May 19, 1942. A. HOLLANDER 2,283,207

ROTARY WELL DRILLING SYSTEM

Filed Nov. 18, 1939 3 Sheets-Sheet 1

Fig. 1

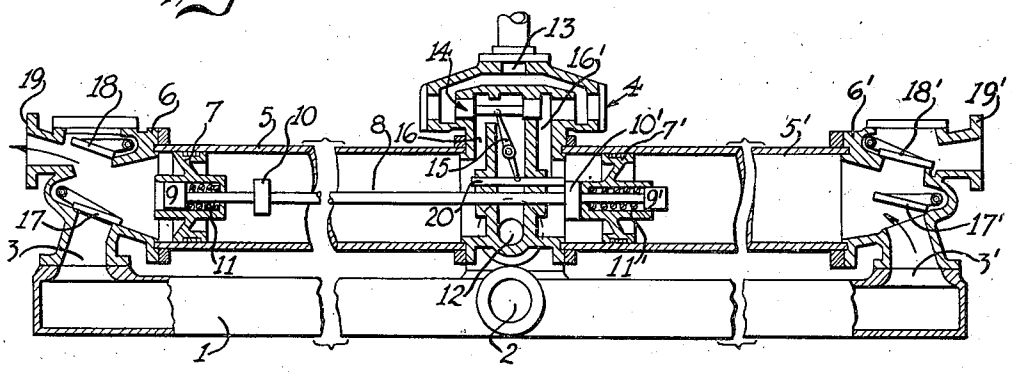


Fig. 2

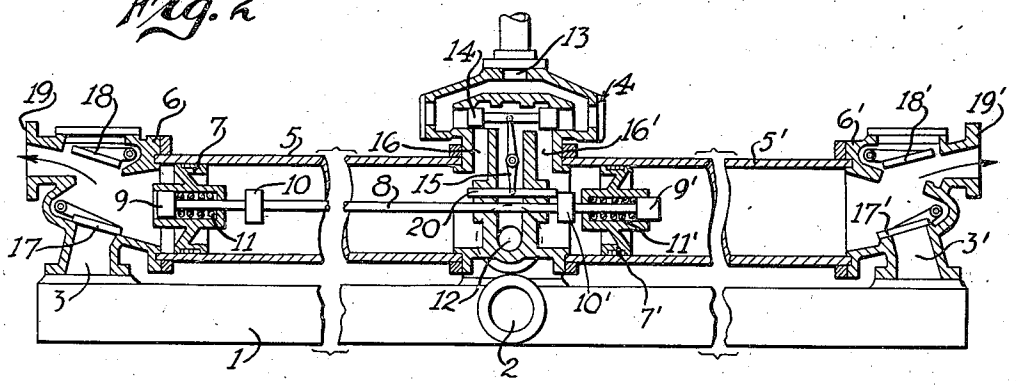
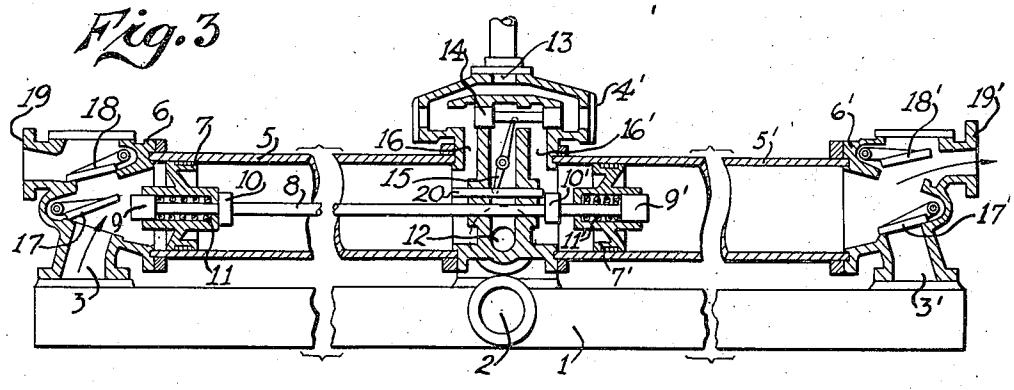


Fig. 3



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May 19, 1942. A. HOLLANDER 2,283,207

