Rod-Counterbalance Hydraulic Pumping Units

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PURPOSE

Rod counterbalanced hydraulic pumping offers a means of producing wells of almost any depth and fluid rate, and of utilizing the recognized advantages of long, slow strokes, with minimum initial investment and subsequent operating costs.

DEFINITION

Rod counterbalancing is a system in which the sucker rod string in one well is balanced by the sucker rod string in a second well. The two wells may be parallel, dual-completed zones, or they may be on offset locations, hundreds of feet apart.

BACKGROUND

The basic idea is not new, but the design under discussion represents a fresh approach, and incorporates several new concepts that permit greatly reduced manufacturing cost as well as simplified operation and maintenance. For the past year our company has been engaged in research and development on this system, and have drawn on experience with its present line of unbalanced hydraulic pumping units, for many of the techniques of design, manufacture, and application are similar. Several of the rod counterbalanced units are now in service, and operators report satisfactory operation.

DESCRIPTION

In Fig. 1, it can be seen that the principal parts of the system consist of a control cylinder, slave cylinder, power pump, booster pump, reversing valve, and a reservoir.

One cylinder is installed on the well head of each well or zone. The piston in each cylinder is attached to a polish rod, which extends out the lower end, and through a packing gland. The sucker rod string, in turn, is attached to the polish rod. The cylinders are connected at their lower ends by means of a fluid conduit, designated as the balance line. Connected at the upper end of each cylinder is a fluid conduit, called the power line, which runs to its respective port on the reversing valve.

The control cylinder has at its upper and lower ends valve ports, which open into a common conduit, with line check valves at the upper and lower ends of this conduit. Between the check valves, the valve shifting line branches out from this common conduit and runs to the head of the reversing valve.

The slave cylinder has no controls on it, except for a port near its upper end, which opens to the dump line. The dump line runs back into the slave cylinder power line.

The other components shown in Fig. 1 are all mounted on the power unit skid, and consist of power pump, booster pump, reversing valve, and reservoir. The power pump is a high-volume, low-pressure rotary pump, which has its suction connected to the reservoir and its discharge to a port in the reversing valve. It has a pressure relief valve (not shown) which in case of overload discharges back into the reservoir. The booster (or makeup) pump also has its suction connected to the reservoir, but it discharges directly into the balance line. The booster pump is also a rotary pump having high-pressure, low-volume design. There is also a pressure relief valve on the discharge of the booster pump, but it is not shown. Both pumps are driven by the same prime mover, also not shown. The return line runs from a port in the reversing valve to the reservoir. The reversing valve. shown here schematically, consists of a spool-type pilot valve and special, 4 way, spool type main valve.

OPERATION

During normal operation, the system functions as in Figs. 1 and 2. Fig. 3 shows the conditions when the unit is first put into service.

Fig. 1. Control Piston on Upstroke

The power pump discharges through reversing valve and power line into the top end of the slave cylinder, and forces the slave piston downward against the balance fluid, which communicates with the bottom end of the control cylinder through the balance line, in a U-tube effect, and drives the control piston upward. As the upper end of control cylinder, through its power line and through the reversing valve, discharges into the reservoir at atmospheric pressure, the control piston is free to move upward. The booster pump discharges continuously into the balance line and makes up any balance fluid lost from beneath the two pistons, the loss of fluid occuring because of reversing valve operation, or piston blow-by.

As the control piston passes the upper valve port, balance fluid is introduced, through the valve shifting line, into the head of the reversing valve, and shifts it. The speed of shifting is governed by the setting of the cushion valve, which is simply a needle valve, that restricts the flow into the reversing valve. This restriction allows a gradual deceleration of the control piston, and also of the slave piston, for the latter is governed entirely by the action of control piston. When the resersing valve reaches the mid-point of its shift, both control and slave pistons have come to a stop and are ready to reverse their directions.

Fig. 2. Slave Piston on Upstroke

When the reversing valve completes its shift (as begun under Fig. 2) the reversing valve "crosses over" and the power pump fluid is now being directed to the top of the control piston; the slave cylinder has its upper end vented back to the reservoir and causes control piston to move downward and force slave piston upward.

Fig. 2 also illustrates another phase of the operation, the "dumping" action of the slave piston. As mentioned

