ADVANCEMENT ON DRILLING TECHNOLOGY IN PETROLEUM INDUSTRY

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Akpedeye, Kelvin Uruemu

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Author	Akpedeye, Kelvin Uruemu
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ABSTRACT

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ABSTRACT

Since the birth of petroleum business, in the mid-19th century, cable tool and rotary drilling have been the only two techniques applied in the drilling phase till date. Although the rotary drilling technique has proved very successful, applying laser technology in this drilling; which is a newer technology that is already at hand, has the potential of displacing both techniques from operation.

Cable tool drilling is the first of these techniques. Hole boring is achieved by repeatedly lifting and dropping a heavy string of drilling tool into the bore hole with the bit crushing the rocks into small fragments. Comparatively, much success was not achieved with this because it is time consuming, has a very low penetration rate, blowout preventers were not easily adapted and it is almost limited to drilling consolidated formations. However, at the turn of the 20th century, the rotary drilling technique was introduced and it immediately displaced the cable tool from operation. The major difference between both is that with the cable tool, drilling has to be stopped in other for cuttings to be removed from the hole, whereas with the rotary drilling, a mud circulates through the system and carries away cuttings from the whole whilst drilling continues.

Rotary technique operation is more like a common hand held drill, rotating drill bit with an applied force to drill down the earth crust. The prime mover, hoisting equipment, rotating equipment, circulating equipment and blowout preventers complement each other to give the rotary technique its status in today's drilling. These five distinct components make a complicated looking rotary facility very understandable. Unlike the cable tool; it can drill through most rock formations, has a high penetration rate and can drill deeper wells, blowout preventers are easily adapted and can drill directionally as well.

However, applying laser technology in petroleum drilling, a fairly recent development has the potential of mitigating the limitations of the state-of-the-art technique. Experiments carried out so far on different types of lasers have shown very positive tendencies. One was conducted on MIRACL (Mid Infrared Advanced Chemical Laser) to determine its feasibility for drilling and perforating petroleum wells and another was on COIL (Chemical Oxygen-Iodine Laser) to determine the least specific energy (SE) needed to destroy varying rock types. Each of these has cleared the doubts of whether or not lasers technology can be applied in well operations.

Keywords Drilling, blowout, laser, petroleum.

Pages 54 pp. + appendices 2 pp.

CONTENTS

1 INTRODUCTION

Even at the beginning of the 21st century, the petroleum industry is yet to overcome some major problems it faces in the operations. A major focus is on the drilling practices. This makes it difficult for the industry to get the results they require within the shortest possible time. Hence a lot of time is put into drilling, sometimes weeks or even months, just a single well.

‘‘Edwin Drake drilled the first well, for the purpose of petroleum production, in 1859 in Venango County, near Titusville in Pennsylvania’’. (Department of Environmental Protection, 2009). Although, some claims of prior art do exist, (e.g. Germany in 1857 and Canada in 1858), Drake’s well at Titusville is still registered as the first to be copied. He and his crew drilled in the manner of salt well drillers but used a steam engine to power the drill and a piping to prevent borehole collapse, allowing for the drill to penetrate further into the ground. This gave a progress of three feet (1m) per day. However, they hit their first production depth of 69.5feet (21m) drilling from spring to August 27. Since then, a variety of drilling mechanisms has been developed and modified to sink a borehole into the ground. Each has its own advantages and disadvantages, in terms of depth to which it can drill, the type of sample returned, the cost involved and penetration rate achieved.

A radical change occurred at the turn of the 20th century. The introduction of the rotary drilling that displaced the then very popular cable tool drilling as a standard method for reaching oil and gas "traps" down through the formation. Limitations such as; downtime due to dull bits, lack of precise vertical or horizontal wells, formation fluid leakage during drilling and waste created by drilling mud still persist with this state-of-the-art basic mechanical method. In addition, drilling for petroleum and gas get increasingly difficult by the day. Nowadays, we are required to drill as far as 25000feet (7620m), most times, in deep stormy waters in order to get a satisfying volume. Hence the need for a more efficient drilling technique still remains a constant goal.

