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EARLY OIL WELL DRILLING EQUIPMENT AND PRODUCTION PRACTICES

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R. J. Heemstra
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EARLY OIL WELL DRILLING EQUIPMENT AND PRODUCTION PRACTICES

by

R. J. Heemstra,[1] K. H. Johnston,[2] and F. E. Armstrong[3]

ABSTRACT

A detailed description of early-day cable-tool drilling rig construction and drilling practices is presented. Intimate descriptions of various parts of drilling rigs and prime movers are given as to materials of construction as well as to their use. The body of material is broken down into two main categories: well drilling methods, and well completion and production methods. This information is largely directed to the need for locating abandoned well sites by identification of equipment parts and layouts. These abandoned wells are potential hazards to people in the coal industry if they intersect coal seams under development. The material is well illustrated from documented sources, and general nomenclature is given.

INTRODUCTION

The contents of this information circular serve a threefold purpose. First, this report permits the reader to embrace casually the subject matter from a point of view of general historical interest with perhaps some perspective to the present.

Second, the details are developed in such a way so as to give an intimate knowledge and familiarity of the various types of drilling and production equipment used in the last 100 years. This information could be used as an illustrated supplement to other sources in educational institutions wishing to present a history of petroleum drilling methods and equipment in the United States.

Third, and most important, occasionally a need arises for the identification of metal parts from old oilfield machinery and equipment for the purpose

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[1]Research chemist.
[2]Petroleum engineer, now retired.
[3]Project leader.
All authors were with the Bartlesville Energy Research Center, Bureau of Mines, U.S. Department of the Interior, Bartlesville, Okla., before its transfer in January 1975 to the Energy Research and Development Administration.

of locating abandoned well sites (6).[4] This report serves this purpose by giving an in-depth historical treatment of oilfield machinery, their construction and use, and their general nomenclature.

Early drilling and producing methods are discussed and are well illustrated to acquaint the reader with a logical layout of equipment used and their construction (1-5, 7-8). Various parts associated with such equipment are listed.

The body of material is broken down into two main categories: well drilling methods, and well completion and production methods. Although the methods in each category exhibit parallel development in terms of materials used and power sources needed, each category is individualistic in terms of design know-how at that particular time in history.

ACKNOWLEDGMENTS

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American Institute of Mining, Metallurgical, and Petroleum Engineers, AIME Library: Figures 28, 37, 38
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American Petroleum Institute: Figures 23, 24, 30, 34
University of Oklahome Press, Norman: Figures 29, 35, 36, 40, 43
United Natural Gas Co.: Figure 32

OIL WELL DRILLING METHODS AND EQUIPMENT

In drilling oil and gas wells, sand and other formations must be penetrated, drill cuttings must be removed, and casing must be set to prevent sloughing of the walls and to seal out formation waters. The methods used in drilling oil and gas wells may be classified into two main groups, each using fundamentally different systems for penetrating rock and radically different types of equipment. These are percussion (cable-tool) methods and rotating drill (rotary) methods. The percussion method of drilling was in use many years before the rotating method was known. Although a rotary rig was used at Spindletop, Tex., in 1901, very little, if any, rotating drill equipment was used in the Appalachian area prior to 1935. However, rotary-drill equipment is used there commonly today.

Percussion Drilling Systems

Standard Cable-Tool Rig

The standard drilling rig and wooden derrick used in the operation of a string of cable tools are shown in figure 1. The derrick, which supports in

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[4] Underlined numbers in parentheses refer to items in the list of references at the end of this report.

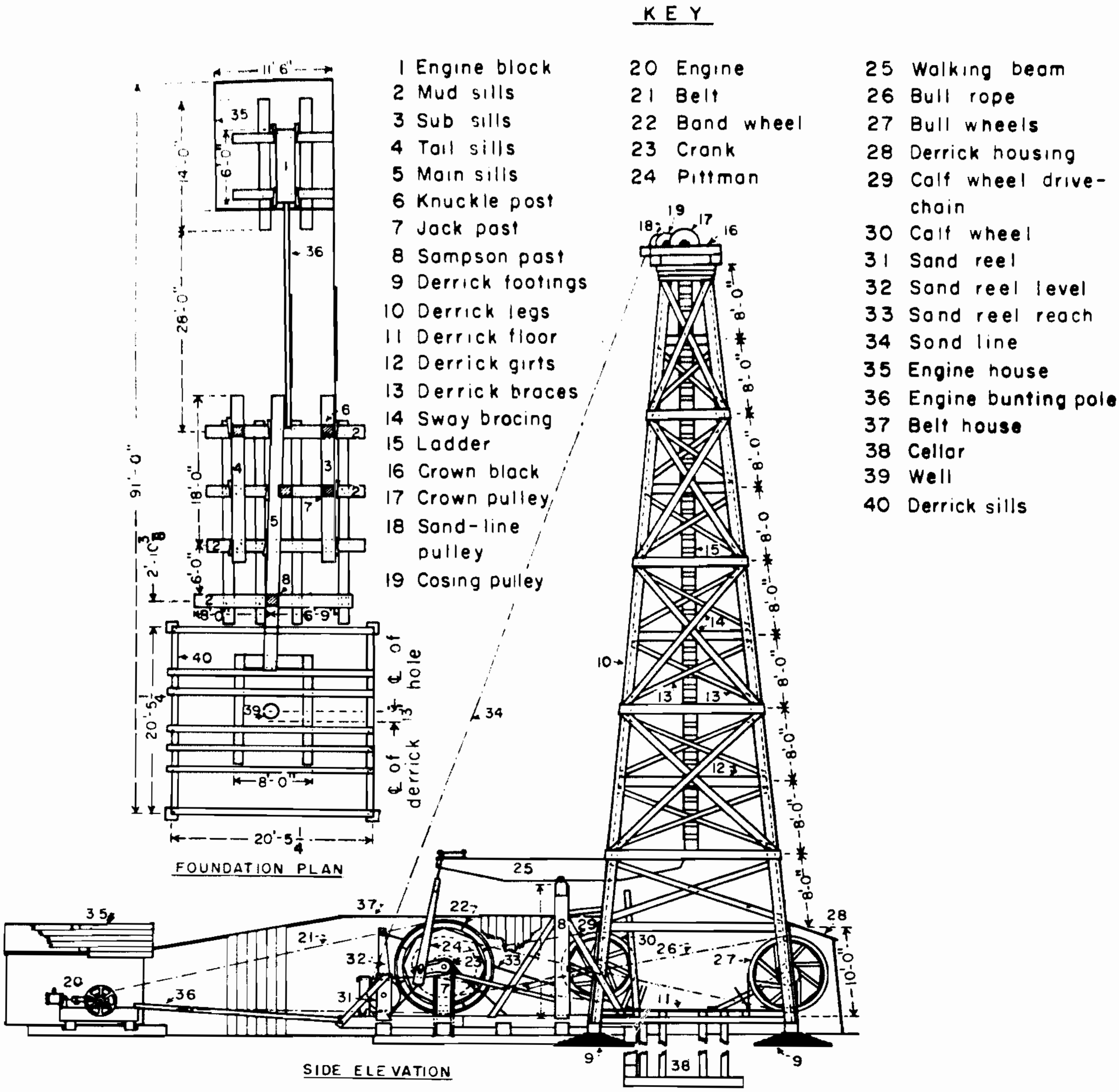


FIGURE 1. - Plan and elevation of an 82-foot standard cable-tool rig and wooden derrick with all parts numbered.

position various tools, wheels, sheaves, and cables, and provides a support to pull against in handling long strings of tools and casing, must be braced in all directions and securely anchored on firm foundations so that it will not collapse or be pulled over.

Cable-tool derricks, constructed of either wood or steel, vary in height with the depth to be drilled and the amount of casing to be handled. Derricks for cable-tool drilling vary from 60 to 82 feet in height and are from 16 to 24 feet square at the base and from 4 to 6 feet square at the top. The derrick usually was built from lumber and timbers readily available near the drilling site. The bull wheel and calf wheel shafts and posts, pitman, jack posts, and crown blocks were made from hard woods, preferably oak. For the derrick and other timbers, common pine, hemlock, and other soft woods were used.

As drilling depths became deeper, heavier and stronger materials were needed for the construction of derricks, and in 1892 the first steel derrick was built. Steel derricks may be classified in two general types: (1) Structural steel derricks, which are made of ordinary structural steel shapes, such as angles, channels, and 1-beams; and (2) tubular steel derricks made of steel pipe.

Surface equipment for an early model cable-tool drilling rig (fig. 2) consisted of a prime mover, a band wheel, a bull wheel for handling the drill line, an eccentric, a pitman, and a walking beam from which hung the temper screw and clamps. The prime mover, either a steam engine or an internal combustion engine, rotated the band wheel and band-wheel shaft, to which the eccentric was connected. The pitman operated off the eccentric, imparting alternate up and down motion to each end of the walking beam, which was supported in the center by a sampson post. The temper screw (fig. 3) attached to the derrick end of the walking beam supported the clamps that held the wire drilling line at the desired length. As the bit penetrated the formations, the line below the clamp was lengthened by "playing out" the temper screw, or if composed of steel wire, by slipping the line through the clamps. Most temper screws had a range of 60 to 70 inches.

One end of the drilling line was spooled on the bull-wheel shaft, and the other, which passes over the crown sheave on top of the derrick, was attached to the tool in use. The bull wheel was driven by large manila-rope belts from the band wheel. The calf wheel, on which one end of the casing line was spooled, was used to run the casing into holes of reasonable depth. It was driven by chain and sprockets from the band-wheel shaft. The bailer, which was used to remove material loosened by the drill, was raised and lowered by a sand line spooled on the sand reel. The reel was driven, either from the band-wheel shaft by chain and sprocket, or from the band wheel by a friction pulley. The drilling line was a steel cable, or a steel cable with a manila-rope "cracker" on bottom, or a manilar rope from top to bottom. For a rope line or "cracker" line, a stiff socket was used because the rope was pliable enough to allow the tools to rotate.

A string of standard cable tools (fig. 3) consisted of several parts securely connected by tool joints. The drill cable was attached to the tools by a special connection called a swivel, or rope socket. The lower part of the swivel was screwed to the top of a pair of massive telescoping metal links called drilling "jars," which had a stroke of from 12 to 16 inches. As additional weight was required on the drill bit, a drill stem or sinker bar was placed between the swivel and jars. The jars were connected to the top of a long cylindrical drill stem which in turn was connected to the top of the drill bit.

A heavy bar of steel or iron from 4 to 11 feet long (usually 7 or 8 feet) and somewhat wider than it was thick was used to make a bit. The bar was

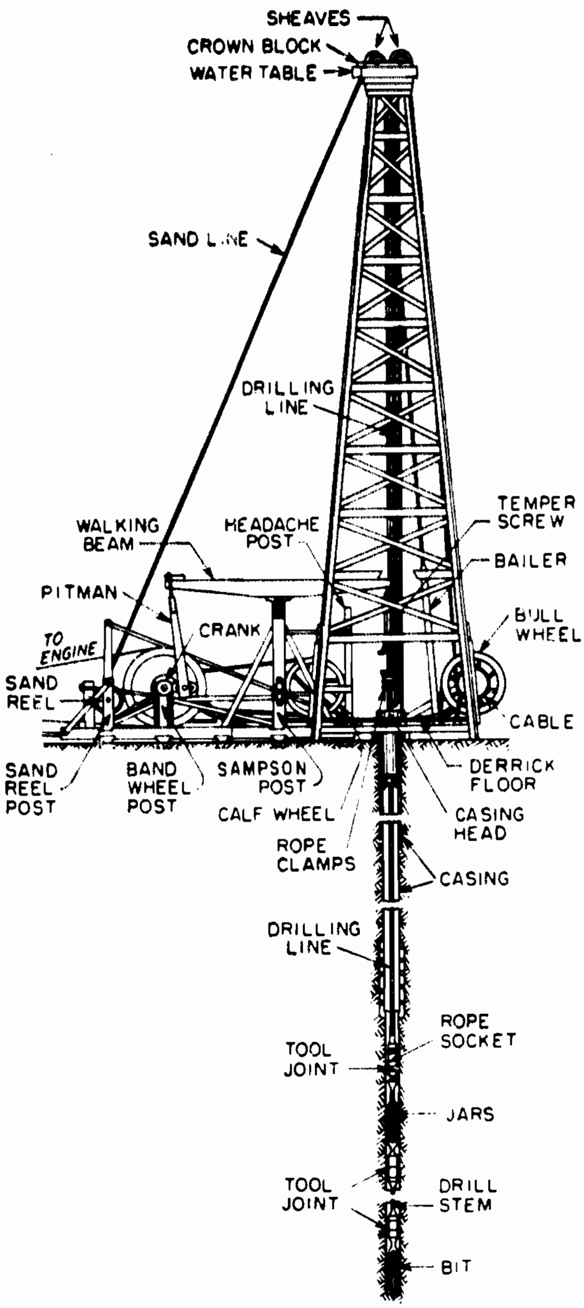


FIGURE 2. - General features of an early model cable-tool drilling rig. (From Elements of the Petroleum Industry, 1940, AIME Library.)

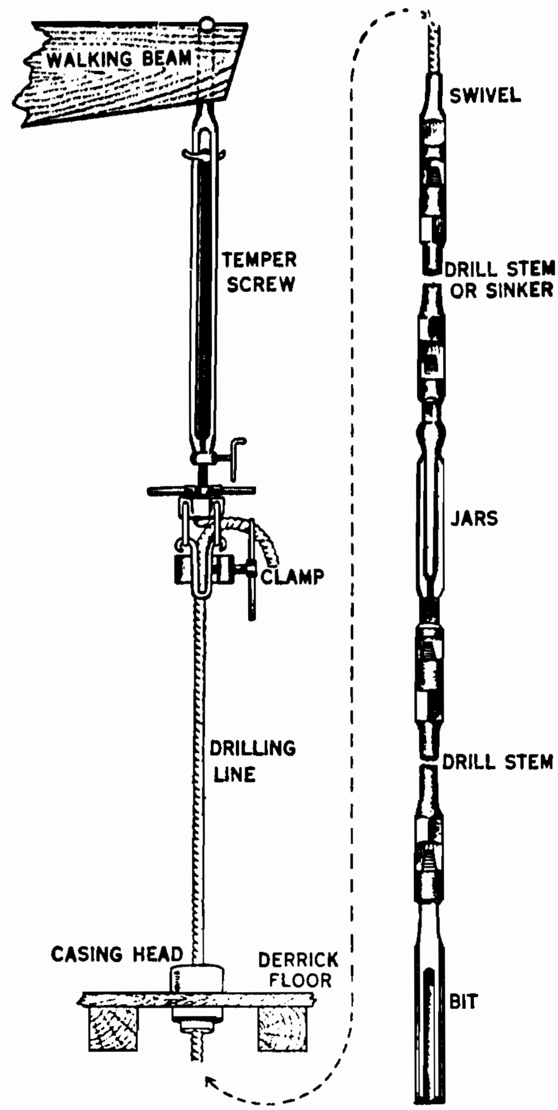
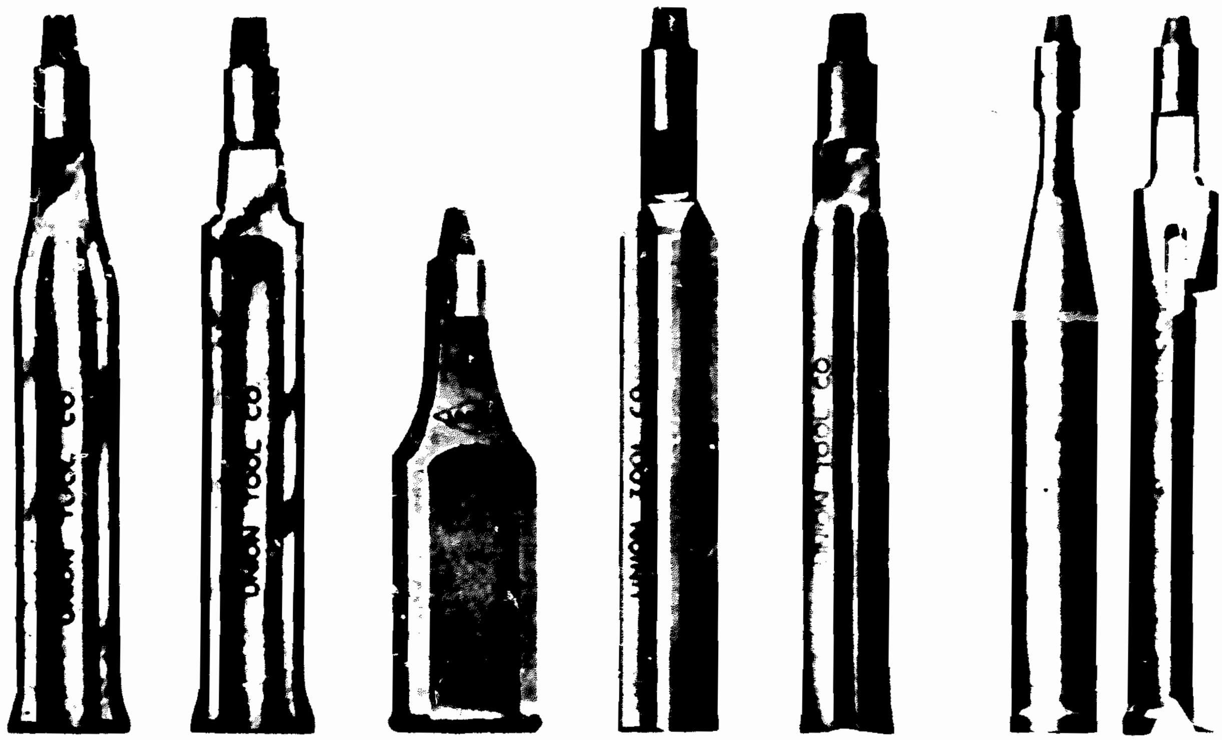


FIGURE 3. - Details of an early model string of cable-drilling tools.

dressed to a blunt edge on one end and terminated in a tapered tool joint on the other. The faces of the bit on the cutting end were grooved to form water courses which permitted the cuttings and mud to pass around the bit, and water to freely follow the cutting surfaces. The form of the cutting edge was varied to conform with the characteristics of the formation penetrated. A fairly sharp chisel edge was used for hard rock drilling and an almost flat bit with only a blunt edge at the center was used for shale or soft formations. Several common types of bits used for different kinds of formations are shown in figure 4.



A B C D E F

FIGURE 4. - Types of cable-tool drill bits. *A*. California pattern. *B*. Mother Hubbard pattern. *C*. Spudding bit. *D*. Star bit. *E*. Round reamer. *F*. Overman bit.

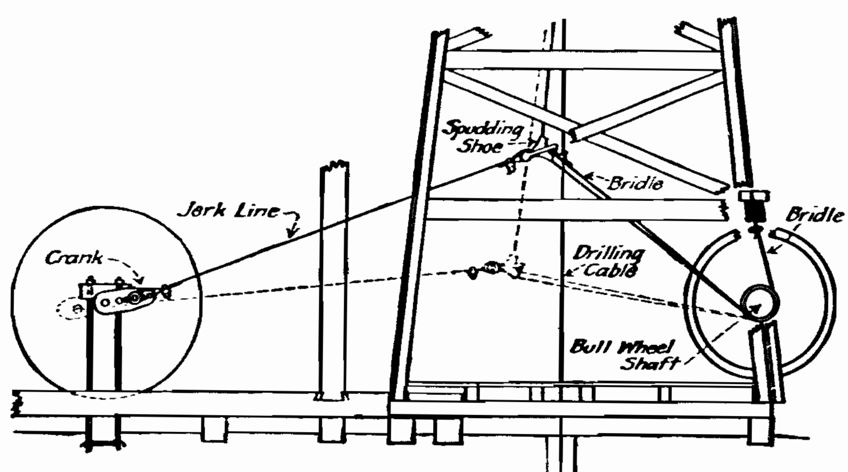


FIGURE 5. - Illustration of spudding operation. (From Petroleum Production Engineering, 4th Ed., by Lester C. Uren. Copyright 1956 by McGraw-Hill Book Co., Inc. Used with their permission.)

Since the complete string of cable-drilling tools was 40 feet or more in length, there was not sufficient room to conduct drilling operations with the aid of a walking beam until at least 60 feet of depth was attained. Therefore the first 60 feet, or sometimes as much as several hundred feet, was drilled by a process known as "spudding." The process, which did not require the use of a walking beam, involved the use of a special spudding bit (part C, fig. 4) and a short drill stem without jars. The up and down motion of the bit was obtained by connecting one end of a jerk line, by a spudding shoe, to the drill cable slightly above the bull wheel and the other end to the wrist pin on the band-wheel crank, as shown in figure 5.

As the crank revolved, the drill cable raised and lowered the drill bit. When sufficient hole was spudded, the equipment was removed, the temper screw was adjusted on the end of the walking beam, and the complete string of cable tools was assembled as shown on the right in figure 3. The actual drilling was accomplished by raising and lowering the string of tools by the up and down motion of the walking beam.

