PDHonline Course M548 (8 PDH)

Oil & Gas Drilling Technology – General Overview – Part 1

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OIL & GAS DRILLING TECHNOLOGY
GENERAL OVERVIEW – PART 1

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I. INTRODUCTION:

The preparation of this course, divided in part 1, 2 and 3, tries to follow the fundamentals of oil & gas drilling wells since surveillance, site preparation, rig mobilization, drilling stimulation, completion, well connection, production facilities, processing and transportation. Side tutorials are presented on all the major drilling topics including drilling history, rig structure, rig equipment, the drilling process, drilling fluids, casing and cementing, well control, drill bits, drill pipe, drilling tools, fishing, directional drilling and well evaluation techniques. This first part is a general overview.

Petroleum is an oily, flammable liquid that occurs naturally in deposits, usually beneath the surface of the earth, also called crude oil. Petroleum is a naturally occurring liquid found in rock formations consisted of a complex mixture of hydrocarbons and gases of various molecular weights, with traces of various nitrogenous and sulfurous compounds.

The word petroleum may come from the Greek: "*petra*" for rocks and "*elaion*" for oil, as well from the Medieval Latin, "*petra*" (or petrous) for rock and "*oleum*" for oil. The term was also found in the 10th century Old English sources (with the word "petraoleum", as same spelling) and used in the treatise *De Natura Fossilium*, published in 1546 by the German mineralogist Georg Bauer, also known as Georgius Agricola.

Upstream, Downstream, and Midstream: The oil and gas industry is usually divided into three major sectors: upstream, downstream and midstream. The upstream sector is commonly known as the exploration and production (E&P) sector. The downstream sector commonly refers to the refining of petroleum crude oil, the processing and purifying of raw natural gas. Midstream operations are often included in the downstream category and considered to be a part of the downstream sector, as well the marketing and distribution of products derived from crude oil and natural gas.

The upstream stage of the production process involves searching for and extracting raw materials including the searching for potential underground or underwater crude oil and natural gas fields, drilling of exploratory wells, and subsequently drilling and operating the wells that recover and bring the crude oil and/or raw natural gas to the surface, there has been a significant shift toward including unconventional gas as a part of the upstream sector, and corresponding developments in liquefied natural gas (LNG) processing and transport.

The upstream part of the production process does not do anything with the material itself, such as processing the material. This part of the process simply finds and extracts the raw material. Thus, any industry that relies on the extraction of raw materials commonly has an upstream stage in its production process. In a more general sense, "upstream" can also refer to any part of the production process relating to the extraction stages.

For instance, when the petroleum industry locates underground or underwater oil reserves, characterizes the upstream process. Thus, the upstream process in industry involves bringing oil and gas to the surface. Extraction wells represent an example of a structure operating in this process stage, as the upstream stage in the production sector is by itself, considered as a supplier providing raw materials to manufacturers or other businesses that ultimately process the materials.

In the oil and gas industry, the downstream process consists of converting crude oil into other products and then selling those products to customers. The downstream stage in the production process involves processing the materials collected during the upstream stage into a finished product. The downstream sector touches consumers through products such as gasoline or petrol, kerosene, jet fuel, diesel oil, heating oil, fuel oils, lubricants, waxes, asphalt, natural gas, and liquefied petroleum gas (LPG) as well as hundreds of petrochemicals.

Thus, oil refineries represent structures that operate within the downstream process. However, any kind of plant that processes raw materials may qualify as operating within the downstream stage of production. A company that combines both upstream and downstream processes is an integrated company. The downstream stage further includes the actual sale of that product to other businesses, governments or private individuals. The type of end user will vary depending on the finished product. Regardless of the industry involved, the downstream process has direct contact with customers through the finished product.

