Selection & Analysis of Hydraulic Production Systems

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INTRODUCTION

The selection of a proper application of hydraulic pumping for any set of conditions is only as accurate as the information available. The adaptability of hydraulic pumping, however, minimizes any unusual expense by wrong assumption or incorrect information. This paper will handle two phases of hydraulic pumping: the selection of size and type of installation and the analysis of various operating characteristics.

SELECTION OF SIZE AND TYPE OF INSTALLATION

Very seldom is all the desired information available on a lease and well when designing an installation; however, if obtainable the following is useful:

1. Lease:

   a. Number of wells (present and future)
   b. Terrain (Mountainous, swampy, water, etc.)
   c. Treating system and tank battery installed
   d. Type of power available

2. Well:

   a. Distance of well from tank battery
   b. Type of well (single zone, dual, etc.)
   c. Casing size (liner if present)
   d. Producing formation (or formations)
   e. Fluid to be produced:

      1) Total oil
      2) Total water
      3) Saturation pressure of oil
      4) Chemical properties of fluid (corrosive, chloride, etc.)
      5) Solids (sand, iron, sulfide, etc.)

   f. Well depth
   g. Static fluid level
   h. P. I. of well (Bbl per lb pressure drop)
   i. Gas to produce - (GOR)
   j. Paraffin

With the above information it is possible to approach the subject objectively. A single zone application presents fewer factors to be considered; however, even in a multiple zone well each zone must be handled separately. In effect, it only reduces the various types and pump sizes which may be selected. This paper will consider only one zone, and the restrictions imposed by the selection of tubing sizes possible.

SPECIFICATIONS OF KOBE PRODUCTION UNITS

Nominal Pump Size	Assembly Number: Conventional Unit	Assembly Number: Free Pump	Outside Diam.	Pump Length, In.	Approx. Wt., Lbs.	Shipping Wt., Lbs.	Stroke, In.	Piston Sizes: Engine	Piston Sizes: Pump	Area Ratios: E/P	Area Ratios: P/E	Rated Speed SPM	Pump Displacement at Rated Speed B/D	Displacement B/D per SPM: Engine End	Displacement B/D per SPM: Pump End	Max.* Setting Depth
2x13/16	1080-403	1080-409	1 7/8	78 1/2	42	80	12	1	13/16	1.83	.55	83	95	2.15	1.14	15,000
2x1	1080-003	1080-009	1 7/8	78 1/2	42	80	12	1	1	1.00	1.00	83	174	2.15	2.10	10,000
2x1 3/16	1080-503	1080-509	1 7/8	78 1/2	42	80	12	1	1 3/16	.63	1.55	83	270	2.15	3.25	6,300
2 1/2x1	1100-601	1100-609	2 5/16	105	85	147	18	1 3/8	1	1.92	.52	71	182	5.02	2.56	15,000
2 1/2x1 3/16	1100-401	1100-409	2 5/16	105	85	147	18	1 3/8	1 3/16	1.34	.75	71	261	5.02	3.67	13,400
2 1/2x1 3/8	1100-001	1100-009	2 5/16	105	85	147	18	1 3/8	1 3/8	1.00	1.00	71	349	5.02	4.92	10,000
2 1/2x1 11/16	1100-501	1100-509	2 5/16	105	85	147	18	1 3/8	1 11/16	.70	1.43	71	500	5.02	7.04	7,000
3x1 1/4	1120-601		2 13/16	136 1/2	168	256	24	1 5/8	1 1/4	1.69	.59	64	358	9.61	5.59	15,000
3x1 7/16	1120-401		2 13/16	136 1/2	168	256	24	1 5/8	1 7/16	1.27	.79	64	475	9.61	7.42	12,700
3x1 5/8	1120-001		2 13/16	136 1/2	168	256	24	1 5/8	1 5/8	1.00	1.00	64	604	9.61	9.44	10,000
3x1 15/16	1120-501		2 13/16	136 1/2	168	256	24	1 5/8	1 15/16	.68	1.48	64	896	9.61	14.0	6,800
4x1 5/8	1160-401		3 13/16	173	370	540	30	2	1 5/8	1.46	.69	57	822	21.44	14.4	14,600
4x2	1160-001		3 13/16	173	370	540	30	2	2	1.00	1.00	57	1,200	21.44	21.0	10,000
4x2 3/8	1160-501		3 13/16	173	370	540	30	2	2 3/8	.65	1.55	57	1,850	21.44	32.5	6,500

*Maximum setting depths are calculated on reasonable design factors, but may require modification for specific well conditions.