ROTARY WELL DRILLING SYSTEM

Filed Nov. 18, 1939 3 Sheets-Sheet 2

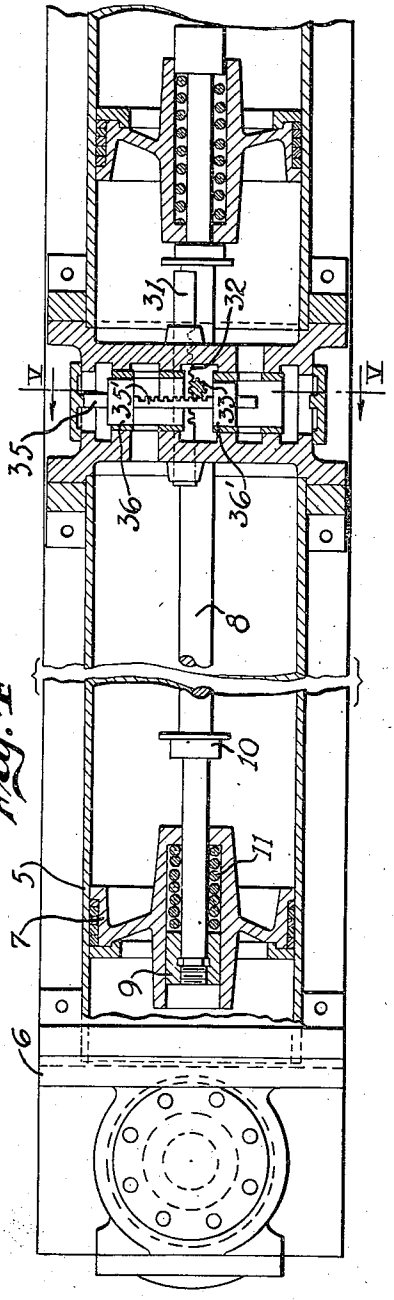


Fig. 4

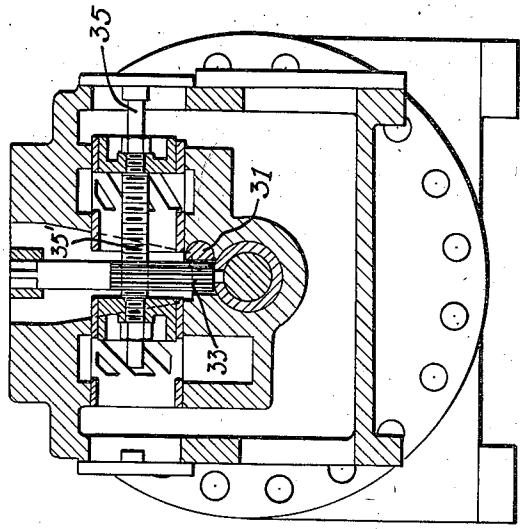


Fig. 5

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May 19, 1942. A. HOLLANDER 2,283,207

