Principles of Sucker Rod Pumping

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You have come here in the hope of learning something about the Principles of Sucker Rod Pumping. I have been studying that subject for about 20 years and I am certain that I have much yet to learn. It is quite unlikely that you will leave here knowing all that is known about that subject. Sucker rod pumping, unfortunately, is an illusion, in that it looks quite simple whereas the problems involved are extremely complicated, and little understood. And, for that reason, many things we "know" about sucker rod pumping aren't true at all. By the word "principles" we mean the truths or facts upon which other facts or truths depend. It logically follows that we must start with the most simple facts if we are to comprehend the principles involved in sucker rod pumping and from them be able to reason our way to pertinent facts and conclusions.

I suppose every one here has operated the handle of a pitcher pump. All reciprocating pumps are identical in principle though they vary in construction to meet a multitude of requirements. The pitcher pump in principle is precisely the same as the pump which is run in a deep oil well. The pitcher pump has a plunger operating up and down in a cylinder; an inlet valve, known as a standing valve, and an exhaust valve, known as a traveling valve. All reciprocating pumps have a plunger operating in a cylinder, an inlet valve and an exhaust valve. On the outward stroke fluid enters the cylinder through the inlet valve and occupies the space or volume swept out by the plunger. On the return stroke the inlet valve is closed and the fluid previously drawn into the cylinder is discharged through the exhaust valve. The space or volume swept out by the plunger is called the displacement of the pump and may be calculated by multiplying the area of the plunger by the length of the stroke. This represents the volume of fluid passing through the pump at each stroke if there were no leakage or loss of any kind. This is true of a pitcher pump, a mud pump, an oil well pump, or any reciprocating pump whatever. So all that is necessary to pump is to cause the plunger to move to and fro in the cylinder. That, of course, is not strictly true for we could not pump an oil well with a pitcher pump. You see, the only reason that the fluid enters the pump through the inlet valve is because the outside pressure is greater than that inside the cylinder. Since a pitcher pump operates at atmospheric pressure, the greatest difference in pressure possible is the atmospheric pressure of 14.7 lb. per sq. inch. This pressure is sufficient to balance a column of water 33 ft. high, so it would be impossible to lift water by suction more than 33 ft. Imperfections in the pump limits a pitcher pump to about a 20 ft. lift by suction. Thus, it follows that the plunger cannot be more than 20 ft. above the static level of the liquid to be pumped. Hence, in pumping an oil well we have to lower the cylinder far down into the well in order to fill the cylinder at each stroke of the pump. We connect the plunger to the pump handle (that is the walking beam) by means of long steel rods (sucker rods). Thus, in principle we have a pitcher pump except that the sucker rod may be hundreds of feet long instead of only one foot long. And, you might reasonably ask the question, "So what?"

That's the 64 dollar question which I have been trying to answer for 20 years. Of course, the long string of sucker rods are quite heavy and the fluid has to be lifted many times more than 20 feet, so the handle of our oil well pitcher pump must be very large. But that is a simple engineering problem and we can very well design a walking beam and its support (the Samson Post) of sufficient strength to withstand the large forces involved. That is not a serious problem. Then, wherein lies the difficulty?

Going back to our hand operated pitcher pump, we see that if we raise the top of the sucker rod say 3 inches, the plunger raises 3 inches; also, whatever motion is given to the top end of the sucker rod that motion is transmitted practically unchanged to the plunger. Steel, however, is elastic; that is, it stretches under strain and, of course, the sucker rod on the pitcher pump does stretch but being only one foot long the stretch is maybe a few tenths of one thousandths of an inch and has no practical effect upon the motion of the plunger. But, when when we lengthen sucker rod to several thousand feet or perhaps to a mile and three quarters, the stretching of the sucker rods has a profound effect upon the motion of the plunger. The plunger motion is entirely changed and the longer the sucker rods the greater the change. Most of you have undoubtedly noticed in rod line pumping that the motion of the pumping jack may be quite unsteady while the motion of the pitman at the knock-off post is quite smooth. And, this perhaps with only 2,000 ft. of rod line rods. Imagine if you can, how much more that motion would be changed if the rod line were—say a mile and one half long. Thus, we see that in order to understand what happens at the pump, we must know the principles of how sucker rods stretch.