Although, laser drilling experiments dates back to the 1960s, it is only recently that experts started looking towards applying it to petroleum and gas drilling. “In 1997, the Gas Technology Institute (GTI) initiated a two-year study exploring the feasibility of adopting high-powered military lasers for a revolutionary application in the oil and gas exploration and production." (Gahan., Richard, Gas Technology Institute; Samih, Colorado School of Mines; Humberto Figueroa, PDVSA-Intevep, S.A.; Claude, Xu, Argonne National Laboratory. 2001) The experiment shows that laser drilling stands a viable option to improve drilling technologies, especially in offshore operations. Downtimes created by dull bits are drastically reduced as bits are replaced with laser heads that have no contact with the rock and also waste created by drilling mud is eliminated. It seals the wall of the well bore as it bores by creating a ceramic sheath. This eliminates the cost of employing steel wall casing, as influx/out-fluxes of fluids in and out of the well is eliminated and hence, problem of formation collapse is drastically reduced. In addition, it penetrates over 100 times faster than conventional rotary methods.

2 AIMS AND DELIVERABLES

Although, this report was submitted to Glyndwr University, Wrexham, Wales – United Kingdom, in April 2010, as my bachelor's dissertation. It is as well submitted to Hamk University of Applied Sciences, Finland in December 2010 and serves as my bachelor's thesis. This was so because I went on exchange to Glyndwr University and completed my dissertation there as part of my graduation modules.

This project is aimed at highlighting a new drilling technique that can be applied by petroleum and gas industries to optimize drilling practices and hence, production. This research work briefly outlines the first petroleum and gas drilling techniques and follows the trend to today's methods in a chronological order. Emphasis will be on the problems associated with each method and how they were overcome by subsequent ones.

However, a major part of this research will be on analysis of a viable drilling technique that stands a chance of supplanting the present state-of-the-art method that was invented over 100years ago. Laser technology in petroleum well drilling offers a very new approach and might just be another long awaited revolutionary change in petroleum and gas drilling technologies.

Notice that the units used in this report is not S.I. standard. This is because this report was made in United Kingdom as mentioned earlier. However, here are conversion factors to S.I standard.

- 1 foot = 0.3048 meters.
- 1 inch = 0.0254 meters.
- 1 ppg = 119.83 kg/m^3
- 1 psi = 6894.78 Pa
- Second / Quartz (s/qt) is a generally accepted unit for funnel viscosity in petroleum operations.

3 ANALYSIS OF TASKS

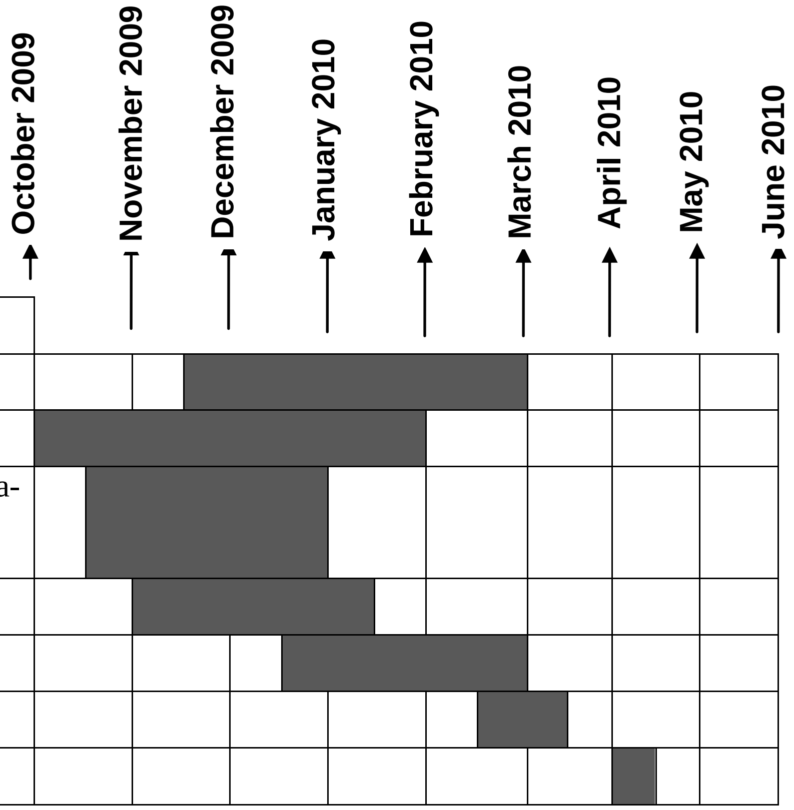
Research materials and information on the overview of this subject were gathered from textbooks, journals as well as materials from the internet. Laboratories and organizations carrying out tests on the feasibility of applying laser technology to drilling for petroleum and gas were also contacted. This was to get first hand results and observations. However, companies directly involved in the drilling phase of petroleum and gas exploration and exploitation were also contacted. This is to appreciate the realistic problems they face using varying drilling techniques as well as to have their opinion on the research. The research materials were collated, studied and comprehensively discussed. Afterwards, realistic conclusions were drawn.