Portable and Semiportable Cable-Tool Rigs

Portable and semiportable drilling machines are often used for prospecting and for drilling wells in shallow areas. They operate on the same principle with quite similar equipment, but are much lighter than the standard cable-tool rig. Each part of the standard rig, often changed in form and size to adapt it to available space and render it more transportable, is found on most portable rigs. The design of the mast probably is the greatest difference noted in the several types of portable and semiportable rigs. The mast, which serves the same purpose as the derrick, must provide a support at a suitable height, for the sheaves used in changing the direction of the drilling cable, sand line, and casing lines. Two types of mast in common use were the single-post mast, consisting of a heavy timber (metal used later) mounted on the ground or on one end of the truck on which the machine was mounted, and the two-legged braced mast, built of metal channels latticed together or two heavy timbers suitably braced by horizontal girts and mounted on the sides of the truck. In some cases, the mast was entirely independent of the drilling mechanism. The mast had to be slightly inclined from vertical to clear the top sheaves from the supports and braced in several directions by guy wires.

During the early part of the century, many skid-mounted and wheel-mounted drilling rigs were built. However, they were designed primarily for shallow drilling, and as the search for oil and gas went deeper, the standard cable-tool rig was used almost exclusively. A few machines, such as the Star, Keystone, and Wolf drilling rigs and the Fort Worth and Bucyrus-Erie spudders survived into the 1930's and 1940's, and some are in use at the present time, but most of them have been modernized and improved or replaced by the steel machines of modern times.

Both walking beam and spudder-type drilling machines were used. A spudder-type rig imparts up and down motion to the tools by means of a floating sheave that rolls down and up on the drilling line as it leaves the drum. Illustrations of both walking-beam and spudder-type portable and semi-portable drilling machines, that were used from the turn of the century to the 1940's and probably later, are shown in figures 6 to 13, inclusive.

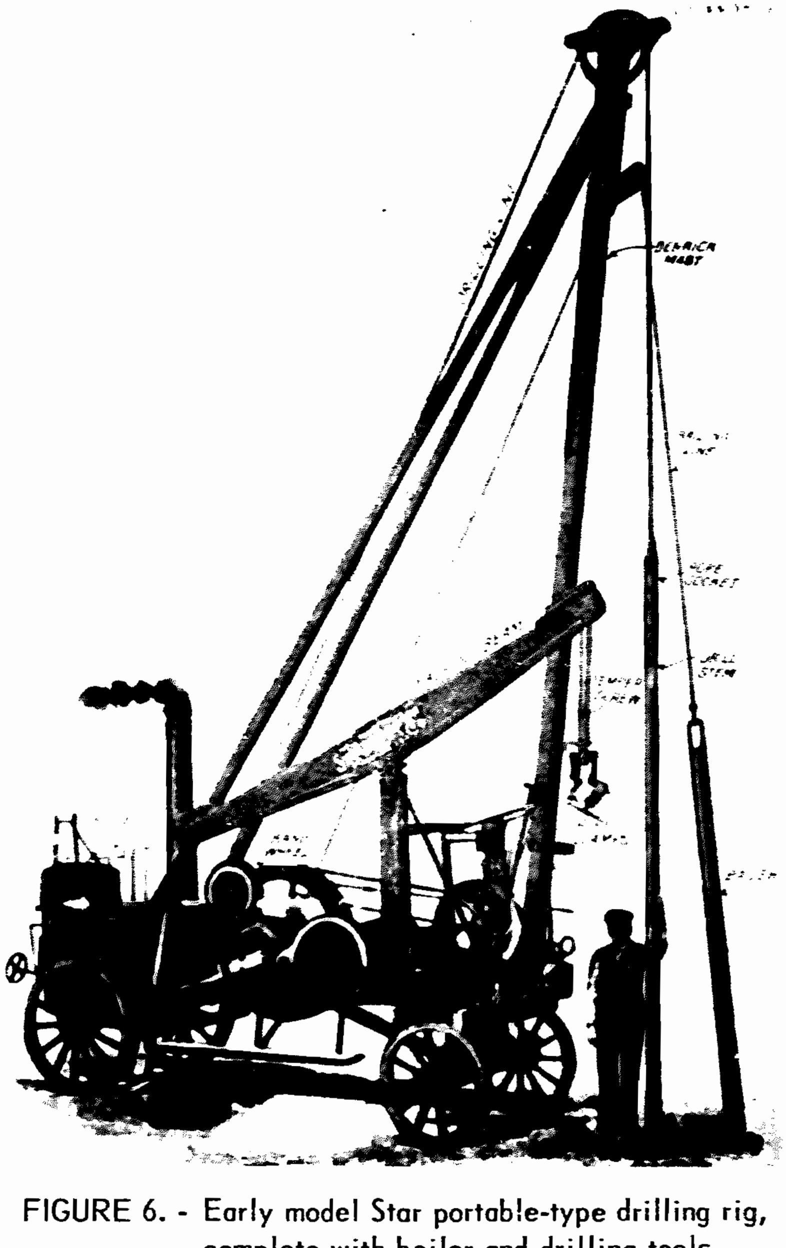


FIGURE 6. - Early model Star portable-type drilling rig, complete with boiler and drilling tools.

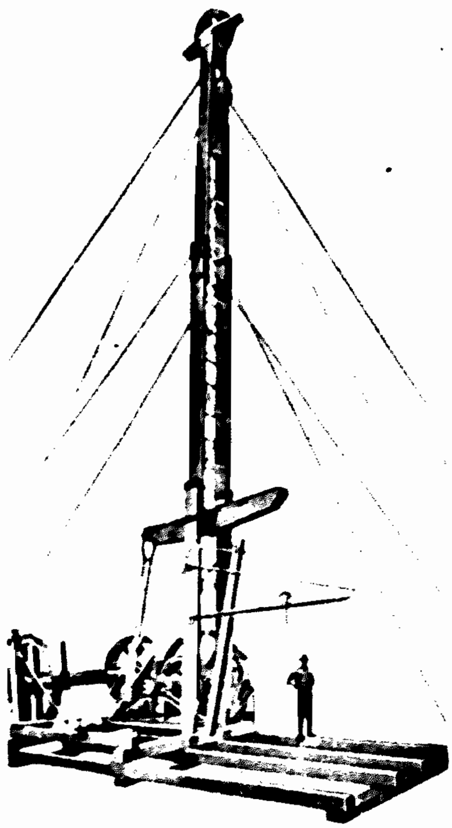


FIGURE 7. - National semiportable-type drilling rig with braced two-legged mast; in use about 1900.

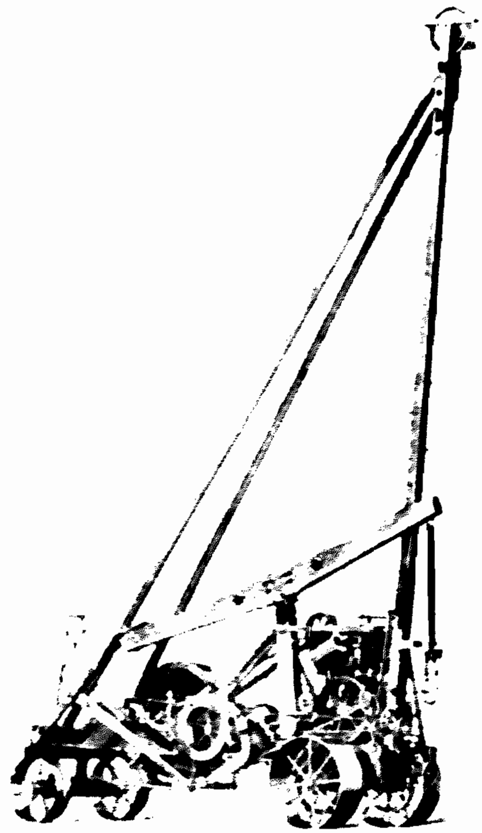


FIGURE 8. - Star portable-type drilling machine with 35-hp steam engine and 60-foot single-post mast.

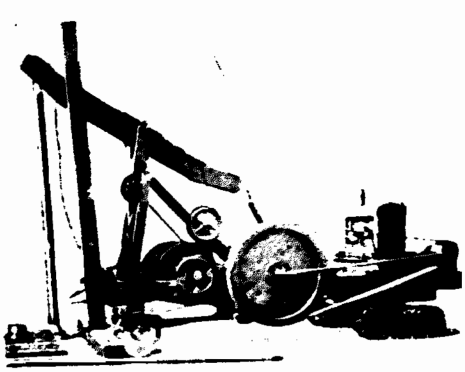


FIGURE 9. - Star portable-type drilling machine with 90-hp gasoline engine. (From Deep Well Drilling, 3d Ed., by Walter H. Jeffery. Copyright 1931 by W. H. Jeffery. Courtesy Gulf Publishing Co.)

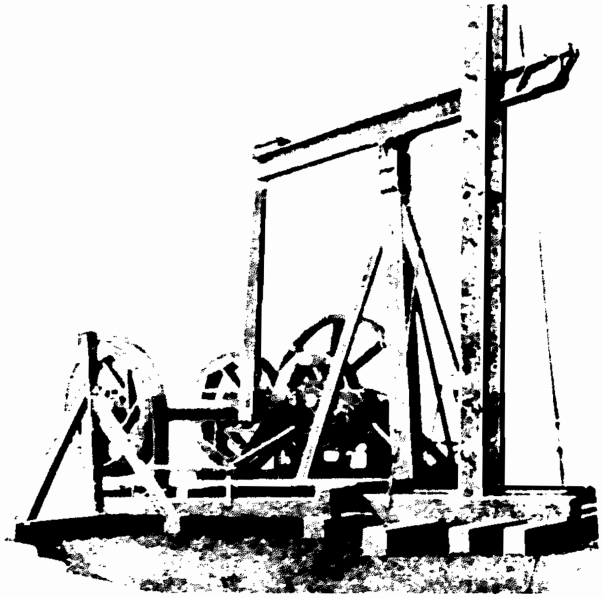


FIGURE 10. - Parkersburg combination wood and steel portable-type drilling machine. (From Deep Well Drilling, 3d Ed., by Walter H. Jeffery. Copyright 1931 by W.H. Jeffery. Courtesy Gulf Publishing Co.)

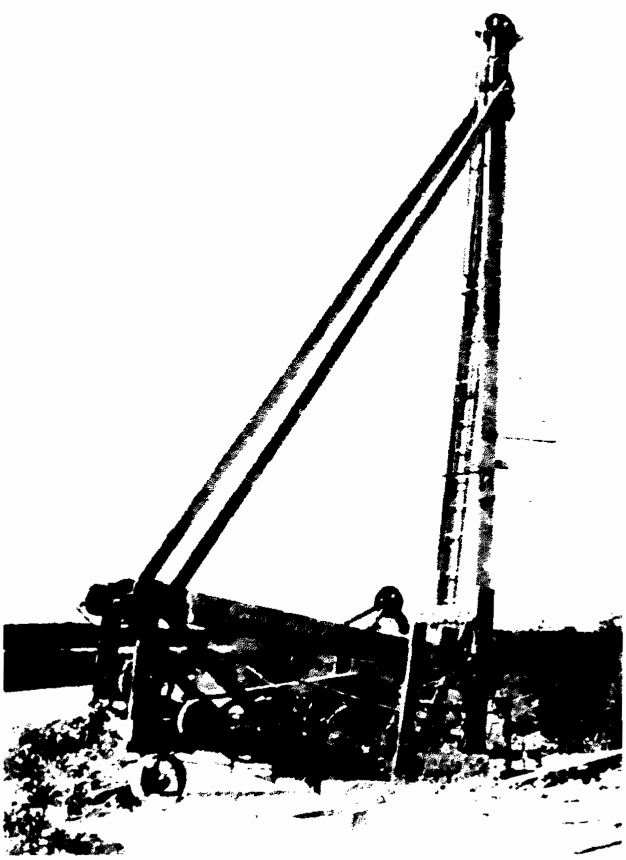


FIGURE 11. - Ft. Worth spudder-type portable drilling machine with 48-foot A-type mast. (From Deep Well Drilling, 3d Ed., by Walter H. Jeffery. Copyright 1931 by W.H. Jeffery. Courtesy Gulf Publishing Co.)

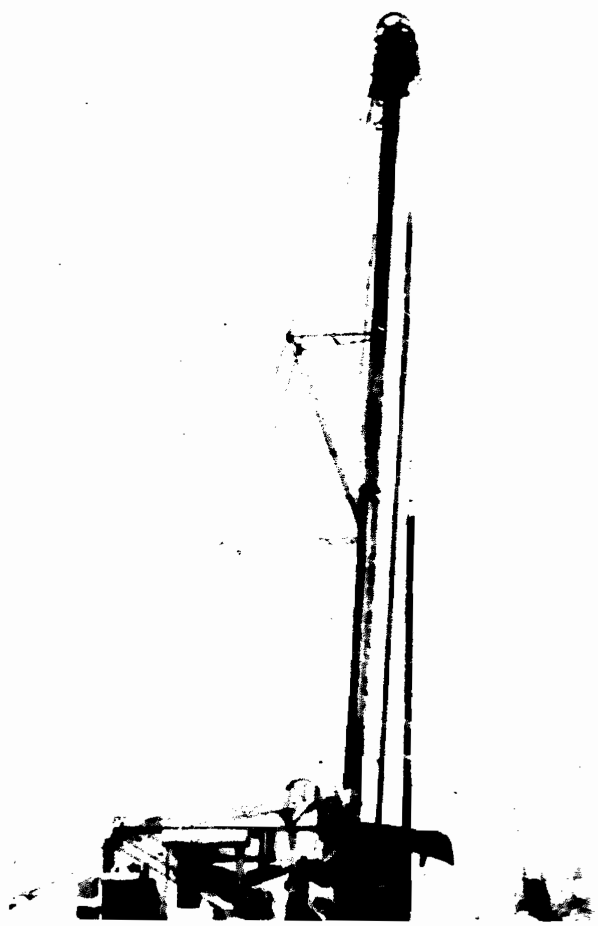


FIGURE 12. - Bucyrus-Erie spudder-type portable drilling machine.

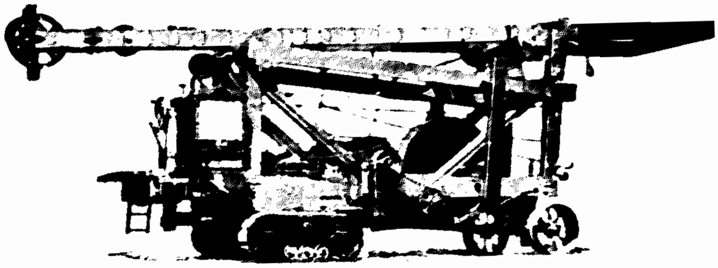


FIGURE 13. - Star spudder-type portable drilling machine with 38-foot mast. (From Deep Well Drilling, 3d Ed., by Walter H. Jeffery. Copyright 1931 by W. H. Jeffery. Courtesy Gulf Publishing Co.)

Power Plants

Cable-tool rigs of the several types were powered by steam, internal-combustion engines, or electric motors. The single-cylinder, heavy-flywheel steam engine (fig. 14) undoubtedly provided the most satisfactory motion to the tools and was preferred where boiler-feed water and fuel were available. However, steam engines were not shown in 1940 general oilfield catalogs, and by 1954 the use of steam engines for powering cable-tool rigs had practically stopped. The early efforts to adapt the gas engine to cable-drilling service were made with horizontal, single-cylinder type engines. Adaptability of these engines was found to be poor because of the lack of flexibility in speed and power. This failure prejudiced operators against all types of gas engines. However, tests made with vertical, four-cylinder engines indicated that larger sizes of multicylinder engines were capable of operating cable-drilling equipment in a satisfactory manner and at considerable less cost than with the less efficient

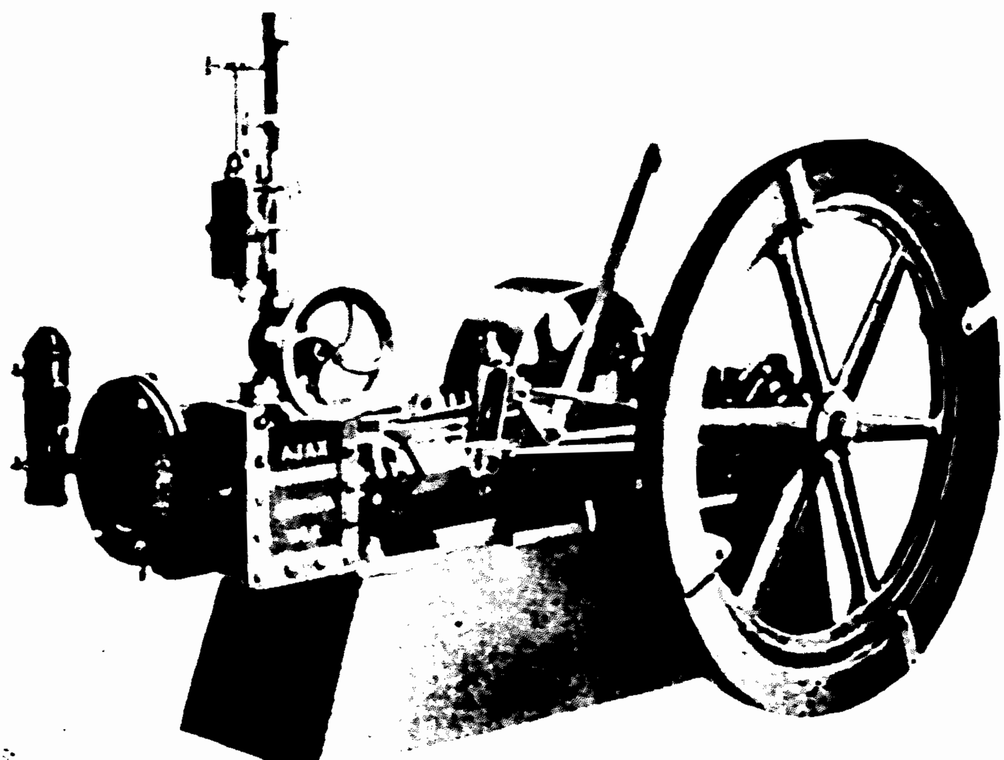


FIGURE 14. - Single-cylinder, reversible slide-valve steam drilling engine.

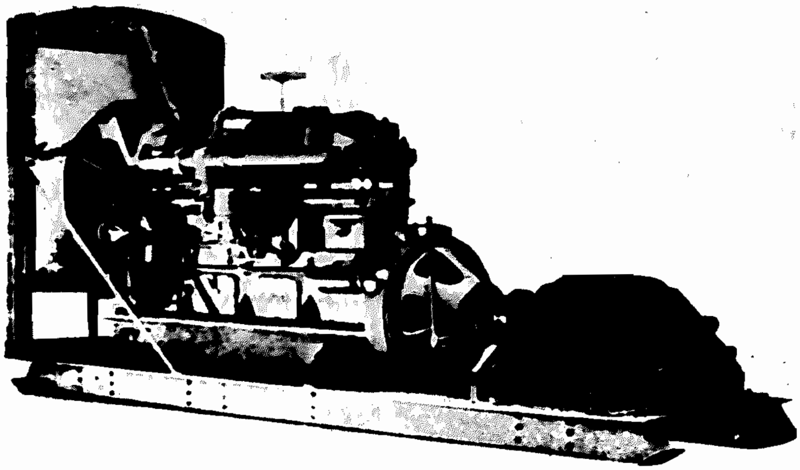


FIGURE 15. - Eight-cylinder, 200-hp engine powered by gas, gasoline, or distillate. (From Deep Well Drilling, 3d Ed., by Walter H. Jeffery. Copyright 1931 by W. H. Jeffery. Courtesy Gulf Publishing Co.)

steam engine. The eight-cylinder, 200-hp, internal combustion engine powered by gas, gasoline, or distillate, shown in figure 15, is an example of this type of engine. On light-duty, shallow holes, for which portable equipment is usually employed, steam (figs. 6 and 8), diesel, gasoline (fig. 9), natural gas or butane-fuel, prime movers were used. No great amount of cable-tool drilling has ever been done with electricity, but from time to time it had been found advantageous to use ac motors where transmission lines were available.

