THE JET FREE PUMP - PROPER APPLICATION THROUGH COMPUTER CALCULATED OPERATING CHARTS

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INTRODUCTION

Extensive Jet Pump field operating experience has shown that the Jet Pump is a viable method of deep well pumping. Properly applying this pump to a given well installation involves 14 factors relating to the well and its production characteristics, and involves determining the optimum pump nozzle and throat size required to do the most effective job.

Since many of the production characteristics of a well are interdependent, many reiterative calculations are required to determine the proper nozzle and throat size for each producing condition. The computer is the only practical method for using the producing conditions to make the many calculations that are required to generate an accurate and easily understood Jet Pump Operating Chart. This paper shows the factors involved and their effect upon Jet Pump operation.

JET PUMP OPERATING PRINCIPLE

A jet pump consists of three principal parts — the nozzle, the throat, and the diffuser — as shown in Fig. 1. The arrows show the flow of fluids through the pump. Power fluid (oil or water) at high pressure is conducted to the pump by the pump tubing string. The power fluid then enters the pump nozzle and is converted from a high pressure head to a high-velocity head jet. The "pumping action" occurs when the well fluids entering the production inlet chamber are entrained in the high-velocity jet stream emerging from the nozzle and the combined fluids are carried into the throat. In the throat, the momentum of the power fluid jet is transferred to the produced fluids and the combined fluids enter the diffuser. As the combined fluids pass through the diffuser, their high velocity is reconverted into a high pressure head which is sufficient to move the fluids to the surface. This "pumping action" is shown graphically in Fig. 2.

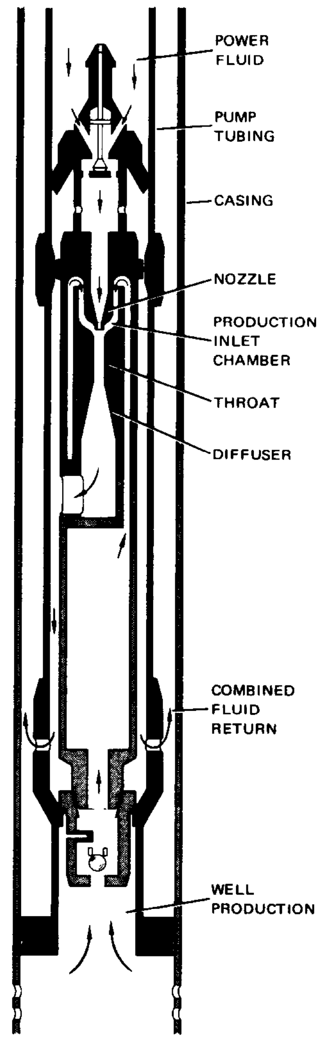

FIG. 1—JET FREE PUMP, CASING TYPE

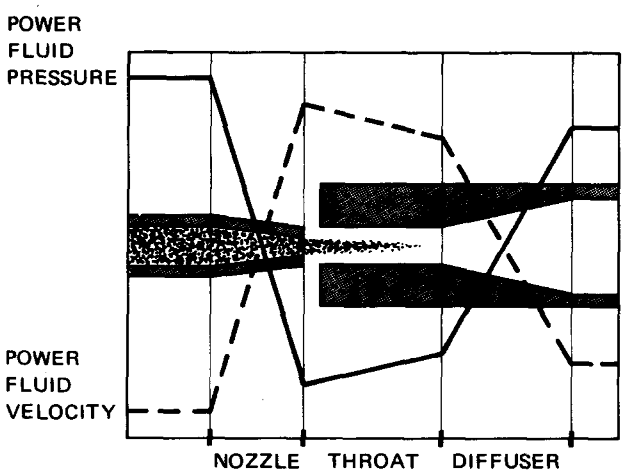

FIG. 2

The tubing arrangement, shown in Fig. 1, is called a casing-type free pump installation, and is the most common type of tubing system used. With the pump tubing string set on a packer, the tubing-casing annulus is used to conduct the combined power and produced fluids back to the surface.