4 PROJECT TIMELINE

The tasks highlighted in chapter 3 above are shown in the table 1 below with allocated time line.

Table 1. Project timeline

	TASKS
1	Textbooks and Journals
2	Internet
3	Laboratory and Organizations
4	Contact companies
5	Compilation of content
6	Conclusion
7	Presentation



5 BACKGROUND

Drilling is a cutting process in which a hole is produced or enlarged in a solid material. In petroleum production, the solid material is the earth's formation. Hence, creating or enlarging a hole with specifications through the formation to the traps in the reservoir rocks deep down in the subsurface to suck out petroleum, which has been collected over years, safely is what petroleum drilling phase is all about. Over the years, many processes have been invented and modified. From the bamboo rigs used by the Chinese, to cable tool used in the 19th century, down to the state-of-the-art rotary drilling and now to the expected laser drilling, the race is still on for the most effective process to optimize cost, time and efficiency.

Laser is an acronym for Light Amplification by Stimulated Emission of Radiation. It is a device that emits light (electromagnetic radiations) through a process called stimulated emission. Basically, lasers convert different forms of energy such as chemical, electrical, heat, etc., into energy of light (intense photon) (Mustafiz et al., 2004). Lasers can be operated either in Continuous-Wave (CW), Normal Pulsed (NP), or Repetitively Pulsed (RP) mode respectively. (Graves & O'Brien, 1998) They added that the output power P is the main energetic parameter for a laser operating in the CW mode, the output energy Q for the NP mode and the average power P and pulsed energy Q for the RP mode.

However, three basic phenomena; reflection, scattering and absorption determines the process of transferring this radiant energy into the rock. This transfer eventually causes destruction of the rock and under controlled conditions, drilling fine hole. Absorption is the process by which heat is collected by the rock and thus results in tearing the rock apart. On the other hand, both scattering and reflection represents the energy losses or the heat not absorbed by the rock. In conventional drilling systems, factors such as weight-on-bit (WOB), mud circulation rate, rotary speed, hydraulic horsepower bit design and hole size all affect the rate at which a borehole is created. With Laser drilling, this rate only depends on the delivered power and the size of the hole, thus, eliminating the complexities of the current drilling system. (Graves & O'Brien, 1998).

6 LITERATURE REVIEW

6.1 Ancient Chinese Bamboo Drilling

The earliest evidence of wells in China, in Zhejiang Province comes from the era when humans were first turning to agriculture in this region, some 7,000 years ago. (Oliver, n.d.) He added that about 5,000 years ago, the Chinese boiled sea water to produce salt and as the need for salt increased with increase in population, they needed to go underground and started digging for brine, to meet up with the demand of salt. He pointed out that the first recorded salt well in China was dug in Sichuan Province around 2,250 years ago.

Around 2,000 years ago, there was a noticeable change from the use of hand and shovels dug wells to percussively drilled ones. The drilling technique used is still seen today in China in the rural areas. Basically, the drill bit is made of iron and the pipe, bamboo. He added that the rig is constructed from bamboo; one or more men stand on a wooden plank lever, like a child's seesaw, and this lifts up the drill stem about 1m. The pipe is allowed to drop down with one man holding it and ensuring that it goes straight in the direction needed. As it crashes into the rock, it pulverizes it and slowly, the drilling progresses. This might take months in most cases (Oliver, n.d.). This is shown in the figure 6.1 below.