ROTARY WELL DRILLING SYSTEM

Filed Nov. 18, 1939 3 Sheets-Sheet 3

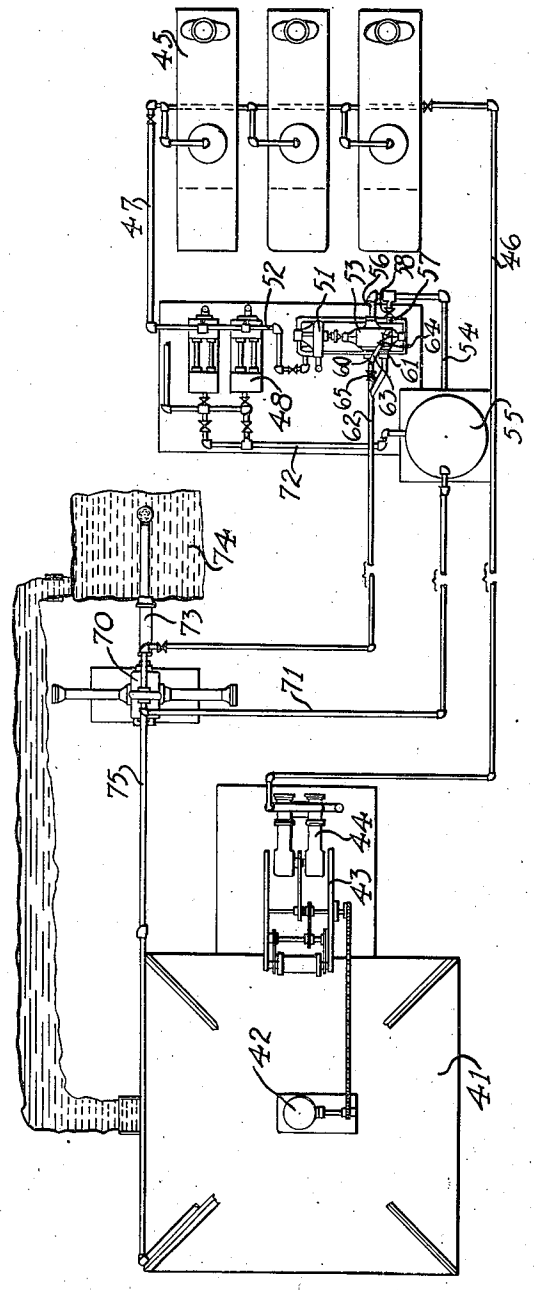


Fig. 6

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UNITED STATES PATENT OFFICE

2,283,207

ROTARY WELL DRILLING SYSTEM

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Original application March 21, 1938, Serial No. 197,139. Divided and this application November 18, 1939, Serial No. 305,136

3 Claims. (Cl. 255—24)

This invention relates generally to well drilling by the rotary method, and more particularly to a system for circulating drilling fluid in a well during the drilling operation.

In drilling wells by the rotary method, the bit is rotated by a string of hollow drill pipe suspended from the surface and through which drilling mud is circulated downwardly to the bit and upwardly outside the drill pipe to the surface. The upward circulation carries the cuttings to the surface where they are separated from the mud prior to recirculation of the mud in the well. Settling pits, screens, and separators of various types are employed to remove the cuttings, but complete removal thereof is never effected. Consequently the mud pumps are required to handle fluid containing a considerable amount of abrasive material, resulting in rapid abrasion of pump parts.

It is well established that the jetting action of the mud issuing from the bit passages has a pronounced effect on the rate of penetration of the bit into the formation, and, inasmuch as the force of the jets is a function of the mud pressure at the bit, the drilling speed can be materially augmented by maintaining a relatively high mud pressure. The pressure required at the pump discharge in order to obtain the desired jetting action depends on the length of the drill pipe, the internal diameter of the drill pipe, and the size of the mud passages in the bit. Since the size of the drill pipe necessarily decreases with greater depth, the mud pressure at the pump must be increased greatly for deep wells. Pressures ranging from 300 lbs./sq. in. for shallow depths up to 1600 lbs./sq. in. for depths of around 8000 feet are typical. In the event the drill pipe becomes stuck or the bit openings become clogged it is sometimes necessary to boost the pressure to as high as 5000 lbs./sq. in. to overcome this condition. The volume requirements are from 200 to 800 gal./min. It is thus seen that the mud pumps are required to handle a wide range of volumes of abrasive-laden fluid at a wide range of high pressures.

The only available type of pump capable of handling mud in the volume and pressure ranges required is the duplex double acting reciprocating pump. This type of pump is, however, far from ideal for this purpose, and is used only because nothing more suitable is available. Of the many defects inherent in such pumps, the following are among the most troublesome:

1. The pressure differential across the pistons is the full discharge pressure. In order to avoid piston leakage lip-type rubber pistons are used; while they prevent leakage, the drag exerted on the cylinder walls is tremendous, resulting in rapid wear of cylinder liners and pistons, not to mention the energy consumed in overcoming this drag. With full measure differential across the pistons, the size of cylinders is definitely limited at the prevailing pressures because of the piston drag, which increases with the pressure and in proportion to the piston diameter. Small pistons necessitate high piston speeds in order to obtain the required volume, and the resulting high velocity of abrasive fluid causes rapid abrasion of cylinder liners. With the full pressure differential across the pistons, any leakage rapidly develops into high velocity jets which cut the rubber pistons as though a knife were used.

2. Even with duplex pumps the discharge is pulsating, and, at the high pressures prevailing, this pulsation causes destructive vibration of the pumps, piping connections, and drill pipe.

3. The piston rods are necessarily under compression when moving in one direction, and the length of stroke is therefore limited due to the tendency of long rods to buckle.

4. Pump rod stuffing boxes are exposed on one side to the drilling mud, requiring frequent servicing of stuffing boxes and replacement of piston rods.

5. Because of the short stroke and small diameter pistons, the number of valve actuations per unit of time is necessarily high, and the rapidity of change from extremely high pressure to suction at each piston reversal causes pounding of the valves, resulting in relatively short life of valves and valve seats.

6. When changing to smaller size drill pipe after reaching considerable depth, it is cutomary to replace cylinder liners and pistons with ones of smaller size, in order to obtain higher pressures. This is a troublesome and expensive practice.