Crude oil is a mixture of many varieties of hydrocarbons, which has many sulphur-containing compounds. The oil refining process commonly includes the hydro-desulphurization that converts most of that sulphur into gaseous hydrogen sulphide. The raw natural gas may also contain hydrogen sulphide and sulphur-containing methanethiol, removed in natural gas processing plants before the gas is distributed to consumers. The hydrogen sulphide removed in the refining and processing of crude oil and natural gas is subsequently converted into elemental sulphur, which is a byproduct.

Natural gas is a mixture of lightweight alkanes. A typical sample of natural gas when it is collected at its source contains 80% methane (CH4), 7% ethane (C2H6), 6% propane (C3H8), 4% butane and isobutane (C4H10), and 3% pentanes (C5H12). The C3, C4, and C5 hydrocarbons are removed before the gas is sold. The commercial natural gas delivered to the customer is therefore primarily a mixture of methane and ethane. The propane and butanes are by products from natural gas, and then usually liquefied under pressure and sold as liquefied petroleum gases (LPG).

II. HISTORY:

Petroleum: According to the historians Herodotus and Diodorus Siculus, more than 4000 years ago, asphalt was used in the construction of the walls and towers of Babylon. Great quantities of crude oil were found on the banks of the river Issus, one of the tributaries of the Euphrates. Ancient Persian tablets indicate the medicinal and lighting uses of petroleum in the upper levels of their society. By 350 B.C, oil was produced from bamboo-drilled wells in China. Early British explorers to Myanmar documented a flourishing oil extraction industry based in Yenangyaung that, and in 1795, had hundreds of hand-dug wells under production.

The process of distilling crude oil/petroleum into kerosene, as well as other hydrocarbon compounds, was first written about in the 9th century by the Persian Rhazes. Kerosene is a combustible hydrocarbon liquid and the name is derived from the Greek “keros” meaning wax. In his *Book of Secrets*, he described two methods for the production of kerosene, termed "*white naphtha*", using an apparatus called as “*alembic*”.

In the 19th century, kerosene was produced from *coal oil* (or shale oil) and *bitumen* by heating rock to extract the oil, which was then distilled. Since, the cost of extracting kerosene from coal was too high, in 1846 a Canadian geologist Abraham Gesner gave a public demonstration of a new kerosene process extraction he had discovered, in Charlottetown, Prince Edward Island, using a mi-neral asphalt, very similar to coal rock, designated as *albertite*.

The history of the petroleum industry in the United States goes back also to the early 19th century, when petroleum was discovered in Pennsylvania in 1859. The oil rush began in Titusville, Pennsylvania, when "Colonel" Edwin Drake, for the sole purpose of finding oil, drilled the first successful oil well in the Oil Creek Valley. The wells were shallow, less than 50 meters (15 feet), but could give quite large production for that time. The picture below shows the Oil Creek Valley where the oil was flowing initially at 4000 barrels per day, in October 1861.

The Drake Well, Titusville, PA, 1859

Natural Gas: In 1859 an oil explorer, H.C. Tweedle, found a natural gas seep near Moncton, New Brunswick, Canada, what became the Dover field, but water seepage prevented production of these wells. In 1889, Eugene Coste, a young geologist who became the father of Canada's natural gas industry, brought in the first producing gas well in Essex County, Ontario. In 1891, Canada started to export natural gas from the Bertie-Humberstone field in Welland County to Buffalo, New York. Later, gas was exported to Detroit from the Essex field using 8 inches pipeline under the Detroit River.