Another noticeable change, as documented by Oliver, n.d., happened around 1050 AD. Solid bamboo pipe was replaced by thin, light, flexible bamboo. This allowed for deeper wells to be drilled as well as it lowered the weight that needed to be lifted from the surface. By the 1700s, wells as deep as 300 – 400m deep were drilled and in 1835, the Shanghai well was the first in the world to exceed 1000m in depth. About that time in the US, the deepest wells were around 500m in depth. This drilling method on its own is impressive, especially when compared to what the rest of the world had to offer about that time.

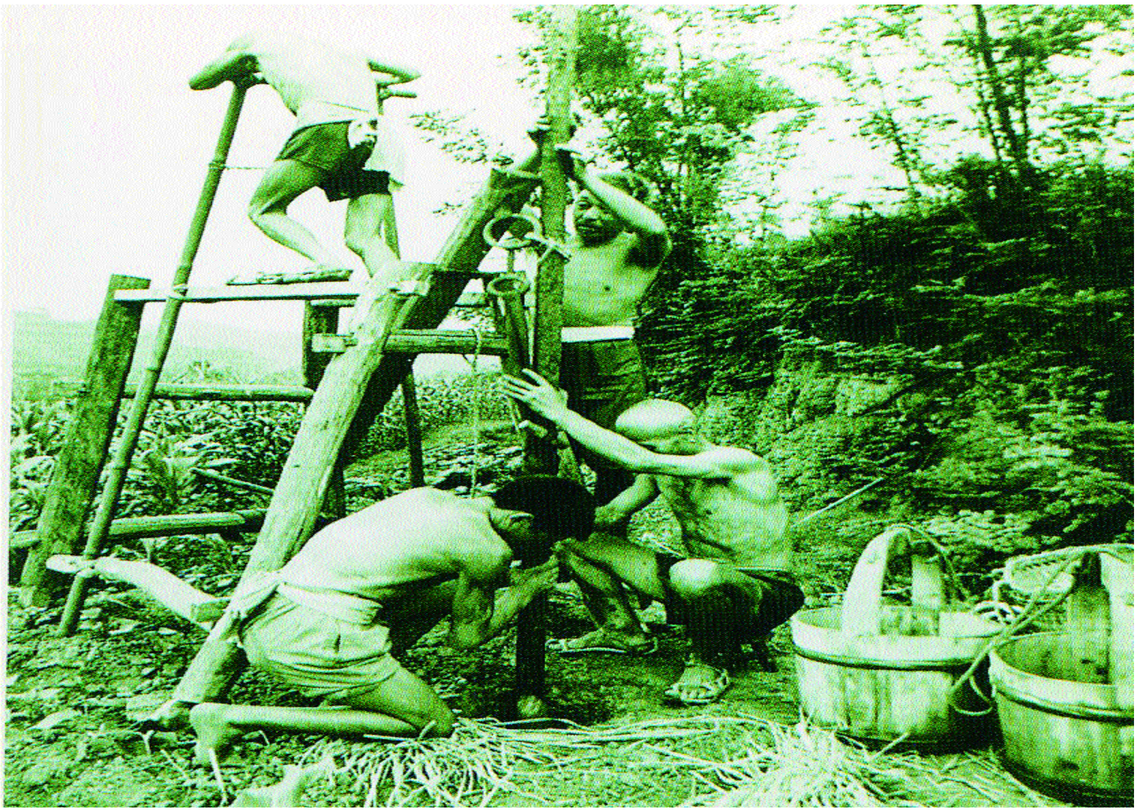


Figure 1: A modern recreation of the ancient Chinese bamboo drilling technique.

6.2 Cable Tool Drilling Technique

The basic principle employed in cable-tool-drilling operating has remained virtually unchanged since its inception in China during the early days of the Christian era. (Kurts et al., 1940) Drilling is done by repeatedly lifting and dropping a heavy string of drilling tool into the bore hole, with the drill bit crushing consolidated rocks into small fragments. However, vast improvements have been made to the basic ancient Chinese bamboo drilling technique. Kurts, DeGolyer, MacNaughton and McGhee; Eugene, University of Kansas (1940) highlighted some improvements in rig mechanisms and labour-saving devices. For example, the old spring pole originally operated by the weight and brawn of three or four men being replaced with the modern all-steel rig powered with an internal-combustion engine, electric motor, or steam engine.

