JET FREE PUMP
A PROGRESS REPORT ON TWO YEARS OF FIELD PERFORMANCE

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INTRODUCTION

From September 1970 to May 1971, prototype jet pumps were installed in five wells in California, West Texas and New Mexico. These five wells were selected to give a wide variation in operating conditions and were used primarily for correlating actual field data with laboratory data and with computer calculated operating charts. During this nine-month period, the cavitation zone of the operating charts was defined and various materials were tested for the nozzle and for the throat of the pump. Three of the test wells used water and two used oil for the power fluid. Depths ranged from 1900 ft to 9500 ft and production ranged from 80 BFPD to 1000 BFPD. In May of 1971, after the jet pump was established as a viable deep well pump, it was formally announced and introduced at the International Petroleum Exposition in Tulsa. By November 1972, 18 months later, approximately 125 jet pumps were operating in the U.S. and abroad.

In addition to these 125, another 50 had been installed and later removed—removed because of pumped-off conditions, insufficient surface horsepower, too much gas being produced through the pump or abandonment of the wells. All of these 50 pumps were installed in wells already pumping with hydraulic piston pumps, and as might be expected, most of these piston pumps were the ones experiencing the highest operating expense. But because the jet pump can be made to fit any "Free Pump" bottom-hole assembly and because the surface power was already installed, these were convenient wells for operators wishing to try the jet pump. Many of the 125 operating jet pumps were also installed in wells already equipped with hydraulic piston pumps, and they have survived because they have reduced repair costs. Obviously, the jet pump is the simplest pump made for oil wells and its design allows it to tolerate poor quality power fluid, corrosive well fluids and free gas—conditions that lead to high repair costs for positive displacement pumps.

Figure 1 shows the producing rates and setting depths of 100 jet pumps operating December 1, 1972. Approximately half of the dots on this chart represent wells in the Permian Basin and the cluster at 9300 ft are wells in Lea County, New Mexico. This chart illustrates the broad application of jet pumping—depths from 1550 ft to 14,750 ft and producing rates from

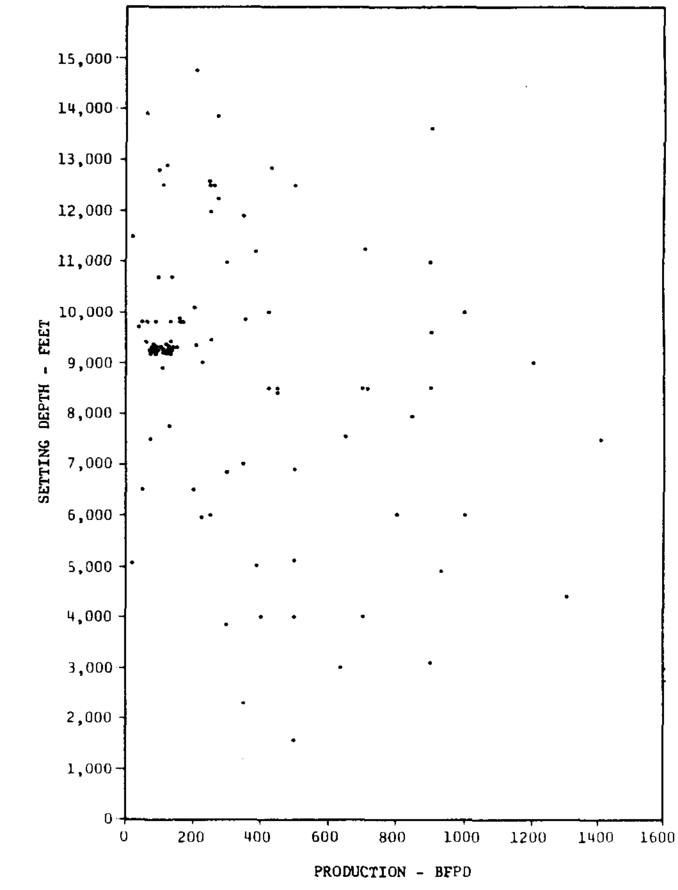

FIG. 1—JET PUMPS OPERATING IN DECEMBER, 1972

20 BPD to 1400 BPD. Two pumps not shown on the chart are set at 4500 ft and produce 2700 BPD and 3000 BPD.

In Fig. 2 the principal parts—nozzle, throat and diffuser—of the pump are shown. Power fluid (water or oil) at high pressure is supplied to the nozzle which converts the pressure head to a high velocity jet. Pumping action begins when the fluid in the production inlet chamber is entrained by the jet stream emerging from the nozzle. In the throat, the produced fluid acquires high velocity from the power fluid and in the diffuser this velocity head is reconverted to a pressure head—pressure sufficient to move the fluid to the surface.