Because of the excessive wear and tear on pump parts as the result of the above-mentioned causes, the maintenance cost is very high. For example, the time required to drill an 8000-foot well is, on an average, about 120 days; during this time the mud pumps are operating about 90 days. It is customary to replace cylinder liners, pistons, cylinder heads, valves, and valve seats as many as 15 to 20 times in this 90 day period, resulting in a replacement cost per pump for pump parts alone on a single 8000-foot well, in the neighborhood of $3000, which is practically the initial cost of a pump.

The most common sources of power for mud pumps are steam, electricity, and internal combustion engines. Various combinations of the latter two have been tried in recent years, none of which are entirely satisfactory. They require expensive and cumbersome equipment, and unless additional speed reduction and speed control mechanism is provided they lack the required range of flexibility. Furthermore they lack the feature of automatic adjustment to

load, and in the event of sudden stoppage of flow of mud the pressure is likely to rise to the bursting point before it can be relieved. To the best of my knowledge, there is not available at present a pressure relief valve capable of handling such a situation at the prevailing pressures.

Steam is preferred by operators as a source of power for the mud pumps, chiefly because it is preferable as a drive for the drawworks and the rotary table and is readily available. It also is more flexible than the so-called "power" drives. The mud pumping units almost universally used at the present time comprise direct-acting steam-driven duplex pumps, in which the engine piston rods are connected directly to the pump piston rods. These units, however, have several outstanding defects in addition to the defects inherent in the pumps per se, such as:

1. A large majority of boilers used with drilling rigs are designed to operate at a pressure of about 225 lbs., and it is obvious that with a direct-acting steam engine operating at this pressure it is impossible to obtain the high mud pressures mentioned above while also maintaining the required volume of mud. Consequently, it is customary to operate 225-lb. boilers at pressures up to 350 lbs., creating a highly dangerous and otherwise unsatisfactory condition.

2. In order to increase the mud pressure it is the usual practice to admit steam to the engine cylinders for the full stroke of the pistons, thus failing to utilize the adiabatic expansion of the steam. This obviously results in low fuel efficiency, and requires a boiler plant of higher steam capacity than would otherwise be necessary.

3. It is customary to mount the mud pumps in close proximity to the well, whereas the boilers are required to be set back a distance sufficient to remove the fire hazard. Consequently, long steam lines are required from the boilers to the mud pumps, resulting in considerable heat loss.

With the aforementioned defects in view, I have invented a novel mud pumping system free from all such defects and having other advantages which will be set forth more in detail hereinafter.

Inasmuch as one of the chief causes of trouble in prior mud pumps is the existence of full pressure differential across the pistons, a principal object of this invention is to provide a mud pumping system employing a pump in which the pressure differential across the pistons is reduced to a minimum. This I have accomplished by the provision of a single cylinder divided centrally by a transverse partition, forming in effect two coaxial cylinders. A piston in each cylinder is connected to opposite ends of a common piston rod extending through the partition. One cylinder contains a driving or motive liquid under pressure and drilling mud under pressure, the two liquids being separated by the piston and the motive liquid being under a pressure only slightly greater than the mud pressure. The other cylinder contains spent motive liquid and suction mud on opposite sides of its piston, both of these liquids obviously being under substantially equal pressure with the motive liquid pressure slightly higher than the mud pressure. The motive liquid is alternately admitted to the two cylinders, causing reciprocation of the pistons and the pumping of mud from one cylinder while the other draws in mud.

A hydraulic pump of this type functions similarly to a single cylinder, double-acting pump direct-connected to a single cylinder, double-acting hydraulic motor, and is therefore properly characterized as a simplex, or single cylinder pump, as distinguished from a duplex, double-acting pump.

With the substantial equalization of pressures on opposite sides of the pistons, the sealing effect of the piston need not be so nearly perfect, and the drag exerted by the pistons on the cylinder walls is reduced in proportion to the reduction in pressure differential across the pistons. The wear resulting from this piston drag is thus eliminated. With a slightly higher pressure on the motive liquid side of the pistons, any leakage across the pistons will be of clean motive liquid rather than of drilling mud, and the peripheries of the pistons will be kept washed clean. Contamination of the clean motive liquid by drilling mud is also avoided by this arrangement. The leakage of a small amount of clear water into the drilling mud is not objectionable since it is necessary to add make-up water to the mud from time to time.

The elimination of several other defects of prior pumps is also made possible by the substantial equalization of pressure on opposite sides of the piston. The limitation on piston diameter, imposed by the piston drag as discussed above, is removed and relatively large pistons and cylinders may be employed. With increased piston area the piston speed, and consequently the fluid velocity, may be reduced while still maintaining the same output volume of mud. Reduction in fluid velocity results in additional reduction of wear on the cylinder walls.