Fig. 1.

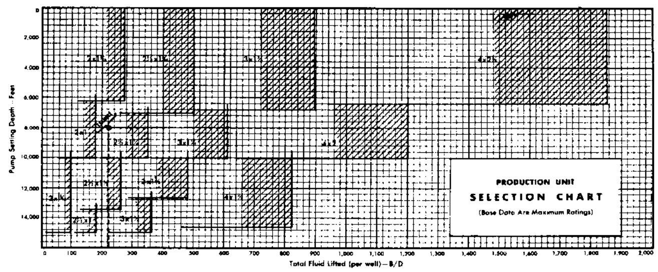


Fig. 2.

Pump Selection

The first step is the proper pump size selection which is dependent upon the volume to be produced, and the density of the fluid and fluid lift. The fluid lift may be determined in the following manner:

$$h = \text{pump setting depth} - \frac{(\text{static fluid level} - \text{vol. to be prod.})}{PI}$$

Where:

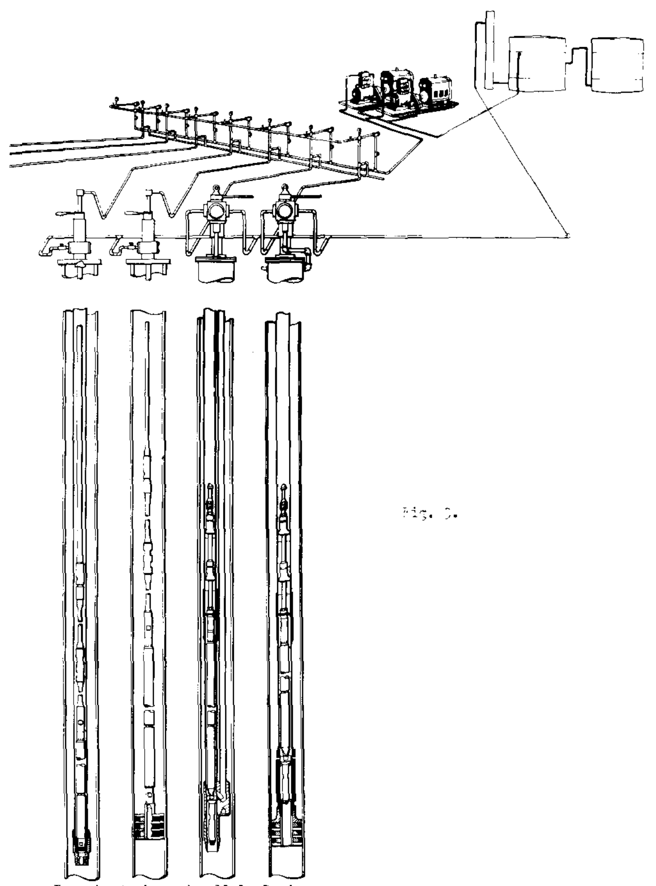
h = Fluid lift in ft
Pump setting depth = from surface in ft
Static fluid level = above pump in ft
Volume to be produced = BPD
PI = BPD per lf pressure drop

With the fluid lift and volume known a pump size may be selected if it also fits the other requirements such as tubing size available, type of installation ultimately selected, etc. Fig. 1 is one of many available specification tables listing various pump sizes. These ratings are also presented in the form of a graph in Fig. 2. Listed are the single pump piston pumps but also available are double pump piston pumps with double the listed displacements.

In the chart, Fig. 2, the designations of the various sizes of pumps are placed so that the first vertical dark line to the right represents the displacement of the pump end piston of the unit at maximum rated speed, and the first dark line below the designation represents the maximum fluid lift for that unit. The diagonal lines mark the 80 to 100 per cent range of maximum displacement for each unit.

The broken line on the chart illustrates the problem of selecting a pump size to produce 220 BPD with a fluid lift of 8000 ft. In the table and chart, maximum setting depth and fluid lift are comparable. As can be seen, two 2 1/2 in. pump sizes, three 3 in. and two 4 in. can handle the well. Naturally the production tubing size in the well and fluid characteristics will limit this

KOBE HYDRAULIC PUMPING INSTALLATIONS



selection, but, in general, the pump selected should be the one with the deepest setting allowed. This setting provides the pump with the lowest operating pressure.