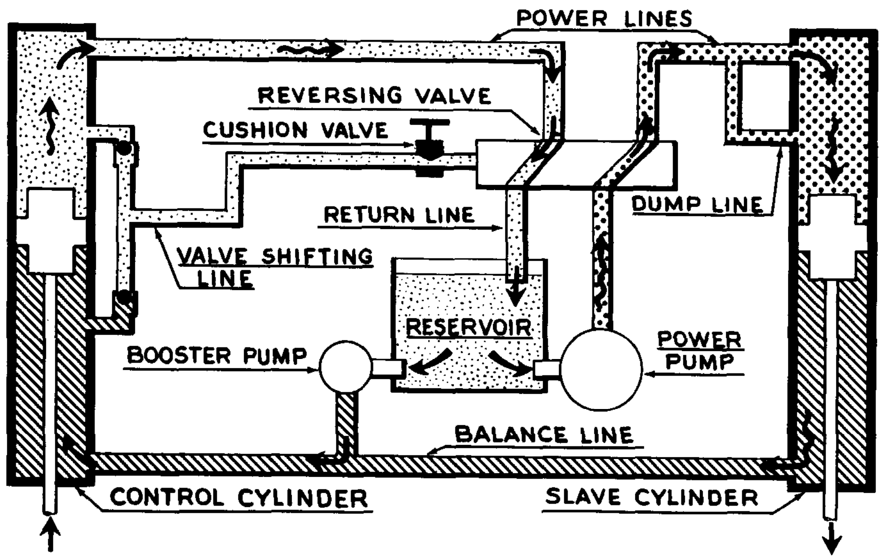

FIG. I. CONTROL PISTON ON UPSTROKE

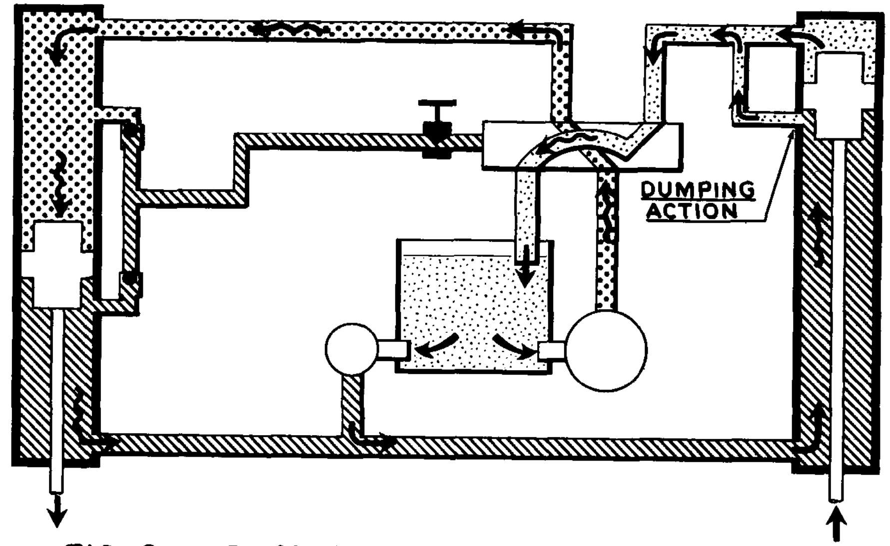

FIG. 2. SLAVE PISTON ON UPSTROKE

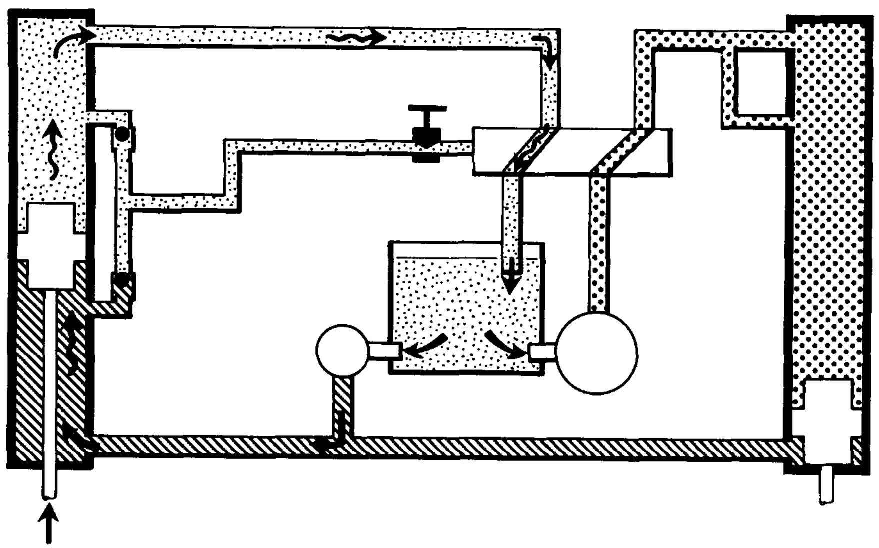

FIG. 3. STARTING PHASE

BALANCE PRESSURE: HYDRAULIC FLUID UNDER PRESSURE DUE TO COMBINED WEIGHT OF RODS AND WELL FLUID ON UPSTROKE PISTON.

POWER PRESSURE: HYDRAULIC FLUID UNDER PRESSURE DUE TO WEIGHT OF WELL FLUID ONLY ON UPSTROKE PISTON.

RESERVOIR PRESSURE: HYDRAULIC FLUID AT ATMOSPHERIC PRESSURE.

← DIRECTION OF HYDRAULIC FLOW.

FIG. 4. LEGEND FOR FIGS. I, 2, and 3.

before, the booster pump functions to make up losses from the balance system, and it is necessary to operate this pump at an output volume slightly in excess of anticipated losses. This operation means that, as the system continued to operate, the separation of the two pistons would become greater and greater until the slave piston would eventually bump the top of its cylinder, unless some method of getting rid of the excess fluid were employed. This method is accomplished by the use of the "dump" port, which allows the slave piston to "wait" while the control piston completes its downstroke. Thus the two pistons are always in phase, and of a consistent stroke range and length.