They continued that during this period of mechanical advancement, man power is highly needed one way or another in the drilling practice. Although each driller has his own peculiar technique in operating the cable-tool, the good driller is distinguished from the poor one by the footage he makes in a given period of time, they added.

6.3 Rotary Drilling Technique

Dr. Claude, (2009) pointed out clearly that it was at the turn of the 20th century (approximately 100 years ago) that saw to the birth of the rotary drilling as a standard method of reaching oil and gas formations. It was about this time that this basic mechanical method served as an option and phased out the cable tool drilling method, he added. Since its birth, major improvements have occurred but in the last couple of decades, the method of drilling has not changed at all. (Irfan, Mohit, Nakul, Vickey, Nikhil, Anand, SPE, Maharashtra Institute of Technology, Pune. 2009)

The American Oil & Gas Historical Society (2006) summarized the basic difference between the rotary and the cable-tool drilling technique. "Instead of the repetitive lift and drop of heavy cable-tool bits, the rotary drilling introduced the hollow drill stem which enables rock debris to be washed out of the bore hole with re-circulated mud while the rotating drill bit cuts deeper." They added that the rotary drilling fluid (drilling mud), that is used to circulate out the chipped rock, washes the bore hole clean and makes the drilling exercise more efficient. The drilling mud equally helps the well against bursting forth unexpectedly. This is so because the mud controls the pressure difference between itself in the bore hole and that fluid in the formation.

6.4 Laser Technology in Petroleum Drilling

The work accomplished so far on laser drilling has resulted in some positive indications (Mustafiz, Bjorndalen, and Islam. 2004). They added that although experiments on laser drilling were conducted between 1960s and 1970s, it is only very recently that the application of laser technology is directed to drilling petroleum wells. However, a suggestion in 1990 had it that application of laser technology in petroleum drilling is not feasible, but this was because the experiments conducted then, in this regard, were made with low powered lasers (less than 1kiloWatt). However, current experiments have proved it otherwise. (Mustafiz et al., 2004)

Graves & O'Brien (1998) highlighted some very significant importance laser drilling would have over conventional rotary drilling method. These include:

- drilling over 100 times faster
- cutting off downtime due to dull bits
- drilling more precise vertical and horizontal wells
- eliminating formation fluid leakage during drilling
- eliminating wastes created by drilling mud and rock cuttings
- cost effectiveness by decreasing current drilling times.

They added however, that a combination of laser and rotary drilling is not out of thought, as this would result in an increase in bit life. Other possibilities with the advancement of laser technology include; development of down hole drilling machine, laser-assisted drill bits, laser-perforation tools, and sidetrack and directional laser drilling devices. Hence, the thought of applying laser technology being a viable option for enhancing the petroleum drilling phase.

7 HISTORICAL BACKGROUND

7.1 Prehistoric – 18000

The earliest holes dug into the earth were done in search of food, water, protection and for building habitats or escape route from enemies. Many of these holes, especially by those who spent their lives underground were done developing special parts of their bodies as digging tools such as adaptations of claws and feeds, jaws, heads, etc.

Early man, having no usable claws, found it necessary to use hand tools – such as sticks, bones and naturally shaped stones – as digging tools. After many many years of evolutionary processes, he eventually learned to shape sticks and poles to make them more efficient digging tools. He was then able to dig reasonable vertical wells with these tools and throwing the cuttings to the surface.

About 600 B. C. In China, Confucius wrote of wells drilled for brine. Although, the exact depths of these wells were not given, but they were apparently deeper than hand dug wells. The Chunking region near the border of Tibet where these wells were drilled is still undergoing drilling for brine from near 600 B.C. To present times. These wells varied in depths of around 4,000ft and an estimation of wells as deep as 1,500 ft (approximately 460m) dug as early as 1200 A.D.

During the years preceding 1800, there has never been much need to go beneath the surface of the earth except in the arid country. In England and around Europe, the industrial revolution made a modest beginning for going more underground. The water required then by these industries however, were gotten from shallow hand dug wells or just on the surface of earth. (Dr. Brantly 1971.)