As mentioned above, the shaded areas on the chart show the 80 to 100 percent range of each pump's rated displacement. It normally is practical to design to 80 per cent of a given pump's displacement and still have a margin of safety for long wear lift. In the example, the 2 1/2 x 1 1/4 in. pump would be selected unless the fluid were free of gas, in which case the 2 1/2 x 1 1/8 in. pump may be chosen.

Type of Installation

The next step in the procedure is to select the proper type of installation. Fig. 3 shows the four basic types available, one of which, or a combination of two or more, will handle most pumping applications.

To be guided in this selection one must consider the following:

1. Casing size
2. Chemical properties of fluid produced
3. Solids
4. Free gas to produce
5. Paraffin
6. Accessibility

Assuming that the casing is large enough to make the proper selection, one will find that each type of installation contains desirable features on which to base a selection.

Fixed Insert (Fig. 3a): This installation allows separation of gas in the well, positive paraffin control, chemical injection for inhibiting all surfaces in the well, and a minimum of trouble due to solids. To replace the pump a pulling unit is required.

Fixed Casing (Fig. 3b): The fixed casing installation is normally used where gas separation is not necessary and where large volumes are required. It has the cost advantage of eliminating the production string. A pulling unit is required to replace the pump.

Parallel Free Pump (Fig. 3c): The free pump where applicable has several desirable features. Among those included in the parallel type are:

1. Gas separation in the well
2. Positive paraffin control
3. Chemical injection for inhibiting all surfaces in the well
4. Accessibility of well data by use of a bomb
5. Retrievability of the pump by lease labor only. (This feature is particularly desirable in inaccessible locations.)
6. Ability to handle solids.

Casing Free Pump (Fig. 3d): The casing free pump does not incorporate all the features of the parallel free pump; however, it has several desirable features: retrievability of pump by lease labor, low initial cost, accessibility of well condition data by use of a bomb and use of larger pump size if desired. However, this application does not allow for gas separation in the well.

In the process of selecting one of the above, the tubing string design must be considered from the standpoint of tubing, casing clearance, and setting depth. To assist one in this matter there are available many publications such as Kobe's Technical Service Data releases #47TS10 and #60TS1, titled Tubing String Design and Dual Tubing in Casing, Dimensional Clearance Data.

After selecting the pump size and type of installation the next step is to design the central plant.

Central Plant

To produce a given volume of fluid from any depth one must apply the necessary hp to the engine end of the pump. In the hydraulic production system this hp is in the form of volume and pressure, as shown on nomograph, Fig. 4.

$$HP = .0000170 \times BPD \times psi$$

Where:

HP = Hydraulic hp

$$.0000170 = \frac{5.61 \text{ ft}^3/\text{B} \times 144 \text{ in.}^2/\text{ft}^2}{1440 \text{ min/d} \times 33{,}000 \text{ ft-lb/min}}$$

BPD = Bbl per day power fluid

psi = operating pressure (lbs per sq in.)

In computing BPD power fluid the inefficiencies in both the pump and engine end of the pump must be considered. A conservative estimate for normal conditions is 65 per cent over all.

$$BPD = \frac{\text{Volume to produce (bbl. per day)}}{.65} \times \frac{(AE)}{(AP)}$$

Where:

BPD = Bbl. per day power fluid

$\frac{(AE)}{(AP)}$ = Ratio of engine piston to pump piston areas.

In determining the operating pressure the following factors must be considered:

$$psi = h \times d \frac{(AP)}{(AE)} + friction$$

Where:

psi = operating pressure
h = fluid lift
d = density factor of fluid being pumped (lbs per sq in. per ft)

$\frac{(AP)}{(AE)}$ = Ratio of pump piston to engine piston area.

Friction = Friction in power oil surface line + friction in power tubing + friction in pump + $(1 + \frac{AP}{AE})$ x (friction in production tubing + friction in flow line + separator pressure.)

To assist in determining these sometime unusual frictions, there are available charts such as Kobe's Technical Service Data release #47TS7-R-1, titled Pressure Drop in Pipe and Annular Areas, an excerpt from which is shown in Fig. 5. The total friction under normal condition may safely be assumed to be 10% of the resultant of fluid lift and density.