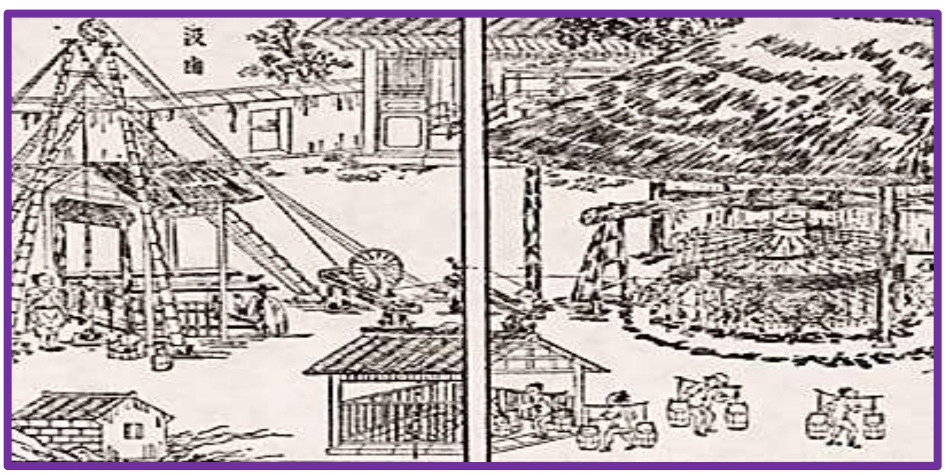
In 1897, the pipeline stretched the Essex gas supply to its limit with the extension of exports to Toledo, Ohio, but the Ontario government revoked the license for the pipeline, and in 1907 the province passed a law prohibiting the export of natural gas and electricity. In 1909, New Brunswick's first successful gas well came in to supply customers at Stoney Creek near Moncton, although, nowadays, the city has a propane air plant to augment the limited natural gas supply.

The first large scale liquefaction of natural gas in the U.S. began in 1918 when the government liquefied natural gas to extract helium, which is a small component of the natural gas, when helium was intended for use in British dirigibles for World War I. The key patents having to do with natural gas liquefaction came in 1915 and the mid-1930s. In 1915 Godfrey Cabot patented a method for storing liquid gases at very low temperatures, using a Thermos bottle type design which included a cold inner tank within an outer tank; the tanks being separated by insulation.

In 1937, Lee Twomey received patents for a process for large scale liquefaction of natural gas. The intention was to store natural gas as a liquid so it could be used for shaving peak energy loads during cold snaps. Because of large volumes it was not practical to store natural gas, near atmospheric pressure. However, when the natural gas was converted to a liquid form, cooled to -162ºC (-260ºF) to shrink the volume 600 times, it could be stored in a volume 600 times smaller. Thus, this became a practical way to store the natural gas, stored at -260°F.

Drilling Wells: The drilling of wells for the manufacture of salt began by the Song Dynasty in China. Archaeological evidence of the drilling tools used in deep-well dwelling are kept and displayed in the Zigong Salt Industry Museum. Cable tools were the earliest drilling method, constructed of bamboo, and had its beginning 4000 years ago in China. Salt is one of the "seven necessities of life" mentioned in proverbs and "salty" is one of the “five flavors" which form the cosmological basis of Chinese cuisine.

The Chinese drilling system has the size of a drinking bowl, while the depth of the borehole amounts to some feet. Large bamboo stems are used and fitted together by male-female joints to form the well, thus keeping the fresh water out so that the salty spring water comes up by itself. Smaller bamboo tubes are also used which travel up and down in the wells as buckets. They have no bottom, but an orifice is mounted at the top. A piece of leather of several inches in size is hung up. As the tubes go in and out of the brine, the air pushes and sucks closing and opening the leather valve. Each tube brings up a small quantity of brine.