The parallel-type free pump system, shown in Fig. 3, can be used in wells with a high gas-liquid ratio (GLR). This allows the gas to vent up through the casing instead of having to be produced by the jet pump, as it is in the casing-type installation.

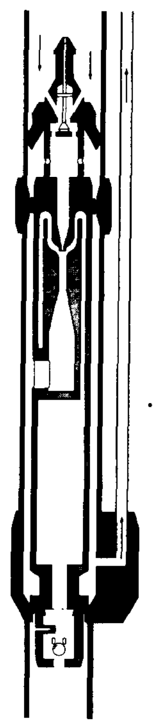

FIG. 3—JET FREE PUMP, PARALLEL TYPE

JET PUMP SIZES

Since the jet pump is not a positive displacement type pump, but rather a special class of the kinetic-type pumps, it must be applied to well installations following the rules that govern the performance of this type of pump. Proper pump performance depends upon knowing all of the system factors and fluid properties and then selecting the pump size that best fits these requirements.

Selecting the proper size pump really means selecting the proper size nozzle and throat. The number of possible sizes and combinations of nozzles and throats is infinite. For practical reasons, a discrete area ratio and geometric matrix of nozzles and throats were selected, resulting in 15 standard nozzle sizes and 5 standard throat sizes for each nozzle. This means there are 75 combinations, or pump sizes, to choose from when making a well application.

Jet pump* sizes are designated in the following manner:

Pump Size – 2-1/2 B x 11 A

1. The first number (2-1/2) is the nominal pump size and corresponds to the nominal API tubing size the jet free type pump can be run in. This can be 2 in., 2-1/2 in., 3 in. or 4 in.
2. The first letter (B) is the jet pump design type and can be either Type A or Type B. Type A is the standard design, which has the well fluids from the pump suction, ported internally within the pump. This limits the nozzle and throat size that can be used compared to the Type B design, which ports the pump suction externally through the bottomhole assembly. For a given nominal pump size, the Type B jet pump can use nozzles and throats two sizes larger than can be used in the Type A pump, making the Type B jet pump capable of higher production rates. The Type B jet pump can be operated only in a Type B bottomhole assembly, but the Type A jet pump can be operated in almost any hydraulic pump bottomhole assembly.
3. The second number (11) is the nozzle size. The nozzle numbers range from 1 to 15, with Number 1 being the smallest diameter.
4. The second letter (A) designates the ratio, or throat size, and there are 5 sizes available for each nozzle size. These throat sizes are designated by the letters A through E, with A

*Kobe specifications

being the smallest diameter throat and E the largest diameter throat that can be used with a given nozzle size.

JET PUMP OPERATING CHARTS

Jet pump performance in an actual well installation depends upon knowing the well's mechanical completion data, production characteristics, and well fluid properties, and then selecting the proper pump size to operate efficiently under these conditions. Equations for describing the effects of viscosity, fluid friction, multiphase flow, GOR, etc. are available and fully verified from many field applications. These can be found in technical papers by Standing[1], Beal[2], Brown and Coberly[3], and Brown[4]. Utilizing these and other equations which adequately describe the dynamics of oil well production, and the appropriate equations that describe jet pump performance, the computer calculates solutions that satisfy all these equations and provides an output that gives the pertinent pump operating information. The computer processing that is required is shown pictorially in Fig. 4.