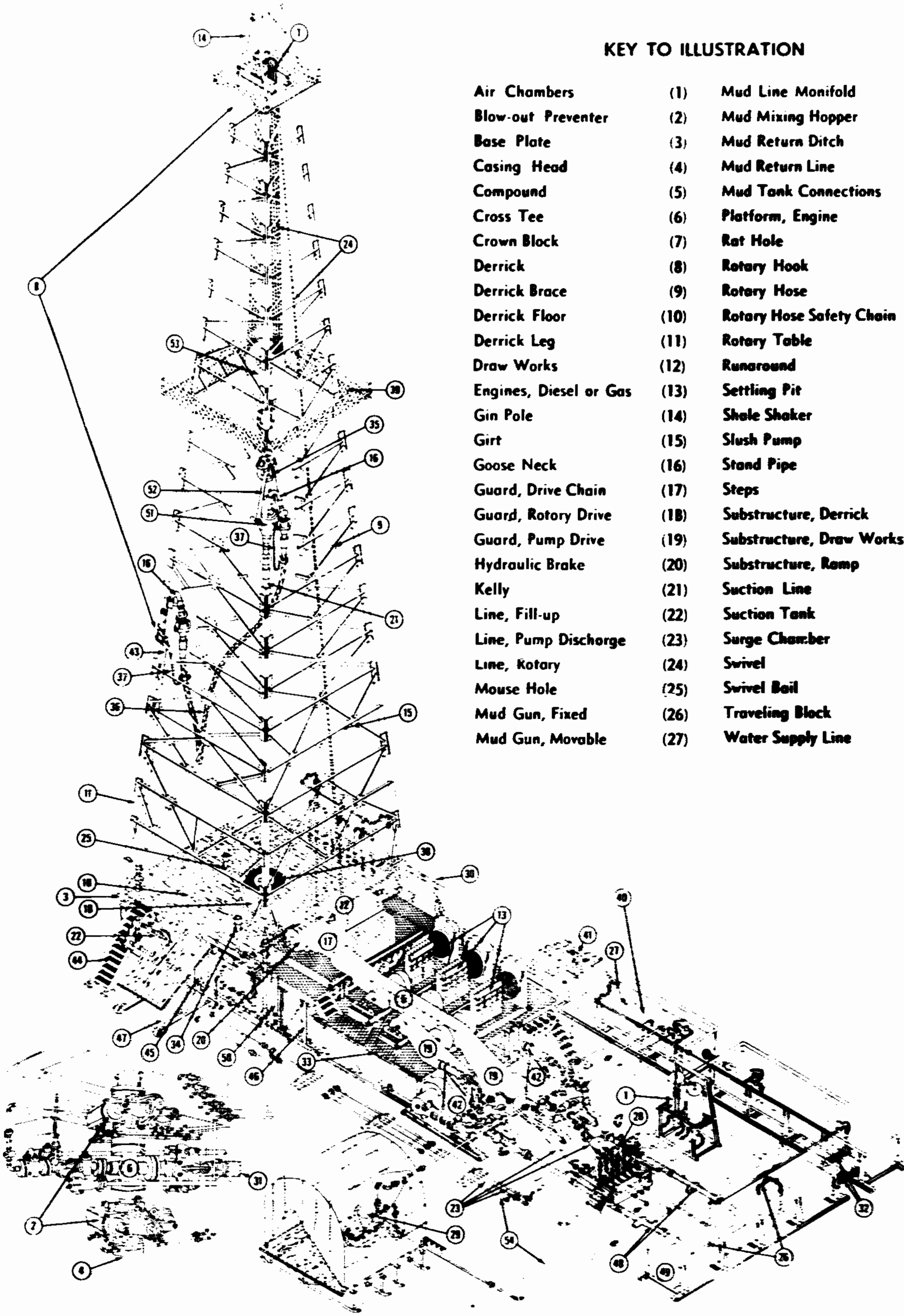
Rotating Drill Systems

The essential difference between rotating and percussion methods of drilling is that in the rotating method the formation is bored through by rapidly rotating a column of pipe with a cutting bit on the lower end, whereas in the percussion method the formation is shattered by raising and lowering the string of tools with the up and down motion of the walking beam.

Rotary-Drilling Rig

The rotary-drilling rig differs from the standard cable-tool rig in that it has no walking beam, bull wheel, band wheel, or sand-line reel. It is composed of a derrick; equipment with a "rotary," which is a device for rotating the bit; a "draw works" or "hoist," which is used for raising and lowering the drill pipe and tools; boilers and steam-, gas-, diesel-, or electric-powered engines, to drive the draw works and rotary table, as shown in figures 16 and 17.

The rotary derrick is a higher and heavier structure with a larger base than the standard cable-tool derrick, but is otherwise similar in design. The larger derricks, which range from 84 to 176 feet in height, are needed to rack the drill pipe, which is pulled from the well when it is necessary to change or inspect the drill bit. The extra height permits the drill pipe to be broken out in larger and consequently fewer stands, which decreases the time required to pull and rerun the drill bit.



KEY TO ILLUSTRATION

Air Chambers	(1)	Mud Line Monifold	(28)
Blow-out Preventer	(2)	Mud Mixing Hopper	(29)
Base Plate	(3)	Mud Return Ditch	(30)
Casing Head	(4)	Mud Return Line	(31)
Compound	(5)	Mud Tank Connections	(32)
Cross Tee	(6)	Platform, Engine	(33)
Crown Block	(7)	Rat Hole	(34)
Derrick	(8)	Rotary Hook	(35)
Derrick Brace	(9)	Rotary Hose	(36)
Derrick Floor	(10)	Rotary Hose Safety Chain	(37)
Derrick Leg	(11)	Rotary Table	(38)
Draw Works	(12)	Runaround	(39)
Engines, Diesel or Gas	(13)	Settling Pit	(40)
Gin Pole	(14)	Shale Shaker	(41)
Girt	(15)	Slush Pump	(42)
Goose Neck	(16)	Stand Pipe	(43)
Guard, Drive Chain	(17)	Steps	(44)
Guard, Rotary Drive	(18)	Substructure, Derrick	(45)
Guard, Pump Drive	(19)	Substructure, Draw Works	(46)
Hydraulic Brake	(20)	Substructure, Ramp	(47)
Kelly	(21)	Suction Line	(48)
Line, Fill-up	(22)	Suction Tank	(49)
Line, Pump Discharge	(23)	Surge Chamber	(50)
Line, Rotary	(24)	Swivel	(51)
Mouse Hole	(25)	Swivel Bail	(52)
Mud Gun, Fixed	(26)	Traveling Block	(53)
Mud Gun, Movable	(27)	Water Supply Line	(54)

FIGURE 16. - Rotary-drilling rig and steel derrick with all parts numbered.

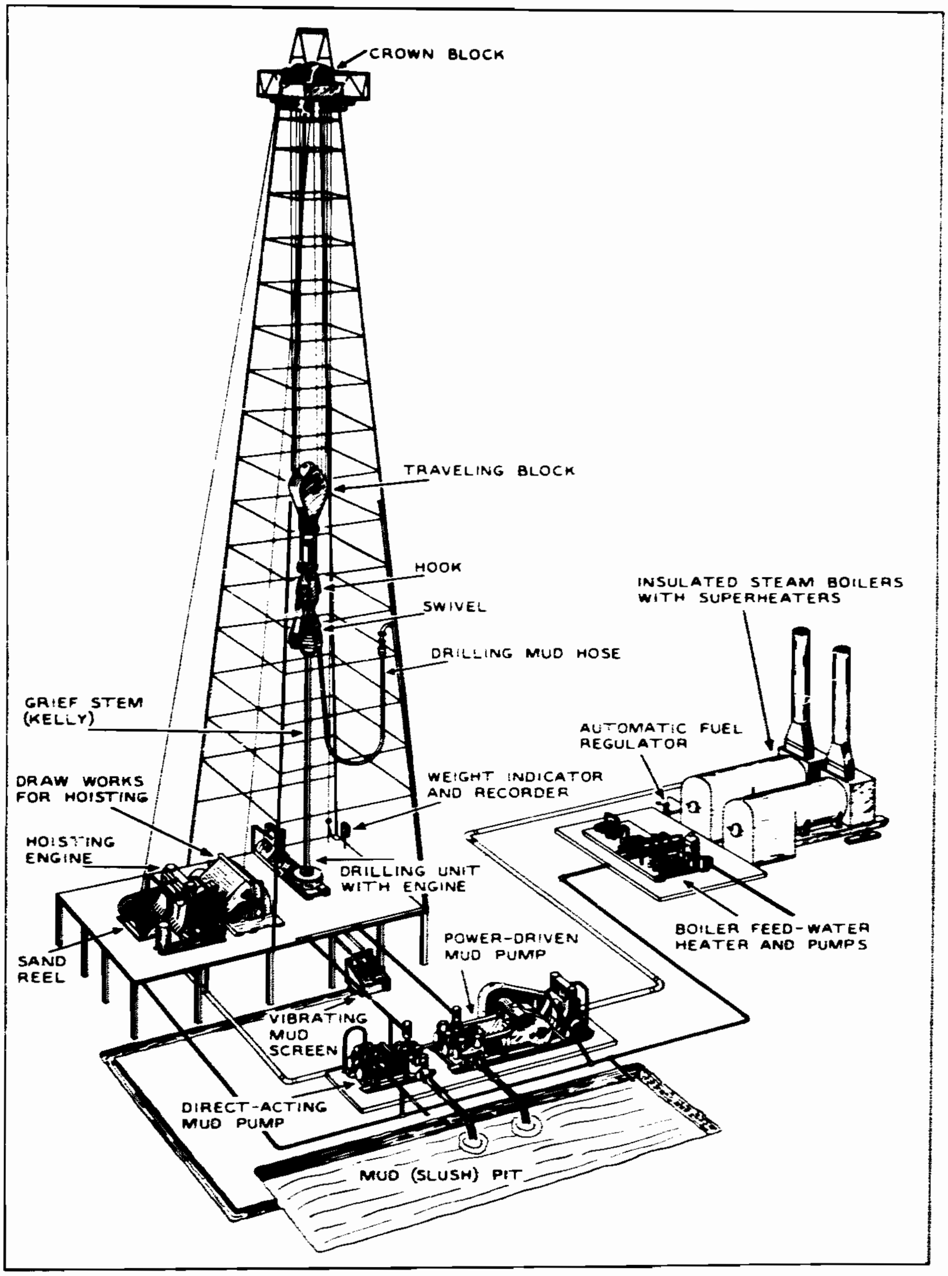


FIGURE 17. - Steam-driven rotary rig of the 1930's, showing surface equipment and boiler-plant layout.

The swivel, drill column, and bit are raised and lowered in the well by means of a steel cable operating through a massive traveling block strung from sheaves at the derrick crown. The free end of the cable passes down through the derrick and is wound on a heavy hoisting drum, which is driven from a line shaft by chain belts and sprockets. The line shaft, during early years of operation, was driven by a chain belt from a sprocket on the crank shaft of a steam engine, as shown in figure 18.

In later years, power was furnished by variable-speed electric motors and by diesel-, gas-, and gasoline-driven internal combustion engines. On the line shaft there was also a sprocket for a chain drive, which operated the rotary table (fig. 18). The hoisting drum with its supporting shaft, the drive shaft, sprockets, brakes, clutches, and supports are known collectively as the "draw works."

In the rotary system of drilling, the rock mass, through which the well is drilled, is abraded and chipped away by the downward pressure and the cutting and grinding action of a revolving steel bit that may assume various forms, as shown in figure 19. The usual form of bit was the "fish tail," which was used by preference whenever the formations to be penetrated were

FIGURE 18. - Early model rotary-drilling rig equipped with an open chain drive (in use about 1921).

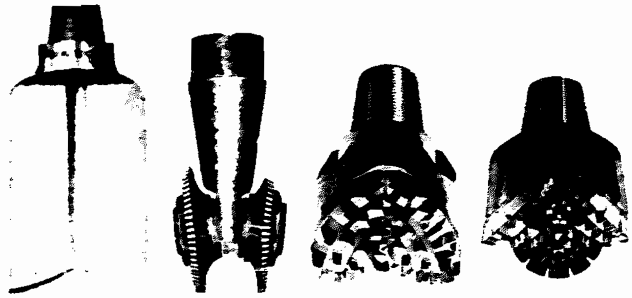


FIGURE 19. - Rotary-drill bits: fish tail, disk, two-cone rock bit, and tri-cone rock bit.

soft or moderately soft rock, loosely cemented sands, shales, or clay. For drilling in hard formations, various types of disk and revolving cone bits have been devised. Examples of these bits are the fish tail, disk, and two- and three-cone rock bits shown in figure 19. The cutting bit is revolved by a "drill column," extending from the top of the drilling tool to a point some distance above the derrick floor. At derrick-floor level the "grief stem" or "kelly" passes through a gripping device in the rotary table, which is mounted over the mouth of the well. The form of the gripping device is such that, while the rotary table has a positive grip on the kelly, the latter is free to move vertically through the table even while rotating. To the top of the kelly, a massive "swivel" is attached, supported by a large hook suspended from the traveling block. The drill column may thus rotate with the table while the upper part of the swivel, the traveling block, and the supporting cables remain stationary. The drill column and swivel are hollow, so that water or mud can be pumped, as shown in figure 20, by slush pumps (A) from the mud pit (H) down through swivel (B), kelly (C), and drill pipe (D), to bit (E), and out into the wellbore through holes in the bit. The fluid sweeps under the cutting elements of the bit, picks up drill cuttings, and carries them to the surface through the annulus (F). At the surface, a pipe carries the cuttings in suspension through a shale shaker (G), which removes the cuttings from the drilling fluid. From the shaker, the drilling fluid goes back to mud pit (H) and the cycle is begun again. Figure 21 shows a typical heavy-duty, direct-acting, steam-driven slush pump.

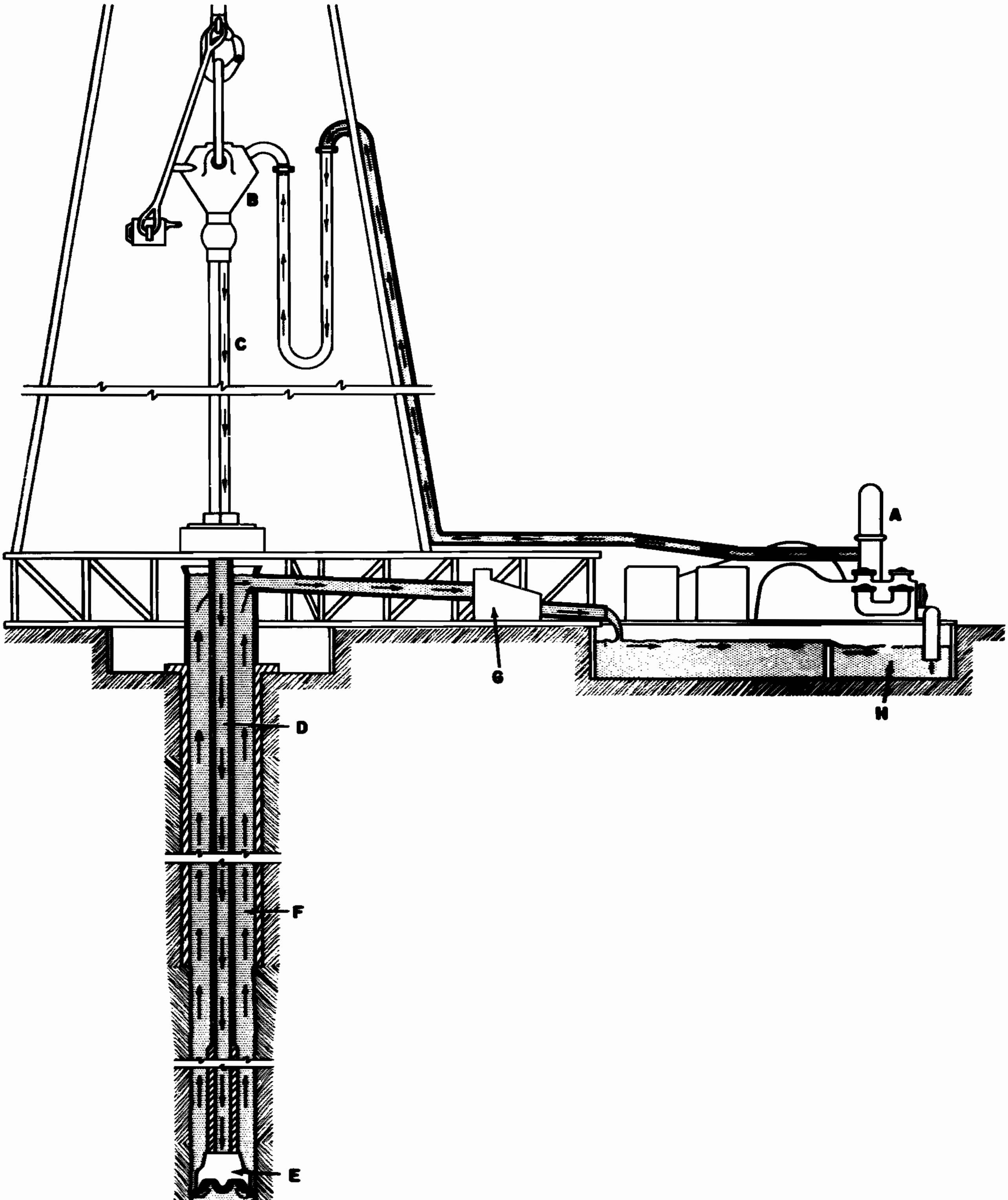


FIGURE 20. - Mud-circulating system, modern rotary-drilling rig.

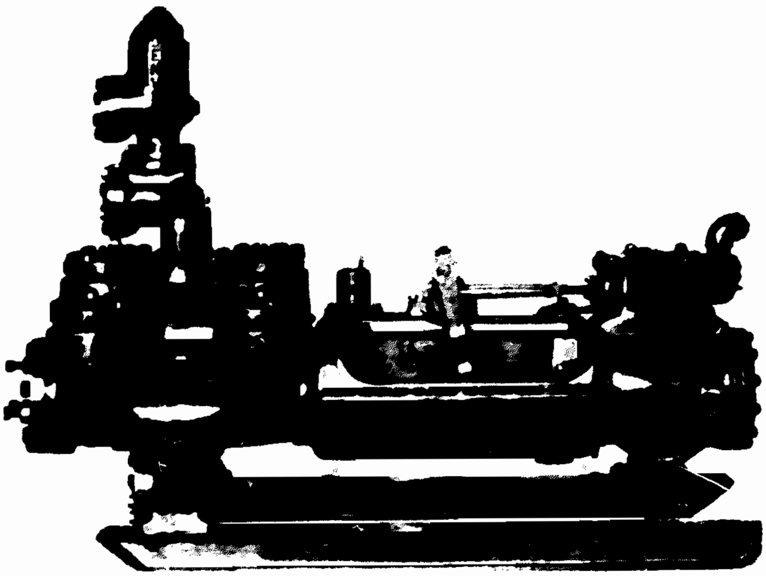


FIGURE 21. - Heavy-duty direct-acting duplex steam-driven slush pump.

Portable Rotary-Drilling Rigs

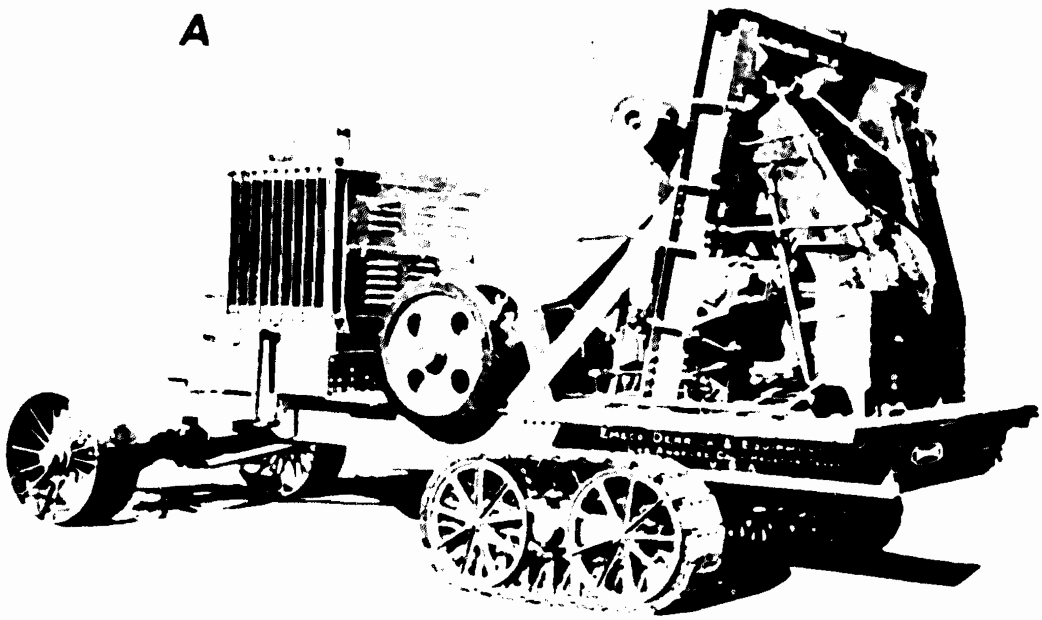
Portable rotary-drilling equipment may be designed and unitized so that a minimum amount of rigging and tearing-down time is required in moving from one location to another. Portable drilling equipment may be classified as self-propelled, truck-mounted, and skid-mounted rigs. Truck-mounted rigs have the prime mover, draw works, and slush pumps mounted on one or more trucks or tractors. Portable masts or derricks may be used in conjuction with these rigs. More recent models have the masts mounted on the trucks. Figure 22 is an example of an early type portable rig with draw works and gas engine to drive it mounted on one truck and slush pumps with engine to drive them on another. With this arrangement, the rotary table was not a part of the equipment, and any standard type rotary table was mounted on the derrick floor. A relatively recent model truck-mounted portable rotary, complete with rotary table and collapsible mast, is shown in figure 23. Skid-type portable rigs are unitized and grouped for convenience in rigging up and transporting but are not attached permanently to the vehicle on which they are moved. However, they are attached permanently to steel- and wood-base skids and can be moved without disassembly except for connection between unitized sections. Figure 24 is a modern skid-type portable rotary rig with a cantilever mast, and figure 25 is a schematic drawing of a typical setup for a skid-type rig.

Power Plants

Power consumed in operating a rotary-drilling rig is used primarily in three different phases of work; rotating the drill column, operating the circulating pumps, and pulling out the drill column. The first two of these functions draw upon the source of power simultaneously. When hoisting operations are in progress, the other functions are not operating.