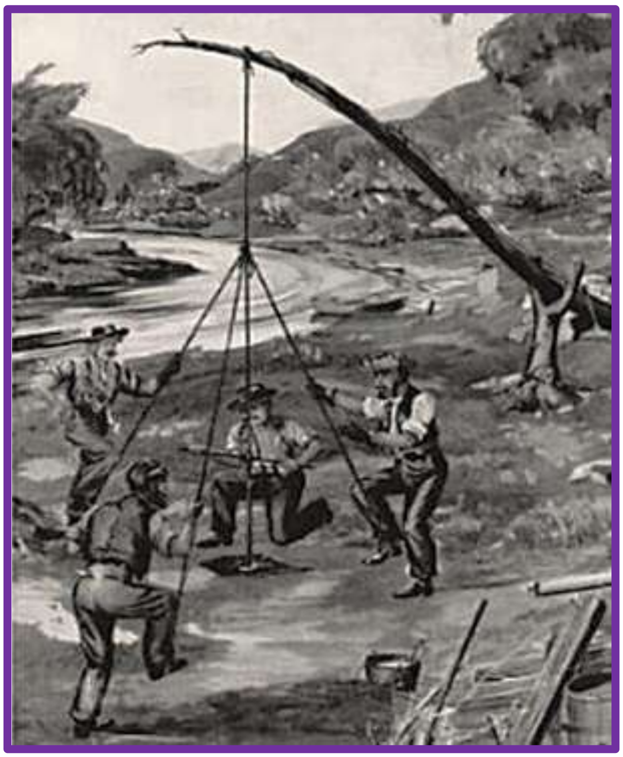


Raising brine from the bottom of a salt well (Sichuan)

The salt-making process of the Song Dynasty through well-drillings included acquiring brine, drying brine, and frying salt. Zigong is the birthplace of the cable tool drilling technique. Haijing in 1835, constructed the first well in the world over 1000 m (300 ft) deep, and the spread of deep drilling techniques in Zigong made it the wealthiest county in Sichuan during the Qing Dynasty. In 1939, Zigong became a city, largely because of the prosperous salt industry.

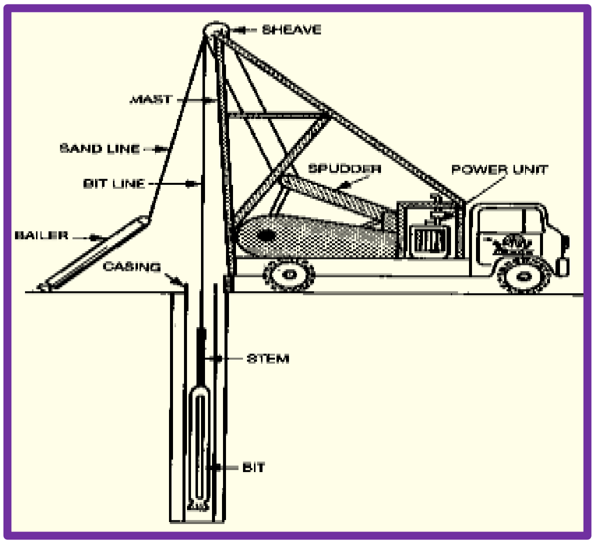
Cable Tool Rigs: Are sometimes called pounders, “spudders”, percussion or ballistic, these rigs raise and drop a drill string with a heavy carbide tipped drilling bit that chisels through the rock by finely pulverizing the subsurface materials. The drill bits breaks or crushes consolidated rocks in small fragments. Water is also added by the driller, to mix with the crushed or loosened particles in slurry at the bottom of the borehole. At this point, the slurry is removed from the borehole by a bailer system, then, the bit is reinserted into the hole and the drilling operation continues.