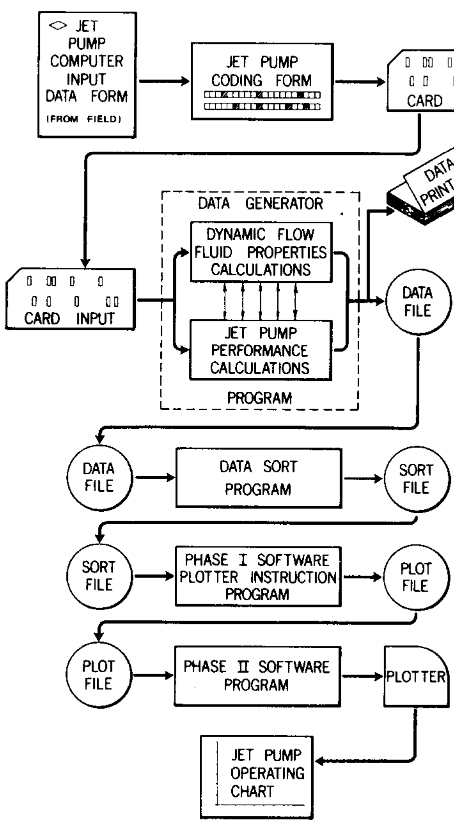

FIG. 4

Rather than using a tabulated data printout from the computer, it was found more useful to have the computer plot this information in the form of a jet pump operating chart as shown in Fig. 5. This chart is for a 2-1/2B x 11A jet pump in a specific well as described by the input data used. The input data used for this chart is given in Table 1.

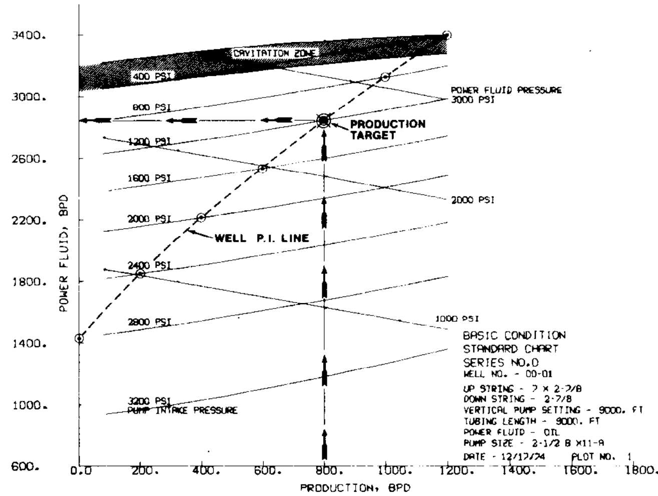

FIG. 5—JET FREE PUMP

TABLE 1

	WELL INFORMATION	BASE VALUE
1.	Max. Pump Vertical Setting Depth-------FT	9000
2.	Tubing Length (If Directional)---------FT	9000
3.	Well Head Temperature------------------°F	100
4.	Bottom Hole Temperature----------------°F	120
5.	Flow Line Back Pressure----------------PSI	50
6.	Separator Pressure---------------------PSI	50
7.	Pump Tubing Size (Nom.)----------------IN.	2-1/2
8.	Return Tubing Size (Nom.)--------------IN.	7 x 2-1/2
9.	Type of Bottom Hole Assembly-----------NOM.	2-1/2B CSG OPF
10.	Power Oil Gravity----------------------°API	30
11.	Power Water Gravity--------------------SP. GR.	1.0
12.	Total Produced Fluid-------------------B/D	800
13.	Production Water Cut-------------------%	0
14.	Gas Oil Ratio--------------------------SCF/STBO	0
15.	Well Productivity Index----------------(B/D)/PSI	0.5
16.	Produced Oil Gravity-------------------°API	30
17.	Produced Water Gravity-----------------SP. GR.	1.0
18.	Produced Gas Gravity-------------------SP. GR.	0.7
19.	Static Bottom Hole Pressure------------PSI	2800
20.	Pump Intake Pressure (@ 800 B/D)-------PSI	1200