By the present arrangement, the piston rod is always under tension, and never under compression, making it possible to provide a long stroke such as would be impossible if the piston rod were under compression, because of the tendency of the rod to buckle. Of equal importance is the fact that there is no stuffing box exposed to mud—the only stuffing box is exposed to clear motive liquid on both sides.

An actual embodiment of a pump according to my invention has two coaxial cylinders each 6 feet long and 10 inches in diameter. It will be apparent that by the provision of cylinders of this length and diameter a long, slow stroke is possible, resulting in relatively few reversals per minute. The number of valve actuations is proportionately reduced, and the pounding of valves on their seats as the result of rapid valve actuation is eliminated entirely.

A still further object of this invention is to provide a mud pumping system wherein the highly desirable performance characteristics of a centrifugal pump may be availed of, without subjecting the centrifugal pump to the harmful effects of the abrasive mud. The performance characteristics of a centrifugal pump are ideally suited to pumping drilling mud. When driven at constant speed it has no definite head or capacity, but is dependent on the resistance to flow of the pumped liquid for the establishment of any fixed head or capacity. It has, however, a definite shut-off head for a given speed, and regardless of flow resistance it will not develop a greater head. It also has a definite maximum capacity at zero head for any given speed. By merely varying the pump speed or throttling the discharge, the pressure and volume can be varied through a wide range. There is no necessity of changing the size of the mud pump liners and pistons to obtain varying pressures, as in pumps now in use. These characteristics make the centrifugal pump ideal

for pumping drilling mud, so far as hydraulic performance is concerned.

However, because of the abrasive nature of drilling mud, it would not be practicable to handle the mud directly by a centrifugal pump. Replacement of worn parts would be required even more frequently than with pumps now in use. In a system in accordance with this invention, however, the volume and pressure characteristics of a centrifugal pump may be transferred to the drilling mud indirectly through the novel balanced-piston hydraulic pump, wherein the displacement of mud equals that of the clear motive liquid, and the mud pressure is always only a few pounds less than that of the motive liquid.

A still further object of this invention is to provide a hydraulic mud pumping system comprising a prime mover, a centrifugal pump driven thereby and delivering clear motive liquid, and a hydraulic mud pump actuated by the motive liquid.

Another characteristic of centrifugal pumps which makes them especially well adapted to supply motive liquid for hydraulic pumps handling drilling mud is their capability of being compounded either in series or in parallel, providing unusually wide pressure and volume ranges. When drilling at relatively shallow depths, a large volume of mud at pressures ranging from 600 to 800 lbs./sq. in. is required while at great depths a decreased volume at pressures from 1000 to 1500 lbs./sq. in. is required. These pressure and volume requirements are obtainable with a series-parallel multi-stage centrifugal pump, or a plurality of pumps connectible in series or in parallel, while being driven at constant speed.

A still further object of this invention is to provide a hydraulic mud-pumping system including a prime mover, a series-parallel centrifugal pump driven thereby, and a hydraulic mud pump operated by motive liquid by the centrifugal pump.

As stated previously, the steam-driven mud pumps now in use are very inefficient from a standpoint of fuel economy, chiefly because steam is admitted to the cylinders during the full stroke of the pistons and the adiabatic expansion of the steam is not utilized. In the system of this invention, however, the prime mover may be a steam turbine, the most efficient of any steam-driven prime mover. Or, if desired, any other type of prime mover may be used, such as a Diesel engine or an electric motor.

Another object of this invention is to provide a hydraulic mud pumping system including a centrifugal pump and a hydraulic mud pump actuated by motive liquid supplied by the centrifugal pump, the latter being driven by a steam turbine, a Diesel engine, an electric motor, or any other prime mover of high efficiency.

Other objects and advantages will become apparent from the following description, in conjunction with the accompanying drawings, in which

Fig. 1 is a central vertical longitudinal section through one form of the invention, illustrating conditions near the end of piston travel to the left;

Fig. 2 is a view similar to Fig. 1, with the reversing valve in mid-position;

Fig. 3 is a view similar to Figs. 1 and 2, with the reversing valve completely reversed and the stroke of the pistons to the right begun;

Fig. 4 is a central horizontal longitudinal section through a slightly modified form of the invention;

Fig. 5 is a transverse section taken substantially on line V—V of Fig. 4; and

Fig. 6 is a plan view of the hydraulic mud pumping system installed at a well being drilled.