As the control piston passes the lower valve port, the reversing valve, through the valve shifting line, is now free to exhaust into the control cylinder above the piston. Again, the setting of the cushion valve governs the deceleration of the control piston, and, therefore, the deceleration also of the Slave Piston.

Fig. 3. Starting Phase

Before power is applied to the system, both pistons are naturally resting at the bottom of their respective cylinders, and, before normal operation can commence, it is necessary to get one of them up while the other is down. As shown, it is necessary only to start the pumps, and the following sequence of events automatically take place: 1) the booster pump immediately builds up pressure and positions the reversing valve as shown, and allows Power Pump to discharge on top of the slave piston; 2) the power pump bypasses through its relief valve and firmly holds the slave piston against the bottom; 3) the booster pump slowly pumps the control piston upward, since this piston has atmospheric, or reservoir, pressure on its top end; 4) the control piston passes the upper valve port and shifts the reversing valve; and normal operation, as in Fig. 2, begins.

When it is necessary to bleed off pressure from the system, the pumps are stopped and the booster pump relief valve is opened manually; this action allows both pistons to settle to the bottom. And as soon as both pistons are resting on the bottom, all pressure is gone from the system.

ANALYSIS OF OPERATION

It is apparent, from Figs. 1 through 4, that, if one neglects friction, and assums that the well fluid level is at pump intake on the upstroke well, the upstroke piston lifts the weight of well fluid on the net plunger area. The rod string weights will cancel out except for the buoyancy effect in the downstroke well. (This fact can be assured by using identical rod strings if wells are the same depth or by weighting the rod string on the shallower well, if there is any great variation in depth). This bouyancy, in effect, adds to the load on the upstroke well, so that the upstroke piston actually can be considered as lifting the well fluid weight on the gross plunger area in the upstroke well. This statement means that the power required is that which can lift the gross fluid weight on the given plunger size. This power is in contrast to that of a single-counterbalanced pumping unit of any type, wherein the required power is only that to move one-half of the gross plunger load; but it must be remembered that the rod counterbalance system is pumping two wells.

The balance pressure is that required to lift the rod weight, plus net fluid weight in the upstroke well, plus acceleration load. This circuit is not a dynamic one, for the hydraulic fluid simply serves as a means of transmitting power and movement from one piston to the other. If there were no fluid losses, the booster pump would be unnecessary, except for the original charging operation, as seen in Fig. 3.

DESIGN DETAILS

In actual practice, the cylinders are available in a wide range of bores and strokes, as can be seen in Fig. 5. They are made of half-inch wall, cold drawn, seamless tubing; and the pistons are cast iron with automotive-type, cast-iron piston rings. At the lower end of each cylinder is a double hydraulic packing gland, with a spacer between the two glands. Any hydraulic oil seepage around the upper gland is thus immediately returned to the reservoir. After long experimentation and testing, it has been found that the most successful polish rods are those whish have been colmonoy-coated, a treatment which gives them a very smooth surface that is virtually impervious to wear, scoring, and corrosion of any type. The packing is a special, heavy-duty chevron type, non-crushable by over-tightening. The foregoing combination of double gland, colmonoy polish rod, and special packing has eliminated almost completely one old bugaboo of hydraulic equipment, that of hydraulic oil loss. Another convenient arrangement is that the polish rod has a long bolt thread at its upper end and allows 18 in. of adjustment for respacing the bottom hole pump after the cylinder is on well. It also serves to permit accurate spacing before the cylinder is placed on well.

The Cylinder can be mounted on the well in a variety of ways, but for parallel, dual units, the quadrupod, as shown in Figs. 6 and 7, is the most popular. This mounting permits a slightly wider center-to-center distance for the two cylinders than is possible down at the well head. It has been found by experience that this slight drift of the polish rods does not cause packing trouble and that it is unnecessary to stagger the cylinders or offset the rod couplings. Where a single cylinder is mounted on a well, as in Fig. 9, the short support cage is usually employed; and this cage can be mounted on the pumping tee, or, with an adapter it may be mounted on the casing flange. This support cage mounting can be used on dual wells, where the centers of the two tubing strings are identical with the cylinder centers.

Power units vary in capacity from 7 hp to 270 hp and are skid-mounted with provision for any type or make of prime mover (cf. Figs. 6, 8 and 10). As can be seen, the power and booster pumps are both driven by the same prime mover, the larger being the power pump. The reversing valve and the relief valves are all mounted on a control panel, which is attached to the side of the reservoir; and all piping converges to this panel. Also mounted on the reservoir is a micronic filter, through which a portion of the return oil is continuously filtered. This filtration removes all outside dirt, water, and any contamination which might have been drawn into the system by the polish rod (when the support cage mounting is used). This filter also keeps the hydraulic oil in a perpetually new condition.