Most of the jet pump operating chart is self explanatory. The vertical scale is the power fluid rate (BPD) required to operate the pump at a given production rate. The horizontal scale is the pump production rate (BPD) for any given operating point along the well's P.I. line, which is shown plotted on the chart. Using the data from Table 1, the desired production rate is 800 BPD at 1200 psi pump intake pressure. This "production target" is shown on the chart and it corresponds with 800 BPD on the horizontal production rate scale and the 1200 psi pump intake pressure line on the chart. The pump power fluid rate required for this production rate can be found by moving horizontally to the left from the production target, and reading the value found on the power fluid scale, giving 2840 BPD. The power fluid pressure required to operate the pump can be found by interpolating between the 2000 and 3000 psi power fluid pressure lines on the chart, giving 2540 psi. Having found the power fluid pressure and flow rate, the input hydraulic horsepower can be calculated:

$$2540 \text{ psi} \times 2840 \text{ BPD} \times 1.7 \times 10^{-5} = 123 \text{ Hp}$$

Any point along the P.I. line is a pump operating condition for the well, and for each point the production rate, pump intake pressure, power fluid pressure and power fluid rate can be read. In actual operation the production rate of the pump is controlled by controlling the amount of power fluid being supplied to the pump.

If enough power fluid is supplied to the pump, its operating point will move up the P.I. line until it is finally operating in the cavitation zone. Once the lower cavitation line has been crossed, cavitation is taking place in the pump throat, and damage to the throat will result. If the pump is operated so that the upper cavitation line is reached, then complete cavitation occurs and no additional production flow can be attained. Any time a jet pump is operated in the cavitation zone, throat damage due to cavitation occurs, and pump performance will decline with time.

JET PUMP PERFORMANCE

If jet pump performance data (power fluid rate and for each production rate) is plotted on the jet pump operating chart, the data will plot along the well's P.I. line with good accuracy. If the pump performance data does not correspond with the P.I. line on the chart, generally it is found to be the result of inaccurate computer input data being provided for plotting the chart. The importance of obtaining accurate well, production and fluid properties information, corresponding to the data listed in Table 1, cannot be stressed enough. By changing the value of just one of the factors in Table 1, the performance of the pump can be altered significantly, and this effect can be seen by the change it makes in the input hydraulic horsepower required. The input horsepower required by a jet pump is a direct measure of its performance, or efficiency, and, therefore, is a good indicator to use for comparison of jet pump performance.

EFFECT OF SINGLE-VARIABLE CHANGES

The easiest way to show the effect of the different factors listed in Table 1 is to change the value of just one of them at a time and then compare the jet pump performance with the base condition, using the change in input hydraulic horsepower as an indication of the magnitude of the effect. The pump size (2-1/2B x 11A) is held constant for all of the following examples.

The first factors changed from the base condition values directly affect the amount of back pressure against which the pump must operate. This may result in either an increase, or a decrease, in the input hydraulic horsepower required, as shown in Fig. 6.

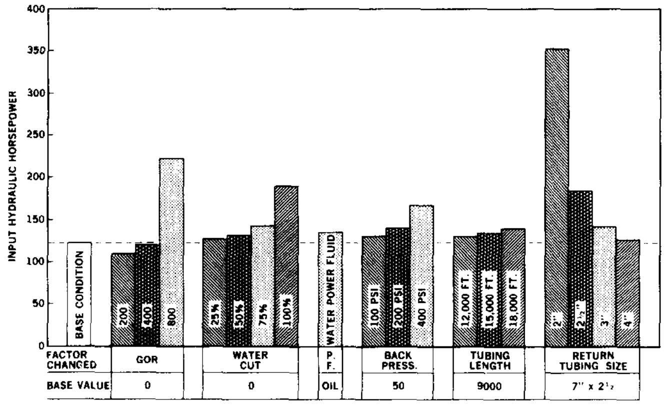

FIG. 6—INPUT HYDRAULIC H.P. FOR TARGET PRODUCTION — 2-1/2Bx11A PUMP

Any given change in pump discharge pressure results in a multiplied change in the pump operating pressure, or power fluid pressure. The multiplier is a function of the nozzle to throat area ratio, and is approximately equal to 2 for an "A" ratio. The multiplier increases with increased throat size.