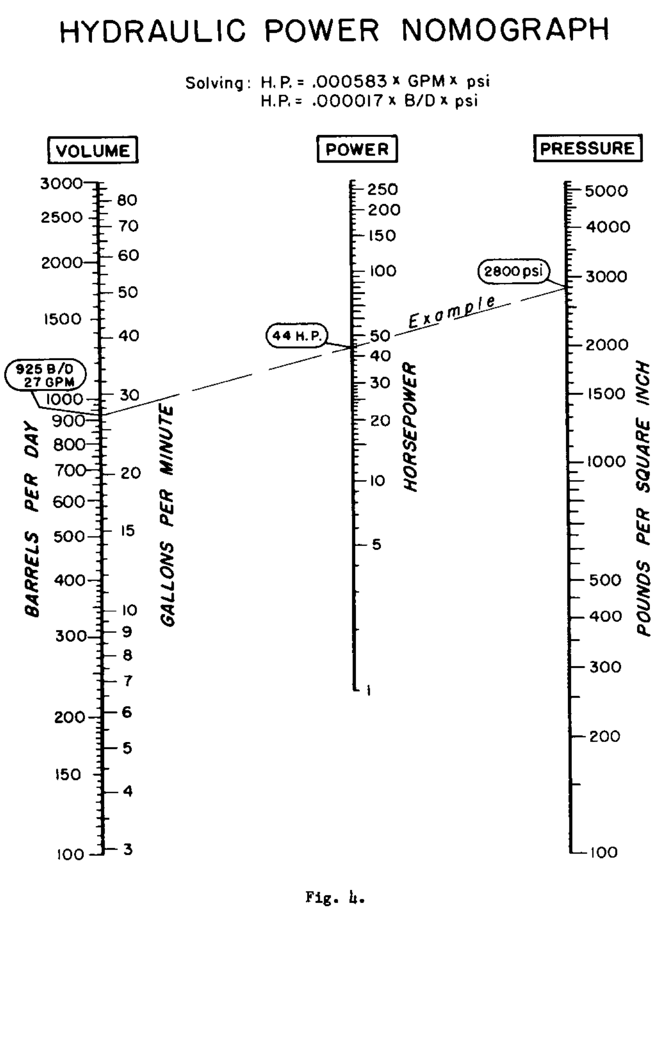


Fig. 4.

In the original example the Hydraulic horsepower demand can be calculated if it is assumed that to be produced are 50 per cent water, 40 A.P.I. crude and 1.10 specific gravity water.

$$HP = \left(\frac{200}{.65} \times \frac{1}{1}\right) \times 1.1 \left(8000 \times .416 \times \frac{1}{1}\right) \times .000017 = 19.1$$

In determining the hydraulic horsepower demand by the use of the nomograph in Fig. 4, for our above example, a line drawn from the pressure requirement (3600 lbs per sq in.) on the pressure scale, to the volume requirements (307 BPD, power oil) on the volume scale, will intersect the power scale at the hydraulic hp required, of 19.1 hp.

The total hydraulic hp demand for the system is the sum total for all the wells operating in the system. Consideration should be given to future additions and abandonments, initial investment, versus long range planning, etc. The flexibility of the hydraulic production system allows for a minimum of initial investment with the opportunity of adding hp later if required with no loss of the original investment. Careful planning will, however, reduce the ultimate cost per hp. And as one moves along in his planning he must weigh the advantages of multiple well application versus single triplex per well application. For small volume pumping the cost per well may be higher in the single triplex per well versus the multiple well application; however, more important may be other factors, such as ease of automation, etc. On the other hand, for large volume pumping the difference may be slight or could favor the single triplex per well installation.

There are several sizes of triplexes available by each manufacturer. Fig. 6 lists the displacement and hydraulic horsepower output of the Kobe Size 3 Triplex. In selecting the triplex one must be sure the volume and pressure figures are suitable to his application.

In the example, if one assumes that there will be additional wells to be added to the central plant one could select this size unit and select the proper size of plungers and liners to fit the type of prime mover to be used. Further, if electric power is to be purchased the plungers and liners will be sized so all power is utilized. These may be changed for a small cost in the Kobe triplex, but this factor is not critical if other means of fuel is utilized. At a later date if more hydraulic hp is needed as wells are added this requirement may be met by the addition of more triplexes in the central plant.