7.2 1800 – 1860

During the late 1700 and early 1800, most families in America moved with the early explorer's westward beyond the blue-ridge mountain and settled in areas like Western Virginia, Western Pennsylvania, Western New York, Ohio and Kentucky. Before long, a modest rural economy was created that required everyday commodity like sodium chloride salt. This initiated the collection of brine by the early hunters. They dug shallow pits on the seepage areas, accumulated brine, concentrated it by boiling and the salt was precipitated off.

David and Joseph Ruffner – brothers – carried on their fathers brine business with hand dug pits. At some point, the demand exceeded their supply. "They conceived the idea of drilling a hole into the earth to intercept the source of the brine, thus increasing the supply and obtaining a more highly concentrated liquid" (Dr Brantly, 1971, 6). Between 1806 – 08, they completed the first well drilled in America for the purpose of brine. It is about 58ft deep. Following the success of the Ruffner well, many others were drilled succeeding 50years or more for brine from which salt could be precipitated. However, it was discovered that the brine being sought was associated with petroleum traces.

Whereas, the Ruffner brothers developed the earliest American well-boring tool for the purpose of brine, William Drake developed on their technique by introducing a steam engine to power the process, and drilled for the purpose of producing oil and gas for commercial use in 1859. (Dr. Brantly, 1971.)

7.3 1860 – 1901

The Drake well drilled in 1859 to 69.5ft was the first in America drilled for petroleum production in commercial quantity. Following the next 40 years, several others were drilled in many other countries including; Canada, around Europe, the middle east, the east Indies, Argentina, New Zealand, and others. "During this period in America, cable tool drilling equipment developed from the rather crude rigs of the 1850's to common cable tool drilling rig of the 1870's" (Dr. Brantly, 1971, 9). This became the standard cable tool drilling that was used across countries until about 1925.

Although wooden drilling rods were famous with percussion tool drilling prior to 1860, American operators changed to manila drilling cable after 1860 and to steel cable in the early 1900's. Whereas in Canada, wooden drill rods were retained in the early 1900's and was moved to the Galacian (Poland) oil fields. Rods became the standard on European rigs; wood in the lighter rigs, and steel or wrought iron on heavy/big hole tools.

"In the early 1880's, the Baker brothers of South Dakota developed a fluid circulating rotary rig for drilling shallow water wells in the unconsolidated formations of the Great Plains" (Dr. Brantly, 1971, 10). The Texas oil field was discovered during the 1890's and the cable tools could not be used satisfactorily in that, the formation is soft and unconsolidated. The new rotary rig that were drilling water wells of comparable formations was then employed in this Corsicana field about 1895, and by 1900 several hundred wells were drilled along the Gulf coast. (Dr. Brantly, 1971.)

7.4 1901 – 1930

Around late 1890's and early 1900's, great attention was giving to developing tools and drilling practices for drilling wells in the relatively soft and unconsolidated beds of the Golf coastal formations. This Corsicana rig, which is a modification of the Baker brother's fluid circulating rotary rig, was an important one in this regard. The Lucas Spindle top well, which blew in January 10, 1901, was brought under control, completed and produced in commercial quantity by a Corsicana rig and a carefully selected Corsicana crew.

The new rotary rigs were moved to many soft formation areas where cable tool had failed, because of its inability for the tool to get to required depths in soft unconsolidated formations. During the first five years preceding the completion of the Lucas well, some 1000 rotary wells, either for water, petroleum, Sulphur or salt, were drilled in the Gulf coastal plains of Texas. However, in the first six years, nearly 4000 wells were drilled with rotary rigs mainly for petroleum in the coastal regions.

With the rotary rigs unfortunately, difficult problems with drilling through hard formations and hard rocks were encountered. In 1909, Howard R Hughes designed a roller cutter: comprising replaceable rolling cutters and this was successful. The Hughes' and several other roller cutters were developed and improved over the years until about 1930 when the design became similar to that of today. In addition, the combination rotary rig was equally developed, still as a result of the problems encountered by the rotary rigs in drilling hard formations or through hard rocks. They were erected in areas where such conditions were known or expected. The combination rig has a cable tool built inside. This invention persisted until about 1930 as well. (Dr. Brantly, 1971.)