The effects of the single-variable changes made are discussed below.

Gas Oil Ratio

The base condition, as shown in Table 1, was for a zero GOR and required 123 Hp. When the production GOR is changed to 200 (SCF/STBO), the input hydraulic horsepower required decreases to 109 Hp. This decreased horsepower requirement is due to the "gas lift" effect of the produced gas in the return column, resulting in a lighter return column gradient and less back pressure against the pump discharge.

It would appear, then, that the more gas a jet pump produces the less horsepower will be required to operate it. But, referring to Fig. 6, when the GOR is increased from 200 to 400, the horsepower requirement increases, but is still less than the base condition; but if it is increased from 400 to 800 GOR, the horsepower requirement increases dramatically to 222 Hp. What has happened is that the amount of gas that the pump must produce has increased to the point that it is choking the inlet to the throat, resulting in an increased horsepower requirement. This increase more than offsets the decreased horsepower requirement gained by the gas lift effect in the return column. This choking effect can be reduced by using a larger throat size. This will be shown later.

Production Water-Cut

The base condition has a zero water-cut so that, as the water-cut is increased in 25% increments (as shown in Fig. 6), the return column gradient increases, increasing back pressure on the pump discharge. Again, the change in pump discharge pressure has a dramatic effect on the input hydraulic horsepower.

Water Power Fluid

Changing from oil to water for power fluid increases the power fluid column weight at least as much as it increases the return column weight, which would seem to result in a lower horsepower requirement. But, since the return column weight has a 2 to 3, or more, multiplying effect on the input pressure, input horsepower requirements are usually greater for power water than for power oil. This would normally be the case, unless the power oil used was very viscous and resulted in very high tubing friction losses. Figure 6 shows 10% more horsepower required for power water than for power oil.

Flow Line Back Pressure

This is one factor over which the operator has some direct control and can result in direct input horsepower savings. As shown in Fig. 6, if the flow line back pressure is increased from 50 psi (base condition) to 100 psi, the input hydraulic Hp increases from 123-129 Hp. If this same pump were producing against a 200 psi flow line back pressure, it would require 141 Hp, or nearly a 15% increase. This effect is greatly increased if gas is present in the production, as will be shown later.

Tubing Length

This shows the effect that would be experienced in a directionally drilled well, where the vertical pump setting depth is the same as the base condition (9000 ft), but the total tubing length is greater, resulting in increased fluid friction losses.

Return Tubing Size

As has been stressed, since the jet pump is sensitive to pump discharge pressure, selecting an adequate size return tubing string to minimize fluid friction is extremely important.

Figure 6 shows the change in input horsepower for different return tubing strings. The base condition has the 7 in x 2-7/8 in. casing-tubing annulus for return fluids. The 4-in. return tubing string results in almost the same horsepower requirement.

EFFECT OF TWO-VARIABLE CHANGES

When only one factor is changed from the base condition, the resulting effect on input horsepower can be seen and is probably what would be expected, except for the choking effect experienced with the higher GOR's. But, if several factors are changed at one time, the interrelationship of the changes may not be as easily predicted.

Figure 7 shows the results of changing two factors at a time from the base condition. The horsepower required for each factor is shown separately and then the horsepower required for the combined change is shown. In the first two examples, the horsepower required for the combined change is greater than for either factor changed individually; but in the third example, the combined horsepower requirement is less than one of the single factors and nearly equal to the smaller horsepower requirement.

Water Power Fluid and Gas-Oil Ratio

In this first example, the higher horsepower requirement of the combined changes results from the continued choking effect on the throat due to the GOR (800); and the use of water power fluid adds to this by increasing the return column gradient, together with reducing the amount of gas breakout in the return column. Both of these changes result in increased back pressure on the pump discharge, requiring 303 input hydraulic Hp.