We shall, of course, not here attempt an academic discussion of sucker rod stretch, but will demonstrate in a fashion the behavior of rod stretch.

I have a simple toy, made of steel as sucker rods are, and because of its construction we may demonstrate how sucker rods stretch.

I have calibrated this toy in such a manner that its behavior in stretch reproduces sucker rod stretch quite exactly in quantity.

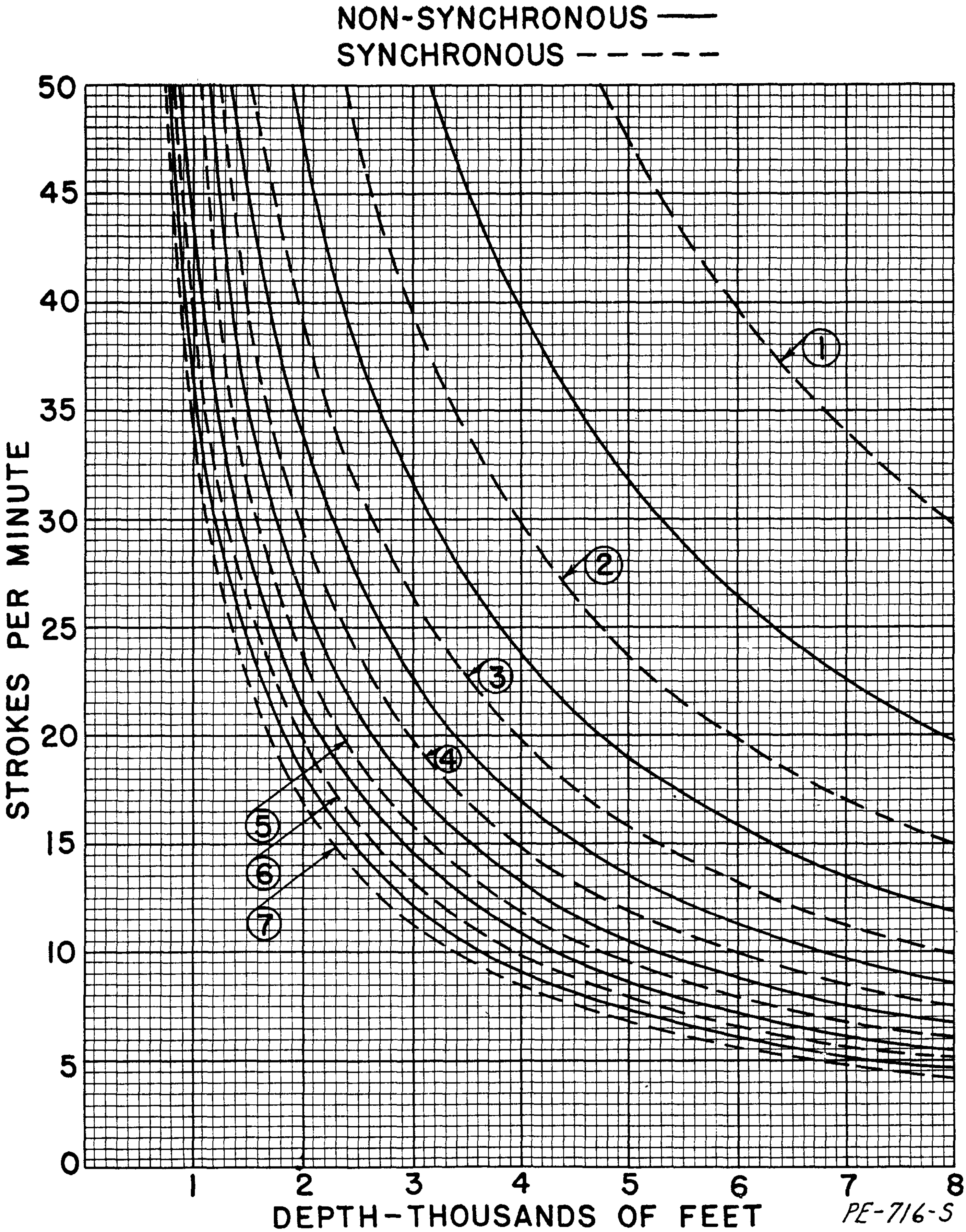
First, sucker rods stretch due to their own weight for each sucker rod must support the weight of all the rods below that particular rod. The top rod must support all the other rods. The second rod must support all the rods except the top rod, and so on, each successive rod is stretched a little less than the one immediately above it, and finally the bottom rod has only the plunger to support.