The flooded pump suctions afforded by the vertical reservoir ensure longer pump life and better performance. Most manufacturers of pumps feel that the vacuum pulled at the pump intake should not exceed five to six inches, during normal operation. With the arrangement shown, the power pump does not even pull a vacuum — usually the intake pressure is about 2 psi — positive pressure. Even with cold oil, the booster pump will not pull more than about 2 in.

The hydraulic pump is the heart, and the heartbeat, of any hudraulic system and must be of the highest quality and dependability. As a result of testing many types and makes, it was concluded that the best pump available is a

FIG. 5. PERFORMANCE DATA AND SPECIFICATIONS

CYLINDER BORE & STROKE	RATED POLISH ROD LOAD		BOTTOM HOLE PUMP BORES 1-1/16"	1-1/4"	1-1/2"	1-3/4"	2"	2-1/4"	RODS
2½" x 3 ft.	6,000#	DEPTH	4250'	3750'	3500'	2750'	2500'	2250'	5/8"
		PROD.	32	44	61	86	108	132	
2½" x 9 ft.	6,000#	DEPTH	3700'	3400'	3000'	2600'	2300'	2000'	5/8"
		PROD.	140	185	260	360	460	595	
3" x 6 ft.	9,300#	DEPTH	6500'	5800'	5000'	4400'	3800'	3400'	5/8"
		PROD.	60	77	106	142	195	245	
3" x 10 ft.	9,300#	DEPTH	5500'	5100'	4500'	3900'	3500'	3100'	5/8"
		PROD.	150	195	265	365	460	600	
3½" x 10 ft.	13,300#	DEPTH	7300'	6700'	5900'	5100'	4500'	4000'	¾", 5/8"
		PROD.	155	200	265	325	450	540	
4" x 12 ft.	18,000#	DEPTH	7400'	7000'	6300'	5600'	5100'	4600'	7/8", ¾"
		PROD.	200	260	350	480	575	685	
4½" x 12 ft.	23,000#	DEPTH	9400'	8600'	7900'	7100'	6400'	5800'	7/8", ¾"
		PROD.	205	270	350	465	550	665	
5" x 16 ft.	29,000#	DEPTH	10000'	9500'	8700'	7700'	7100'	6400'	1", 7/8", ¾"
		PROD.	300	390	510	660	800	1000	

DEPTH RATINGS are derived from rod weight plus net fluid weight plus acceleration load.

PRODUCTION RATES are in bbl/per 24-hr. period, at 100% pump efficiency, but with rod and tubing stretch deducted and with overtravel added. Tubing is assumed anchored at 5000 ft. and deeper. THE PRODUCTION SHOWN IS THAT FROM EACH WELL, AND IS BASED ON 10 STROKES PER MINUTE ON ALL UNITS SHOWN.

TUBING SIZES are 2" for bottom hole pumps through 1½" bore, and 2½" tubing for the 2" and 2¼" pump bores. Where 1" rods are used, tubing is assumed as 2½".

SUCKER ROD STRINGS are designed to give safe rod stresses at peak polish rod loads.

WELL FLUID is assumed to be 1.0 SPECIFIC GRAVITY, and fluid level at pump intake.

worm-gear type, which has been in use for many years in refinery and pipe line service; this type demonstrates the ability to pump all kinds of fluids at high pressures and volumes and has on record many cases of service lives of from 12 to 15 years. This pump is standard equipment on most of the rod counterbalanced units, but on lighter-duty applications, spur-gear and vane pumps have been satisfactory.

OFFSET INSTALLATIONS

The operating principles, and most of the equipment, are the same on offset installations as on dual completions. The main difference is that the balance line and one power line must be approximately the same length as the distance between the two wells. The power unit is placed near the well having the control cylinder, so the valve shifting line needs to be only a few feet long.

On the two long lines, a diameter is selected to keep pressure drop at a minimum. In practice, a pressure drop of from 50 to 100 psi is usually not prohibitive. Thus, in smaller sizes, standard line pipe can be used, and, in larger sizes, seamless is recommended.

The use of electric resistance-welded pipe is recommended over regular line pipe, because the former pipe is both stronger and cheaper, in the X-42 and X-46 grades where a thin wall may be safely used and because the pipe is welded instead of screwed. The type having one end belled is best, for it permits the small end of the next joint to be inserted into the bell and a fillet weld made; and the possibility of welding slag getting inside the pipe is eliminated. Also, welding virtually eliminates the possibility of leaks. Further this pipe is fully reclaimable after welding. Two runs of this pipe can be seen in Fig. 10.

