Design & Operation Of The Double Acting, Reciprocating Hydraulic Production Unit

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INTRODUCTION

The basic principle of hydraulic pumping was first applied to pumping oil by Faucett, in 1875. This device was steam operated and required a large diameter bore hole and incorporated most, if not all, of the features of present day pumps. No commercial use of the Faucett pump is of record, and it was not until after 1920 that increasing well depths led various engineers to seriously study the problem. Humphreys, Crum, Cage and Coberly are names which will be recorded in the history of development. The first sustained effort was made by Kobe, Inc., starting in 1932.

The hydraulic production system now being used commercially is composed essentially of three parts, as shown in Fig. 1 — the power oil treating and storage, central plant, and well installation. Our discussion will be confined to the design and operation of the hydraulic bottom hole pump, a component of the well installation.

FLUID POWER OPERATED PUMPS

Hydraulic bottom hole pumps are fluid power operated, which in the broad definition would include both liquid and gas as the power transmitting means. At the present time the only commercial pumps are liquid operated and the liquid is usually the well oil with the gas, water and sand removed to a practical point. Water may also be used as the power transmitting fluid, and has been tried but is not yet proved. Commercial application of some hydraulic pumps using produced well fluid without any cleaning shows promise of being a practical power fluid answer in some cases.

The type of hydraulic pump which has come into use is a reciprocating engine having a reciprocating pump directly connected to it. Since the pressures are moderately high and the volumes small, positive displacement devices are best adapted. All commercial hydraulic oil well pumping systems today use a system having a continuous flow of power fluid in a closed circuit to transmit power to the bottom hole pump.

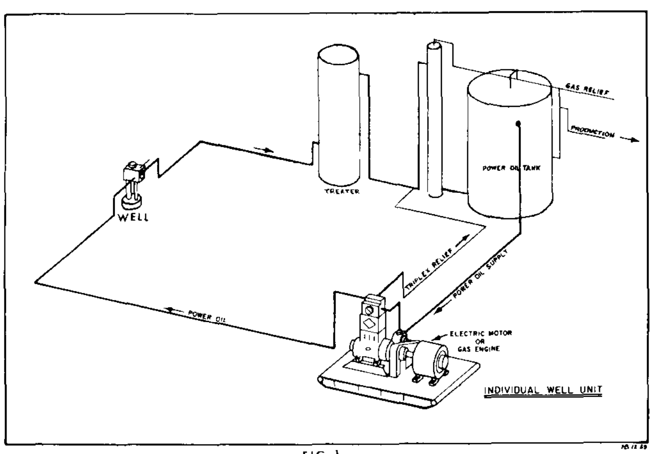

FIG. 1

The bottom hole unit has three elements which may be combined in various ways — a control (or engine) valve, an engine, and a pump. Our paper will be confined to these elements as they comprise the Kobe hydraulic bottom hole pump.

The engine valve has a primary function of reversing the power fluid to the ends of the engine cylinders when the piston approaches the end of its stroke. It has other important requirements, namely speed control and acceleration control.

Fig. 2A shows the differential area engine valve in the "down" position. The ports are fully open and the power fluid pressure is being directed to the top of the engine piston which is moving at full speed. In Fig. 2B the valve is in the "up" position with the power fluid pressure being directed to the bottom of the engine piston and the ports from the top of the piston open to exhaust. The engine piston is moving up at full speed.

The valve rod which functions as the pilot valve has upper and lower ports which connect the lower or operating area of the valve to the power fluid pressure and exhaust respectively to cause the motion of the valve. The valve has designed into it throttling grooves and a control orifice to control the rate of admission of the power fluid to the valve to give it the desired speed and acceleration control. With this governing valve the maximum speed at "pump off" can be limited by selecting the proper throttle area.

The engine as shown in Fig. 2 is a fully balanced, full double acting engine connected to a full double acting pump. The two pistons are connected with a hollow piston rod and have a lower rod and an upper (or valve) rod extending through the cylinder heads to balance the areas.