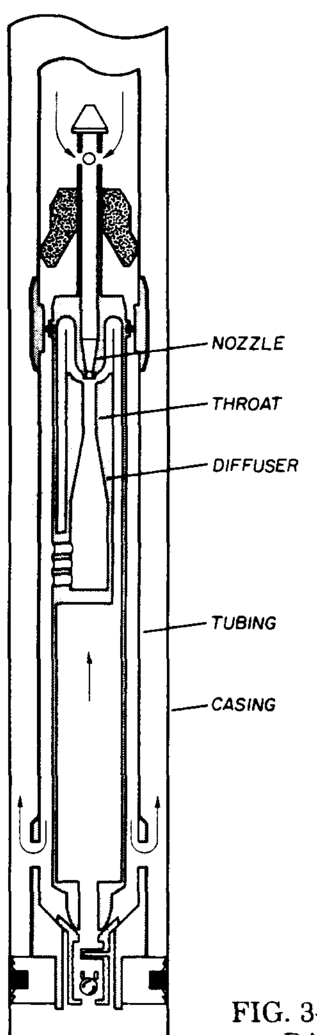

FIG. 2—JET FREE PUMP CASING TYPE

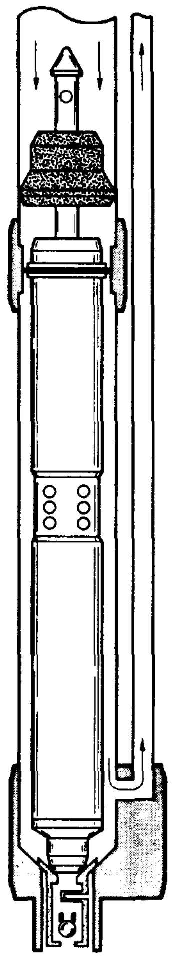

FIG. 3—JET FREE PUMP PARALLEL TYPE

The arrangement of one string of tubing set on a packer in the casing, as in Fig. 2, is called the casing free type system and is the most common type of system used. The parallel type of system shown in Fig. 3 can be used in wells with high gas/liquid ratios, to allow gas to vent through the casing instead of going through the pump.

PERFORMANCE DATA

The six questions most frequently asked concerning the jet pump are:

1. How often will the throat of the pump need replacing?
2. How often will the nozzle of the pump need replacing?
3. How does gas affect the pump?
4. Does the jetting action of the pump create oil and water emulsions?
5. What minimum working bottomhole pressure is required?
6. What is the efficiency of the jet pump?

From the data collected through Nov. 1972, the answers to these questions are:

(1) Approximately 53 throats (the most sensitive component of the pump) have been replaced due to wear, corrosion or cavitation. Approximately two-thirds of these were replaced due to cavitation in the first two months of operation and the pumps have been removed from these wells. The other one-third (approximately 18) were in pumps presently operating and it is not clear whether the failures were due to cavitation, corrosion or abrasion, but cavitation is suspected as the dominant factor—perhaps due to intervals of starved suction conditions. This leaves more than 100 pumps operating with the originally installed throats and many of these have been operating for over a year. Until the throats in a significant number of these 100 pumps have been replaced, a projected average life cannot be made, but present data implies an average life of greater than one year.

(2) Approximately 12 nozzles have required replacement in the 18-month period. Five of these were replaced after continued operation with a foreign particle (welding slag, gravel, etc.) lodged in the nozzle. The other seven were replaced after 8 to 12 months' operation and were judged to have been worn by abra-

sives in the power fluid. This small number of nozzle replacements indicates long life for this component also.