LIMITATIONS OF THE SYSTEM

With respect to well depth or fluid rate, there are practically no limitations to the application of this system, as can be seen from Fig. 5; however, it is necessary that there be two wells, or zones. In the event that one well is drilled and it is desired to pump it before the offset is drilled, or in the case where there are two wells in operation with the offset rod counterbalance and one must be serviced while the other is to be kept in operation, an accessory piece of equipment can be used. It is called the "Auxiliary Counterbalance Attachment" and consists of a dummy cylinder, nitrogen loaded, mounted horizontally on a portable skid, although it can be mounted on a light trailer if desired. It can be attached to either slave or control well in a matter of minutes and will operate the well as a single counterbalanced unit. This accessory works exactly the same as a second well, with the nitrogen charge replacing the rod string. This equipment is available on a rental basis as well as sale; however, with a number of wells in an area, it would usually pay the operator to own one such auxiliary unit, as the prorated cost would be small. This auxiliary can be applied as original equipment on a single well; in fact this application has been made in the West Texas area. However, in this arrangement, there is not the economy inherent in the rod counterblance, except in the case of extremely deep wells and relatively high fluid rates. The example just mentioned is designed to pump approximately 500 BPD from 9600 ft.

Another limitation is encountered when very high hydraulic volumes are required and the well spacing is extremely wide, i.e., 160 acres. In these cases, the auxiliary counterbalance attachment might be employed as permanent equipment, particularly if it were desired, regardless of first cost, to use hydraulic pumping because of the long, slow stroke.

Another possible limitation is caused by the wide variation in well depth. However, in many cases, the rod strings may be designed to weigh about the same, although of different lengths.

In the event that widely different fluid rates are required from the two wells, this problem can be solved in some cases by using different bottom hole pump bores. For example, a water flood operator specified that he wanted to pump 400 BPD from one well and 100 BPD from the off-setting well. Since he was using 2 1/2 in. tubing, this problem was solved by using a 2 1/4 in. pump in one well and an 1 1/16 in. pump in the other. The system was designed to pump both wells at 400 BPD, as this would be the eventual condition. However, when the 1 1/16 in. pump was used, the power demand would vary considerably, but the total power consumption would still be only that needed to move the given amount of fluid from each well. As the system would be working at only six or seven cycles per minute, there would be no undue stress on the prime mover because of the fluctuation.

Still another solution to the variable fluid problem is simply to by-pass, periodically either manually or with a timeclock, the lighter well back to the casing annulus. This bypass will prevent the undesirable pounding of fluid and will cut down on the power consumption as in the annulus the fluid builds up to its static level, and partially counteracts the load on the top of the pump plunger.

CALCULATIONS

It is not within the scope of this paper to go into the many calculations used in applying the rod counterbalance; however, in Fig. 5 is presented a table that shows currently available units with approximate performance data. In practice, these tables in more detail are available to the operator, so that easy selection can be made.

CASE HISTORIES

For a brief discussion three actual installations have been selected that illustrate most of the points covered in the preceding paragraphs.

Case 1.

This installation, shown in Fig. 6, is owned by a major oil company near Freer, Texas It is a dual, quadrupod-mounted unit, with electric motor drive. The cylinders have a 2 1/2 in. bore and 36 in. stroke; and they run at eight strokes per minute and give a displacement rate of about 46 BPD from each zone. The depth of each pump is near 2200 ft. Although this particular unit works at only about half capacity, the estimated saving in initial investment is about 30 per cent under the alternate equipment considered.

Case 2.

This dual quadrupod unit powered with a multi-cylinder gas engine, pictured in Figs. 7 and 8, pumps two zones at approximately 7500 ft at a displacement of 130 BPD from one zone and 100 BPD from the other. It is equipped with 1 1/4 in. and 1 1/16 in. pumps, respectively, and it has a 4 1/2 in. bóre and 12 ft stroke and operates at 6 strokes per minute. The owner is a major oil company, and the unit is located near Palacios, Texas. Estimated savings in initial investment aaverage about 40 per cent.

