A Consideration of Optimum Pumping Conditions

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Before we start to discuss "Optimum Pumping Conditions" let us first see what Webster's Dictionary gives as the real meaning of "optimum": "The best or most favorable degree. Best, most favorable or most conducive to a given end, especially under fixed conditions."

The first and most important key to optimum pumping is the establishment of fixed conditions.

As we all well know, the basic purpose of any pumping installation is to pump fluid from the well to the surface. In order to establish a set of fixed conditions around which we can establish optimum pumping, we must consider all of those factors which are most important and then we must decide to what degree they really are fixed or stable.

The following factors are the most important in defining the problem to be met in any particular pumping well:

1. Volume of fluid in barrels per day
2. Net lift in feet
3. Specific gravity of fluid
4. Gas-oil ratio
5. Viscosity of the fluid.

We shall briefly discuss each one of these.

The first and most important factor to be defined is the volume of fluid that is to be pumped every 24 hours. All too often the volume decided upon is considerably different from that which the well is capable of producing. In other words, it is what the producer hopes the well will make rather than what it will actually produce. A productivity index should be established for each well as a definite guide to what the well is really capable of producing. Establishing the productivity index really means establishing the potential of the well.

After a potential has been established, the actual withdrawal rate is generally affected by several important factors. Proration of the various producing areas by the State regulatory bodies very often determines the allowable producing rate. When a well is pumped hard to try to obtain an allowable which it is not quite capable of producing, the result is often abusive to the pumping equipment. In some fields where allowables are not a factor, competition between producers results in an operation with a very high fluid volume withdrawal. The later history of such fields when they are put under unit operation very often shows that competitive withdrawal rates are not in line with good practice as far as ultimate recovery is concerned.

Of course, the type of natural drive is all-important in the determination of the withdrawal rate from any particular well. Many instances have shown that pumping wells with considerable solution gas at too fast a rate actually hampers the amount of fluid obtainable, because pulling the well bore pressure down too low results in the separation of gas from the fluid back in the formation and the prevention of the flow of solid fluid into the well bore.

In direct contrast, wells in a water-drive field may require increasing rates of fluid withdrawal in order to make them economically sound throughout the pumping life.

The important consideration is the amount the volume of fluid that is necessary to be withdrawn will vary with time, considering all of the factors which have been discussed above.

In the selection of the optimum size of equipment, the next most important factor one must know, after having established the volume of fluid, is what is the net lift in feet or, in other words, the distance that the fluid must be lifted. The net lift in feet may change considerably over a period of time in depletion types of reservoirs. However, in some fields where there is a natural water drive or where bottom-hole pressures are maintained by injection of water or gas, the net lift may be cut down for the entire life of the well. The question is, why should one pump a well from the bottom when Mother Nature will lift the fluid a considerable distance? When one has decided that a well may be pumped from some point up the hole, he must establish the productivity index.

In the sale of crude oil, the API gravity must be determined. This helps one to determine the specific gravity of the actual fluid being lifted from the well. Charts are provided for the determination of the approximate specific gravity of oil-water mixtures, but when gas is present, calculating the true specific gravity of the fluid being produced is somewhat difficult, except that one knows that it is going to be considerably lighter because of the presence of the gas. This brings up the next factor, gas-oil ratio, which is also commonly determined in many areas to establish allowables. High gas-oil ratio usually means an erratic or unstable condition of pumping. Gas must be pumped with the fluid or it must be separated with an efficient gas anchor.

As more and more so-called heavy crudes are being discovered and produced, the problem of viscosity of fluid enters into the picture. A heavy viscous fluid can greatly impair the travel of the pump plunger and can also necessitate having larger standing valves in the pumps to allow filling of the pump on each stroke.

After the well conditions have been defined, the equipment should be selected with optimum conditions in mind. The equipment should be so selected that the best combinations of stroke lengths and strokes per minute can be used to keep load and torque values down and at the same time to obtain efficient pump operation.

Displacement of a given volume of fluid may be accomplished with a large pump and a short effective stroke, or with a small pump and a long effective stroke. The effective stroke length is the actual total motion of the plunger with reference to the pumping barrel. This motion is affected by the tubing motion, by the amount of stretch of the sucker rod string due to fluid load, and by the over-travel resulting from the speed of operation.