The upper rod is subjected to the power fluid pressure and, since it is hollow, this pressure is also applied to the end of the lower rod. Since the pump is full double acting, an intake and exhaust valve is required for each end of the pump cylinder. These valves are multiple ball-type check valves for both the intake and exhaust fluid. All valves are spring loaded with a common follower for each set of three balls in parallel, making the valve action independent of gravity.

Mechanical Movement of Unit

The mechanical movement of the unit with respect to its pumping action is illustrated in Fig. 2. During the downward or compression stroke, Fig. 2A, the power fluid is being directed on top of the engine piston. The spent power fluid below the engine piston is being directed by the engine valve out the engine exhaust. The pump cylinder lower intake valve is closed and well fluid is pumped out the pump cylinder lower exhaust valve. The pump cylinder upper exhaust valve is closed against the column pressure and well fluid is filling the pump cylinder above the pump piston through the pump cylinder upper intake valve.

Completing the downward stroke, the engine valve starts its upward movement and directs power fluid on bottom of the engine piston, Fig. 2B. This started the upward stroke. The spent power fluid on top of the engine piston is directed out the engine exhaust by the engine valve. The pump cylinder upper intake valve is closed against the formation pressure and the well fluid is pumped out the pump cylinder upper exhaust valve. The pump cylinder lower exhaust valve is closed against the column pressure and well fluid is filling the pump cylinder below the pump piston through the lower intake valve. At completion of the upward stroke the engine valve starts its downward movement and the cycle is repeated. In the double acting bottom hole unit a stroke consists of both the downward and upward movement, a complete cycle.