(3) Gas affects the jet pump in two ways. First, in the return column of fluid it reduces the back pressure on the pump; and second, a choking effect exists in the throat of the pump when large volumes of free gas are produced. Initially it was assumed that these two opposite effects would very nearly counterbalance each other but field experience proved that this assumption is not always valid. As the free gas entering the pump increases, due to high gas/liquid ratios or to lower pump intake pressures, the choking effect of the throat becomes the dominant factor. To account for gas, the original jet pump computer program was modified to include gas in the upstring column and through the throat of the pump. This modification has only recently been completed and it correlates very well with field history of high gas/liquid ratio wells. The solution for the choking effect is to use a larger throat or, if this is not possible, to install a parallel system as in Fig. 3 and vent the gas through the casing.

Operating charts for a 9000-ft well producing no water are shown in Figs. 4 and 5. Figure 4 is with no gas (or with a parallel installation) and Fig. 5 is with a GOR of 800 cu ft/bbl in a casing-type installation. The differences in these charts illustrate the necessity of having a computer-plotted operating chart for each and every well.

Gas has another effect, an effect that is not well-defined. Operating in the cavitation zone of the operating chart generally damages the throat beyond usefulness in a matter of a few days or even hours, but when free gas is present, the deterioration is apparently slowed down and in some cases the useful life of the throat is extended to several months.

Of the pumps presently operating in casing-type installations, approximately 10 are in wells with a gas/liquid ratio of 2000 cu ft/bbl or greater, 22 are in wells with a ratio between 1000 and 2000 and 91 are in wells with a ratio less than 1000.

(4) Approximately 175 jet pumps have been installed and there has not been a single report of oil/water emulsions being formed by the jetting action of the pump.

(5) The minimum working bottomhole pressure required is mostly a function of the pump setting depth, but fluid densities and gas are also factors. As a general rule, the pump discharge pressure (hydrostatic pressure plus flow-line back pressure plus friction in the return column) can be no greater than four to five times the pump intake pressure. In a parallel installation set at 10,000 ft and with the power fluid density equal to the production fluid density, this rule would require 2000-2500 ft of submergence, or a working fluid level of 7500-8000 ft from the surface. With 40° API oil this would be 700-900 psi pump intake pressure. The minimum pump intake pressure referred to here is the pressure required to keep the pump out of the cavitation zone, but as mentioned previously, operating in the cavitation zone might be tolerable with gas going through the pump.

(6) Looking at an operating chart it is apparent that the ratio of power fluid to production varies over a considerable range, so volumetric efficiency is not a meaningful term for the jet pump. Power output/power input is a valid measure of overall efficiency and this value can be calculated for any point on the operating chart.

$$\text{Horsepower input} = (P_1)(Q_1)(0.000017)$$

$$\text{Horsepower output} = (P_2 - P_3)(Q_3)(0.000017)$$

$$\text{Efficiency} = \frac{(P_2 - P_3)\ (Q_3)}{(P_1)\ (Q_1)}$$

Where:

P_1 = surface power fluid pressure
Q_1 = power fluid rate
P_2 = pump discharge pressure
P_3 = pump intake pressure
Q_3 = production rate

All quantities except P_2 are read directly from the chart. The computer program calculates a different P_2 for every point on the chart, taking into consideration the variation of gas, production, power fluid and friction. The most common definition of output horsepower, however, is in terms of "net lift of solid fluid." In other words, "net lift" (P_2 - P_3) is usually calculated using the pressure gradient of the produced oil and water only. With this definition, P_2 is simply the pump setting depth multiplied by the pressure gradient of the produced oil and water