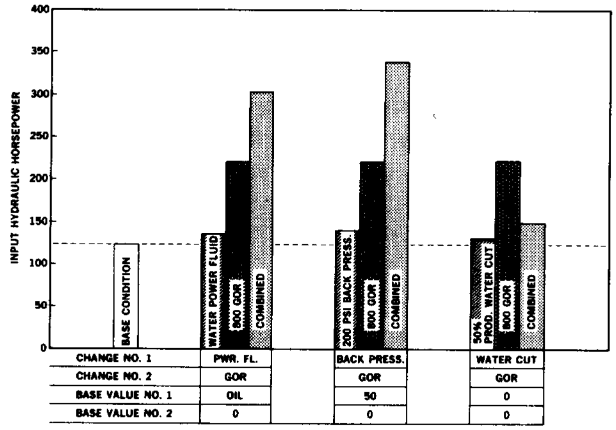

FIG. 7—TWO FACTORS CHANGED INPUT HYDR. H.P. FOR TARGET PRODUCTION — 2-1/2Bx11A PUMP

Flow Line Back Pressure and Gas-Oil Ratio

In the second example, the GOR effect is the same as in the first example, and the increased flow line back pressure has a slightly greater effect than the water power fluid on the return column gradient, requiring 15 added horsepower instead of 12. The combination, on the other hand, adds 215 Hp. As stated previously, the effect of increased back pressure is multiplied when gas is present in the production.

Production Water-Cut and Gas-Oil Ratio

In the third example, since the production has a 50% water-cut, the GLR for the production is one half the GOR, or 400 GLR. This GLR, as seen in Fig. 6 (400 GOR), does not result in the high choking effect that is experienced at 800 GOR. This means that the production water-cut is actually the predominant factor. The combined horsepower required (151 Hp), is greater than with just the water-cut alone (132 Hp), because the choking effect on the throat from the 400 GLR and the increased gradient due to the water-cut more than offset the "gas lift" effect obtained in the return column.

OTHER VARIABLE CHANGES

Some single-factor changes, and some multiple-factor changes, that affect jet pump performance have been discussed, but many more could be considered. Each has an effect on the size pump to be used and the hydraulic horsepower required. Figure 8 shows the effect of changing other factors, one at a time. In all of the examples covered so far, we have used the same nozzle and throat size in the pump. Some of the changes illustrated could have been partially offset by nozzle and throat size changes, as is discussed next.

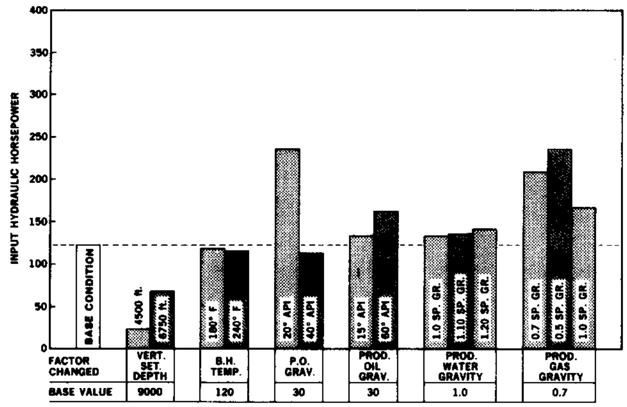

FIG. 8—INPUT HYDRAULIC H.P. FOR TARGET PRODUCTION 2-1/2Bx11A PUMP

JET PUMP NOZZLE AND THROAT RATIOS

As was discussed earlier, a pressure multiplier exists between the pump discharge pressure and operating pressure. The value of this multiplier increases as the throat size, or ratio, increases from "A" to "E". This multiplier is very similar to the pump to engine area ratio (P/E Ratio) of a positive displacement hydraulic pump. The size "A" jet pump throat would be comparable to a small diameter pump piston, while the size "E" throat would be the equivalent of the largest pump piston available. Therefore, an "E" ratio will require more operating pressure than an "A" ratio for a given net lift, but the "E" ratio will also require less power fluid than the "A" ratio for a given production flow rate. This comparison is made assuming that both ratios are sized for maximum operating efficiency.