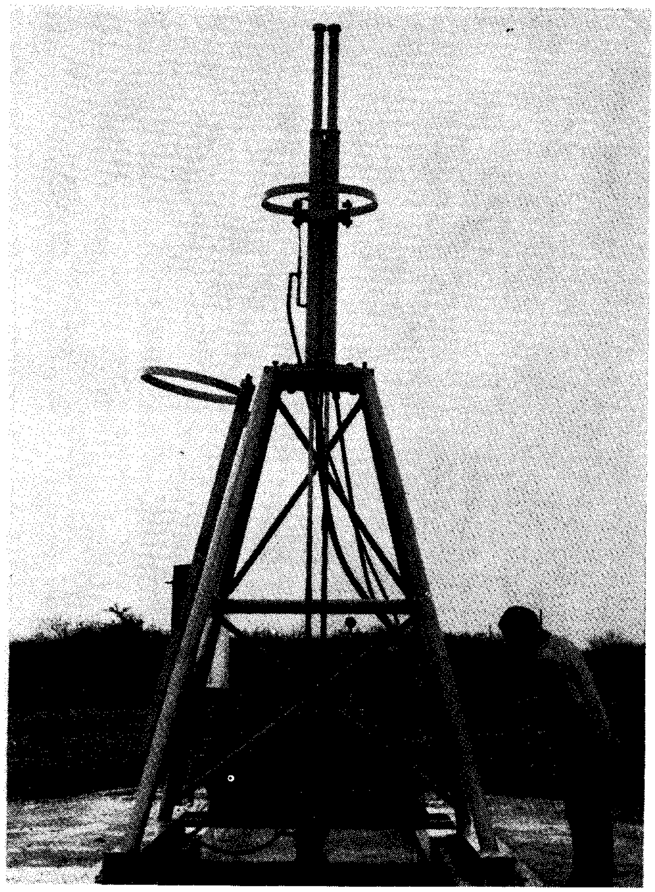

Fig. 6 2200-ft. Dual

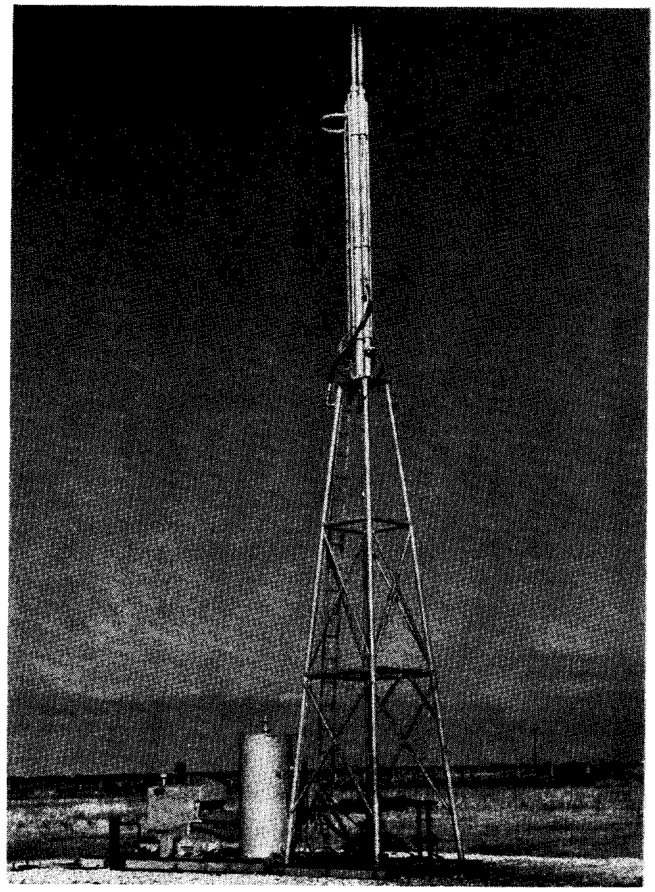

Fig. 7 7500-ft. Dual

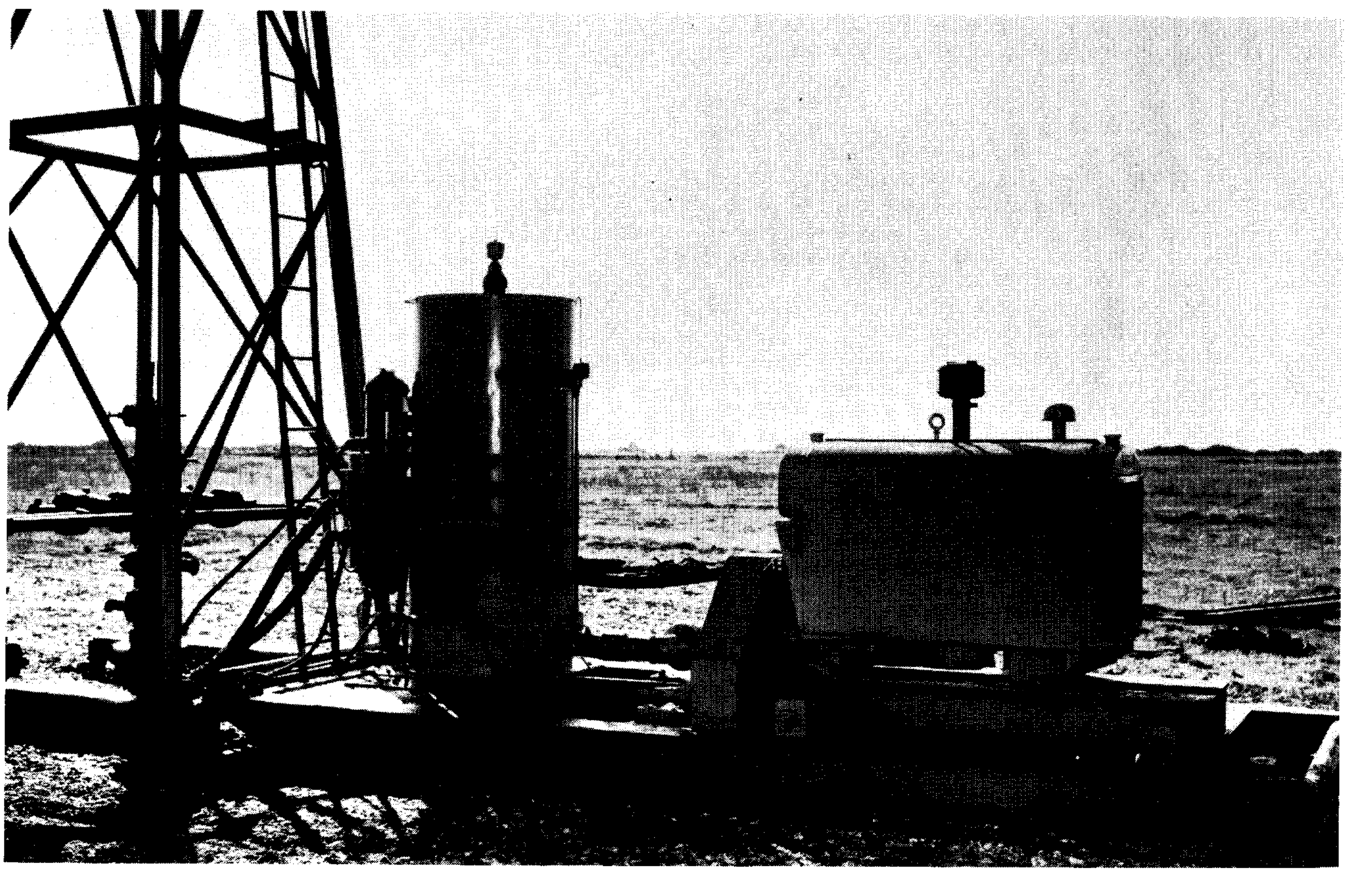