For many years, the chief source of power for drilling was steam. Most drillers believed that no other prime mover possessed the flexibility in speed and torque that is inherent to the steam engine. However, improvements made in internal-combustion engines, electric motors, and power transmission mechanisms during and immediately after World War II resulted in the development of thoroughly satisfactory power plants and in the decline of steam as a source of power.

A



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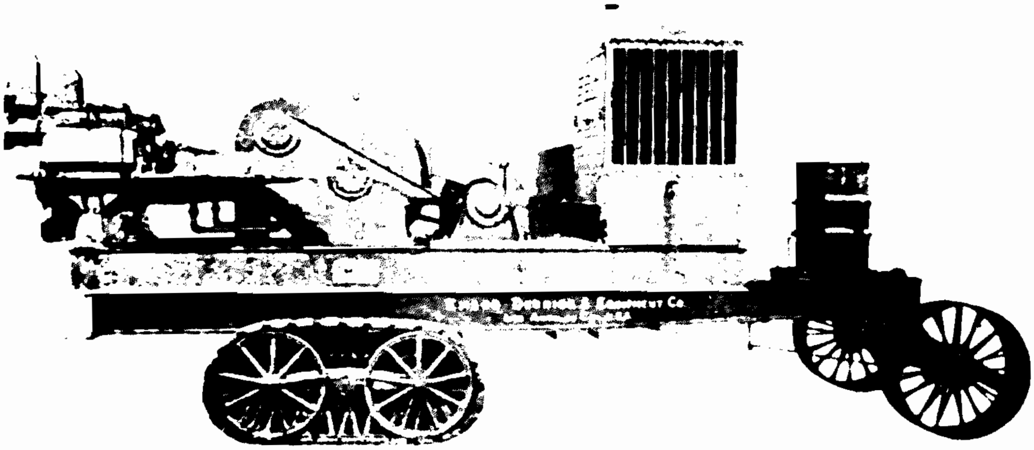


FIGURE 22. - Early model portable-type rotary rig with unit mounted on two trucks and powered by 60-hp gas engines. *A*. Draw works and gas engine. *B*. Slush pumps and gas engine. (From Deep Well Drilling, 3d Ed., by Walter H. Jeffery. Copyright 1931 by W. H. Jeffery. Courtesy Gulf Publishing Co.)

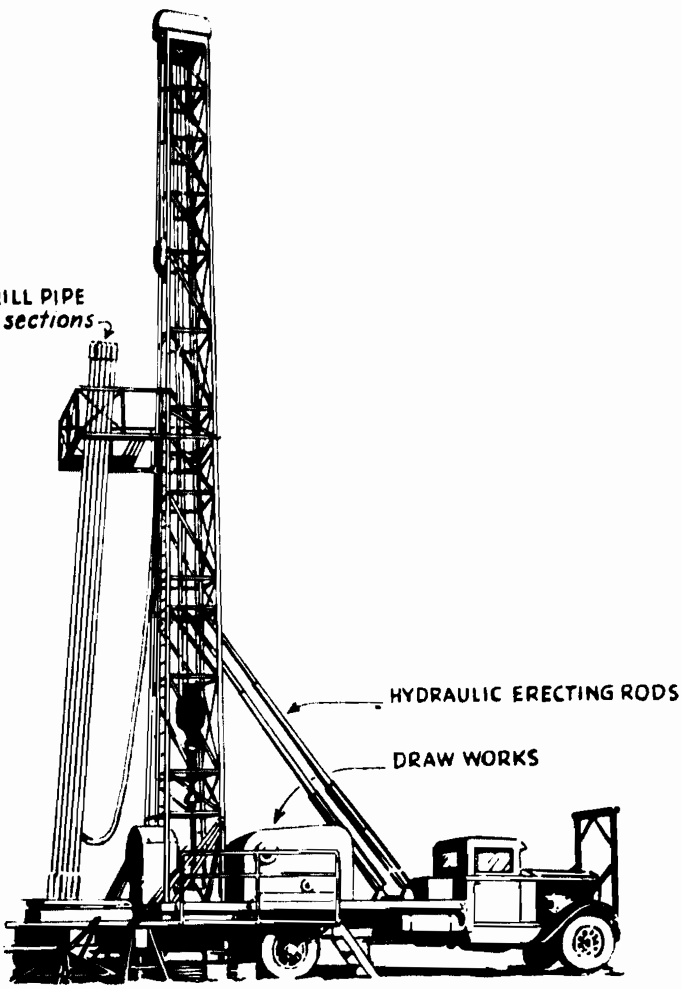


FIGURE 23. - Recent model truck-mounted portable rotary rig with collapsible mast. (Courtesy American Petroleum Institute.)

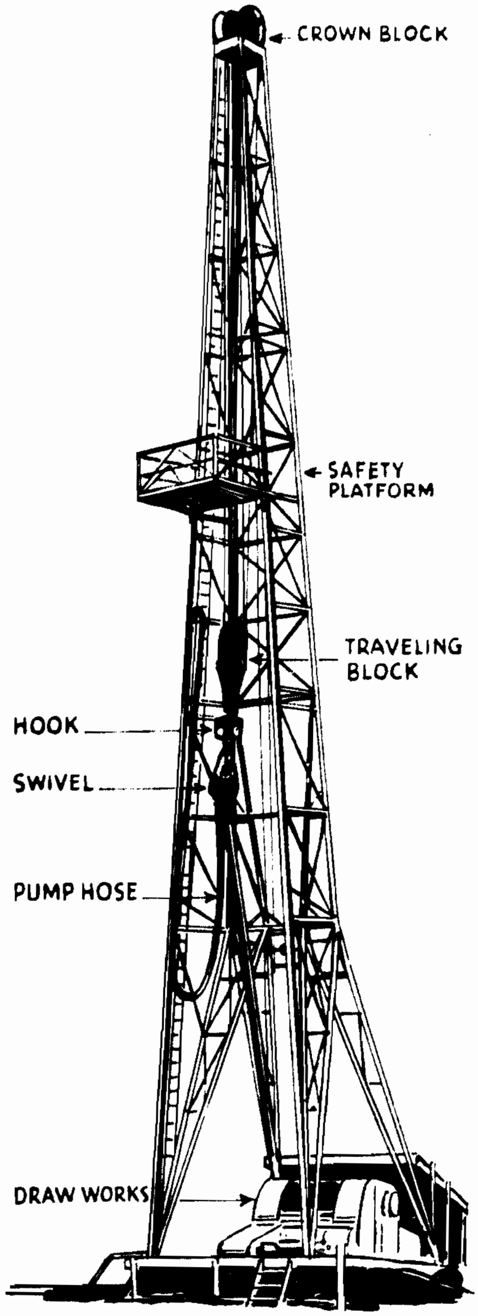


FIGURE 24. - Modern skid-type portable rotary rig with cantilever mast. (Courtesy American Petroleum Institute.)

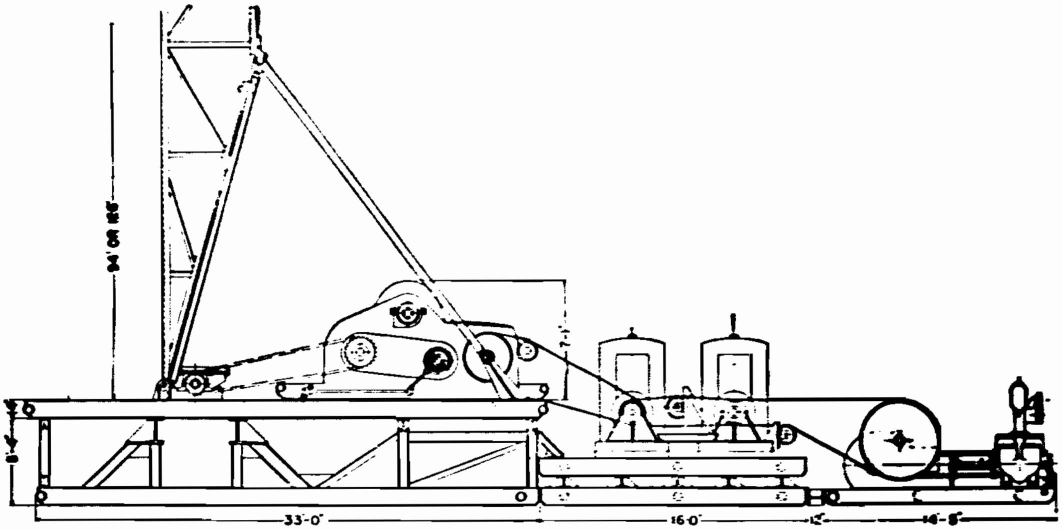


FIGURE 25. - Typical setup for a skid-type portable rotary rig with cantilever-type mast and two 200-hp diesel engines.

The steam-driven rotary-drilling rig was conveniently equipped with one twin-cylinder engine to drive the draw works and rotary table and with two direct-connected, duplex, steam-driven slush pumps. The engine provided to drive the draw works and the rotary table was the principal prime mover and was customarily a horizontal duplex, twin-cylinder type of engine, often with cylinders 12 inches in diameter and with a 12-inch piston stroke, as shown in figure 26.

Internal-combustion engines as a class include all engines operating on gaseous or liquid fuels in which the fuel is burned or exploded within the engine cylinders. These engines may be classified by the fuels employed, as gas, butane, gasoline, and diesel engines. Of the various types of engines tried, the vertical multicylinder gas engines using natural gas or butane for fuel and the vertical multicylinder diesel or semidiesel engines were the most successful. For shallow rotary drilling to 4,000 feet, two 200-hp, eight-cylinder gas engines, as shown in figure 15, or two 200-hp, six-cylinder diesel oil engines as shown in figure 27, are adequate; however, for deeper drilling when two slush pumps are needed, three engines of the same size are required. Prime movers for portable rotary drilling rigs are usually natural gas, diesel, gasoline, or butane engines; however, early portable rigs were steam powered.

Electric power can be utilized to provide the flexibility required in oil well drilling operations. To be adaptable to drilling operations, the electric power must provide a dependable power source and a wide range of speed-torque characteristics. Basically, electric power is developed by generator-driven electric motors, which in turn supply power to run mud pumps, draw works, rotary table, and auxiliary equipment. Some power must be available to drive the generator, and generally this is provided either by an internal-combustion engine, or more rarely, by purchased electric power. Direct-current motors are much better adapted than ac motors to the type of

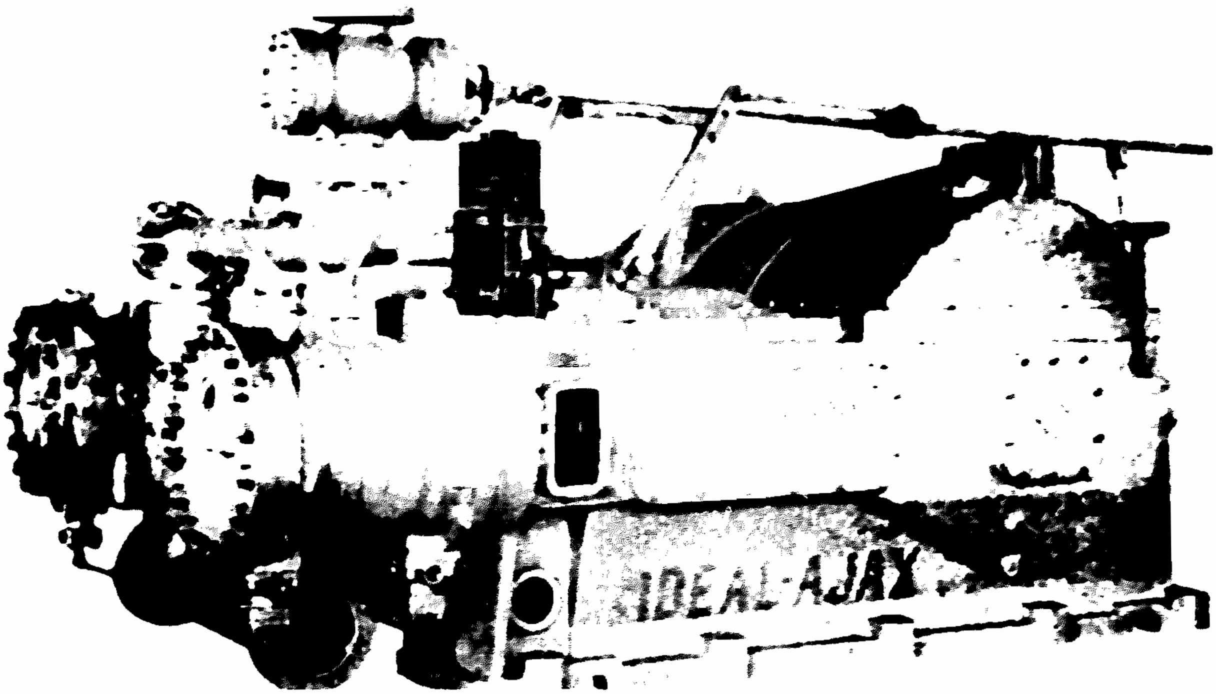


FIGURE 26. - Horizontal-duplex twin-cylinder steam engine.

FIGURE 27. - Six-cylinder 200-hp diesel oil engine. (From Deep Well Drilling, 3d Ed., by W. H. Jeffery. Copyright 1931 by W. H. Jeffery. Courtesy of Gulf Publishing Co.)

service required in rotary drilling, approaching steam engines in flexibility in speed and in torque.

WELL COMPLETION AND PRODUCTION METHODS

Casing Programs

Casing is essential to both drilling and production operations regardless of whether the well is drilled by cable-tool or rotary-drilling methods. In drilling, the chief functions of the casing are to prevent cavings from soft or unconsolidated formations and water from penetrated formations from interfering with drilling operations and to assist in controlling liquids and gases encountered in drilling high-pressure formation. Casing in producing wells is a protective conduit that prevents oil and gas production from escaping into overlying formations and prevents formation fluids from one stratum from entering another through the wellbore. At the surface, the upper end of the casing is a connector for hooking up equipment to control the flow of oil and/or gas to regulate the pressure within the wellbore.

In designing a casing program, the following must be taken into consideration: depths at which casing will be necessary; depth to the producing formation; nature of the formations encountered; the method used in drilling; and the diameter of the final casing string, which is sized to suit completion and production operations. Each outer string is selected to give sufficient clearance for the drill tools and casing to pass through it into the open hole below.

No casing is inserted in a well drilled by rotary tools until the particular size of hole being drilled is completed; whereas, in cable-tool drilling it is often necessary to install casing joint by joint as the hole is deepened. In an ordinary cable-tool drilling operation, a hole is started with a large bit and drilled down to a competent formation. A surface string of casing or conductor pipe is set to support the walls of the hole, and drilling proceeds with a smaller bit through the conductor pipe until the hole caves or water is encountered. Another string of casing is set, and drilling is continued with a bit small enough to pass through the casing until another water flow or cave-in is encountered, or the well is drilled to the desired depth. It is often necessary, particularly in deeper wells, to set intermediate strings to control water flow and caving. Figure 28 is an example of an open hole completion cased with three strings of pipe showing the functions of the various strings.

During early oil and gas development in the eastern part of the United States, little attention was given to casing wells probably because the problems were comparatively simple. Even conduits made from wood were used as conductors to prevent surface cave-ins. The rock formations were hard and did not cave, and in most cases, there were thick beds of hard impervious shale immediately below the water-bearing formation, which provided a tight seat for the casing.

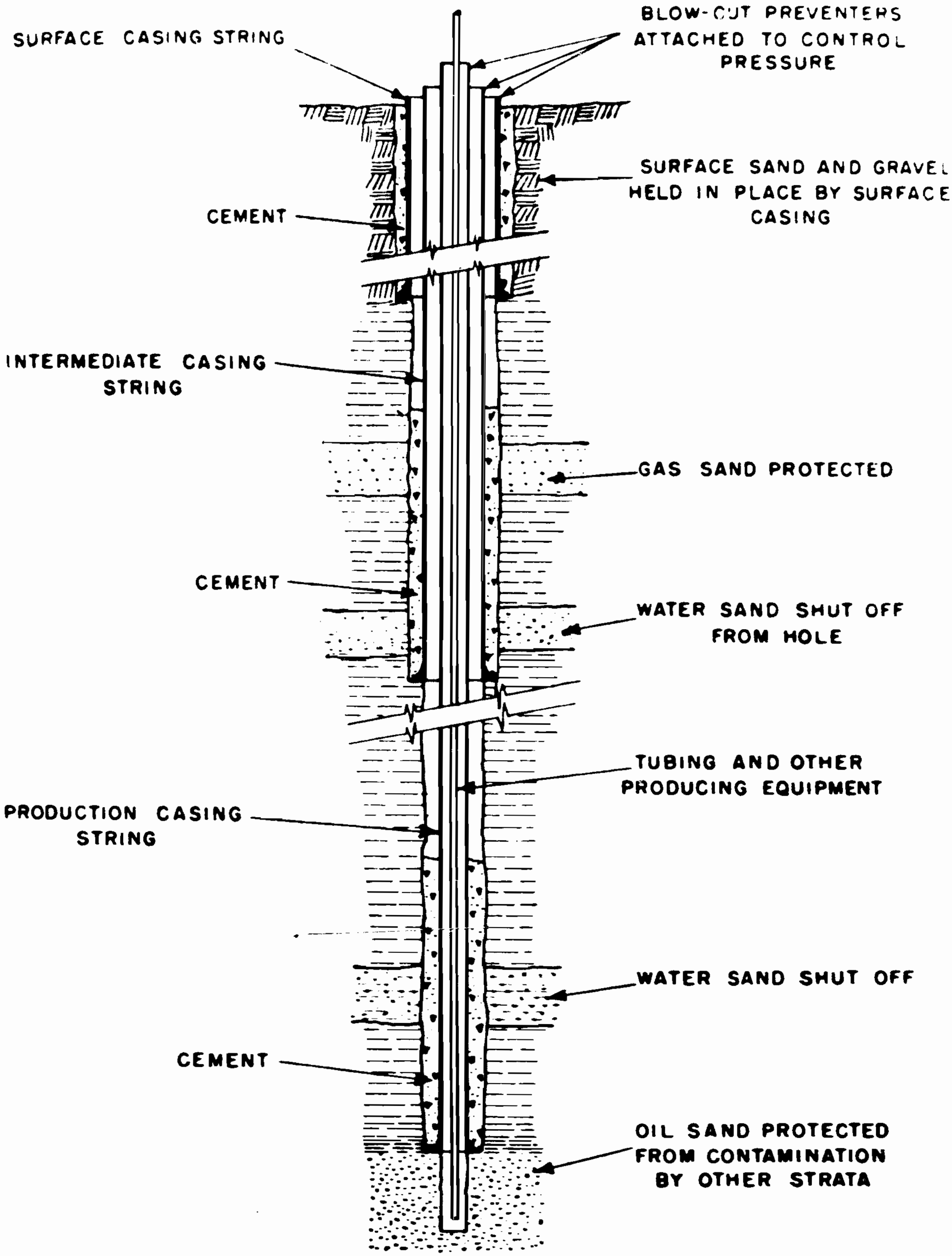


FIGURE 28. - Well cased with three strings of casing, showing functions of each string. (From Elements of the Petroleum Industry, 1940, AIME Library.)

Usually all strings of casing extend to the surface where they are joined by a fluid-tight casing head that closes the annular space between the strings so that oil, gas, water, and drilling fluid may be confined. Suitable valves control the outlets from the spaces between the strings and from the oil string.

Well Completion

If the sand is firm and the walls do not cave, the well usually is completed without casing opposite the productive horizon; a common practice in the Appalachian area of Eastern United States. The oil string, in this case, is run to a point immediately above the oil sand and is set on a firm shoulder of rock and cemented to exclude upper waters and cavings. If no bottom waters are encountered, a hole of reduced diameter is drilled through the oil sand and 10 to 20 feet below. This is called an open hole completion. This provides a sump for the accumulation of sediments and cavings from the wellbore. If the producing formation is soft and friable, with a tendency to cave, or slough off, the casing is set through the sand body and perforated opposite the pay zone with numerous round holes or slots.

By the twenties, explosives were in common use to stimulate production from wells where the producing strata were hard, close-grained rock, and offered resistance to the flow of oil. Liquid nitroglycerin was charged into long cylindrical containers and placed opposite the pay zone, tamped, and detonated. More recently, solidified nitroglycerin has been used more extensively.

Since 1949, hydraulic fracturing, a technique that forces strata apart along joints and bedding planes by applying high fluid pressure, has generally replaced nitro shooting and has been used successfully to stimulate production from many wells completed in hard, close-grained formations. The fluid used is usually thickened brine, crude oil produced on the property, diesel oil, kerosine, or an oil-water emulsion having a suitable viscosity to enter the formation fractures as they are formed. The fracturing fluid carries in suspension carefully graded sand grains that serve as "propping agents" to prevent the fractures from closing when the pressure is released.

Natural-gas wells are drilled and completed with the same kind of tools and equipment as that used in oil wells. In gas wells the surface pipe, water string, and production string usually are cemented to the surface. The tubing or flow string of wells producing small volumes of gas at medium pressures, such as most wells in the Appalachian area, is anchored to the surface by a casing head packer and support, or a bradenhead. For high-pressure, large-capacity wells, the flow string is anchored to buried sills or "dead men." Many shallow gas wells particularly in the Eastern States, are completed with only a gate valve, tee, bull plug, and a flow line. However, surface connections, or Christmas tree assemblies, for deeper, high-pressure, high-volume wells require the use of high-pressure fittings, including a master control valve, bradenhead, gate valves, bull plugs, and trees, as shown for an ideal case in figure 29.