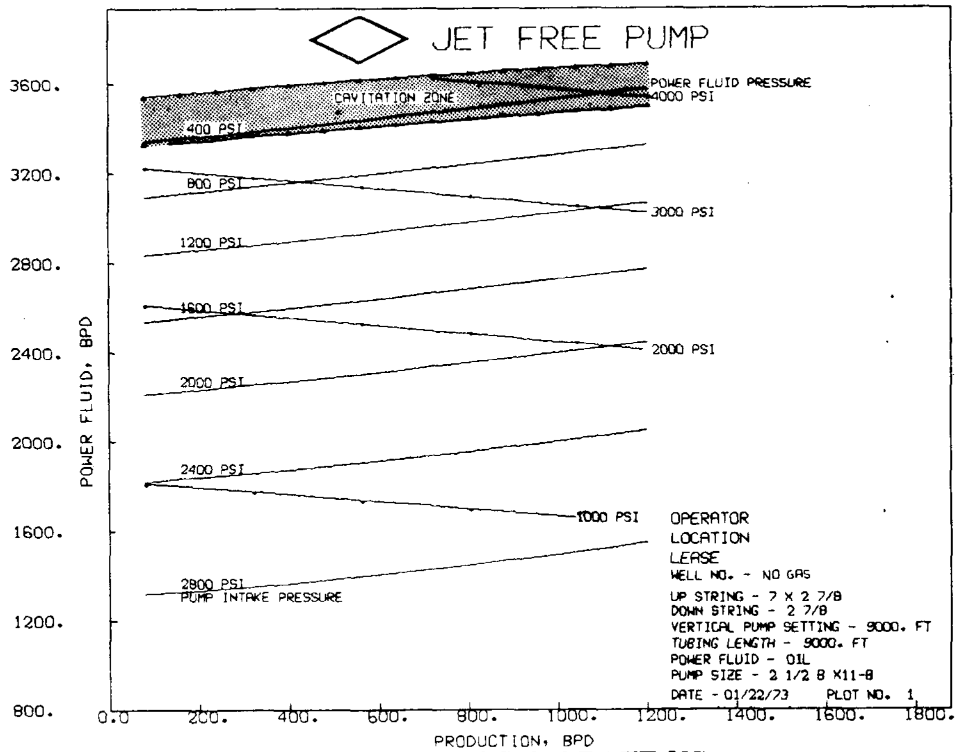

FIG. 4—PRODUCTION RATE VS POWER FLUID RATE COMPARING PUMP WITH POWER FLUID PRESSURE

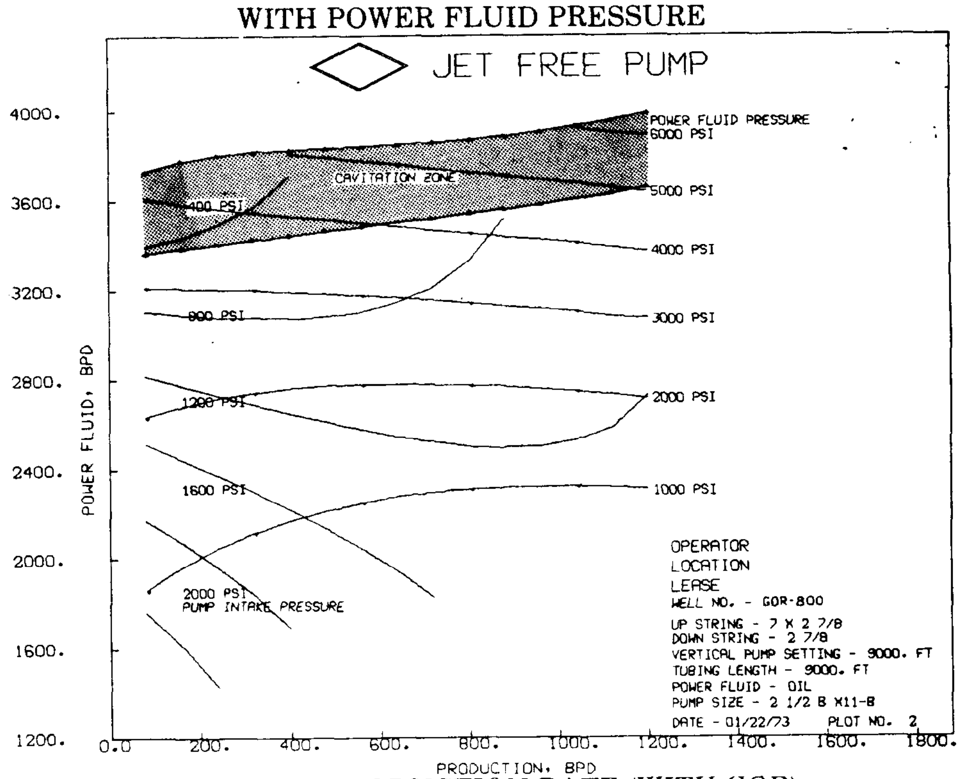

FIG. 5—PRODUCTION RATE (WITH GOR) VS POWER FLUID RATE COMPARING PUMP WITH POWER FLUID PRESSURE

plus, of course, the flow-line back pressure. For Figs. 4, 5 and 6, the production is 40° API oil (0.3574 psi/ft) and the flow-line back pressure is 75 psi—thus P_2 is 3290 psi.