Referring to Figs. 1 to 3 of the drawings, a hollow base plate 1 serves the dual purpose of supporting the pump and of providing a suction reservoir for fluid to be pumped. Inasmuch as the pump is particularly adapted to handle drilling mud, the pumped fluid will for convenience be referred to hereinafter as mud. A centrally disposed mud suction inlet 2 connects the interior of the hollow base with the source of mud, such as the mud pit located adjacent a well being drilled. Mud suction connections 3 and 3' at the ends of the base 1 lead from the reservoir to the outer ends of the pump cylinders.

Secured in coaxial relation on opposite sides of a central body 4 is a pair of cylinders 5 and 5'. Mud valve heads 6 and 6' on the outer ends of the cylinders contain valves controlling the inflow of suction mud and the outflow of discharge mud, the valve heads also serving as supporting connections between the outer ends of the cylinders and the hollow base. Reciprocable within the cylinders are pistons 7 and 7', slidably mounted on the opposite ends of a common piston rod 8. The extent of outward movement of the pistons relative to the piston rod is limited by collars 9 and 9' formed on the ends of the piston rod and engageable by the piston. Inward movement of the pistons on the rod is limited by engagement of the pistons with collars 10 and 10' secured to the piston rod. Springs 11 and 11' interposed between the pistons and collars 9 and 9' yieldably urge the pistons inwardly. The collars 9 and 9' are slidable in bores in the pistons 7, 7' in fluid-tight relation thereto, and are in effect pistons, preventing leakage of fluid from one side to the other of the pistons 7, 7'.

The central body 4 constitutes a valve chamber for motive liquid, hereinafter referred to as water for convenience, although it will be understood that any other suitable liquid may be employed. Water under suitable high operating pressure is admitted from a suitable source to the valve chamber through a water inlet 12, the spent water returning to the source through an outlet 13. The inlet 12 communicates with a central passage between the two valves of a balanced piston valve assembly 14. The valves are operated by a pivoted lever 15 operably connected to a plunger 20 reciprocable in a longitudinally extending bore in the central body and disposed in the path of the collars 10 and 10' to be engaged by one of the latter at the end of each stroke.

The valve 14 alternately admits high pressure water from the inlet 12 to passages 16 and 16' leading respectively to cylinders 5 and 5'. When one of the passages 16 or 16' is connected to inlet 12, the other passage is in communication with outlet 13 to vent its respective cylinder, except for a brief interval during reversal of the stroke, as will be explained hereinafter.

The mud valve head 6 at the outer end of cylinder 5 contains an inwardly opening mud section valve 17 controlling communication between suction connection 3 and cylinder 5, and an outwardly opening mud discharge valve 18 communicating with a discharge nozzle 19. Valve head 6' on cylinder 5' is equipped with similar valves 17' and 18' and discharge nozzle 19'. The discharge nozzles are adapted to be connected

to a common discharge pipe for delivery of mud to the point of use.

The mode of operation of the pump is as follows: Water or other liquid under pressure is supplied to the inlet 12 from a suitable source, preferably a centrifugal pump. When the valve 14 is in the position shown in Fig. 1, the pressure water enters cylinder 5 through passage 16, moving piston 7 to the left and forcing mud out through the discharge valve 18 and nozzle 19. The pressure of the water will exceed by only a slight amount the pressure of the discharge mud, the piston speed depending on the back pressure imposed on the discharge mud. If the power pump is a centrifugal pump, it will be understood by those familiar with the operating characteristics of this type of pump that the pressure developed thereby depends on the resistance to flow, and the slower the piston speed the higher the pressure developed, up to the shut-off head of the particular pump.

At the same time that piston 7 is pumping mud out of cylinder 5, piston 7' is also moved to the left, forcing spent motive liquid out of cylinder 5' through passage 16' and outlet 13, and drawing mud into the cylinder to the rear of the piston from the suction reservoir through suction connection 3' and valve 17'.

During this time the high discharge mud pressure is exerted against the left end 9 of piston rod 8, while the other end thereof 9' is exposed to mud at suction pressure. Consequently the spring 11 will be compressed by relative movement between piston 7 and rod 8. The spring 11', however, exerts initial force greater than that necessary to force spent water out of cylinder 5', and spring 11' will remain extended as shown in Fig. 1.

As the pistons approach the left ends of the cylinders, collar 10' engages the plunger 20 and gradually moves it to the left, thus shifting valves 14 to the right. The spacing of the valves 14 is so related to the distance between passages 16 and 16' that passage 16' is opened to admit high pressure water to cylinder 5' before passage 16 is closed to high pressure water. In the central position of the valve, as shown in Fig. 2, high pressure water is admitted to both cylinders momentarily, thus moving both pistons outwardly and building up pressure on the mud in both cylinders.