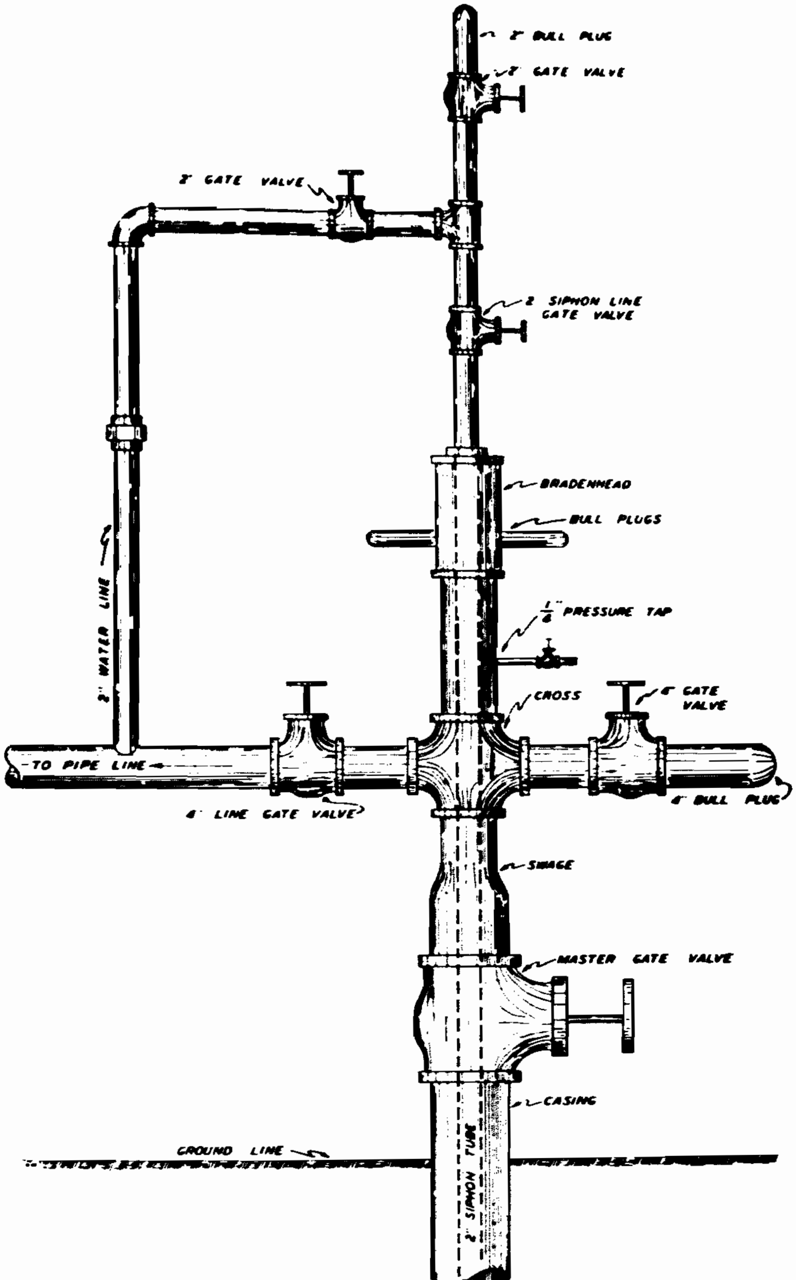


FIGURE 29. - Christmas tree assembly for a high-pressure gas well. (From Petroleum Production, by Wilbur F. Cloud. Copyright 1937 by the University of Oklahoma Press.)

Production Methods

Oil is lifted from the bottom of the hole to the surface by natural flow, gas-air lift, or mechanical lift. The two general types of flowing wells are those in which the flow is a direct result of large volumes of free and dissolved gases expanding and those in which the energy is obtained from the combined pressure of water and expanding gases. Figure 30 shows the casing program and surface equipment used on a deep flowing well.

Screen pipe, set opposite the producing formation, is often used in the Gulf Coast area where some sands are loose and unconsolidated. In the eastern and midcontinent fields of the United States, the producing formations are usually hard, consolidated sands, and the wells are completed with the casing set above, or through the oil-pay zone and perforated. The natural flow usually is restricted by flowing through a string of tubing and adjustable choke, or flow bean, placed in the flow line.

In many fields, particularly those producing from shallow sands, oil wells cease to flow soon after completion because the source of energy has become exhausted, and other means must be provided to produce sufficient energy to lift the oil. Additional energy has been acquired in many wells, particularly in California and the midcontinent areas, by using the gas-air lift method. By this method, energy to lift the oil is induced or supplemented by injecting natural gas or

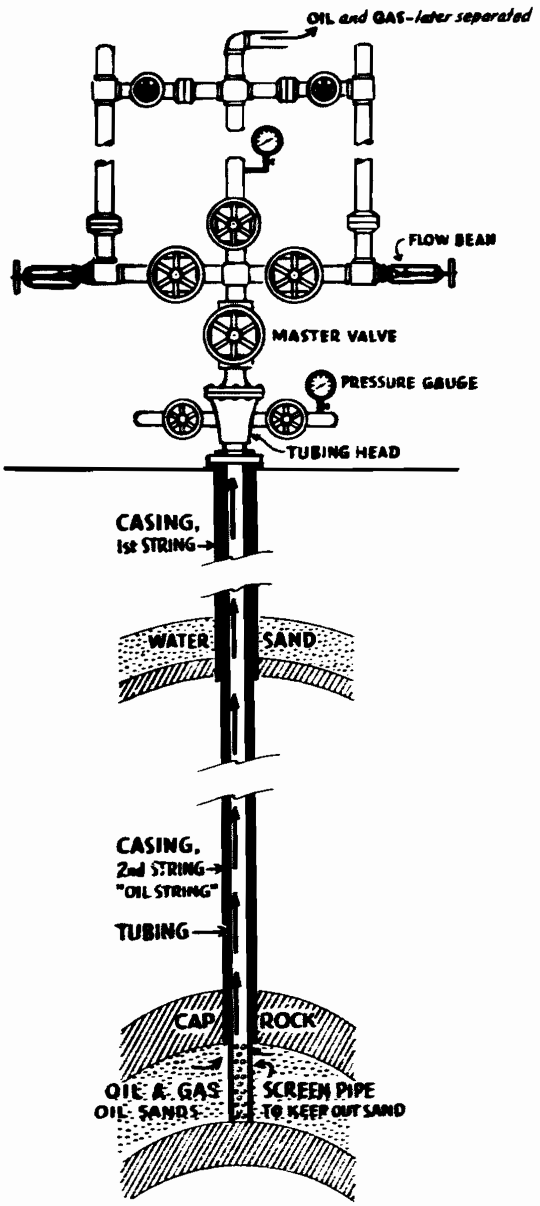


FIGURE 30. - Casing program and surface equipment used on flowing well. (Courtesy American Petroleum Institute.)

air into the well under pressure, either down through the tubing or the annulus between the flow tubing and the well casing.

The gas-air lift method seldom was used in the shallow fields of the Eastern United States. When wells in this area stopped flowing because of reduced gas pressure, mechanical means were provided to produce the oil. Mechanical lifting involves the use of some kind of a pump. A plunger or lift pump activated by a string of rods is the most common type although other types of pumping equipment have been used. There are many variations in the design of a plunger pump, but all must have certain essential parts such as, a working barrel, a standing or foot valve, a plunger or piston, and a traveling or working valve. The pumps may be classified as tubing or rod pumps. Tubing pumps have the advantage of a larger diameter barrel for a given size pump but are inconvenient because the tubing must be pulled every time remedial work is done on the barrel. A rod pump is run and pulled as a complete unit with the rods and therefore must have a smaller diameter for a given size of tubing. Figure 31, A-B is a schematic drawing of a tubing-type pump showing the location of the traveling valve and plunger at the beginning of the down stroke (A) and at the beginning of the upstroke (B); (C) shows a conventional insert or rod-type pump; and (D), a modified insert pump.

Typical surface connections for a deep, high-pressure pumping well and a shallow, low-pressure beam-pumping well are shown in figures 32 and 33, respectively. The major differences between the two hookups are the heavy-duty supporting equipment and safety valves used to control the higher pressures. In both instances, the upper end of the tubing terminates in a stuffing box through which operates a polished rod of brass or stainless steel, connecting at its lower end to a string of sucker rods that activate the subsurface pump. A tee or cross placed below the stuffing box permits oil, gas, and/or water to escape from the tubing to the lead line which carries the fluid to the tank for separation.

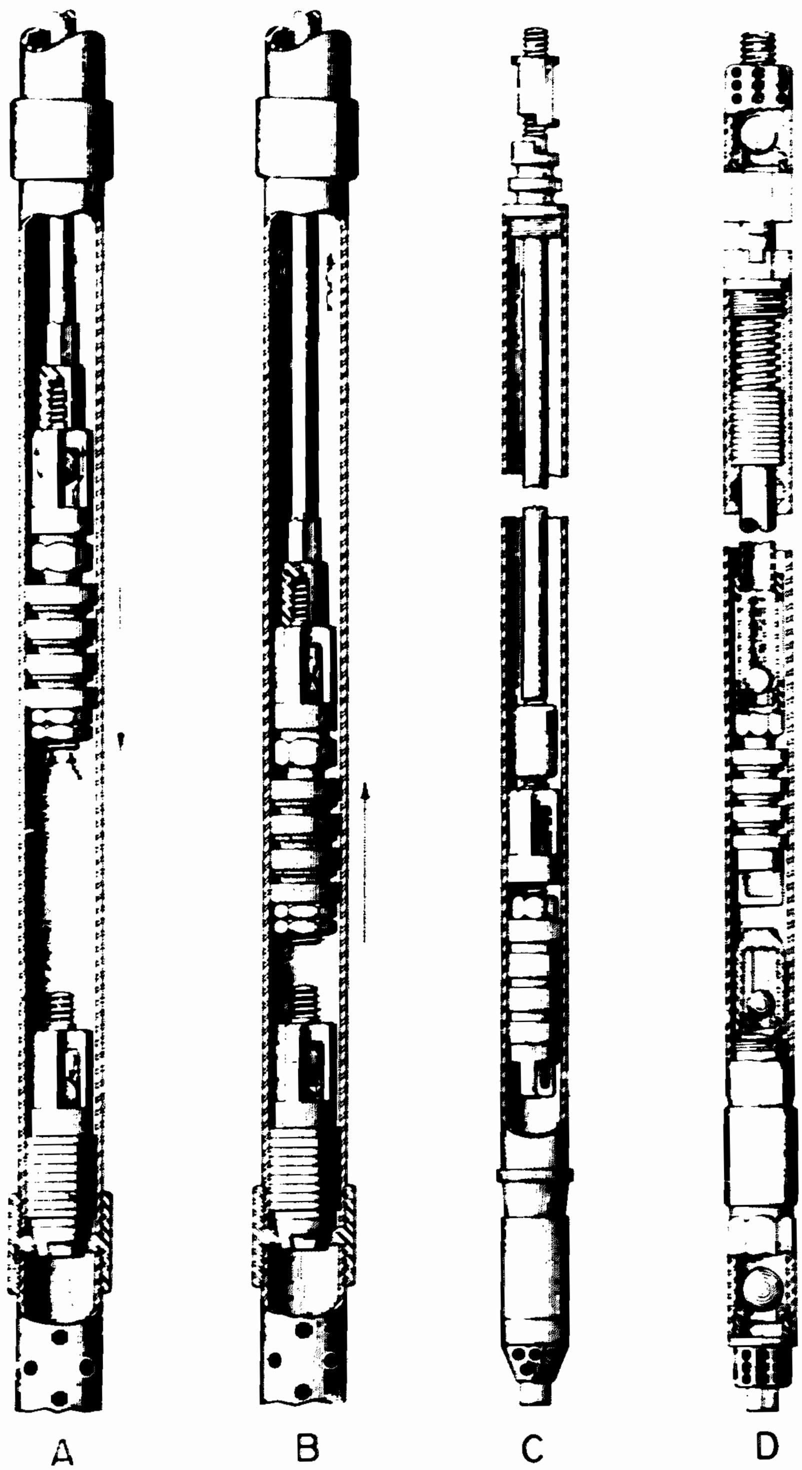


FIGURE 31. - Plunger-type oil pumps. A. Down stroke. B. Upstroke. C. Insert or rod-type pump. D. Modified insert pump.

Power Transmission

Power to activate the sucker rods and operate the subsurface pump is transmitted from the engine or motor by complete pumping equipment at each well or by pull-rod lines from a central power to an individual pump jack. Individual pumping equipment is either a standard cable-tool rig front or a pumping unit.

In the early days of the oil industry, wells that ceased to flow were pumped individually by the walking beam used on the cable-tool drilling rig and often were powered by the steam or gas engine used for drilling. Equipment used to connect the sucker rods to the walking beam is shown in figure 33. The technique used in "beam pumping" is illustrated in figure 34. The walking beam, which was moved up and down by the crank, alternately lifted and lowered the sucker rods, which operated the pump in the bottom of the well, lifting the oil to the surface.

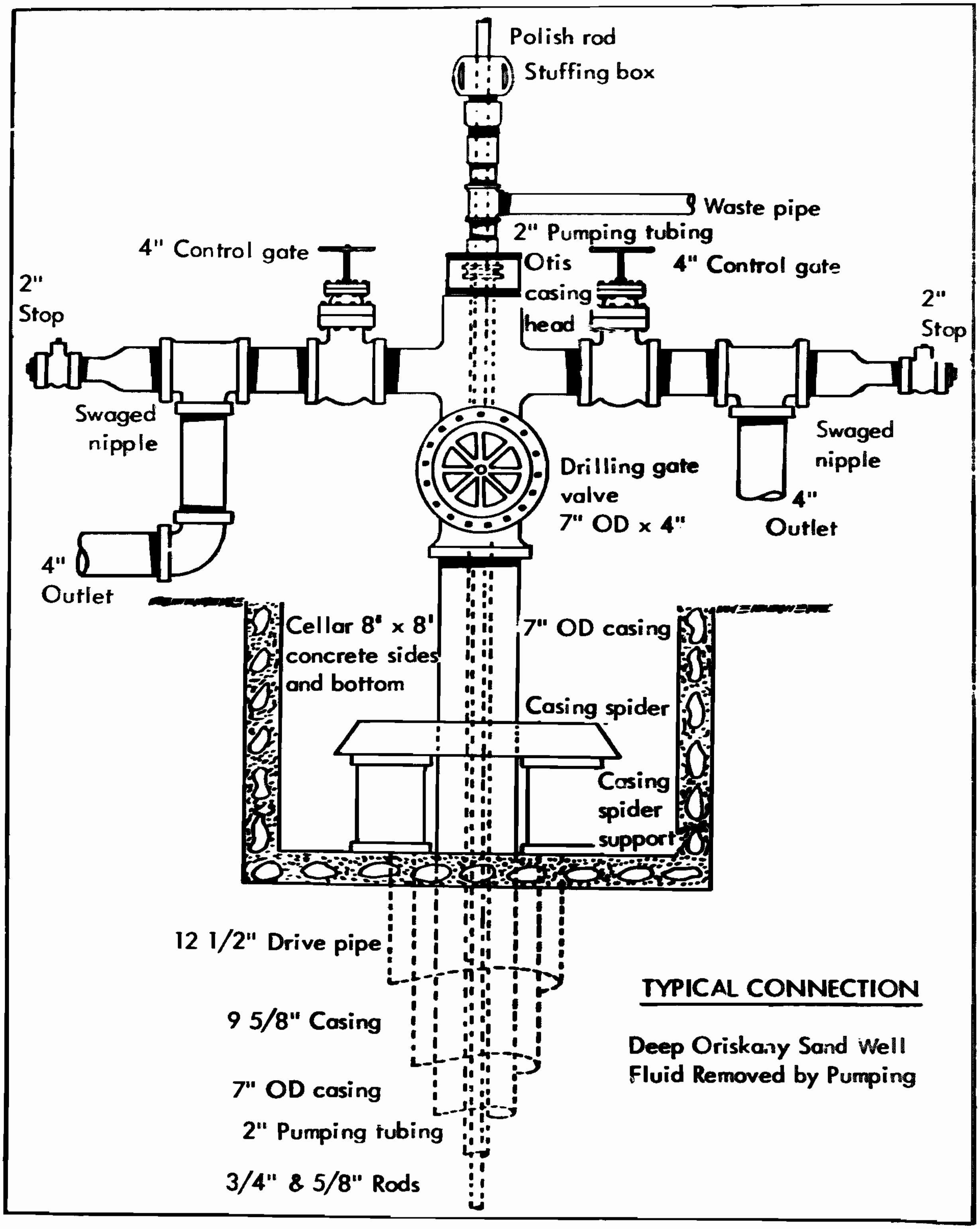


FIGURE 32. - Surface connections for a deep, high-pressure pumping well. (Courtesy United Natural Gas Co.)

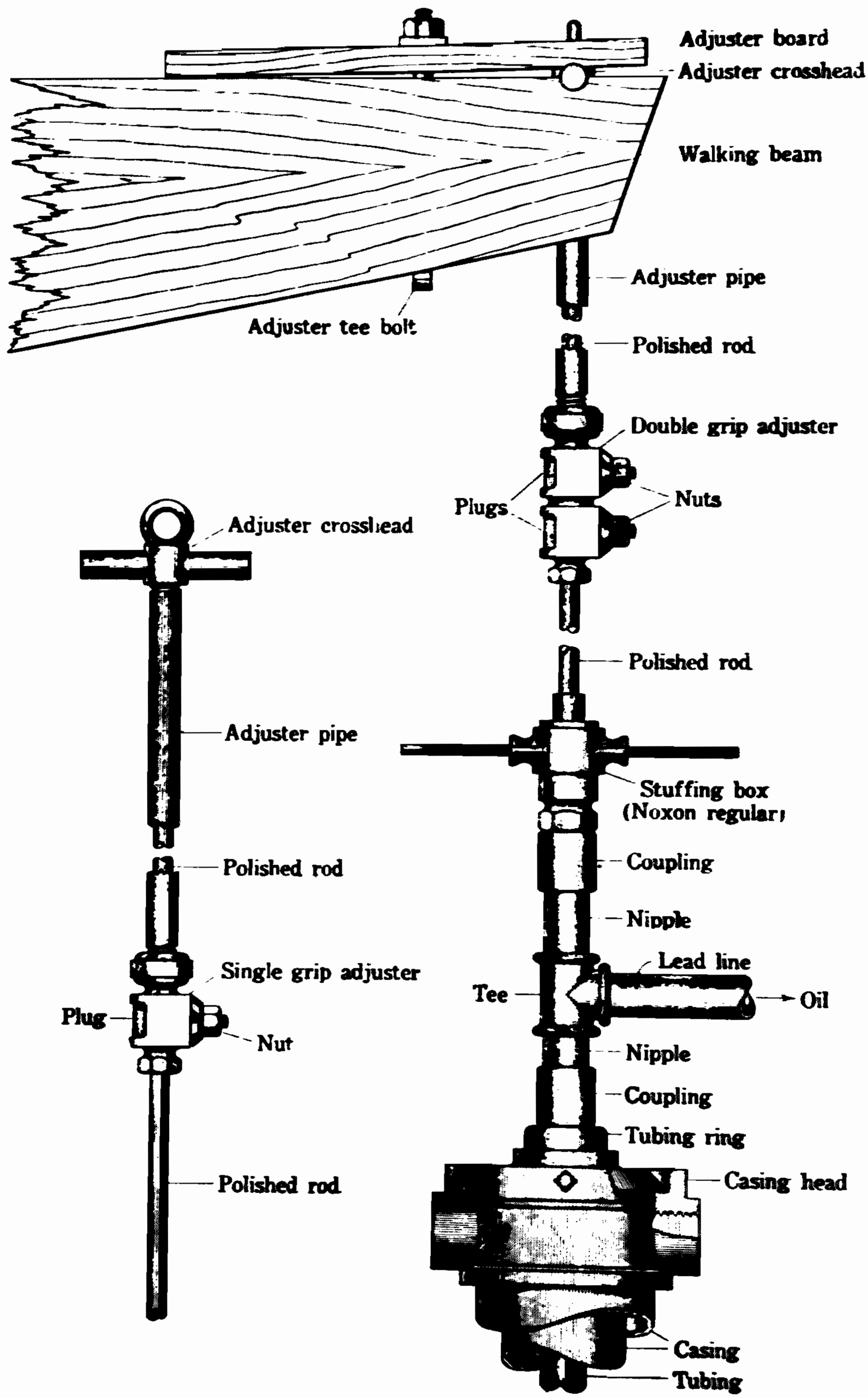


FIGURE 33. - Surface connections for a shallow, beam-pumping well.