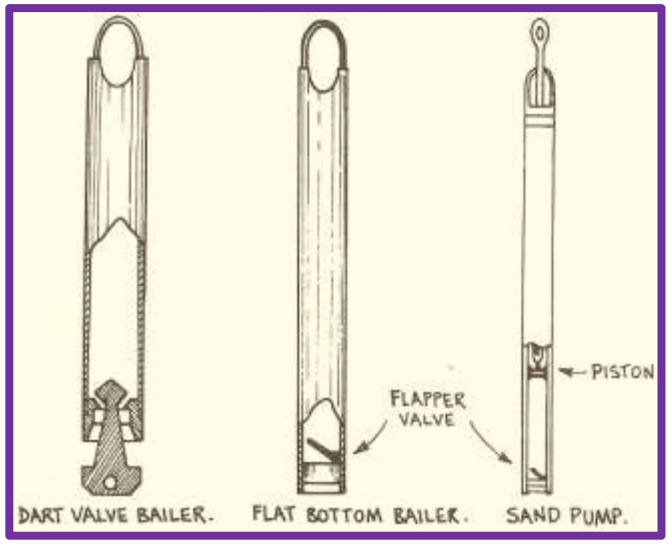
Oil drilling in the old times, also used cable tools to drill wells, as a spring pole (see below), made with a flexible branch mounted on a fulcrum, with the drilling cable and bit suspended on the free end of the pole. The crew would hop up and down in stirrups attached to the pole to make the bit jump up and down and chop a new hole. Mechanized versions of this system, which persisted until about 1970, used cams to rapidly raise and drop the bit tool, with steel cables up to 0.125 in. The photo at the right below, shows the "cable tool bits” and the tools on his right are "drilling jars", which are screwed into the top of the bit to add more weight to the down-hole assembly.



Water from the surrounding rock formations typically flows into the hole during drilling, but if no water is present, it needs to be added, the way pulverized drilling debris can be converted into a thick, muddy mess. These debris are also known as cuttings, and as more and more cuttings accumulate, they eventually need to be removed in order for drilling to continue. To remove the muddy cuttings, the bit is pulled out of the hole, and a "bailer" lowered down in its place.

The bailer is really nothing more than a piece of pipe with a dart valve on the underside. When the dart touches the bottom of the hole, it pushes up and opens the bailer so that mud and cuttings can flow inside. The dart closes when the bailer is raised, thus trapping the cuttings, which are emptied into a pit next to the derrick after the bailer is hauled back to the surface.



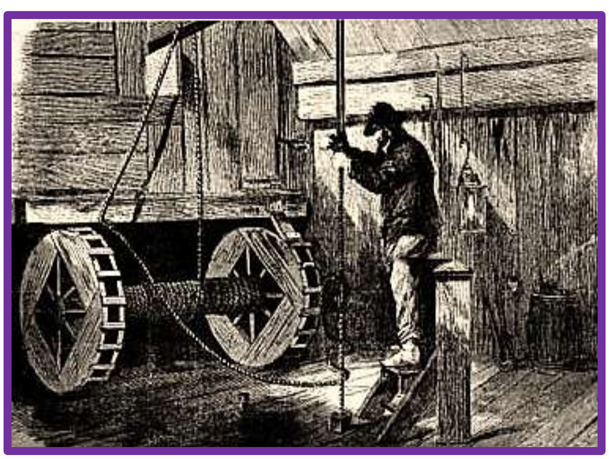


In Titusville, Pennsylvania, when "Colonel" Edwin Drake drilled the first successful oil well in the Oil Creek Valley, he used a steam-powered cable-tool rig to find oil at 70 ft. Later John Grandin also used a spring-pole to drill deeper, designated as spring-pole “kick down” method, for his well at nearby Gordon Run Creek. The well reaches a depth of 134 ft, nevertheless produced no oil, despite his desperate attempts. His drilling attempt could be credited as the first “shooting” of a well with black powder in USA (and the first well ruined by a failed shooting attempt).

John Grandin used a spring-pole to drill deeper than the famous Drake well of 1859

In the early 1860's the cable tool bits may have drilled only 2 or 3 feet, usually a little more, before it was pulled out of the hole for dressing. The drilling rate depends on the hardness of the strata and on the effect of accumulated cuttings. Cable tool bits were used in California and many other states, but, they were not satisfactory along the Gulf Coastal Plain because the strata are too soft there. The photo below shows a “cable-tool bit”, utilized to pulverize the rock at the bottom of the hole. It is commonly 5 ft long and is very heavy.