In the upper left portion of an operating chart, the pump intake pressure and the efficiency are lowest and in the lower right portion these quantities are highest. The values vary from chart to chart also, so no general values can be assumed—a computer-generated chart must be used. To illustrate this variation, Table 1 lists the efficiencies for various points on the charts in Figs. 5 and 6.

The only difference between Fig. 4 and Fig. 5 is the gas/oil ratio, but in practice a smaller nozzle and throat would be used for the no-gas condition, and instead of Fig. 4 we would use the more efficient Fig. 6. The extreme range of efficiencies in Fig. 5 illustrates the complexities of the effects of gas on the jet pump.

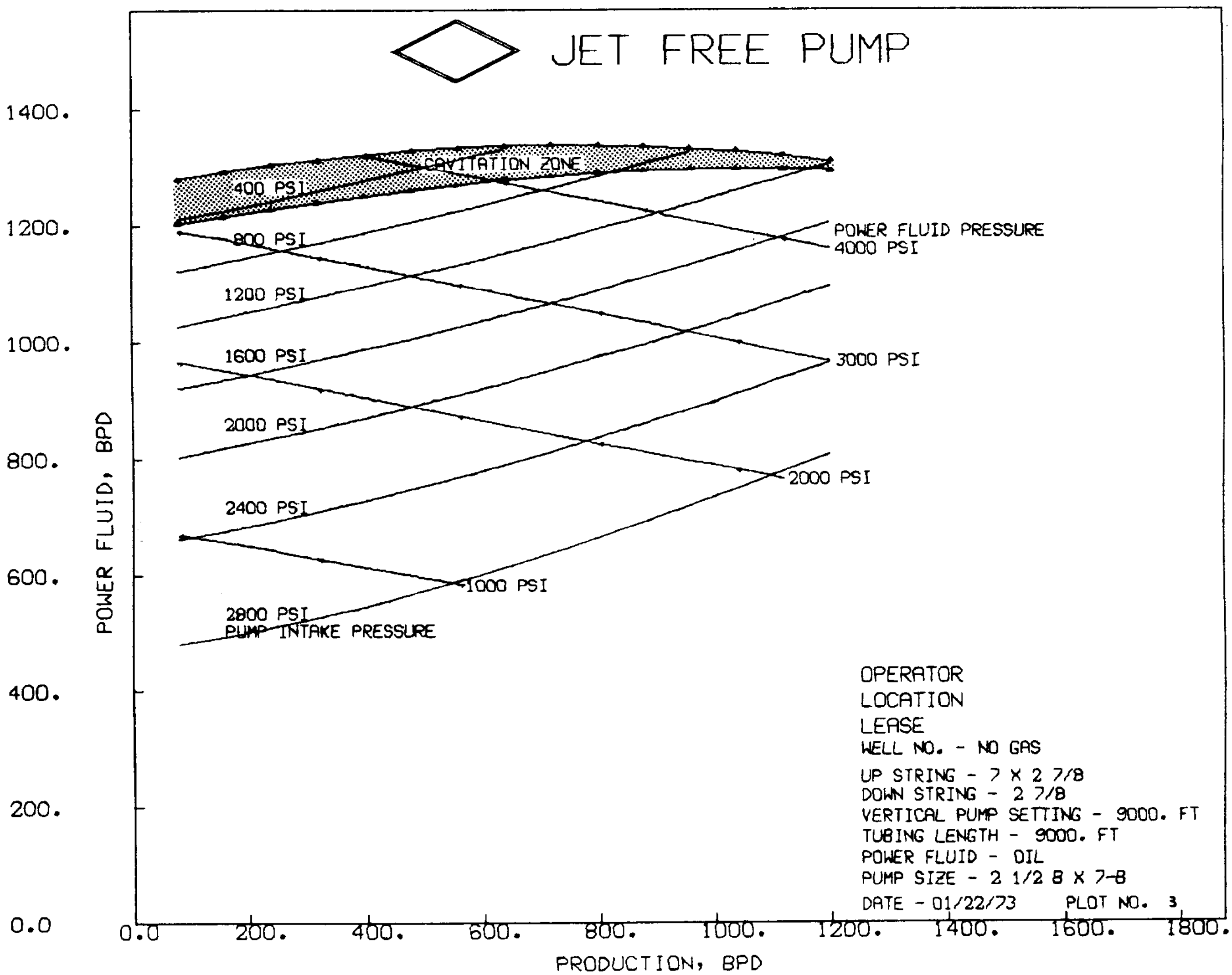

FIG. 6—PRODUCTION RATE VS POWER FLUID RATE COMPARING PUMP WITH POWER FLUID PRESSURE

TABLE 1

Production, BPD	Pump Intake Pressure, psi	Efficiency, percent	
		Fig. 5	Fig. 6
400	800	12	25
800	800	17	36
400	1200	18	27
800	1200	44	38
1000	1200	57	40

PUMP PERFORMANCE FACTORS

Other factors that can affect pump performance are corrosion, calcium deposition, sand, power fluid quality, high temperature, and viscosity.

Corrosion

Because the pump has no moving parts and no highly stressed parts, it can tolerate a certain amount of corrosion without affecting its performance. The nozzle and throat are made of corrosion-resistant tungsten carbide and the rest of the pump is available in stainless steel for highly corrosive wells. Corrosion inhibitors can be mixed with the power fluid to protect the entire tubing string. In other words, corrosive wells can probably be handled by the jet pump better than by any other means. Eight stainless steel pumps are presently operating trouble-free in highly corrosive wells.

Calcium Deposition

Calcium deposits have been troublesome for the jet pump in two or three wells and in these wells they have been replaced with hydraulic piston pumps. Other wells with a history of calcium have not been troublesome for the jet. So the history on this subject is inconclusive.

Sand

Sand is produced by only three or four jet pumps but these are trouble-free. It is expected that the jet pump can tolerate sand better than any other type of pump.

Power Fluid Quality

Because it has no sliding parts, the jet pump can tolerate poorer quality power fluid than hydraulic piston pumps. In fact it can tolerate any fluid that the surface pump can tolerate.