The equalization of the pressures acting on the opposite ends of the piston rod 8 causes the latter to move further to the left until the compression of the springs 11 and 11' is equalized. This movement of the piston rod causes the valve 14 to be shifted to its extreme right-hand position, fully opening the passage 16' to high pressure water and closing passage 16 to high pressure water and establishing communication between the latter passage and the outlet 13. Both pistons then move to the right, forcing mud under pressure from cylinder 5' and drawing mud into cylinder 5.

It will be evident that during the brief interval when pressure fluid is being admitted to both cylinders, both pistons are pumping mud and a continuous flow thereof is thus provided. The flow of pressure liquid into the cylinders is also continuous, thus preventing water hammer. Both of these conditions are made possible by the floating piston arrangement.

The above described arrangement also eliminates the possibility of the reversing valve stalling on dead center, by providing a positive force which acts on the valve to complete the reversal thereof.

Referring now to Figs. 4 and 5, a modified reversing valve assembly is disclosed. It will be observed that with the pivoted lever valve-actuating means shown in Figs. 1 to 3 it is necessary that the reversing valve be reciprocable longitudinally of the main cylinders. In the form shown in Figs. 4 and 5, however, the valve is reciprocable transversely of the main cylinders. This is made possible by utilizing a compound rack and pinion arrangement. The central body, main cylinders, pistons and mud valves of this form of the invention are substantially identical with those shown in Figs. 1 to 3, and hence will not be described in connection with this form.

A plunger 31, corresponding to the plunger 20 of Figs. 1 to 3, is provided with rack teeth 32 along the central portion of one side thereof. Teeth 32 mesh with teeth on an elongated pinion 33 journaled on a vertical axis in the central body. As shown in Fig. 5, the plunger 31 engages the pinion 33 adjacent its lower end, and the toothed portion of the pinion extends a substantial distance along the pinion shaft. Spaced above the plunger 31 and extending at right angles thereto and also at right angles to the pinion 33 is a valve stem 35 having rack teeth 35' along the central portion of one side thereof meshing with the teeth on pinion 33. It will be apparent that reciprocation of the plunger 31 will cause oscillation of pinion 33 about its axis, which in turn will cause reciprocation of valve stem 35.

Formed on the valve stem 35 is a pair of spaced valves 36, 36', corresponding to valves 14 of Figs. 1 to 3, the valves being spaced relative to the parts so as to provide for admission of high pressure water to both cylinders simultaneously for a brief interval during reversal of the valve.

The valve arrangement of Figs. 4 and 5 has one advantage over that of Figs. 1 to 3, in that by the transverse disposition of the valve the longitudinal dimension of the central body may be reduced, being independent of the length of the valve assembly. Both valve assemblies are of relatively simple construction, with a minimum of moving parts subject to wear.

From the foregoing description, it will be apparent that a simple and ingenious arrangement has been provided for continuing the flow of motive liquid and of pumped liquid during reversal of the stroke of the pistons of a simplex hydraulic pump. This result is attained without the necessity of providing auxiliary equipment such as accumulators or air chambers. Furthermore, in addition to the continuous flow referred to above, the floating piston arrangement makes it possible to actuate the reversing valve directly by the piston rod without any danger of the valve stalling in dead center—a defect inherent in directly actuated reversing valves for hydraulically operated devices.

The substantial balancing of the pressures on opposite sides of the pistons is an outstanding characteristic of this pump, reducing to a minimum the piston drag and the consequent wear on cylinder walls. The piston rod is always under tension, and never under compression, making possible a long stroke without the danger of the piston rod buckling. The piston rod stuffing box is exposed only to clear water and never to abrasive-laden mud, thus eliminating the ne-

cessity of frequent servicing of the stuffing box and replacement of the piston rod. Other advantages will be apparent to those familiar with the problems encountered in the pumping of drilling mud.

In Fig. 6 is shown a schematic layout of the hydraulic mud pumping system at a well being drilled. The well derrick floor is shown at 41, the rotary table at 42, the draw-works at 43, and a conventional steam drilling engine at 44. The battery of boilers 45 are shown set back from the well in a customary manner, and connected by a steam line 46 to the drilling engine 44; a second steam line 47 supplies steam to the boiler feed water pumps 48. Thus far the layout follows conventional practice.