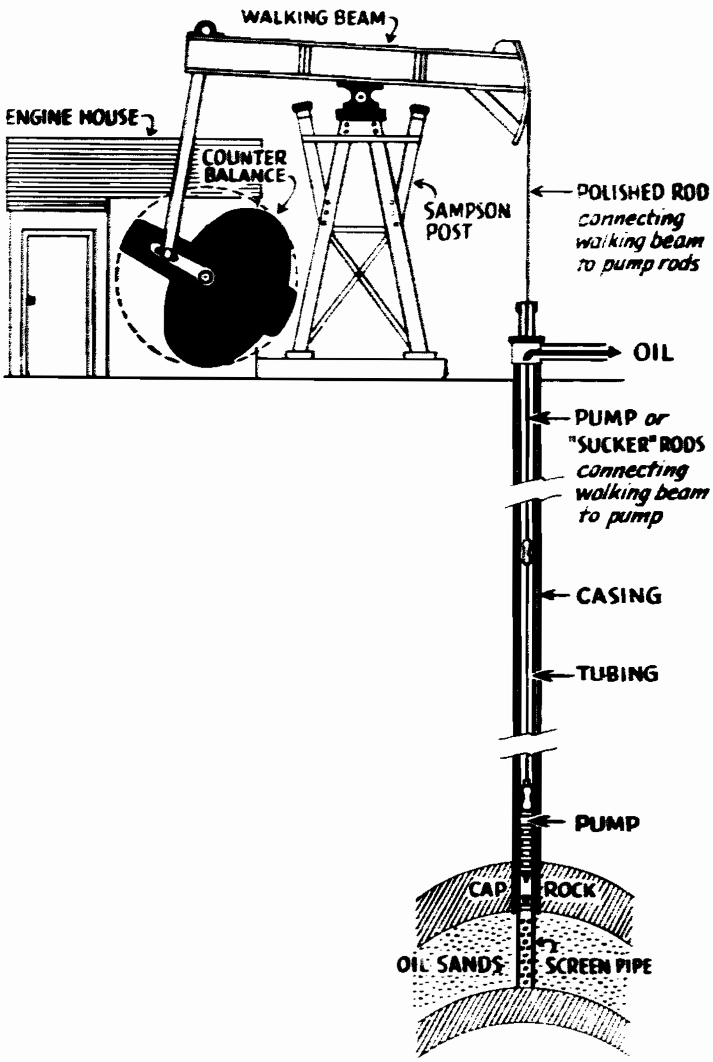


FIGURE 34. - Walking-beam pumping unit. (Courtesy American Petroleum Institute.)

In the early 1920's, individual pumping units were designed to replace the standard cable-tool rig front. These were particularly advantageous and less expensive for pumping wells drilled by the rotary method as they eliminated the expense of installing cable-tool, beam-pumping equipment. The principal parts of an individual pumping unit are a reduction gear assembly, prime mover, pitman, sampson post, walking beam, and a counterbalance. The prime mover is either an electric motor or an internal combustion engine that operates the geared unit by V-belts, chain drive, or direct shaft and reversible clutch drive. Figure 35 illustrates a herringbone-geared unit equipped with adjustable rotary counterbalance, V-belt, steel T-frame sampson post, and a three-point-in-line walking beam. This type of beam increases the power leverage at the pitman end and reduces the arc movement of the polish rod. A dual-pitman and twin-crank type of reduction-geared unit is shown in figure 36. The two cranks permit the use of more counterbalance weight and also distribute the counterbalance load equally over the main shaft and bearings. Figure 37 shows a small pumping unit driven by a 10-hp gas engine with V-belt transmission to chain-reduction unit, twin crank and pitman, beam counterbalance, and hanger designed to give a straight lift to the polish rod. Figure 38 shows a large pumping unit, single pitman, rotary counterbalance, and backside pumping equipment to furnish power to pump jacks on adjacent wells. This method of pumping, known as pumping by jerk line, is set up by installing a second crank on the backside of the pumping crankshaft, or the power may be taken from the walking beam by attaching a pitman pipe, as shown in figure 39-A. Figure 39-B shows an example of two wells being pumped by shackle lines attached by a block to the wrist pin on the crank arm of the bank wheel and delivering power to jacks, one at each end of the well.

The first major innovation developed for transmitting power to activate sucker rods and operate subsurface pumping equipment was the multiple or central power and jack system of pumping. This system, which was developed

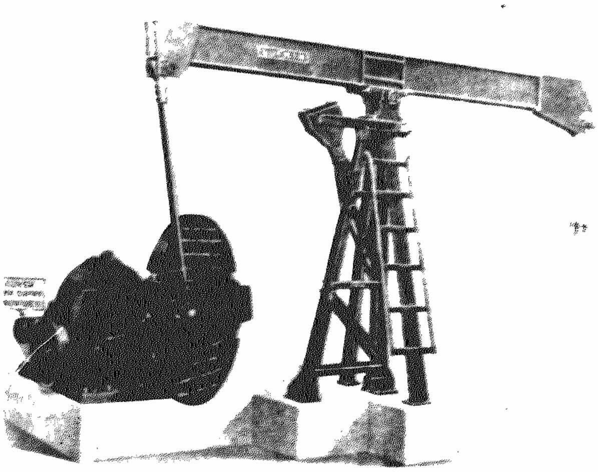


FIGURE 35. - Herringbone reduction-geared pumping unit. (From Petroleum Production by Wilbur F. Cloud. Copyright 1937 by the University of Oklahoma Press.)

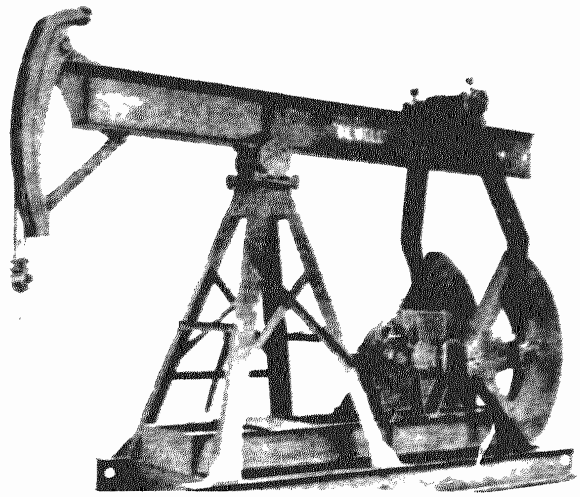


FIGURE 36. - Twin-crank type reduction-geared pumping unit. (From Petroleum Production by Wilbur F. Cloud. Copyright 1937 by the University of Oklahoma Press.)

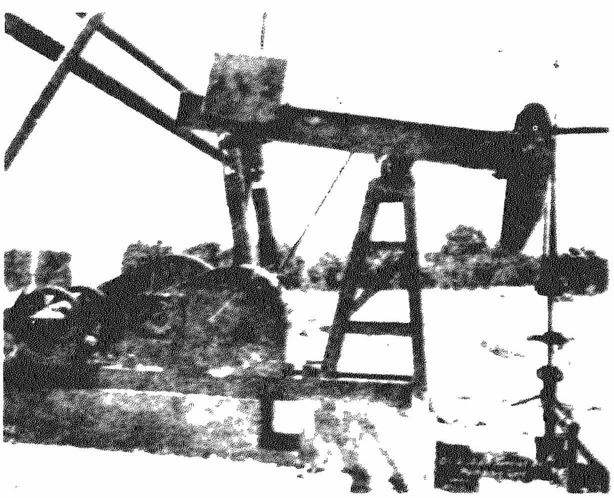


FIGURE 37. - Chain reduction-geared pumping unit. (From Elements of the Petroleum Industry, 1940, AIME Library.)

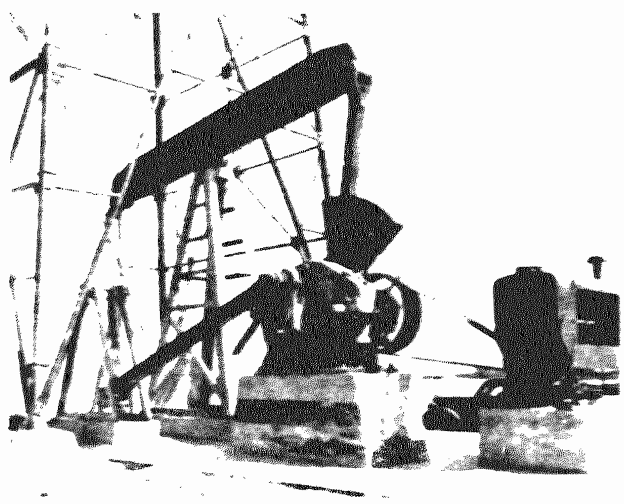


FIGURE 38. - Large pumping unit equipped with backside pumping equipment to operate pump jacks on adjacent wells. (From Elements of the Petroleum Industry, 1940, AIME Library.)

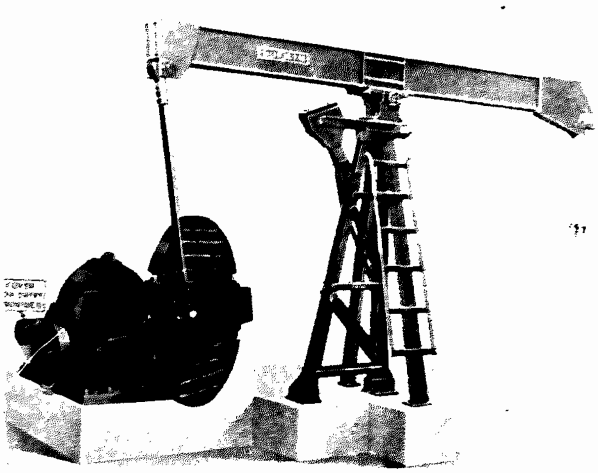


FIGURE 35. - Herringbone reduction-geared pumping unit. (From Petroleum Production by Wilbur F. Cloud. Copyright 1937 by the University of Oklahoma Press.)

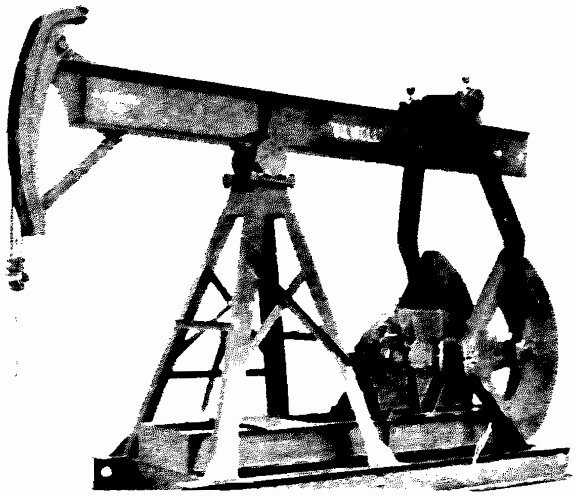


FIGURE 36. - Twin-crank type reduction-geared pumping unit. (From Petroleum Production by Wilbur F. Cloud. Copyright 1937 by the University of Oklahoma Press.)

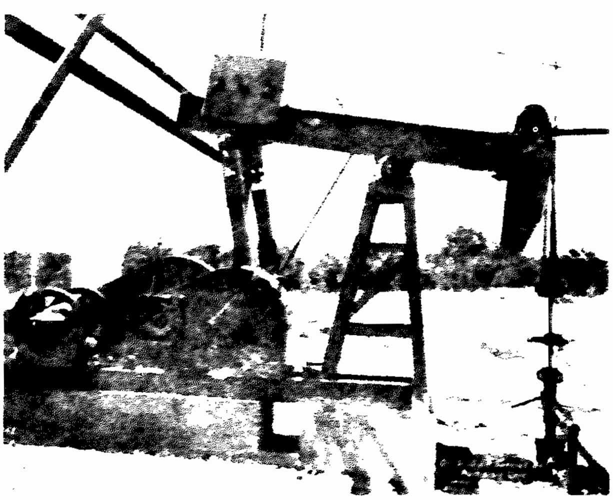


FIGURE 37. - Chain reduction-geared pumping unit. (From Elements of the Petroleum Industry, 1940, AIME Library.)

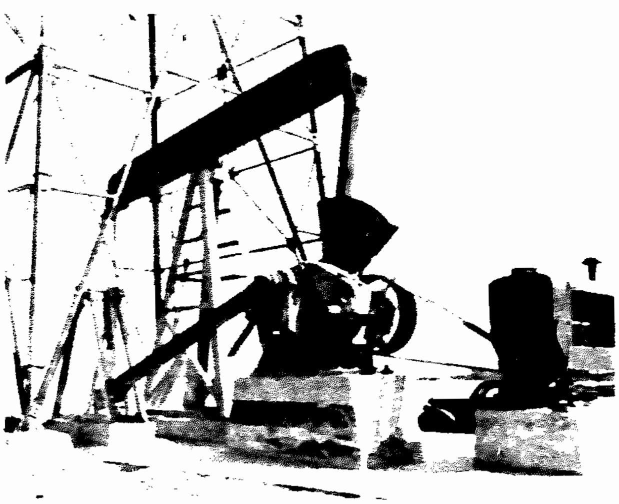


FIGURE 38. - Large pumping unit equipped with backside pumping equipment to operate pump jacks on adjacent wells. (From Elements of the Petroleum Industry, 1940, AIME Library.)

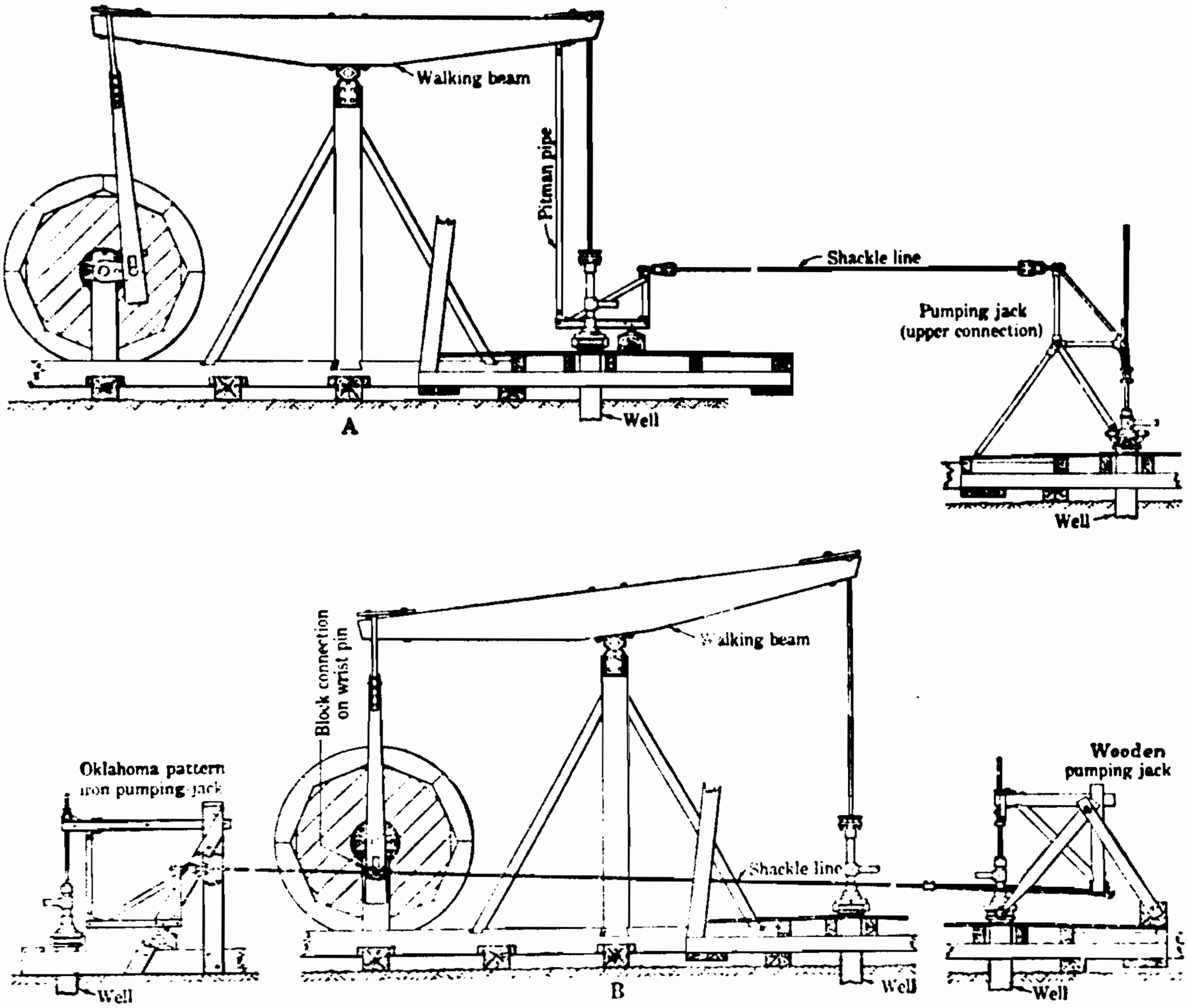


FIGURE 39. - Modifications of beam pumping.

during the 1880's in Pennsylvania to reduce operating costs and compensate for rapidly declining rates in oil production and drastic cuts in crude-oil prices, was widely used to pump wells in the shallow midcontinent and eastern oilfields of the United States until the early 1940's. By this method, power is transmitted from a central plant to the surrounding wells by purely mechanical means. There are three types of jack plants or powers: push-and-pull, geared, and band-wheel. The first and last of these types were constructed of timbers originally, but in later years the tendency was to make all types of powers of iron, although some types of band-wheel powers have wooden band wheels.

One of the first powers developed was the push-and-pull type. Original models were made of timber with wooden pull wheels and 2- by 4-inch main pull lines held together with bolted, steel plates. The unit consisted of a large band wheel mounted on a horizontal shaft which had a crank at each end. A pitman was connected to each crank, and the two were tied to opposite sides of the pull wheel. Shackle lines were attached to spokes on the pull wheels, which oscillated through a short arc as the band wheel rotated. This setup was servicable, but the use of wooden pull lines between the primary and secondary pull wheels was a constant source of trouble because of line parting at the strapped couplings and inability to keep proper tension on the pull lines. Later models of push-and-pull powers were made of iron. They were driven by an engine or motor through a belt to a pulley on a countershaft to which was attached a pinion that meshed with a large gear wheel mounted on a shaft having two crank arms. A piston connected each crank arm to a horizontal iron disk mounted on a vertical shaft and anchored to a concrete foundation.

Geared powers are adaptable for pumping small groups of shallow wells that are all located rather close to a power station. The three general types of geared powers are the spur-gear and crank-arm type, the bevel-gear and disk type, and the beveled-gear eccentric type.

The spur-gear and crank-arm type power is similar to the corresponding parts of a push-and-pull type power. It consists of a horizontal countershaft with drive pulley and a pinion gear that meshes with a spur-gear wheel mounted on a horizontal shaft having two crank arms. Several wells can be attached to each crank arm by adjustable wrist-pin connections.

A bevel-gear and disk-type power consists of a pulley shaft, beveled gear and pinion, wrist pin, and disk mounted on a cast iron bed plate, with the larger gear placed to revolve in a horizontal position. This type of power may be either small and of light construction to pump a few shallow wells, or large and of heavy construction to pump a large number of deep wells.

Bevel-gear and eccentric type powers are similar in construction to the bevel-geared disk type, except that eccentrics, instead of crank and disks, were used on the vertical gear shaft to impart motion to the rod lines. Generally they were made with either one, two, or three eccentrics in accordance with the number of wells pumped, as shown in figures 40 and 41. They can be either underpull or overpull powers, as shown in figures 38 and 39. Figure 42 shows a bevel-geared, single-eccentric underpull unit in operation.

An innovation for geared powers is a worm-geared unit shown in figure 43. This was operated by a shaft and worm gear powered by either an internal combustion engine or an electric motor.

Band-wheel powers are similar to the bevel-gear and eccentric type, except that a large wooden or steel band wheel, 16, 18, 20, or 24 feet in diameter, was used instead of a bevel-gear and pinion drive. The band wheel is supported on a vertical shaft provided with a suitable thrust bearing, and adequately braced in all directions so that it rotates in a true horizontal plane. Either one, two, or three eccentrics are mounted rigidly on the band-wheel shaft, so that they will rotate one above the other in a horizontal plane. In some designs, the eccentrics were placed below the band wheel and in other designs, above.

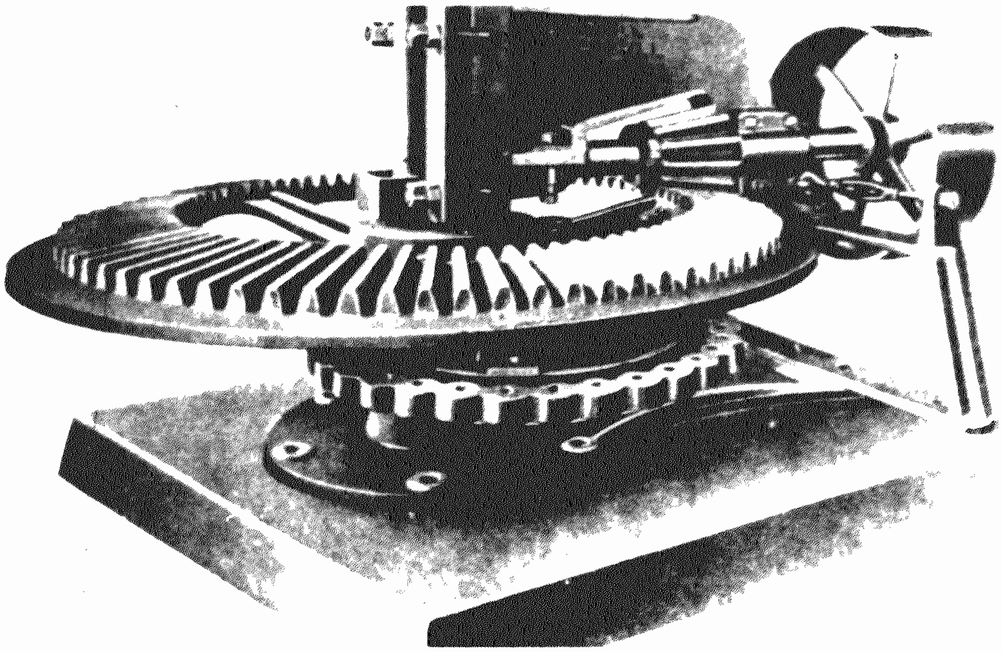


FIGURE 40. - Bevel-geared single-eccentric underpull power unit. (From Petroleum Production by Wilbur F. Cloud. Copyright 1937 by the University of Oklahoma Press.)