7.5 1930 – 1945

Firstly, by 1930, a new rotary drilling rig was designed. This equipment had greater depth capacity per ton of weight, drilled faster holes and was reasonably trouble free compared with the one replaced. As further years role by, many improvements were made – like the introduction of drilling feed control based on weight on the bit in 1934.

During the World War II, when a bulk of engineers became engaged with designing war equipment, drilling efficiency declined drastically. This was obviously as a result of shortages of experienced men and partly shortage in new replacement units for old rigs. Happily, by the end of the war in 1945, it gained back its pre-war status, as design engineers returned to their normal work of designing and preparing drawings for petroleum well drilling equipment.

In addition to what happened at the end of the war, programs on educating drilling crew in care and maintenance of drilling equipment, drilling fluid controls, drilling practices and safety precautions were renewed. Older men, who had gone into the war activities were recruited back and were involved in the intensive training programs, as well as new personnel. (Dr. Brantly, 1971.)

7.6 1945 – 1965

1945 was a very important year for petroleum drilling business because as the war ended, the foundries, forgers and lathes of the oil field equipment manufacturers were cleared off military hardware as quick as possible and was replaced with machinery, tools and equipment required for drilling wells for petroleum production. Many of the new designs and shop drawings were ready including equipment to be built into power rigs. This season marked the end of designing rigs with steam engines.

In addition, improved internal combustion engines, hydraulic drives, clutches, gear trains and chains, etc that were predominant in equipment used during the war had usefulness in oil field equipment. They were improved and incorporated into the drilling equipment. "Pumps were equally redesigned to meet the requirements of new drilling practices, requiring higher pressure drilling fluids than previously used" (Dr. Brantly, 1971, 22). Downhole tools were not exempted in these general improvements. Basically, the predominating roller cutter rock bit was improved and steels were a better option for the roller cutters and body of the tools. In addition, diamond set bits was developed as cutting tools. "They are now one of the principal and most important cutting tools in hard formations" (Dr. Brantly, 1971, 23).

Considerable improvement also took place in the instrumentation applications between these years and specifically in 1969, there were already instruments that indicated the instant value of any given drilling factor gave cumulative values and recorded these values. Drilling parameters including; the nature of the drilling characteristics of the formation, the functioning of the down hole tool and others of interest and assistance to the drillers became easy to get, following these improvements. (Dr. Brantly, 1971.)

8 RESULT: DRILLING TECHNIQUES

A successful well drilling, whether on land or offshore, must be able to provide;

- a means of fracturing and penetrating through rock formations to reach petroleum and gas,
- a means of excavating the rock cuttings off the bore hole,
- a means of preventing the walls of the bore hole from collapsing or caving in, especially when drilling through unconsolidated formations,
- The diameter of the well must be large enough to permit lowering tools down the hole and permit application of newer drilling techniques.

Although the rotary drilling technique is used more frequently today, the cable-tool is still used in some cases nevertheless.

8.1 Cable Tool Drilling Technique

The cable tool rig sometimes called pounder, percussion, spudder or walking beam is basically an improvement on the earliest bamboo drilling method used in China over 3000 years ago. The cable tool is not a drill in the common sense, because it is not power rotated. It operates much like a seesaw with a powered walking beam mounted on a derrick. Penetration is achieved by repeatedly lifting and dropping heavy iron string and a curious variety of drill bits on the borehole. A chiseling effect of the drill bits on the rock crushes consolidated rock into small fragments. “The length of cable is adjusted so that on the down stroke, the tools stretch the line as the bit hits the bottom of the hole, striking with a sharp blow and immediately retracting” (Gene, n.d.).