High Temperature

The effect of extreme temperature on the vapor pressure of the liquid affects the cavitation zone of the operating chart, but otherwise the jet pump is unaffected by temperature extremes.

Viscosity

The effects of viscosity are included in the computer program that generates the operating charts, so the effects are predictable. Unfortunately, no wells producing highly viscous oils have been submitted for appraisal.

CONCLUSIONS

The two years of jet pump field experience have shown that the performance of this new method of deep well pumping is superior in all respects except two: overall power efficiency and pump intake pressure requirements. Although the efficiency is somewhat low at low intake pressures, in most cases it is acceptable, especially in view of the low maintenance and repair costs. The requirement of 20-25% submergence, or pump intake pressure, in these days of no proration, appears restrictive but the following facts should be considered:

1. To pull the bottomhole pressure down to this value with a continuous gas lift installation would require enough gas to lighten the column density to approximately 0.08 psi/ft—a feat not often accomplished.
2. Other pumps producing through a packer frequently do not draw the pump intake pressure lower than this because of the gas that is liberated and must be handled by the pump.
3. In wells with the gas vented through the casing, gas and oil frequently form a foam in the casing, thus preventing any type of pump from lowering the pump intake pressure to near zero.
4. Vogel's curve for Inflow Performance Relationships, Fig. 7, shows that drawing the bottomhole pressure down to 40% of the reservoir pressure produces the well at 80% of its maximum rate. The maximum rate can be obtained only when the

producing bottomhole pressure is zero—a formidable goal for any pump in a deep well. Operating costs, with any type of artificial lift system, go up as the maximum theoretical producing rate is approached and sometimes those last few barrels of oil cost more to produce than their value in the tank. (Please note that 40% on the curve refers to percent of the reservoir pressure and not to percent of full column load. Twenty percent submergence for the jet pump might be lower or higher than this value, depending on reservoir pressure.)