Treadle Rim: A type of foot treadle was also used about 1862, in the early oil drillings, using a spool hoisted cable on a drum shaft. Each wooden wheel (one on each side of the shaft) consisted of two rims about ten inches. The treadles were rungs of strong wood nailed or screwed to the rims about 8 inches apart, installed entirely around each wheel. By using his foot on the rungs, the driller could turn the wheels and shaft and thereby wind the manila line or cable on the shaft. He could also control the lowering of the line, especially if a brake device were installed.



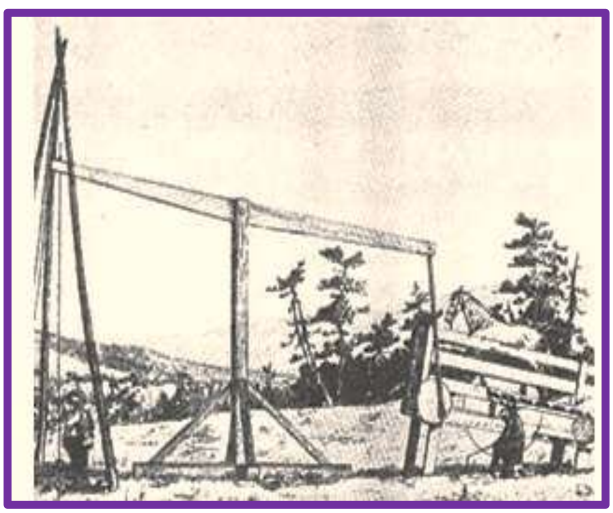
Right: Treadle rim and worker. Left: Treadle rim wheel in this photo of the 1862 in Oil Creek Valley.

The picture below at right shows the foot treadles, and the rungs on the pair of bull wheels. The shaft is a spool for the manila rope which has been hoisted or is ready to run in the hole. Note the wooden ratchet brake on the right hand wheel, which could catch on a rung. The spike on the beam near the left wheel helped to keep the rope from tangling. It is estimated that Drake used this type of treadle bull wheels in his 1859 oil well.

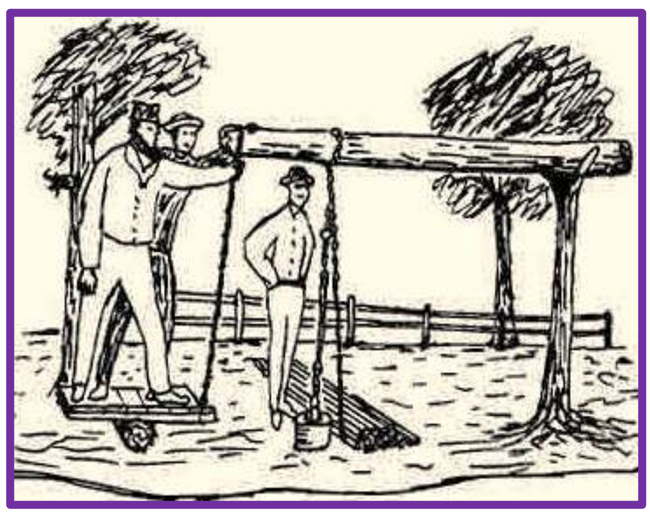
In 1872, a more sophisticated cable-tool device called a horse-driven “spudder” rig was patented. It used a horse on a treadle but didn't require a spring-pole or permanent walking beam and was considered to be portable. A horse and treadle arrangement served to operate a walking beam rig and could have done the same with a spring-pole. This means of drilling goes back to the salt days and, after a fashion, even before then. The picture below shows a horse-powered treadle rigged to a wooden walking beam rather than a spring-pole. This arrangement was in use in the early salt days and also served for drilling shallow water wells.

Teeter Board: There isn't much information in the literature about the teeter board, as a power source. However, since it produced an up and down motion, it must have been able to pull and release the tools. It was tried out with the spring-pole. Brantly (1971) estimated that a teeter board could have worked the drill rods at 60 to 90 strokes per minute, far more than a stirrup-run spring-pole. However, the stroke length was probably quite short. A patent sketch for a well-designed teeter board outfit hasn't been found by the author.