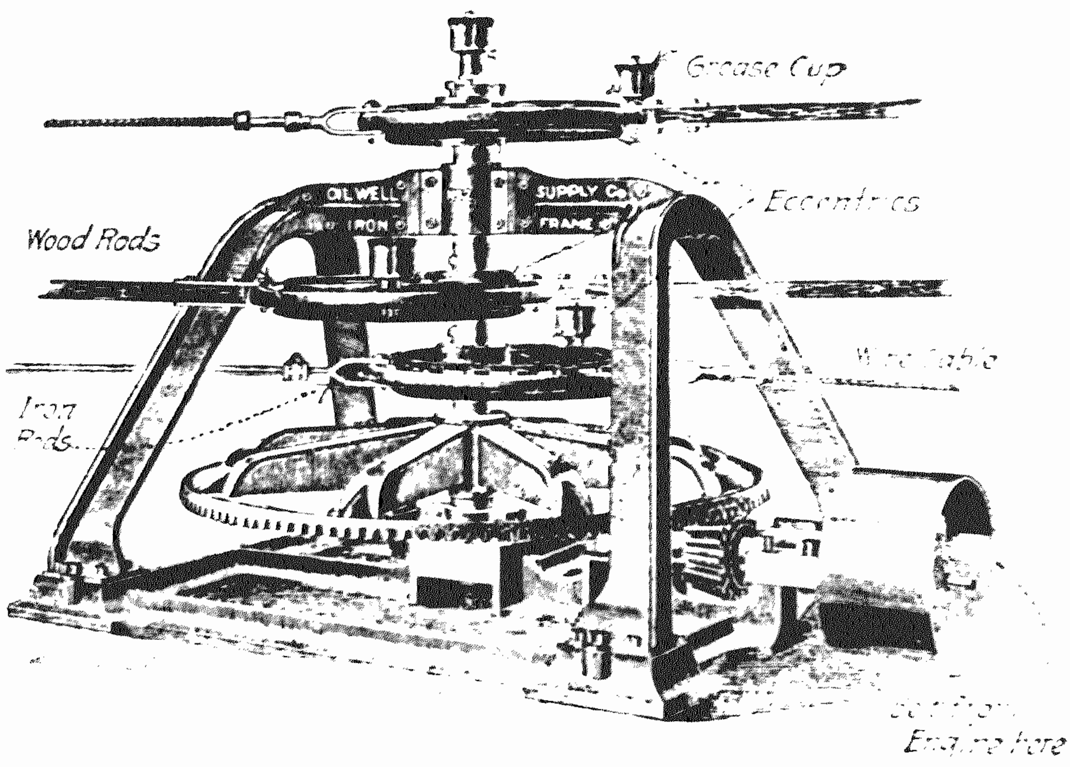


FIGURE 41. - Bevel-geared triple-eccentric overpull power unit. (From Oil-Field Practice, 1st Ed., by Dorsey Hager. Copyright 1921 by McGraw-Hill Book Co., Inc. Used with their permission.)

FIGURE 42. - Bevel-geared single-eccentric underpull unit installed in central power.

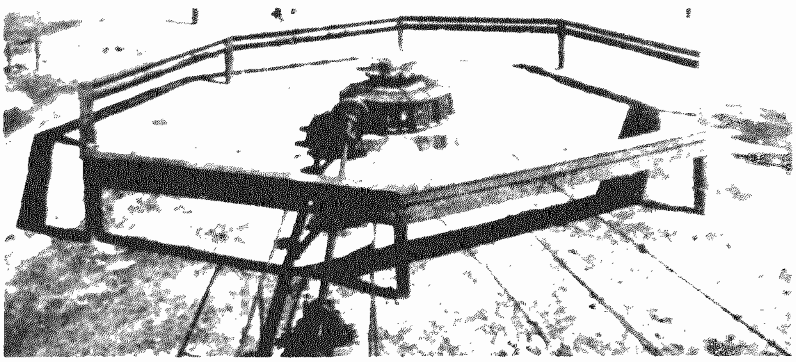


FIGURE 43. - Worm-geared single-eccentric central power. (From Petroleum Production by Wilbur F. Cloud. Copyright 1937 by the University of Oklahoma Press.)

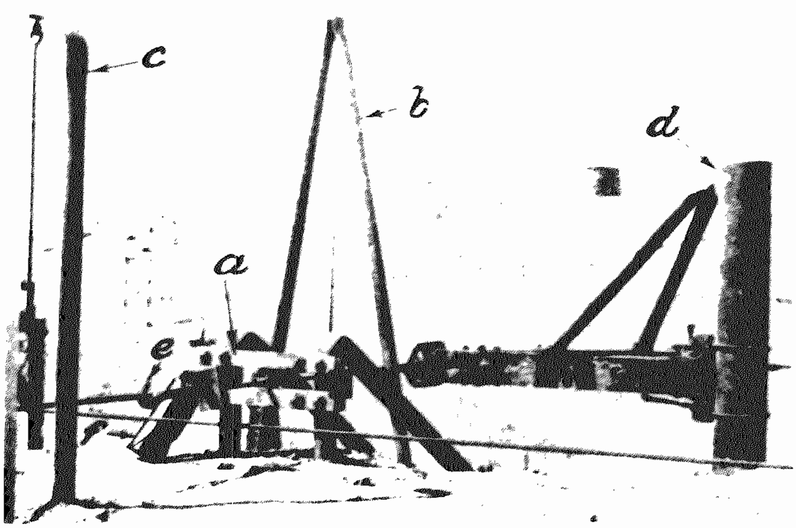


FIGURE 44. - Rod-line structures.

The reciprocating motion derived from a band wheel or geared power is transmitted to the pumping jack at the well by shackle or rod lines. Original shackle lines were made of wood, but later most lines were made from discarded sucker rods and old, steel drilling lines.

Rod-line structures were made from a variety of materials, including discarded joints of drill pipe and casing, timbers, and suitably located tree limbs and boulders. They may be classified as follows:

1. Equipment to remove or replace a well on the power. Examples are the takeoff rail shown in figure 43; the takeoff post (a) and the power and jack attachments (e) shown in figure 44; the takeoff rod (held by man), takeoff rail (under man), and the rod-line attachment (a) shown in figure 45-A; and the rod-line attachment (d) shown in figure 45-B.

2. Equipment to support the rod line. Examples are the steel-rod pendulum (b) and the one-post pendulum (c) shown in figure 44; the heavy-timbered post (a) shown in figure 45-B; the swing post, tripod pendulum, two-post pendulum, and friction-post support shown in figure 46; and the rocker support (A) and pendulum support (B) shown in figure 47.

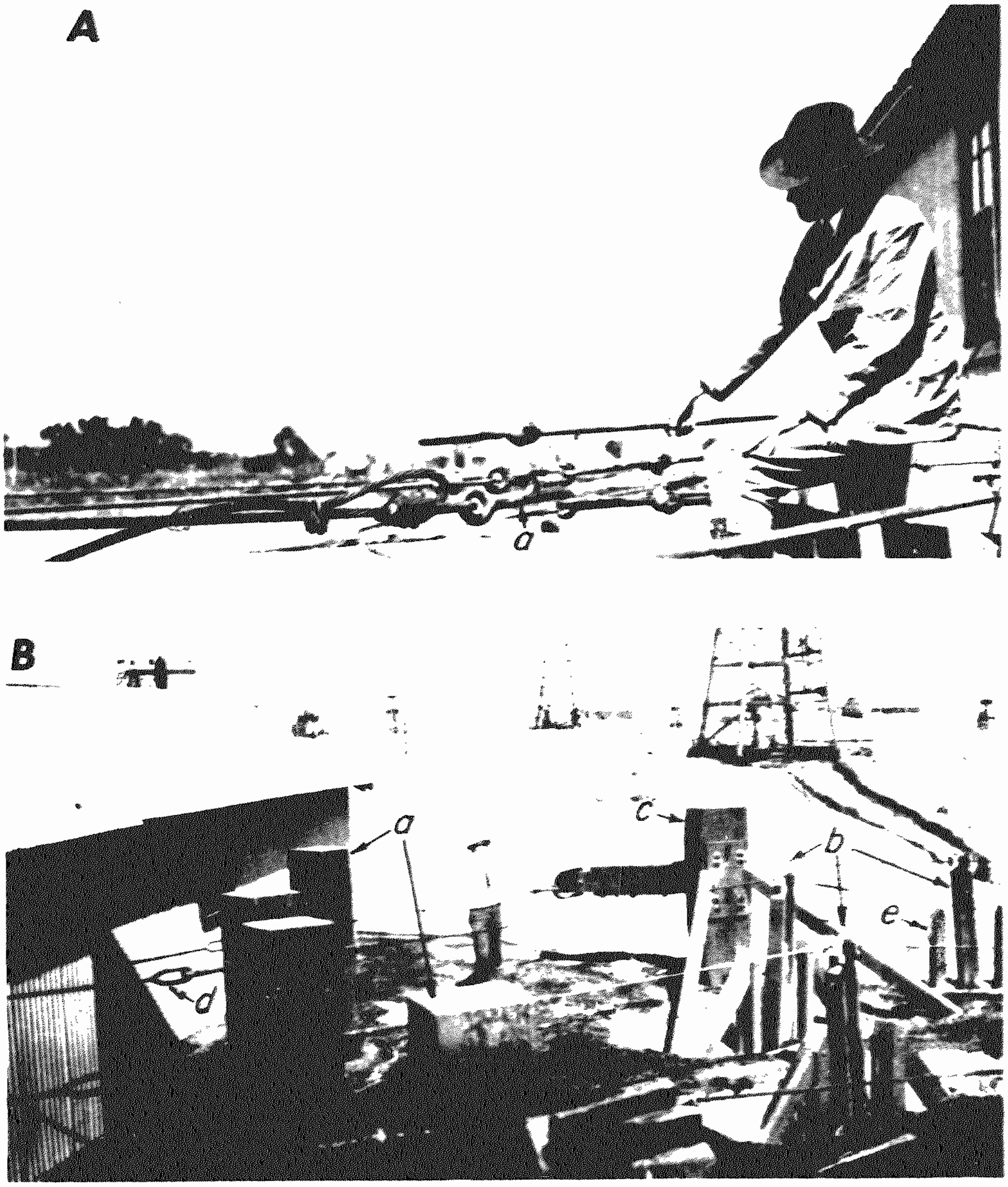


FIGURE 45. - Rod-line structures in use at central power. A. Takeoff rods, takeoff rails, and rod-line attachments. B. Rod-line support, rocker used as holdup, butterfly swing, and rod-line attachments.

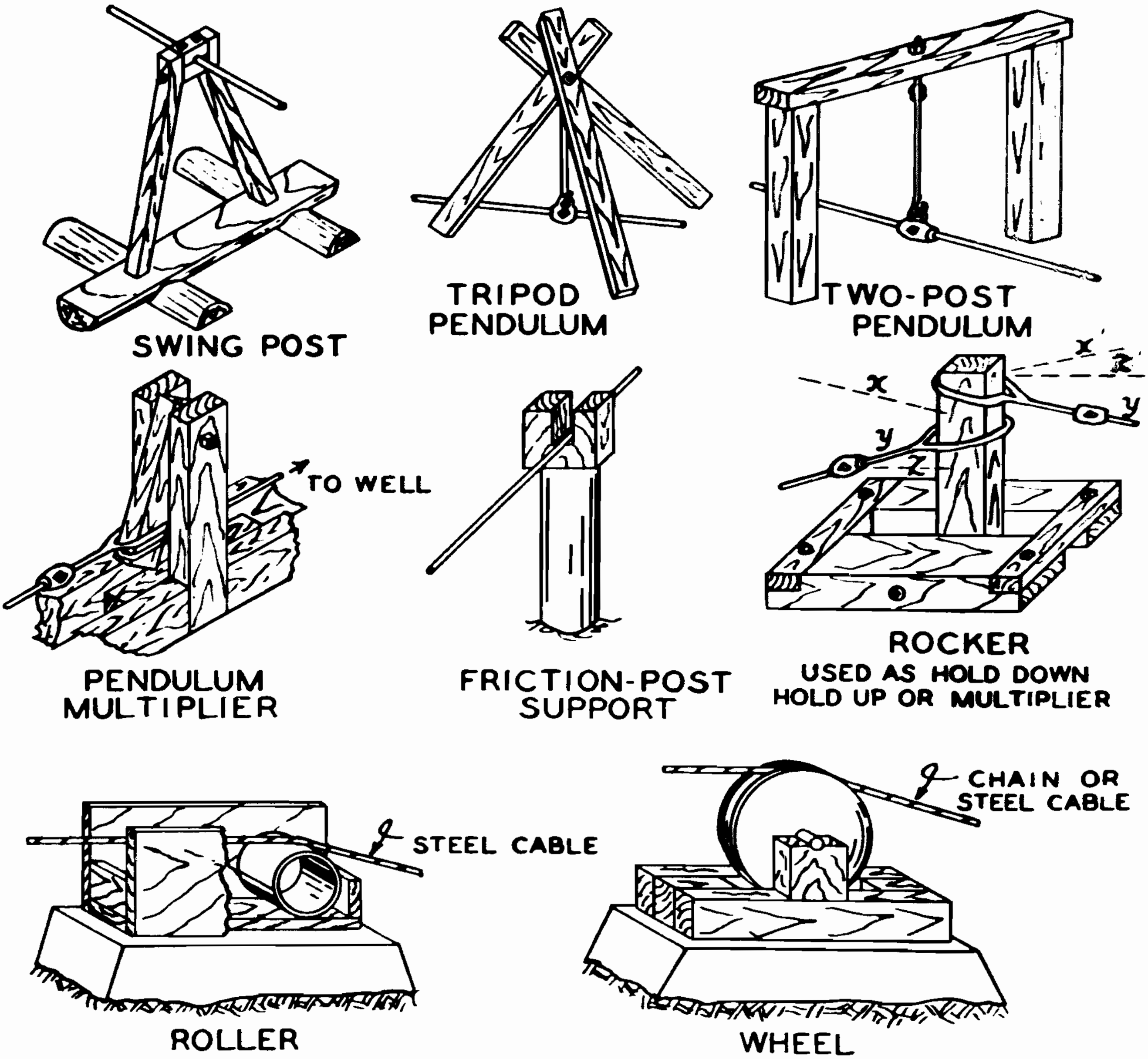


FIGURE 46. - Typical rod-line structures.

3. Supports for changing the length of the rod-line stroke. Pendulums and rockers were often used to make the length of the stroke at the well differ from that imparted to the rod line at the power. When they increase the stroke, they are known as multipliers, and when the stroke is decreased, they are called reducers. Examples are the pendulum multiplier and rocker arm shown in figure 46, and multiplier shown in figure 47-C.

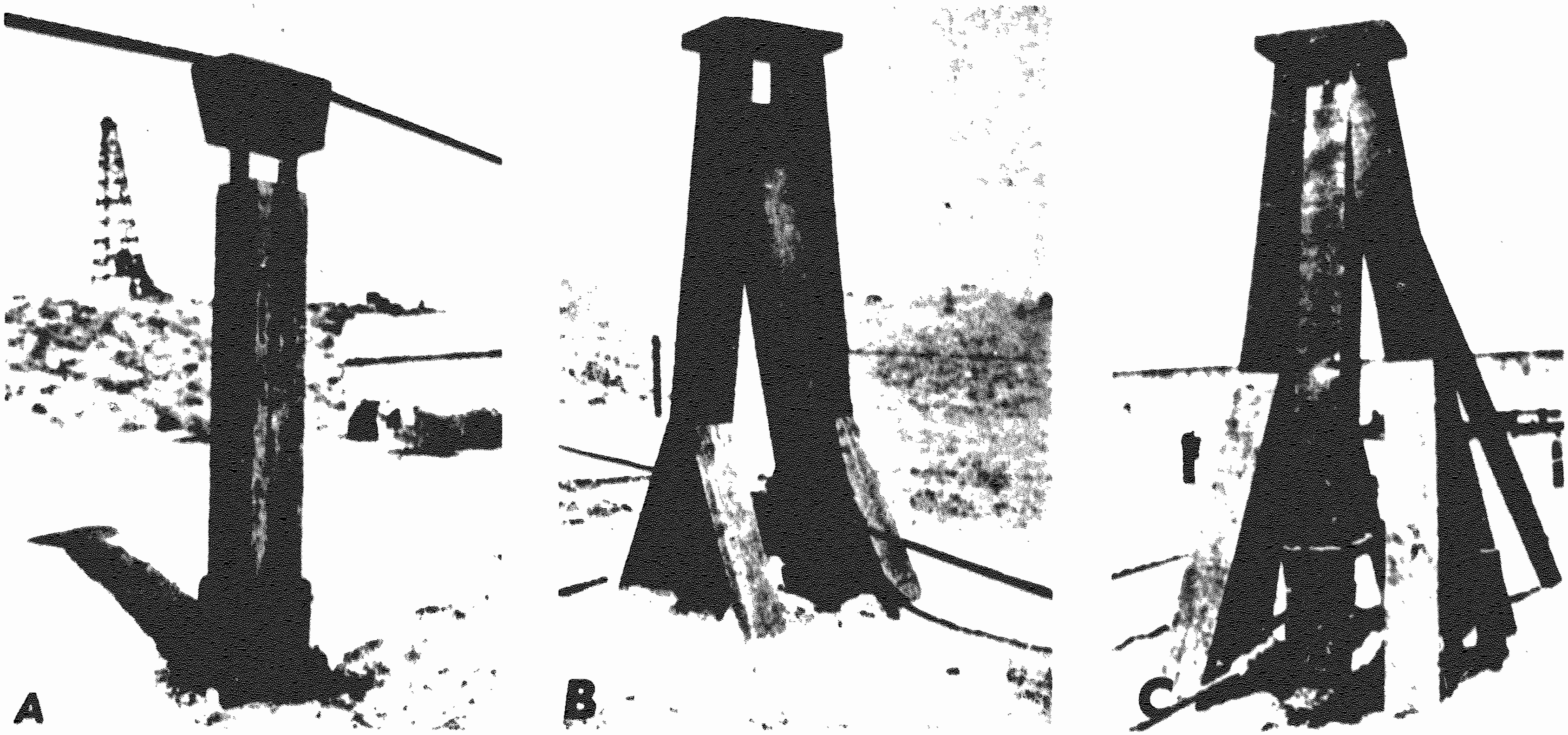


FIGURE 47. - Rod-line supports. *A*. Rocker support for rod line. *B*. Pendulum support for rod line. *C*. Pendulum or multiplier for changing the length of stroke. (From Petroleum Production Engineering, 1st Ed., by Lester C. Uren. Copyright 1924 by McGraw-Hill Book Co., Inc.)