The maximum efficiencies of the various ratios are very close to the same value; therefore, the horsepower required will be the same. The smaller ratios ("A" and "B") are most commonly used in deep wells to keep the pump operating pressure within the pressure limits of the surface power equipment. The larger ratios (C, D and E) are normally used in low net lift applications where the operating pressure requirement is considerably below the surface equipment pressure limitations, and it is desirable to minimize the power fluid flow rate required.

Another aspect of the reason for changing ratios in a jet pump is the choking effect that the smaller throat sizes (A and B) experience at increased GLR's. As mentioned before this choking can be reduced by using a larger throat size. This effect is shown in Fig. 9. For zero to 400 GOR, the "A" ratio throat has the lowest input horsepower requirement, but at 800 GOR, the "B" ratio throat is more efficient (lower Hp required). As the GLR continues to increase, it is apparent from Fig. 9 that larger ratio throats become more efficient.

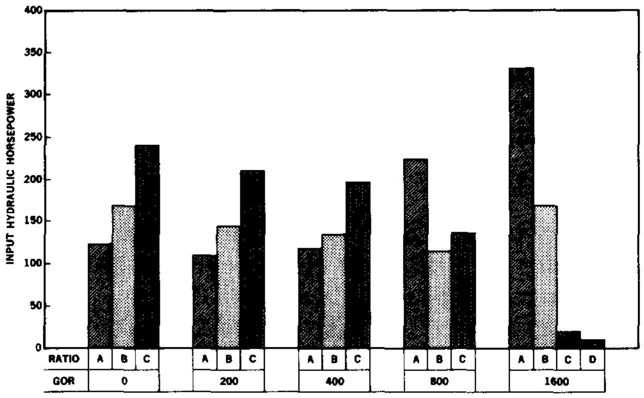

FIG. 9—EFFECT OF NOZZLE-THROAT RATIO WITH CHANGING GOR — 2-1/2Bx11( ) PUMP

JET PUMP OPERATING CHARTS FOR DIFFERENT CONDITIONS

From the well production and jet pump parameters that have been considered, it can be seen that all of the factors listed in Table 1 must be included in the calculations when sizing a jet pump to a well, and when plotting a jet pump operating chart. The chart allows the operator to know just what the pump will do in his particular well over the full range of operating conditions by simply plotting the well's P.I. line on the operating chart. This can be done easily using the pump intake pressure lines and plotting the corresponding production for each intake pressure. This is shown for the base condition (data given in Table 1) in Fig. 10. Figure 11 shows the same data except for 800 GOR. The effect of the GOR on pump performance at a given pump intake pressure can readily be seen by comparing these two operating charts.