To power the triplex or power unit any type of oil field engine or motor of sufficient hp will suffice. This selection will depend upon power medium available and personal preference. In this consideration the hydraulic horsepower demand that one has must be converted to brake hp by dividing by 0.95. Also to be considered are the other hp demands imposed by such auxiliaries as the charging pump, scavenger pump and lube pump. In selecting a prime mover to power the 60 hp output size 3 power unit 10 per cent should be added for a brake hp demand of 66 hp from the prime mover.

Connecting the prime mover to the triplex may be done by means of sheaves and belts, or gear reducers, or directly by means of a coupling. Also available are integral electric driven units. To assist in this selection and adaption various triplex gear ratios are available including the one to one ratio - see Fig. 6. The prime mover may be mounted on the power unit base, crankcase of the triplex, or separately mounted.

Power Oil Settling System

Excluding special applications such as water for power fluid tests, isolated solo units, etc. the crude oil on the lease which is to be used for power oil should be cleaned of water and solids as far as practical. In selecting an adequate power oil settling system it is assumed that all treating of produced fluid is done ahead of the settling tank. Definite recommendations are made in publications such as Kobe's Technical Service Data release #537S1 titled Power Oil Tankage for Kobe Hydraulic Pump Systems. The recommendation set forth in this release is one 24 ft 750 bbl Power Oil Tank connected and equipped as shown for each 60 hp triplex load in the central plant. We have found a practical application of this rule to be also one 24 ft 1500 bbl Power Oil Tank connected and equipped as shown for two 60 hp triplexes or equivalent. In designing the settling system consideration must be given the physical make up of the storage and treating sections of the tank battery.

With the selection of our power oil settling tank the hydraulic pumping system is completed.

ANALYSIS OF VARIOUS OPERATING CHARACTERISTICS

When pumping, it is necessary, on occasion, to analyze various operational factors. Some of these were discussed in the first section of this paper; however, for convenience they are listed again.

The operating pressure is a function of the net pressure and friction loss in the system. From the following equation one may determine any unknown if he have the other information available.

$$Po = h \times d \frac{(AP)}{(AE)} + \text{Friction}$$

Where:

Po = Operating pressure (lbs per sq in.)
h = Fluid lift in ft (pump setting-fluid level above pump)
d = Density factor of fluid being pumped (lbs per sq in. per ft)
AP = Pump piston area
AE = Engine piston area
Friction Friction in power oil surface line + friction thru pump + friction in power oil tubing + $\left(1 + \frac{(AP)}{(AE)}\right)$ x (friction in prod. tubing + friction in flow line + separate pressure)

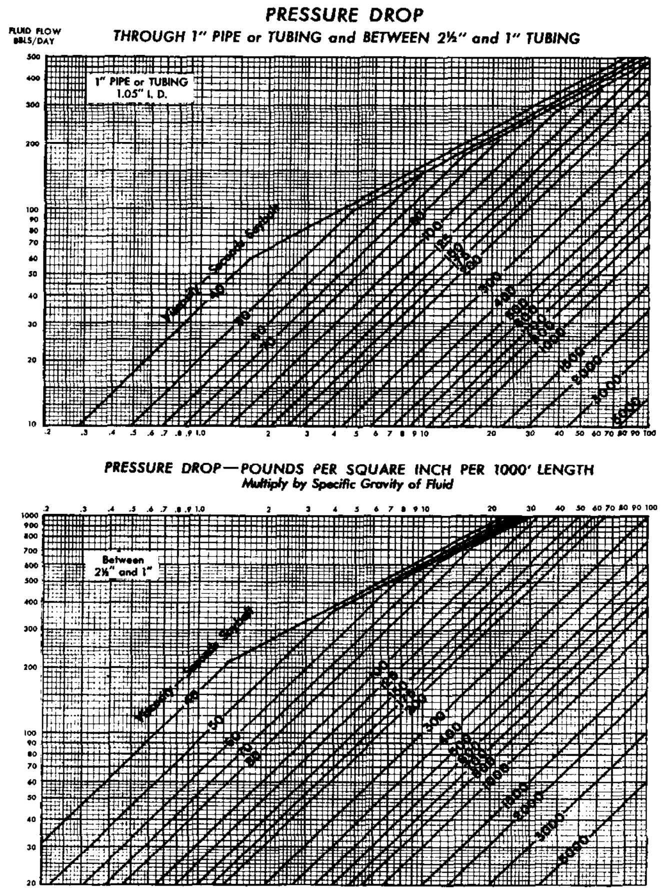


Fig. 5.