Fig. 8 Power Unit on 7500-ft. Dual, showing Reversing Valve.

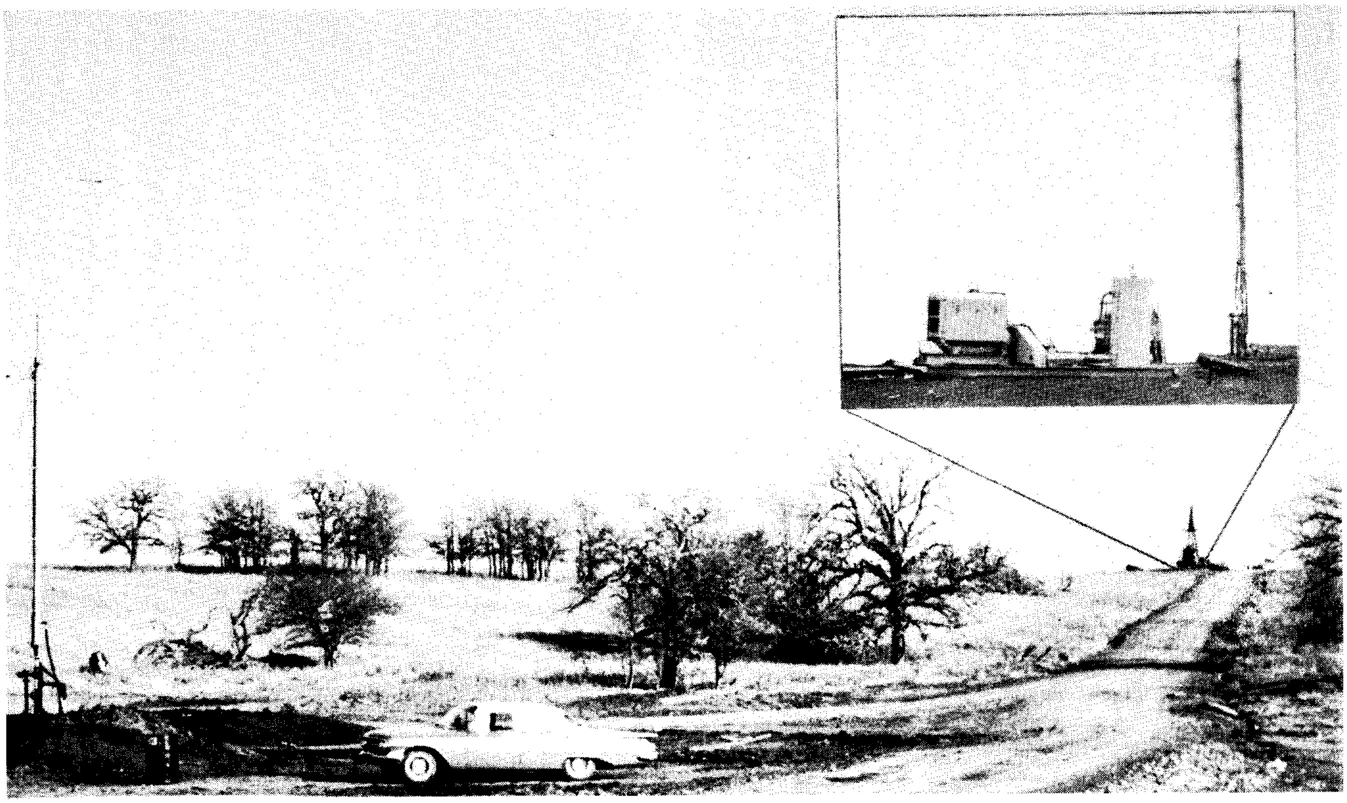

Fig. 9 9500-ft. Offset (40-acre), with Control & Power Unit in inset.