In addition to all this, the sucker rods are still further stretched by the weight of the fluid. If we hang a weight on a spring, the spring is stretched until the forces within the spring can support the weight. We cannot pick up that weight with the spring until we have stretched the spring that amount. Likewise the plunger in the pump cannot be raised until the sucker rods are stretched sufficiently to support the fluid weight. Thus, if an oil well pump was operated very slowly, the polish rod would travel upward sufficiently to stretch the rods enough to carry the plunger load. In the meantime, the plunger would be stationary. Thereafter, the plunger would move upward with the polish rod. On the return stroke, the plunger would again stand still while the rods unstretched and thereby transferred the load to the standing valve. Thus, if the polish rod stroke was equal to or less than the unavoidable rod stretch, the plunger would not move at all and the pump would not produce. Our pitcher pump now has a rubber sucker rod.

Furthermore, the plunger absorbs power in lifting the fluid, hence, power has to be transmitted from the polish rod to plunger through the sucker rods but since we know that the sucker rods stretch we know they store energy in stretching. We wind them up, so

FIGURE I

PUMPING SPEED CURVES



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to speak. Later on, we have to release that energy when the rods are unloaded and in addition to this the rods must be stopped and started twice each stroke cycle. Now, considering that the rods in deep wells may weight 7 or 8 tons, there is a sizeable exchange of work due to starting and stopping the rod. Thus, storing energy and then releasing it induces vibrations in the rod string. Quite the same as stretching a spring and releasing it. The timing of these forces may tend to increase the vibrations and produce excessive stresses in the rods and thereby cause premature failure. The timing, however, may be so chosen as to diminish the vibrations and cancel them out at each half stroke.

The problem is further complicated by the fact that the pump is supported by the tubing which like the rods is also elastic. On the downstroke, the weight of the fluid is transferred to the tubing by the standing valve. The tubing stretches and its lower end moves downward with the plunger until the tubing is stretched sufficiently to support the added load. On the upstroke, the tubing is relieved of as much load as the plunger carries and so its lower end follows the plunger upward until the balance between stretch and load is equalized. Our pitcher pump cylinder is mounted on a spring instead of on a solid foundation. In deep wells the tubing should be anchored to the casing to avoid this tubing motion and thereby the loss of effective plunger travel. In many instances the tubing fails at the couplings if allowed to move up and down with the pumping cycle.

There is no known method whereby a force may be transmitted from one point to another instantly, not even by electricity, which travels at 186,000 miles per second. Forces in steel travel at the rate of about 16,000 ft. per second or in round numbers about 3 miles per second. Thus, in a well a mile deep it would require 1/3 second to transmit **force and motion** from the polish rod to the plunger and also 1/3 second to transmit a force from the plunger to the polish rod. If for instance, the plunger bumped bottom, the shock would not be felt at the polish rod for 1/3 second after it happened. By that time the polish rod may be some distance up on the upstroke. This we call "phase lag." We have no analogy for phase lag in a pitcher pump.

With phase lag, rod stretch, tubing stretch and energy transmission, the problem of sucker rod pumping is very complicated and its complexity is recorded in the sometimes fantastic shapes on the dynamometer cards of pumping wells.

Another point we must remember is that in deep wells the pressure at the plunger may be quite high. It may be as much as 430 lb. per square inch for each 1,000 ft. of depth. Under high pressure the increased friction may require a sizable force to push the plunger down on the downstroke causing rod buckling and rod failure, if no preventative measures are taken.

We cannot go further into details of the problems, but it is hoped that this discourse will help to better understand some of the following recommendations.