The effect of these factors has been well considered in the various formulae which have been evolved for calculating plunger travel. The calculation of plunger travel will not be discussed in this paper, except in the comment that a number of factors involved can give greatly different results with each formula. We do know from tests that the most important factor in obtaining good plunger travel is the size of the plunger itself.

Using a longer stroke length than necessary requires a larger pumping unit and also directly affects the peak torque requirements. Longer stroke lengths also require longer pumps and longer polished rods.

If a stroke is too short, the unit must be run fast, demanding a greater number of reversals on the sucker rods and surface equipment and creating the possibility of a wider range of load.

Many articles have been written and much educational work has been done over the past twenty to twenty-five years to help inform those responsible for the operation of pumping wells, but in spite of this assistance we still find much room for improvement.

Selection of optimum conditions for any and all wells is not simple, but often the simplest considerations are overlooked. Much progress can be made in the economy of operation if the man in charge really understands what is involved when he is using too large or too small a pump and what is the best combination of speed and stroke to minimize load and torque and at the same time to maintain good efficiency.

The question is, how can we best illustrate optimum pumping conditions so that the man in the field will understand whether he is coming close to meeting them? The following charts and discussion purpose to answer this question.

Chart 1, entitled "Dead Weight of Rods and Fluid," shows the weight per foot in pounds, first, for the sucker rods for strings of one size, and second, for combination strings. These are plotted against plunger size, which determines the proper proportioning of combination of strings. Also plotted is the fluid load considering the net area of the plunger, a subtraction of the average area of the rod string from the bottom of the hole to the top, or, in effect, the subtraction of the fluid bouyancy on the rod string. The corresponding fluid load curve for the particular rod string in question is shown with the dotted connecting line.

This chart shows in a most emphatic way that the fluid load increases very rapidly with plunger size. In other words, whenever a plunger that is larger than needed is used, unnecessary load results, a load which may be of great consequence in the over-all picture.

Very often in older fields, pump sizes considered necessary when flush production was in existence are still being used, and rather than cut down the size of the plunger, an attempt is made to run the well extremely slow with as short a stroke as possible. The best way to modify these older wells is to cut down the size of the pump to one which is optimum for the production being considered.