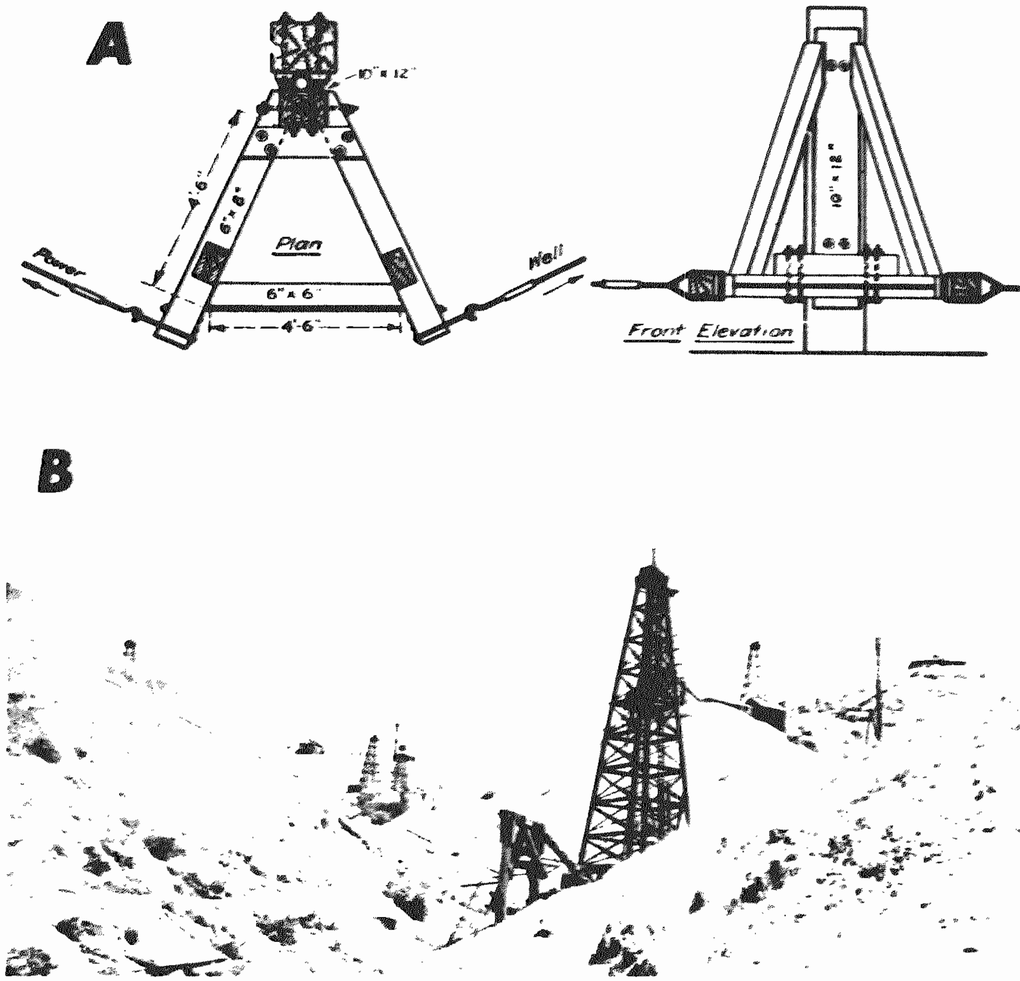
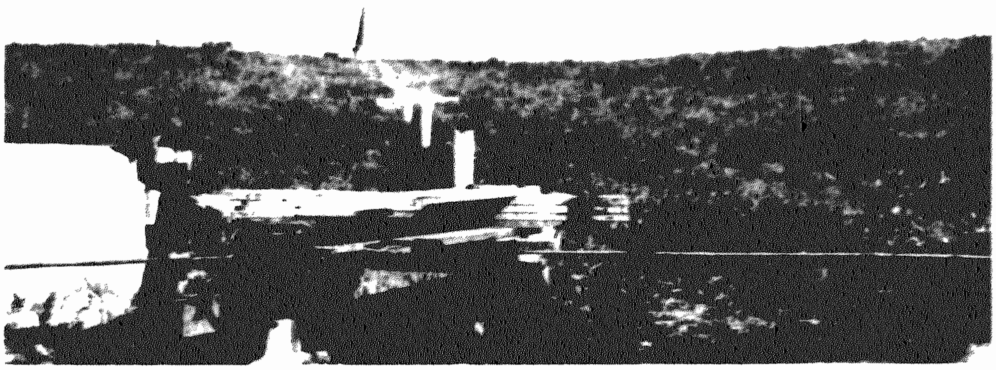


FIGURE 48. - Butterfly swings for changing direction of pull in a horizontal plane. *A*. Diagram of a butterfly swing. *B*. Butterfly-type pendulum used for a holddown. (From Petroleum Production Engineering, 1st Ed., by Lester C. Uren. Copyright 1924 by McGraw-Hill Book Co., Inc. Used with their permission.)

4. Structures for changing rod-line direction in a vertical plane. Devices called "holdups" were used if the rod line led to a lower level and "holddowns" if the line led to higher level. If the rod line crossed a series of gullies and ridges, holdups were put on top of ridges and holddowns in the bottom of the gullies. Examples of these devices are the rocker used as a holdup shown in (b), figure 45-B; the pendulum multiplier, rocker, roller, and wheel shown in figure 46; and the butterfly-type pendulum used as a hold-down in figure 48-B because of the sharp angle in the rod line caused by the rough topography.

5. Structures for changing rod-line direction in a horizontal plane. Swings and rockers were the principal devices used to change the direction of the rod lines horizontally. Examples of these devices are the butterfly swings shown in (d) figure 44, (c) figure 45-B, figure 48-B, and figure 49-A and B. Other examples are the hold-in swing shown in (A), the holdout rocker

A



B

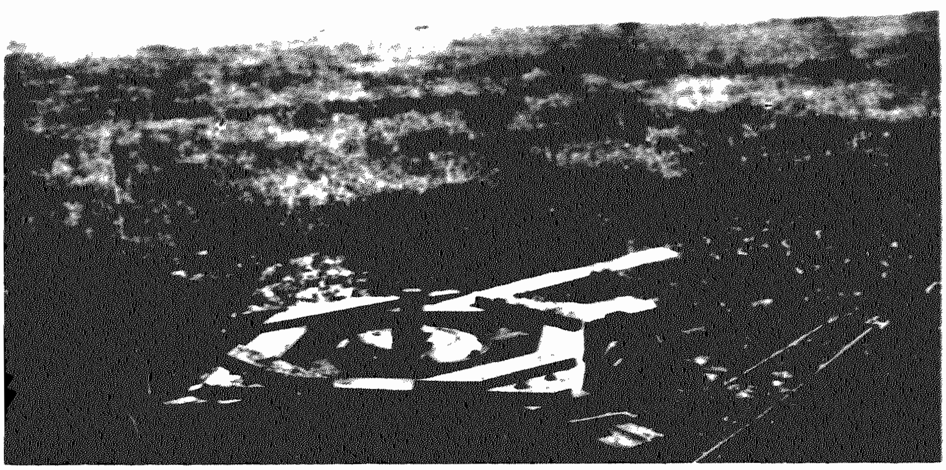


FIGURE 49. - Types of swings used to change direction of rod lines horizontally. A. Two-way swing. B. Four-way swing.

shown in (B), and the beam for changing direction of transmission line through 180° shown in (C), figure 50.

6. Equipment to connect the power to the pump jacks. Rod lines were attached to the power disk or eccentric by a rod equipped with a clevis or yoke at one end, for connecting to the power, and an eye or stirrup at the other, for connecting to the rod line. Examples of these connectors are shown in (e) figure 44, (a) figure 45-A, and (d) figure 45-B.

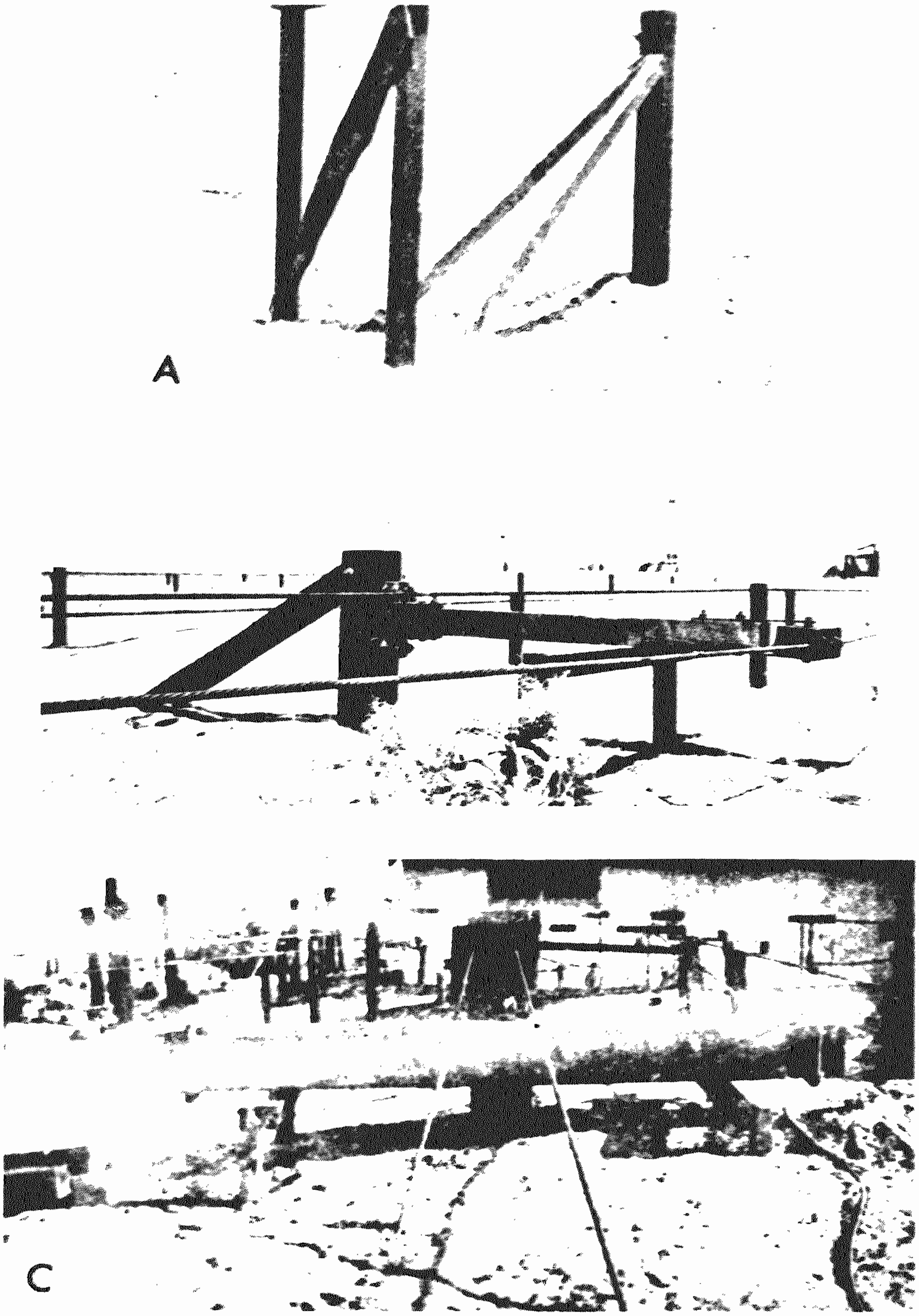


FIGURE 50. - Structures for changing direction of rod line, horizontally. *A*. Hold-in swing. *B*. Holdout rocker. *C*. Beam for changing direction of transmission line through 180°. (From Petroleum Production Engineering, 1st Ed., by Lester C. Uren. Copyright 1924 by McGraw-Hill Book Co., Inc. Used with permission.)

A pumping jack is a device used at a well to transfer the horizontal motion furnished by the rod lines to the vertical motion required by the sucker rods to actuate the pump plunger, shown in figure 51. Jacks are made of pipe, timber, structural steel, or from a combination of these materials. The two general classes of pumping jacks are the direct pull or Pennsylvania type and the indirect pull or Oklahoma type. Figure 51-A shows a Pennsylvania-type pump jack made of pipe; where (a) is the back supports, (b) the supporting legs, (c) the rod line, (d) the arm, (e) the polish-rod clamp, and (f) the work arm of the jack. Figure 51-B is an Oklahoma-type steel and wood-constructed jack; where (a) is the rod line, (b) the structural steel jack, (c) the pitman, (d) the structural steel beam, and (e) the pivot. Pumping jacks are made with either overhand or underhand pull, as shown in figure 52.

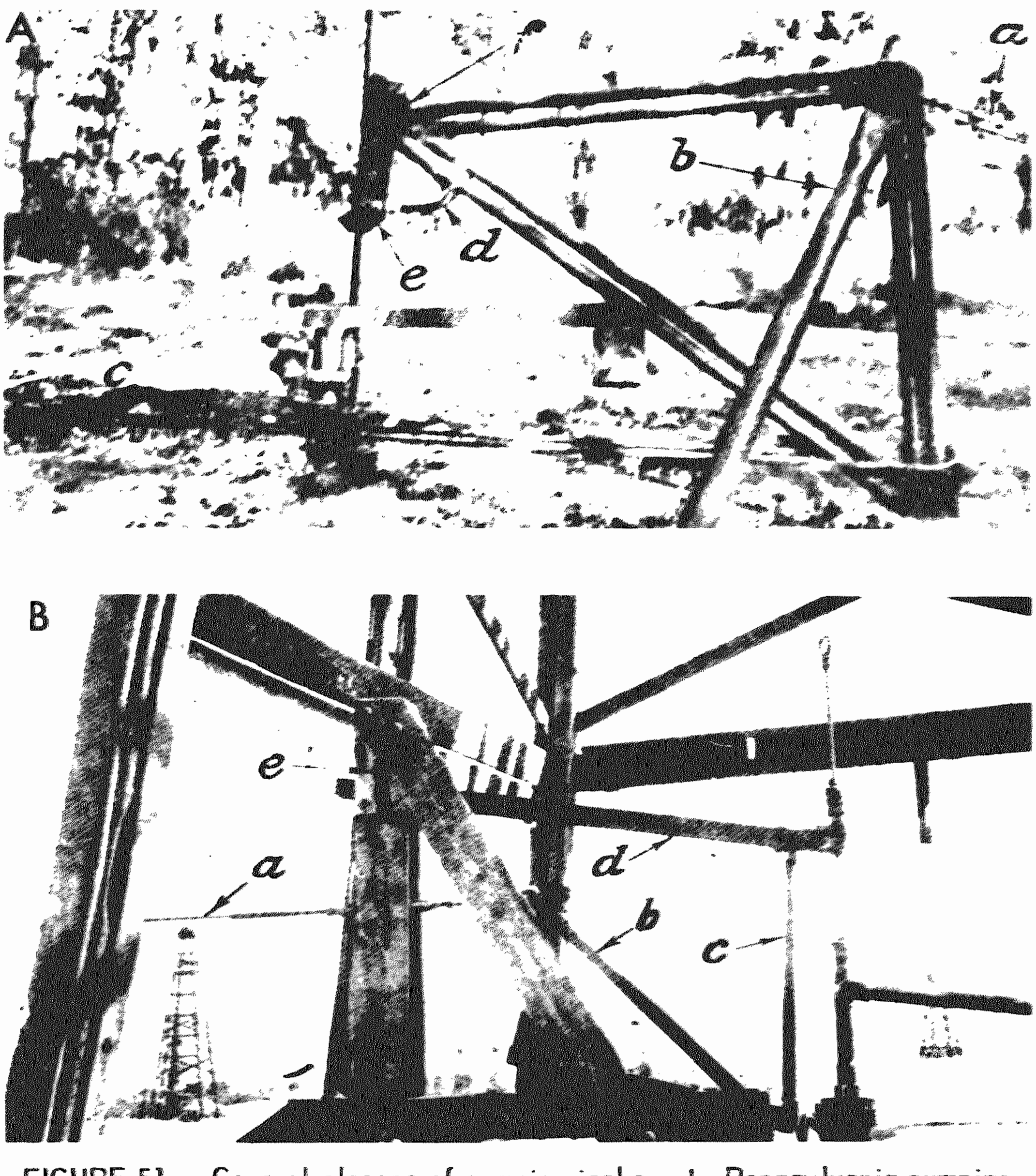


FIGURE 51. - General classes of pumping jacks. A. Pennsylvania pumping jack made from pipe. B. Oklahoma pumping jack made from structural steel and wood.

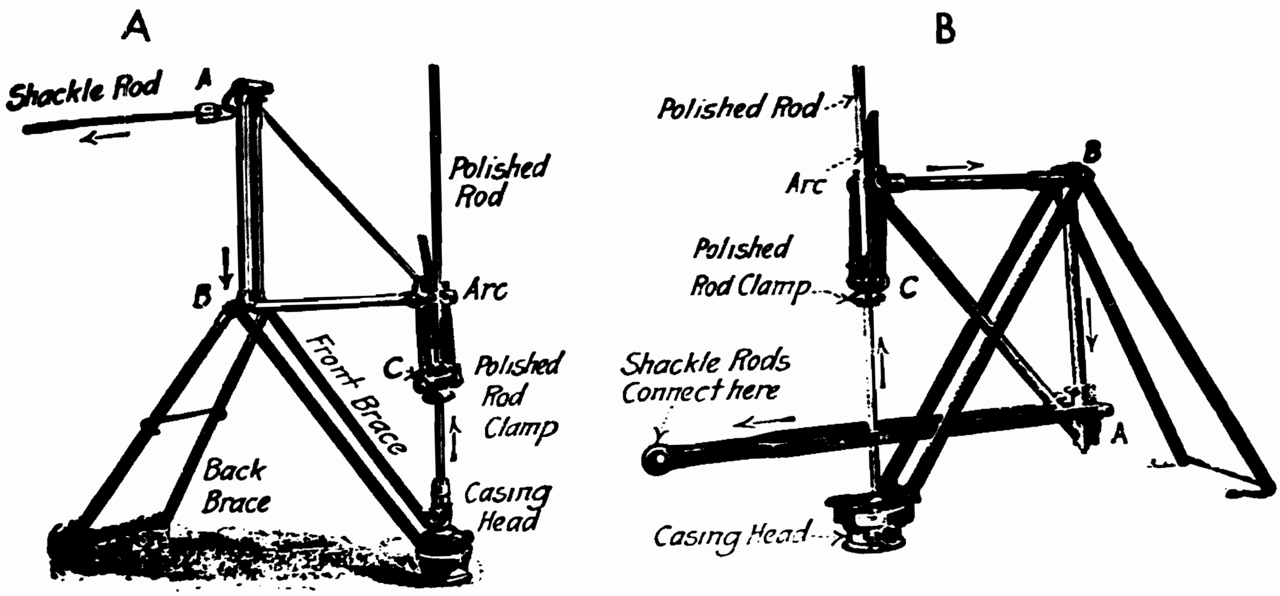


FIGURE 52. - Types of pumping jacks. *A*. Overhand pull. *B*. Underhand pull. (From Oil-Field Practice, 1st Ed., by Dorsey Hager. Copyright 1921 by McGraw-Hill Book Co., Inc. Used with their permission.)

A B

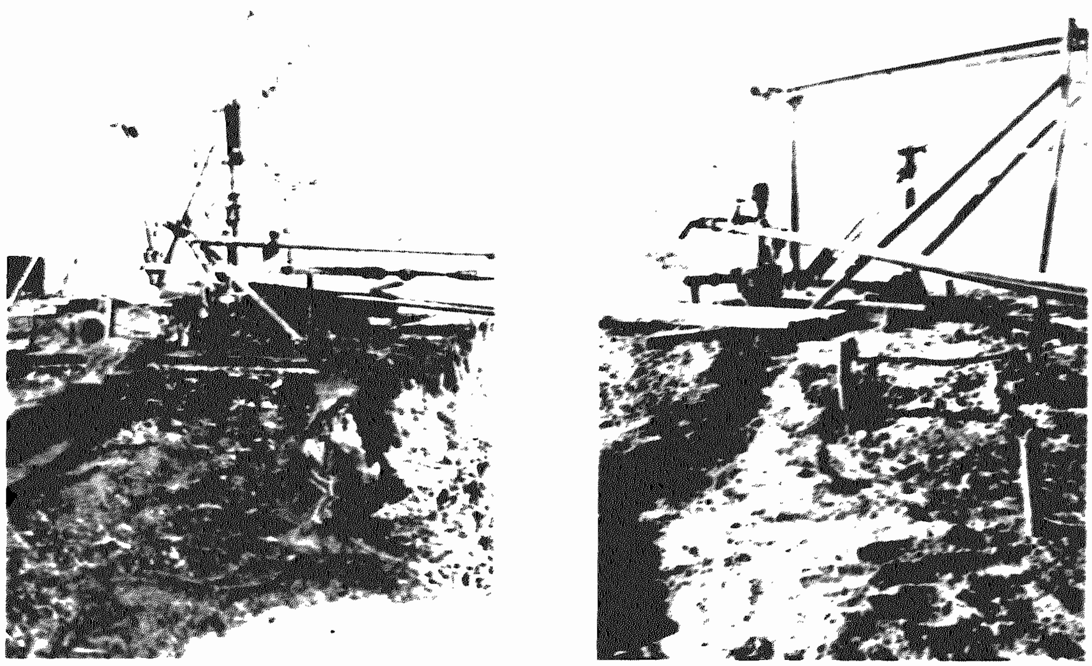


FIGURE 53. - Pumping jacks operating in the Field. *A*. Pennsylvania-type pumping jack. *B*. Oklahoma-type pumping jack.

In both cases, the application of power is at (A), the fulcrum at (b), and the weight lifted at (C). The overhand pull-type jack was not too common but was used at many wells in hilly country to give a more direct pull to the jack in areas where the ground level was lower than the rod line and power. The first jacks used in the shallow Appalachian oilfields were made of timber and were of the Pennsylvania class. Later both Pennsylvania and Oklahoma class jacks, made of pipe and structural steel, as well as timber, were used. Examples of Oklahoma and Pennsylvania class jacks in operation are shown in figure 53.

DISCUSSION

Examples and description of nearly every type of equipment commonly found in the field have been presented. Drilling machinery and prime movers of very early vintage as well as later models were described showing clearly a progressive development as modifications were made to allow deeper drilling. The parallel development of power sources was of great influence in the subsequent development of drilling rigs used in modern operations.

A large number of figures have been used for the purpose of acquainting people in the coal industry with past methods, techniques, and sources of information needed to aid in the location of abandoned and/or lost oil and gas wells. These wells could possibly intersect coalbeds under development by mining, and the mining through of such an undetected well would present a serious methane hazard.

Today, with emphasis on energy, there is a great need for experienced and knowledgeable people who are capable of returning old abandoned and productively marginal oilfields and gasfields back into production. There are also many who have lost touch with the past. For those who are unfamiliar with some of this earlier equipment and methods used, this information hopefully fills that need.

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