1. Some pumping speeds are more desirable than others. See attached chart for synchronous and non-synchronous pumping speeds. Non-synchronous pumping speeds mean less rod stress and vibration and better pump performance.

2. Use as small a plunger as will get the job done. In deep wells too large a plunger will not pump as much as a smaller plunger due to excessive stroke loss by rod stretch.

3. For best results, the tubing in wells over 4,000 ft. deep should be anchored and the number of strokes per minute should be carefully selected to avoid rod trouble.

4. In most wells, it is wise to use oversize rods or sinker bars immediately above the pump to assist in returning the plunger on the down-stroke.

5. "Pounding fluid" near mid-downstroke, or later, should be avoided. Shorten the stroke or install a smaller pump.

6. Pounding gas should also be avoided if possible. A properly constructed gas anchor often solves the problem, but not always.

7. Agitating wells need not be stroked rapidly. With light fluid loads high speed pumping has a tendency to cable tool the rods since the fluid load may not be sufficient to absorb the energy of stopping the rods on the upstroke and thus allow the rods to overtravel on the upstroke, and thereby causing buckling and failure.

8. Excessive rod or tubing trouble should be investigated. A dynamometer record properly taken will reveal the trouble which can then be corrected. Except for corrosion, rod and tubing trouble can be avoided. Even corrosion can be minimized.

9. Most frequent causes of rod failures are (a) synchronous speed especially of the 3rd order; (b) buckled tubing caused by the tubing resting on the bottom or not properly stretched above anchor, or because the anchor may have crept up the casing; (c) crooked hole, cannot be corrected—crooked holes cannot be pumped fast; (d) rod buckling due to excessive resistance or friction in pump on the downstroke; (e) under counterbalance which makes for unsteady motion of the polish rod and thereby increases vibration. Careful counterbalancing pays off in many ways.

And, finally, a few words about the pump. There are a great variety of design in pumps, each suited to some purpose but that is beyond the scope of our subject. A pump is an exceedingly finely made piece of equipment. It should be handled very carefully and must not be subjected to any force liable to distort it. In pumping never allow the plunger to strike top or bottom. Any repairs should be made in a good pump shop having the proper tools to perform the work required. Fortunately such shops abound near every oil field.

We have said that there is a wrong and a right way to pump an oil well. It would be quite impossible to discuss all of the factors which enter into choosing the correct equipment and cycle operation, nevertheless it may be enlightening to give an example of what can be accomplished.

In the attached figure will be found a duplicate of two dynagraphs taken from the same well. The first graph was taken to determine the cause of excessive tubing and rod trouble. The tubing was being parted at about ten (10) day intervals. The rods were also breaking but not as frequently as the tubing.

A study of this graph showed that the tubing was vibrating up and down about 32 inches at the pump. It so happened that the tubing was vibrating three times to each complete pumping cycle. One need not be an expert to see that there are undesirable fluctuations of the load and that the change in load is very rapid. Obviously, this is quite an undesirable type of graph.

The second graph was taken to observe the improvements on operation wrought by the changes made. Briefly, these were the changes made:

1. The tubing was anchored.
2. 100 ft. of 7/8" rods were run immediately above the pump.
3. The stroke was shortened from 64 inches to 54 inches.
4. The SPM were increased from 18 to 22. This from a synchronous speed to a nonsynchronous speed.