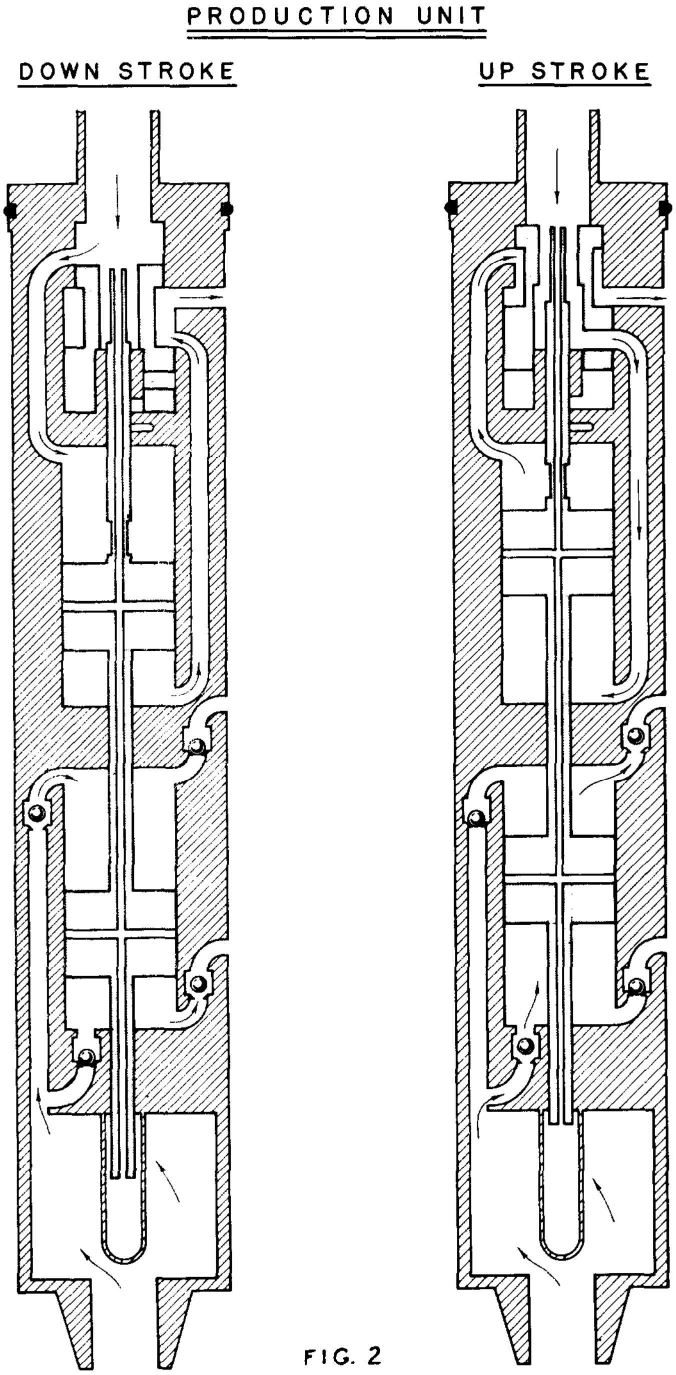

FIG. 2

A B

The bottom hole unit has a top intake for power fluid and a bottom intake for well fluid. The pump takes in fluid at formation pressure and discharges it into the well tubing against the column pressure. The net pressure on the pump is the column pressure minus the formation pressure. When the engine and pump pistons have the same diameter, the differential pressure on the engine is equal to the net pressure on the pump.

With power oil and pumped fluid of equal density, the engine and pump column pressures are balanced. The engine takes power oil at column pressure plus the differential pressure and discharges into the column pressure. The power of the engine and pump are determined by the differential and net pressures respectively, and the absolute value of the pressure is of interest only in determining the hydraulic and mechanical design.

The operating pressure is a function of the net pressure and friction loss in the system.

$$Po = h \times d \frac{(Ap)}{(A_E)} + \text{friction}$$

Where

Po = Operating pressure (Lbs. per sq. in.)
h = Fluid lift in ft. (pump setting depth - fluid level above pump)
d = Density factor of fluid being pumped (Lbs. per sq. in. per ft.)
Ap = Pump piston area
A_E = Engine piston area

Lubrication with power oil is provided to all sliding fits, through the system of hollow rods and pistons, in both the engine and pump. This is accomplished by the differential of power fluid pressure to exhaust pressure in these fits. Lubrication of the unit reduces wear and permits the use of close fits and piston rings. The length of fits used are much shorter than has been the practice with rod pumps.

The stroke length of hydraulic pumps is positive, and close spacing of the piston relative to the end of the cylinder is possible. Also, the clearance volume can be reduced to that of the valve cage. This gives a high compression ratio, which is essential with gassy fluid to prevent excessive loss of efficiency. Where lubricated plungers are used, this clearance volume is further reduced and complete gas lock is impossible. The leakage of lubrication fluid into the pump cylinder will fill the clearance volume and give an infinite compression ratio on the top end and an increase in compression ratio on the lower end of the double acting pump.

The engine end efficiency is affected by the pressure losses and the volumetric losses. The volumetric efficiency may be determined by

$$\text{Eff. eng.} = \frac{\text{S.P.M. x Displacement (Bbl. per day per S.P.M.)}}{\text{Power Fluid Rate (Bbl. per day)}}$$

Where

Eff. eng. - Engine end volumetric efficiency
S.P.M. - Speed of bottom hole unit
Displacement - Displacement of engine end in bbl. per day per stroke per minute
Power fluid rate - Measured in bbl. per day

The pump end volumetric efficiency may be determined by

$$\text{Eff. pump} = \frac{\text{Production rate (Bbl. per day)}}{\text{S.P.M. x Displacement (Bbl. per day per S.P.M.)}}$$

Where

Eff. pump - Pump end volumetric efficiency
S.P.M. - Speed of bottom hole unit
Displacement - Displacement of pump end in bbl. per day per stroke per minute
Production rate - Measured in bbl. per day

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 horsepower requirement of the system, all pressure and volumetric losses must be considered. The efficiency of the bottom hole unit is therefore only one of the factors involved.

HP = B/D x Po x .0000170

Where

HP = Hydraulic horsepower
B/D = Bbl. per day power fluid
Po = Operating pressure (Lbs. per sq. in.)