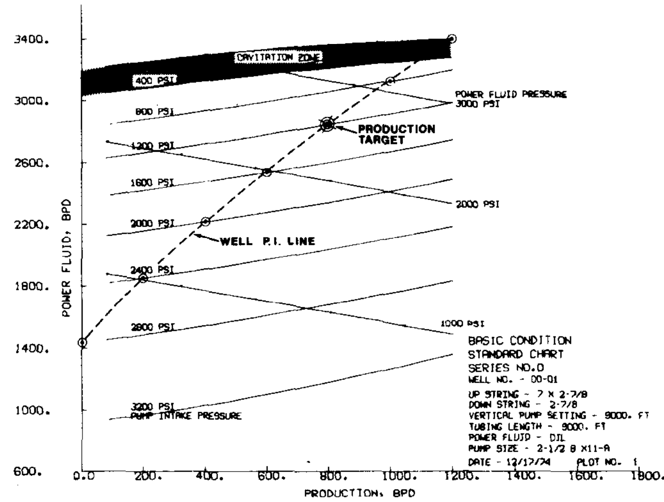

FIG. 10—JET FREE PUMP

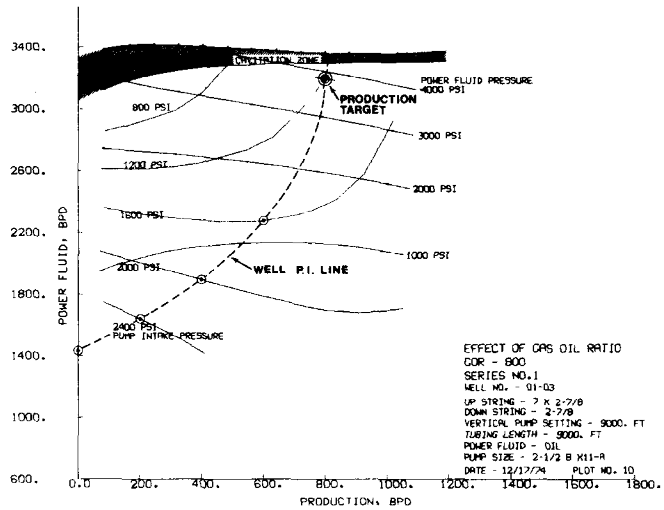

FIG. 11—JET FREE PUMP

PRACTICAL EFFECTS OF INPUT FACTOR CHANGES

We have looked at the effect of single and multiple variable changes on jet pump performance, letting the change in input hydraulic horsepower be an indication of the magnitude of the effect. The practical aspect of this investigation is what it can actually mean in terms of field operating problems. From a field-operating standpoint, a change in a factor usually means that a value is given for the factor when providing the jet pump input data for the installation, and then it is found that in actual operation, the factor value is not correct.

As an example of the results obtained in field operation when there is incorrect jet pump input data, assume that the input data provided for a well installation is the same as given in Table 1, except for the GOR. Assume that the GOR was reported to be 800 on the input data form, when actually it was only 400. Referring to Fig. 9 for 800 GOR, the "B" ratio pump would be the logical choice since it requires the least horsepower (114 Hp) to obtain the target production. But, if this pump were installed and the well only has 400 GOR, the "B" ratio pump would require 136 Hp to obtain the desired production (Fig. 9 for 400 GOR) and the performance data would not agree with the operating chart.

If a 125 Hp surface power unit had been installed, assuming that only 114 Hp would be required to produce the well, then the target production (800 BPD) could not be obtained. Once it is determined that the reason for the discrepancy is the lower GOR value, the problem can be corrected by changing the jet pump throat to an "A" ratio. As shown in Fig. 9, this pump ratio would require 119 Hp to obtain the desired production. This is only 5 Hp higher than originally expected, and within the surface power unit capabilities.

Numerous other examples could be given which would show the difference between the expected pump performance and the actual performance obtained in field operation, but these comparisons should be apparent when looking at the effects of the different factor changes shown in Figs. 6 through 9.

SUMMARY

Nearly all of the factors concerned with a well's mechanical completion, production fluid properties and producing characteristics, influence the efficiency of the artificial lift equipment used to produce the well. By knowing these factors and using them to properly select and size the equipment to all of the well conditions that will be encountered results in optimum equipment efficiency.

When the jet pump is applied to a well installation, a computer is used to include all of these well factors and their interrelationship with the jet pump performance. As result of these calculations, the computer provides a plot of the pump performance under well conditions. This jet pump operating chart provides the field operator with complete information for pump performance over the full range of operating conditions in his well.

The jet pump operating chart accuracy is a direct function of the accuracy of the computer input data used. Accurate and complete data for the well application concerned is essential to insure correlation between jet pump performance and the operating chart. When this correlation exists, the jet pump operating chart becomes a profitable production tool.

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