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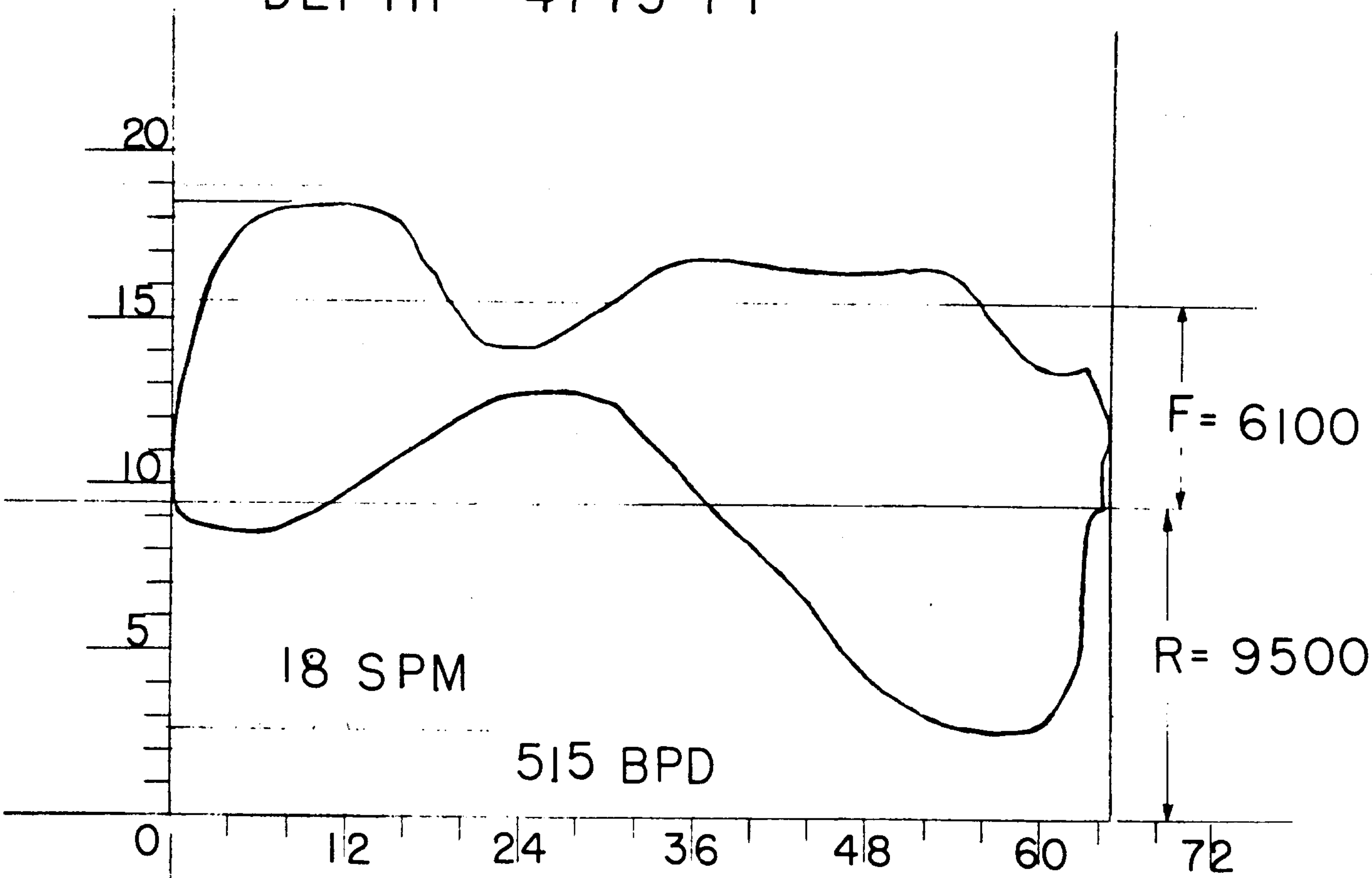
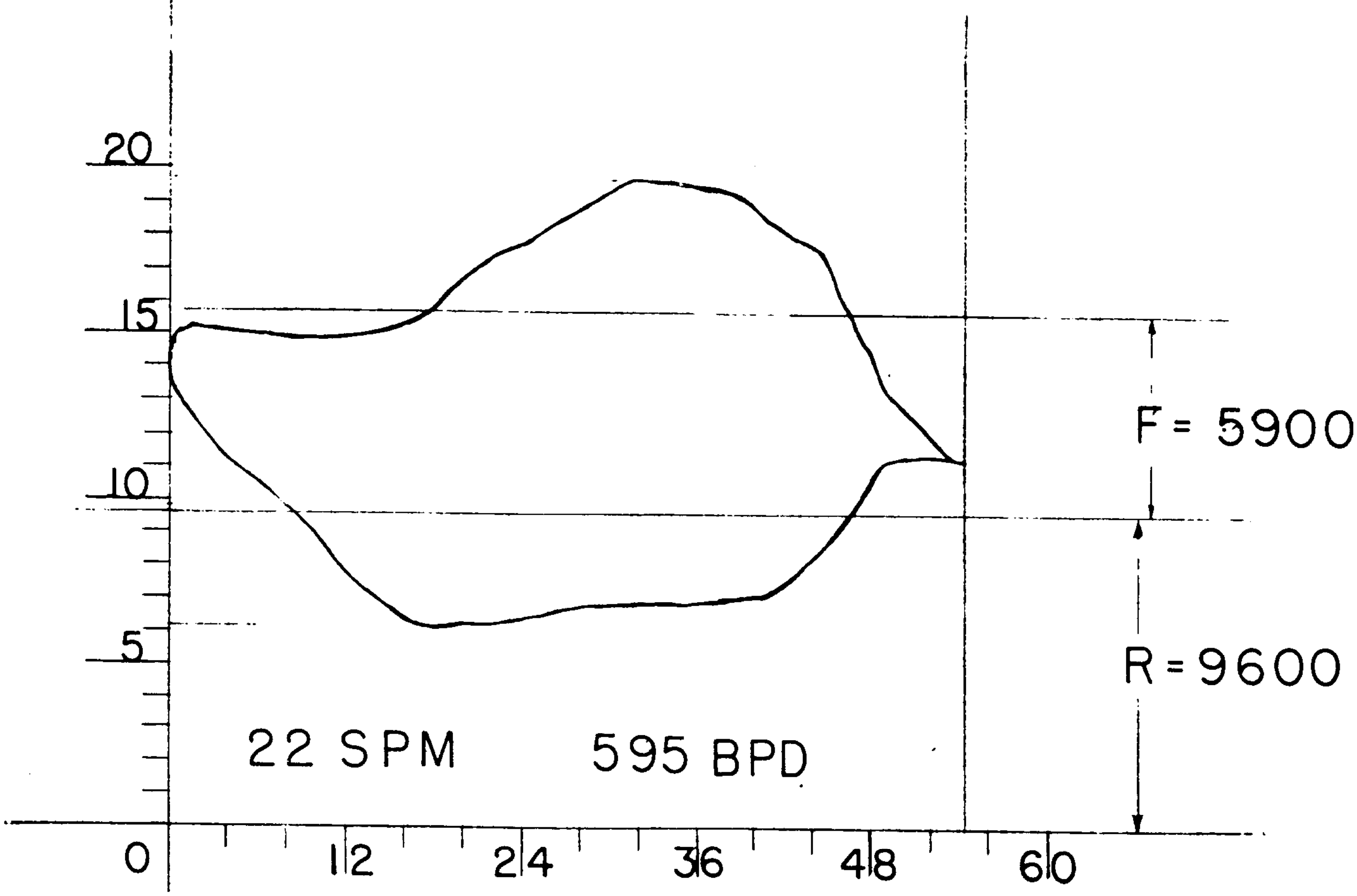
DEPTH 4775 FT





Sucker Rods, Cont'd—

Again one need not be an expert to recognize the vast improvement of the second graph over the first.

The production was increased from 515 BPD to 595 BPD of total fluid. With the exception of one occasion when the rods unscrewed, no further trouble was encountered for the ensuing six months, at which time we had ceased to make inquiry. If further trouble had occured, it is most likely that we would have been notified. These changes were made about 2 1/2 years ago. Later on, other wells in the same field were altered in like manner.

It is hoped that the example shown above may be of some value in recognizing the wisdom of giving careful thought to selecting equipment and method of operation in oil well pumping and when a well becomes troublesome it is wise to call for technical help in solving the problems. Fortunately, more and more operators are making use of the dynamometer to search out trouble and thus more and more men become familiar with its use and the interpretation of the dynagraph.

Sucker rod pumping is indeed a difficult and fascinating problem. None-the-less, it is the most efficient and satisfactory method of producing oil wells yet devised when such production falls within the capacity of sucker rods.