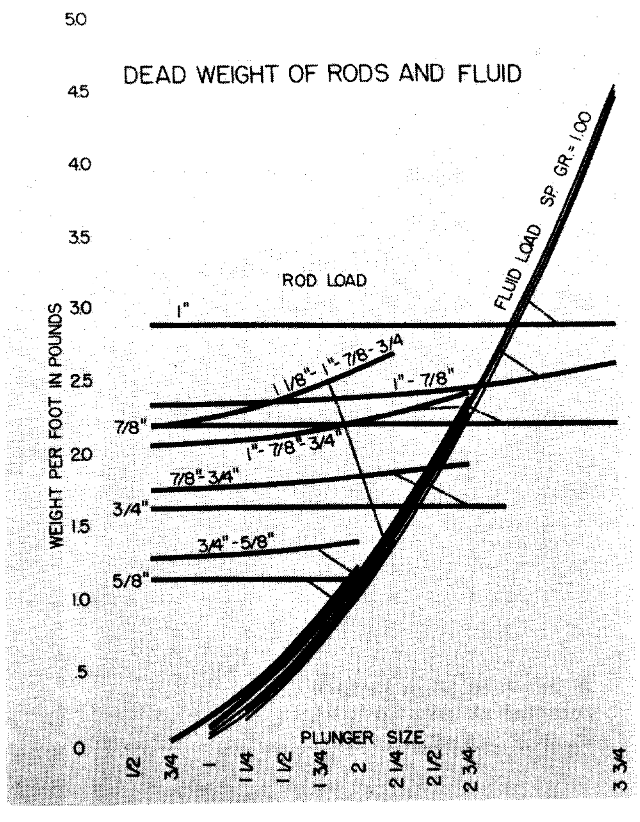

Chart 1

It is quite easy to picture sucker rods stretching under their own weight, then stretching additionally because of the fluid pressure on the plunger, and then being subject to still more stretch because of the acceleration forces on the rods and fluid. It is then not too hard to imagine that as speed of operation increases, the stretch may be turned into useful motion by the spring action of the sucker rod string. Longer strings of rods provide more stretch to be transformed into useful motion of the plunger. As was mentioned before, several formulae have been developed to be used in the calculation of the actual plunger stroke. In the construction of charts 2 and 3, the formula developed by Mr. Rieniets in his paper "Plunger Travel in Oil Well Pumps" given in *Drilling and Production Practice*, Vol. 1937, page 159, of the American Petroleum Institute, was used. Plunger travel calculations were made in each case, with an assumed 54-in. surface stroke and 7/8-in. and 3/4-in. sucker rods, with various plunger sizes.

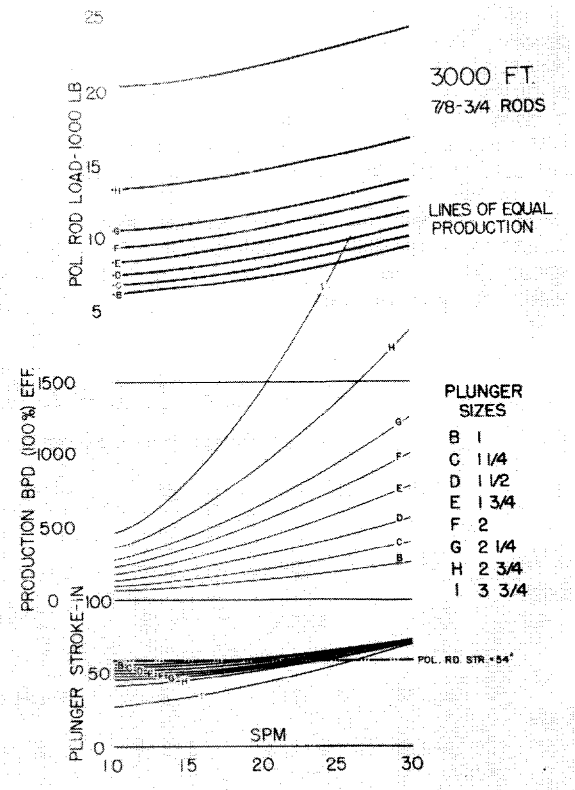

Chart 2

Plunger stroke curves were plotted first at the bottom of the two charts and then were compared with the polished rod stroke. Then for comparative purposes only, the total production for each plunger size was plotted, by using the calculated plunger stroke at a particular speed and plunger size.

Peak load calculations were then made by using the formula proposed by Mr. Mills in his article "Factors Influencing Well Loads Combined in New Formula," given in the *Petroleum Engineer* in April, 1939. This formula has been in quite general use since its publication. The peak polished rod load curves were plotted in the top part of the charts, and, superimposed on them, lines of full production were plotted by projecting upward from the production curves immediately below. These equal production lines readily show what happens when a plunger size too large or too small is used to obtain a given production.

A comparison of the 3000-foot and the 6000-foot charts first shows the availability of considerably more plunger travel at the deeper depth and also the limited plunger sizes at the 6000-foot depth.

On the basis of a family of charts similar to these from the 2000-foot depth down through 8000 feet, optimum pump sizes were selected, these were in turn checked with actual plunger sizes being used in service, and the following tabulation was made.

Table I was originally presented as an AIME paper in 1943 and was later reproduced in *The Sucker Rod Handbook,* published by Bethlehem Steel.

In order for us to take a quick look at what variation in load, torque, and horsepower factors may be encountered in a 6000-foot well for various productions, chart 4 was prepared. The pump size was selected on the basis of the optimum chart, and calculations were made for the design of a complete pumping installation for each production rate. The basic design calculation sheets are included in *The Sucker Rod Handbook,* pages 137 to 141, inclusive. The production rates shown assume an apparent volumetric efficiency of 80%.

From this chart an easy comparison may be made of the rod load, the fluid load, and the dynamic load for each production rate as well as the peak torque and the horsepower required to pump the well.