The volumetric engine end efficiency may be determined by:

$$\text{Eff. eng.} = \frac{\text{SPM x Displacement (BPD per SPM)}}{\text{Power Fluid Rate (BPD)}}$$

DISPLACEMENT AND HYDRAULIC HORSEPOWER OUTPUT*

The figures in this table are not ratings, but simply offer data over a range of operating speeds.

PLUNGER			Max. Press. P.S.I.	TRIPLEX CRANKSHAFT SPEED											
				100 R.P.M.			200 R.P.M.			300 R.P.M.			400 R.P.M.		
Diam. Inches	Area S.I.	Stroke Inches		G.P.M.	B/D	Hyd. H.P.	G.P.M.	B/D	Hyd. H.P.	G.P.M.	B/D	Hyd. H.P.	G.P.M.	B/D	Hyd. H.P.
3/4	.442	4	5000	2.29	78.6	6.68	4.59	157	13.4	6.90	237	20.2	9.18	315	26.8
7/8	.601	4	5000	3.12	107	9.10	6.24	214	18.2	9.36	321	27.2	12.5	428	36.5
1	.785	4	5000	4.08	140	11.9	8.16	280	23.8	12.2	420	35.6	16.3	560	47.6
1 1/8	.994	4	5000	5.16	177	15.1	10.3	354	30.0	15.5	531	45.8	20.7	708	60.2
1 1/4	1.227	4	4120	6.38	219	15.3	12.8	437	30.6	19.1	656	45.8	25.5	874	61.3
1 3/8	1.485	4	3400	7.72	265	15.3	15.4	529	30.6	23.1	794	45.8	30.9	1058	61.3
1 1/2	1.767	4	2860	9.18	315	15.3	18.4	630	30.6	27.5	945	45.8	36.7	1259	61.3
1 5/8	2.074	4	2440	10.8	370	15.3	21.6	740	30.6	32.3	1109	45.8	43.1	1478	61.3
1 3/4	2.405	4	2100	12.5	429	15.3	25.0	858	30.6	37.5	1286	45.8	50.0	1714	61.3
1 7/8**	2.761	4	1830	14.4	492	15.3	28.7	984	30.6	43.0	1475	45.8	57.4	1967	61.3
2**	3.142	4	1610	16.3	560	15.3	32.6	1118	30.6	49.0	1679	45.8	65.3	2239	61.3
2 1/8**	3.546	4	1420	18.4	632	15.3	36.8	1263	30.6	55.3	1895	45.8	73.7	2527	61.3
2 1/4**	3.976	4	1270	20.7	708	15.3	41.3	1416	30.6	62.0	2125	45.8	82.6	2833	61.3

*To obtain brake horsepower, divide hydraulic horsepower by 0.95.
**Cylinder Blocks and Plungers available on special order only.
Available gear ratios are 3.079, 3.579, 4.330, and 4.864.

Fig. 6.

Where:

Eff. Eng. = Engine end volumetric efficiency
SPM = Speed of bottom hole unit
Displacement = Displacement of engine end in BPD per stroke per minute
Power Fluid Rate - Measured in BPD

The pump end volumetric efficiency may be determined by:

$$\text{Eff. pump} = \frac{\text{Production Rate (BPD)}}{\text{SPM x Displacement (BPD per SPM)}}$$

Where:

Eff. pump = Pump end volumetric efficiency
SPM = Speed of bottom hole unit
Displacement = Displacement of pump end in BPD per stroke per minute
Production Rate = Measured in BPD

The overall volumetric efficiency of the bottom hole unit is the resultant of the engine end and pump end efficiencies:

Eff. Unit = Eff. eng. x Eff. pump

In computing the Hydraulic hp requirements of the system, all pressure and volumetric losses must be considered:

HP = BPD x PO x .0000170

Where:

HP = Hydraulic horsepower
BPD = Bbl. per day power fluid
PO = Operating pressure (lbs per sq in.)

$$.0000170 = \frac{5.61 \text{ ft. } 3/\text{B} \times 144 \text{ in. } 2/\text{ft}^2}{1440 \text{ min/d} \times 33{,}000 \text{ ft. - lbs/min}}$$

CONCLUSION

In conclusion we would like to refer to our original statement in this paper; with the knowledge collected, one will be able to adapt to changing conditions or increased demands at a minimum of expense.