A steam turbine 51, located adjacent the boilers, is supplied with steam through an extension 52 of the steam line 47, and is direct-connected to a centrifugal pump 53. This pump is a multi-stage centrifugal pump having a series-parallel hook-up, whereby the pump is divided into two halves, the stages of the two halves being capable of being compounded either in series, for high pressure, or in parallel, for lower pressure and greater volume. A water supply line 54 leading from a tank 55 is connected to the inlets 56 and 57 of the two halves of the pump, the inlet 57 being provided with a shutoff valve 58. Outlets 60 and 61 for the respective halves merge into a common discharge pipe 62. A cross-over 63 having a valve 64 is provided between outlet 60 and inlet 57, and a valve 65 is provided between outlet 60 and the common discharge pipe 62. When valves 58 and 65 are open and valve 64 is closed, the two halves of the pump are connected in parallel, each having an inlet and an outlet, and delivering a relatively large amount of water at relatively low pressure. When valves 58 and 65 are closed and valve 64 is opened, the discharge from the first half enters the intake of the second half, and in the two halves are connected in series, delivering a relatively small amount of water at relatively high pressure.

The common discharge line 62 extends to the hydraulic mud pump 70, and a return line 71 leads from the mud pump to the tank 55. A water line 72 extends from the tank to the boiler feed water pumps. A mud suction line 73 extends from the usual mud pit 74 to the suction inlet of the mud pump, and a mud discharge line 75 leads from the pump to the usual connection to the drill pipe (not shown).

The foregoing illustrates one type of installation, adapted for use at a steam-operated rig. It will be understood that if preferred any other desired type of prime mover may be employed, such as a Diesel engine or an electric motor.

Although the invention has been explained by describing in detail a particular embodiment thereof, it is to be understood that many departures can be made from the specific construction shown without departing from the invention which is to be limited only to the extent set forth in the appended claims.

This application is a division of my copending application Serial No. 197,139, filed March 21, 1938, for Pumping apparatus.

I claim:

1. In a well drilling system, in combination with a drilling rig including a drill string: a source of supply of abrasive drilling mud, and a pumping system for delivering abrasive drilling mud from said source to the drill string in a steady flow and at steady pressure, comprising a centrifugal pump; driving means therefor; and means for impressing on said abrasive drilling mud the pressure and volume characteristics of said centrifugal pump while protecting the latter from the deleterious effect of direct contact of the drilling mud therewith, said means comprising a cylinder and a movable partition in the cylinder dividing the latter into a drilling mud compartment and a motive liquid compartment; fluid connections from the drilling mud source to said drilling mud compartment and from the latter to said drill string; a source of clear, non-abrasive motive liquid having no deleterious effect on said centrifugal pump, and fluid connections from said last-named source to the centrifugal pump and from the latter to the motive liquid compartment of said cylinder; whereby the pressure and volume characteristics of the centrifugal pump are indirectly impressed on the drilling mud through the intermediacy of the motive liquid, and admixture of the drilling mud and motive liquid are substantially prevented by the movable partition in said cylinder.

2. In a well drilling system, in combination with a drilling rig: a mud pumping system for supplying abrasive drilling mud under pressure to the well, comprising a prime mover; a centrifugal pump driven thereby; a hydraulically actuated mud pump comprising a cylinder and a piston reciprocable in said cylinder and dividing the latter into a drilling mud compartment and a motive liquid compartment; a source of abrasive drilling mud, suction connections from said source to said drilling mud compartment and discharge connections from the latter to the well; a source of clear, non-abrasive liquid having no deleterious effect on the centrifugal pump, suction connections from said last-named source to said centrifugal pump and discharge connections from the latter to the motive liquid compartment of said mud pump; the piston of said mud pump being freely movable in its cyclinder to discharge drilling mud from the mud pump in response to delivery of motive liquid thereto from said centrifugal pump, and the opposed pressure areas of said piston being approximately equal, whereby the pressure and volume characteristics of the discharged drilling mud are determined by and are approximately equal to the pressure and volume characteristics of the motive liquid supplied by said centrifugal pump.

3. In a well drilling system, the combination with a drilling rig, of a hydraulically actuated mud pump having a suction pipe connected to a source of supply of drilling mud and a discharge pipe connected to the drill stem; said mud pump comprising a cylinder and a piston reciprocable in said cylinder and dividing the latter into a drilling mud compartment and a motive liquid compartment, the opposed pressure areas of said piston being approximately equal whereby the pressure and volume characteristics of the drilling mud discharged from the pump are determined by and are approximately equal to the pressure and volume characteristics of the motive liquid supplied to the pump; and a source of motive liquid under pressure for actuating said pump, comprising a centrifugal pump having fluid connections with said mud pump for delivering motive liquid thereto in a steady flow and at steady pressure, and a prime mover for driving said centrifugal pump.

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