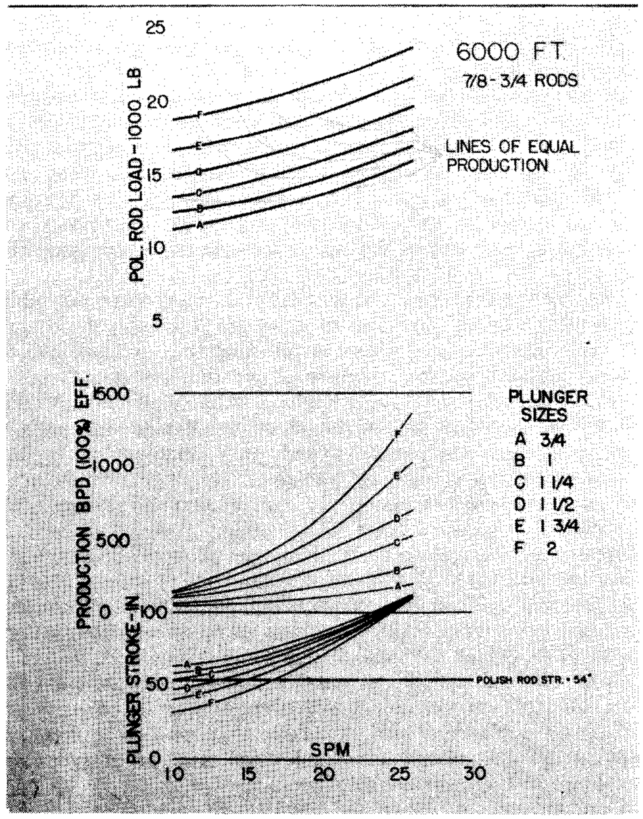

Chart 3

TABLE I. PUMP PLUNGER SIZES RECOMMENDED FOR OPTIMUM CONDITIONS

Depth	Fluid Production - Barrels per day - 80 pct efficiency									
ft.	100	200	300	400	500	600	700	800	900	1000
2000	1-1/2	1-3/4	2	2-1/4	2-1/2	2-3/4	2-3/4	2-3/4	2-3/4	2-3/4
	1-1/4	1-1/2	1-3/4	2	2-1/4	2-1/2				
3000	1-1/2	1-3/4	2	2-1/4	2-1/2	2-1/2	2-3/4	2-3/4	2-3/4	2-3/4
	1-1/4	1-1/2	1-3/4	2	2-1/4	2-1/4	2-1/2			
4000	1-1/4	1-3/4	2	2-1/4	2-1/4	2-1/4	2-1/4	2-1/4		
		1-1/2	1-3/4	2	2					
5000	1-1/4	1-3/4	2	2	2-1/4	2-1/4				
		1-1/2	1-3/4	1-3/4	2					
6000	1-1/4	1-1/2	1-3/4	1-3/4						
		1-1/4	1-1/2							
7000	1-1/4	1-1/2								
	1-1/8	1-1/4								
8000	1-1/4									
	1-1/8									

In this tabulation surface pumping strokes up to 74 in. only are considered.