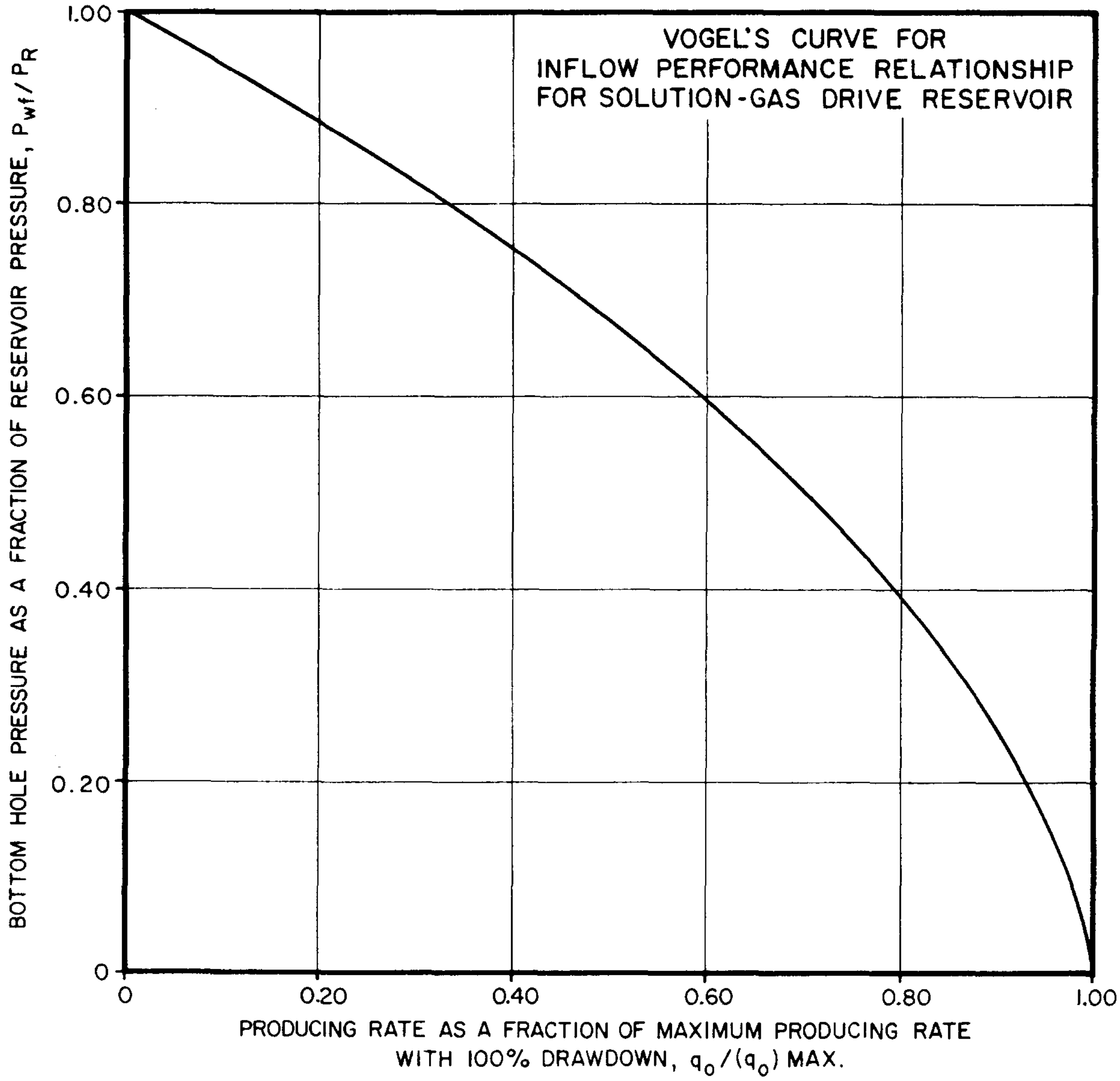

FIG. 7—VOGEL'S CURVE FOR INFLOW PERFORMANCE RELATIONSHIP FOR SOLUTION - GAS DRIVE RESERVOIR

Vogel, J.V.:Inflow Performance Relationships for Solution Gas Drive Wells, SPE 1476, a paper presented at the 41st Annual Fall Meeting of the Society of Petroleum Engineers of AIME, Dallas, Texas, October 2-5, 1966, and later published in Trans. SPE of AIME, Volume 243, 1968.