available deep-well pumping methods.

☆