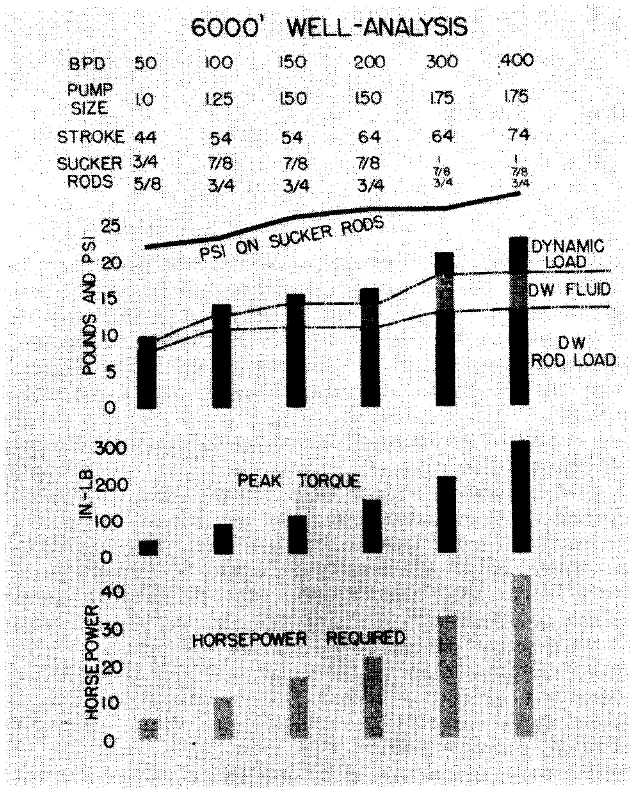

Chart 4

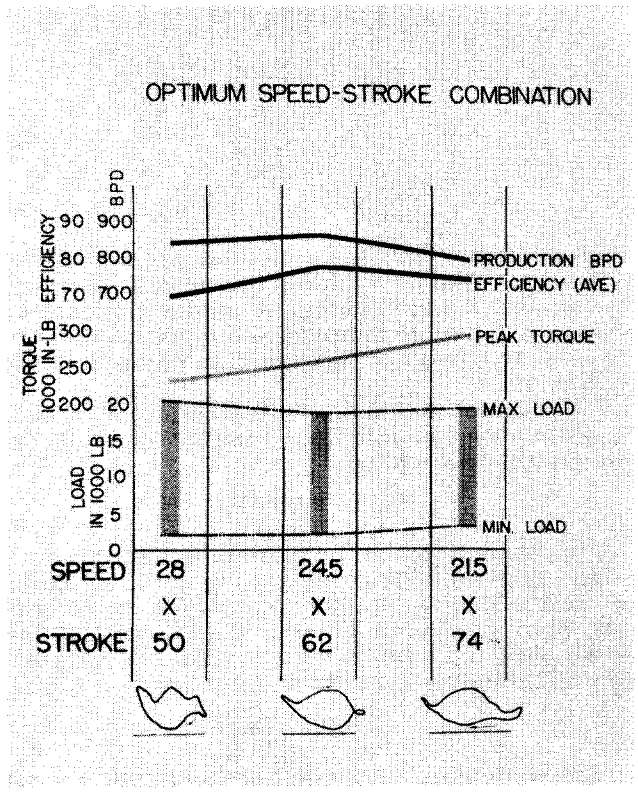

Chart 5

The main consideration for comment in the study of this graph is that if a well is equipped with a large plunger and the long stroke and then, unfortunately, the fluid is not available from the well and the operation is continued without any adjustments, unnecessary load and torque result.

So far each one of the charts has shown the calculated values, but Chart 5 shows a selection of optimum speed and stroke combinations taken from the actual measurement of load and production.

This well was approximately 4000 feet deep and operating with a 2 1/4-in. bore plunger. The well was first run at 28-to 50-in. strokes per minute, and then the stroke length was changed to 62 at 24 1/2 strokes per minute. The peak load was reduced to about 2000 pounds, the production increased from 694 barrels to 775 barrels, and the apparent efficiency increased from 84% to 86 1/2%. The peak torque went up from 321,000 in. lb. to 258,000 in. lb. Since this apparently was a substantial improvement, it was felt that perhaps operating with the 74-in. stroke would be still better. Accordingly, the stroke was changed and the well was operated at 21 1/2 strokes per minute, but the peak load remained very nearly the same, the production fell off to 745 barrels per day, and the apparent efficiency dropped to 79.5%. Also the peak torque had now reached 296,000 in. lb, which was way beyond the capacity of the pumping unit. This experiment shows that selecting an optimum speed and stroke combination for a given installation is practical.

One of the key factors in the consideration of optimum pumping is the apparent efficiency being obtained, and by always endeavoring to keep this efficiency as high as possible, many pumping-well troubles can be overcome.

When efficiency falls off, the tendency always is to attempt to regain any lost volume of fluid by speeding the well up, but in many cases the efficiency is still further reduced.

Good volumetric efficiency can be attained when all of the factors are taken into account. The only time poor efficiency may be excused is one when considerable gas is in solution in the fluid being produced and a subsequent shrinkage occurs, which gives a false indication of the actual efficiency through the pump.

Optimum conditions should always be borne in mind, and an attempt should be made to achieve such conditions, first, by the best selection of the equipment to meet the requirements of the individual well and, second, by the adjustment of the equipment to meet the actual requirements involved after the well starts pumping.