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

In this discussion we have not differentiated between bottom hole units containing one pump piston and the Type A which incorporates two pump pistons. The basic principles apply to both. Fig. 3 contains the Kobe pump capacities and designed lift for both the single and double pump piston units.

The bottom hole unit is identified by the nominal size of tubing it can be installed in. As shown on the capacity chart Fig. 3, the dash and solid lines represent the single pump piston unit, with an engine piston diameter of one-half its nominal size. The pump end piston is listed with the unit size. The shaded lines depict the capacity characteristics of the Type A or double pump end piston unit. The numbers as listed describe the pump components in the following order:

First number - Pump size
Second number - Engine piston size
Third number - First pump piston size
Fourth number - Second pump piston size

Any pistons available may be combined to give the desired operating characteristics. It is possible to lift fluid from below 20,000 ft. with the proper selection of engine and pump piston sizes.

HYDRAULIC OIL WELL PUMPING SYSTEMS

CAPACITIES

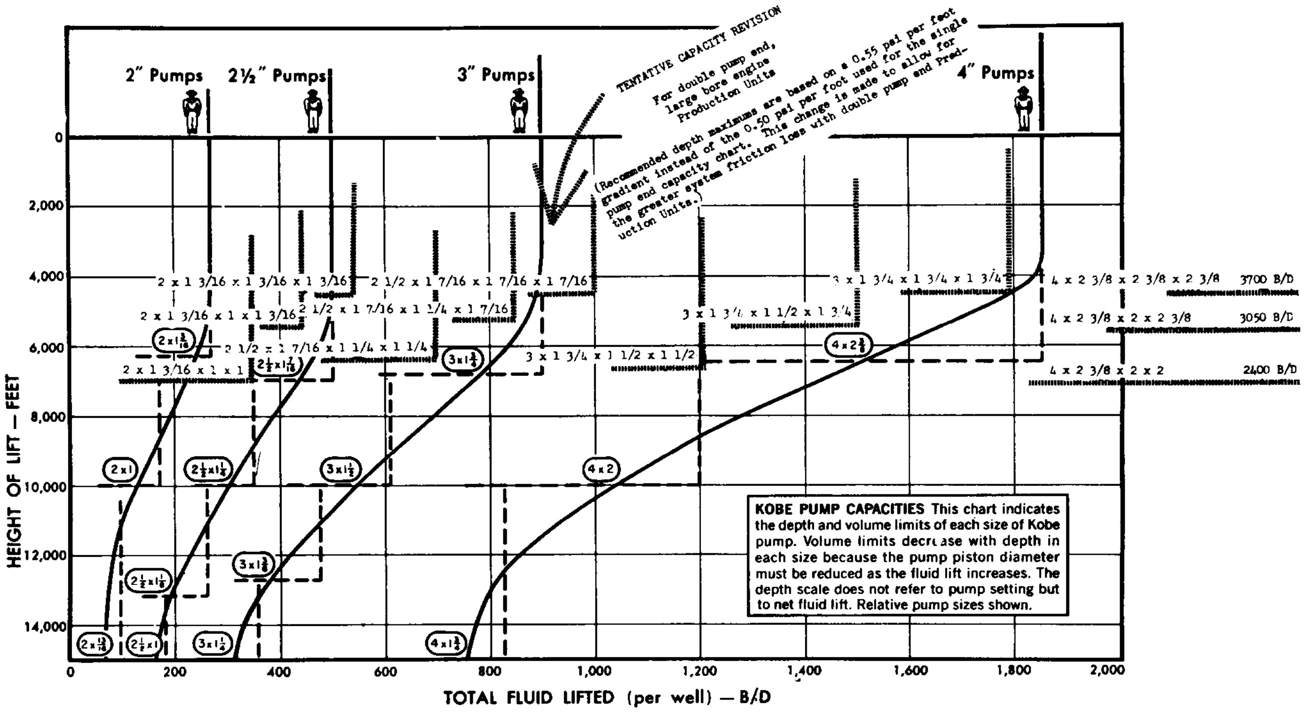

FIG. 3