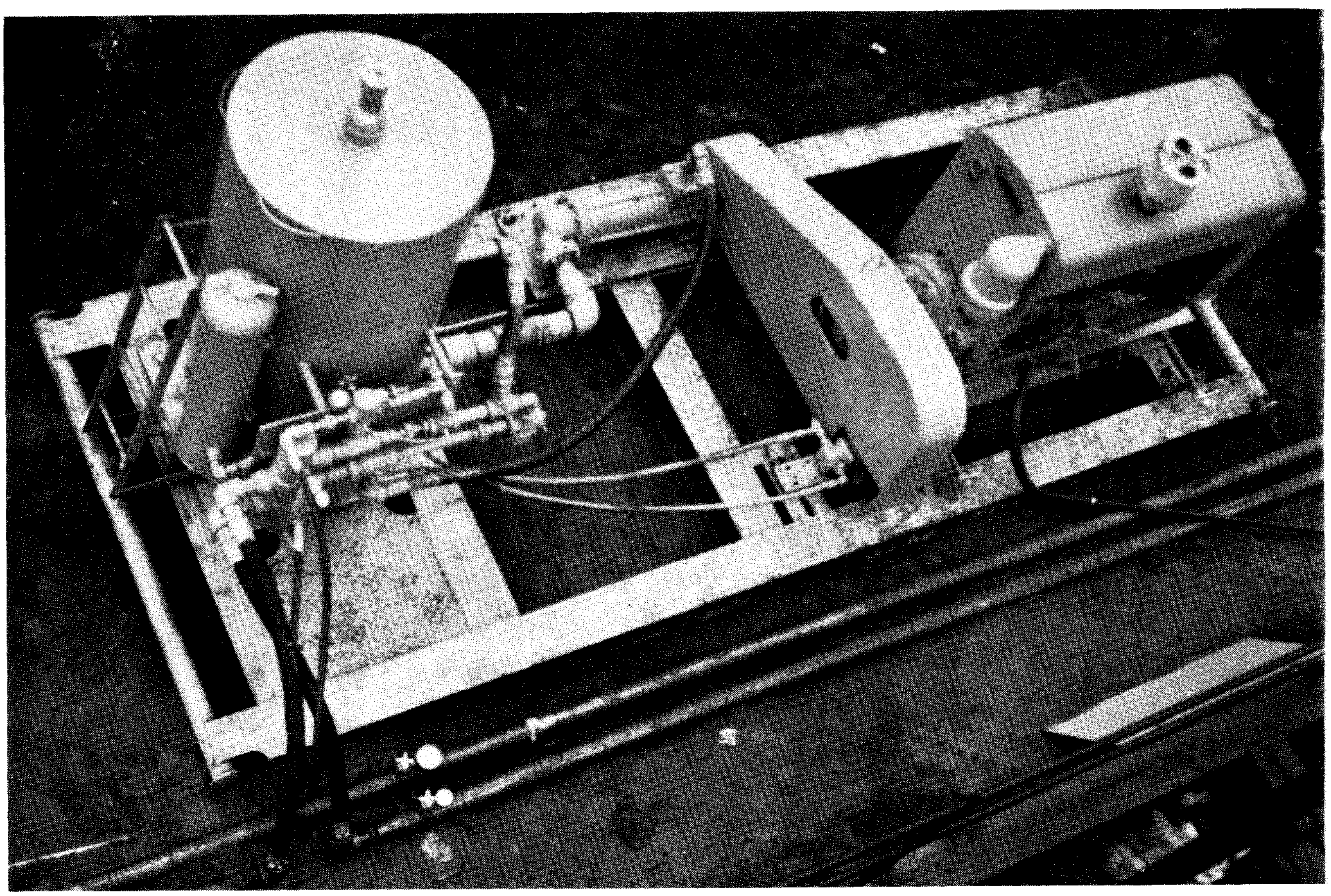

Fig. 10 Power Unit on 9500-ft. Dual, showing Power and Booster Pumps.

Case 3.

This offset installation, pictured in Figs. 9 and 10 and owned by an independent oil company, is located near Healdton, Oklahoma, and has some unusual aspects. The distance between wells is 1320 ft (40-acre spacing) and there is a dual-zone pump in each well, making a total of four zones pumped with two rod strings. The zones are at 9000 ft and 9500 ft. The cylinders have a 5 in. bore and 16 ft stroke, and are operating at 3 strokes per min.; thus they produce a displacement rate of about 115 BPD in each well. The connecting fluid lines are electric resistance welded pipe, X-42 Grade, 3 1/2 in. OD by .125 in. wall. The total installed price of unit, pipe, engine, and all surface equipment except well head, was slightly less than 50 per cent of alternate proposals.

SUMMARY

The foregoing discussion has attempted to show that rod counterbalanced hydraulic pumping units, although having a few limitations, offer a proven, practical means of pumping wells of almost any depth and fluid rate with long, slow strokes, yet represent a substantial saving in initial investment in many cases and operating costs comparable to more conventional artificial lift methods. This economy is possible with either dual completions or with off-set wells on widely-spaced locations. It is felt that this system merits careful consideration, particularly in these times when the oil industry is perhaps more economy-minded than it has been in any previous period in its history.