The drawing below is derived from a sketch believed to represent an early 1800's drilling method. The anchored butt end of the spring-pole would be off the drawing to the right. The connecting rope for the teeter board in this example is tied at the working end of the spring-pole instead of behind the tool string. Drilling rods are piled on the ground ready for use.



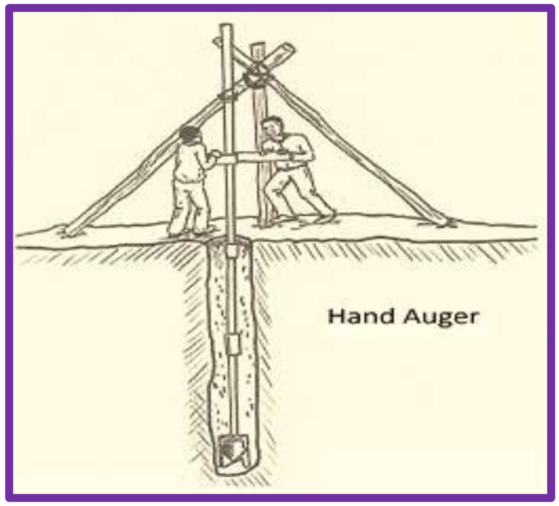
Horse-driven “spudder” rig



Teeter board

Auger Drilling: The other early alternative to the cable tool was the hand auger, which when mounted on a tripod as shown below, used to drill a shallow hole. The problem with an auger was that pipe had to be added to the tool to extend it, as the hole got deeper, which meant the auger got heavier and heavier as the well went down. Often utilized for site investigation, environmental and geotechnical drilling, sampling and boreholes for construction purposes, auger drilling can be an efficient drilling method.

An auger is a drilling device, or a drill bit, that usually includes a rotating helical screw blade called as "*flighting*" to act as a screw conveyor to remove the drilled out material. The rotation of the blade causes the material to move out of the hole being drilled. An auger used for digging post holes is called as “earth auger”, “handheld earth drill”, “soil auger”, or “mechanized post digger”. Common wood augers tools have a screw to pull them into the wood, as a gimlet has, and a cutting lip that slices out the bottom of the hole. In construction, augers are used for special drilling rigs to dig holes for deep foundation piles.



The first auger wells were in the San Joaquin Valley, drilled on seeps with a hand auger in 1867 by the Columbian Oil Company at Coalinga. However, the oil was thick, tarry and hard to flow, so production was minimal. The obvious next step was to use an engine to drive the auger, which gave rise to rotary tools and the "rotary bits". Thus, the first auger rotary rig in California arrived at Coalinga field in 1902, but drilled a so crooked hole, that a cable tool rig had to be brought in to drill again the well.

This happening naturally gave the “rotary tool bit” a bad name in the California oil fields. Nonetheless rotary drilling rigs and crews arrived in California from Louisiana in 1908 and successfully drilled wells at Midway-Sunset field, and erased the embarrassment of the Coalinga drilling experiment that happened six years earlier. The San Joaquin Valley has been the principal source for most of the petroleum produced in the State during the past 145 years.

Rotary Rigs: A rotary rig uses a rotating drill bit, similar to a hand drill and a weight is placed on the drill bit as it is turned. In a rotary rig, an engine provides the power to turn around a flat turntable, or a rotary table, set horizontally in the center of the derrick floor. The drill pipe goes through the center of the rotary table and down into the hole where the bit is attached. The table turns the pipe and bit, which drills through the rocks below.

Instead of the repetitive lift and drop of heavy cable-tool bits, the rotary drilling introduced the hollow drill stem that enabled broken rock debris to be washed out of the borehole with re-circulated mud while the rotating drill bit cut deeper. Rotary drilling uses fluids (drilling mud) to circulate out the rock as it is chipped away. The fluid washes out the drill hole as it goes, making the process