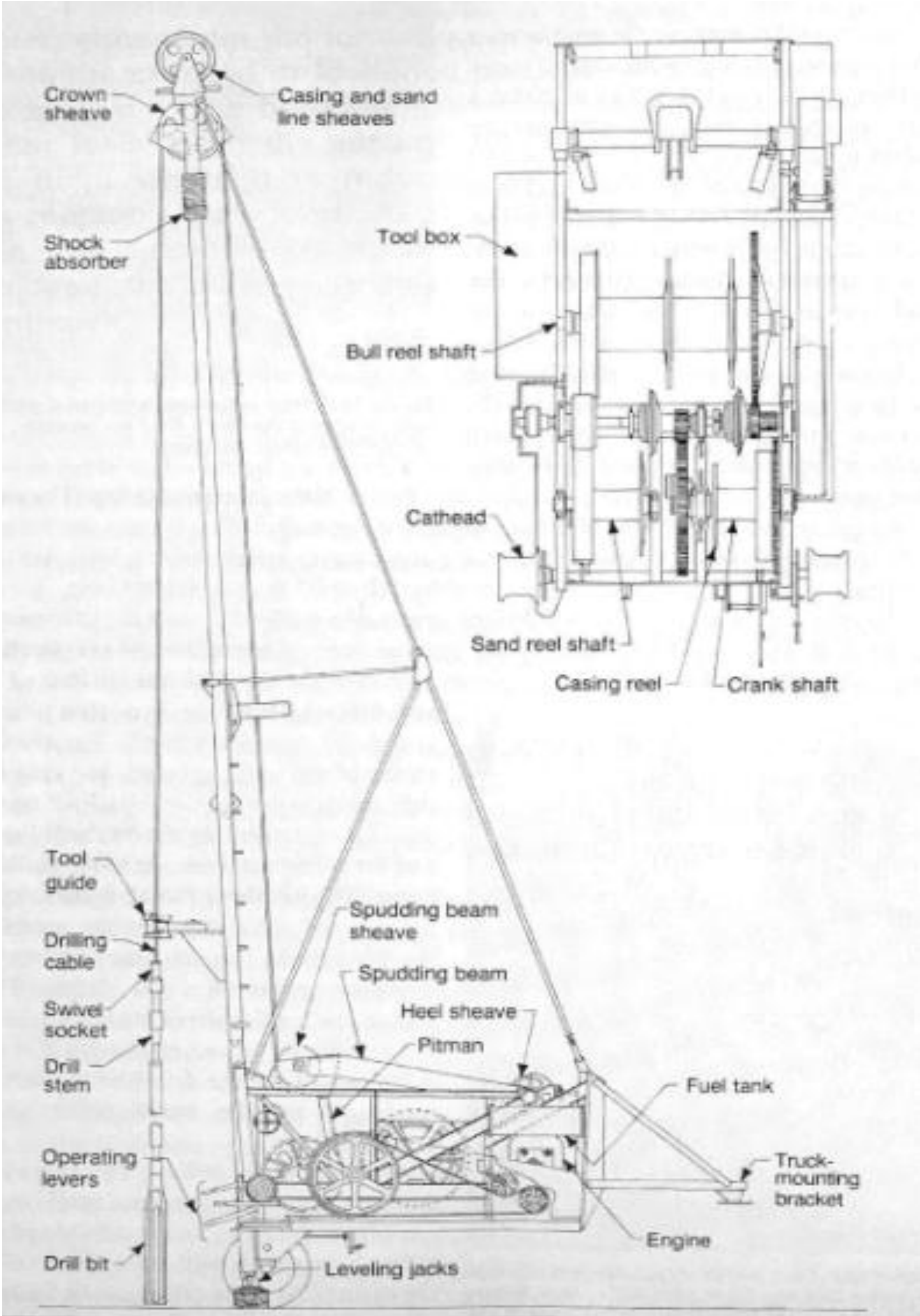


Figure 2: Cable Tool Drilling Rig

The drilling process has to be stopped at intervals to get rock cutting off the bore hole and water is added either by the driller or flows in from the formation to do this. The water mixes with the crushed rock particles and turns it into slurry that settles at the bottom of the bore hole. At a point where the slurry accumulates to a quantity that begins to reduce the penetration to an unaccepted level, drilling is stopped and the slurry is removed by a bailer. The bit is reinstalled into the hole and drilling continues after each stage of removing slurry.

8.1.1 Cable Tool Drilling String Components

A cable tool string has four basic components:

- Drilling Cable – lifts tools, turns tools, controls tool motion.
- Swivel Socket – connects cable to tools, allows cable to unwind.
- Drill Stem – provides weight, steadies and guides bits.
- Drill Bit – penetrates formation, crushes and reams mixes cuttings.

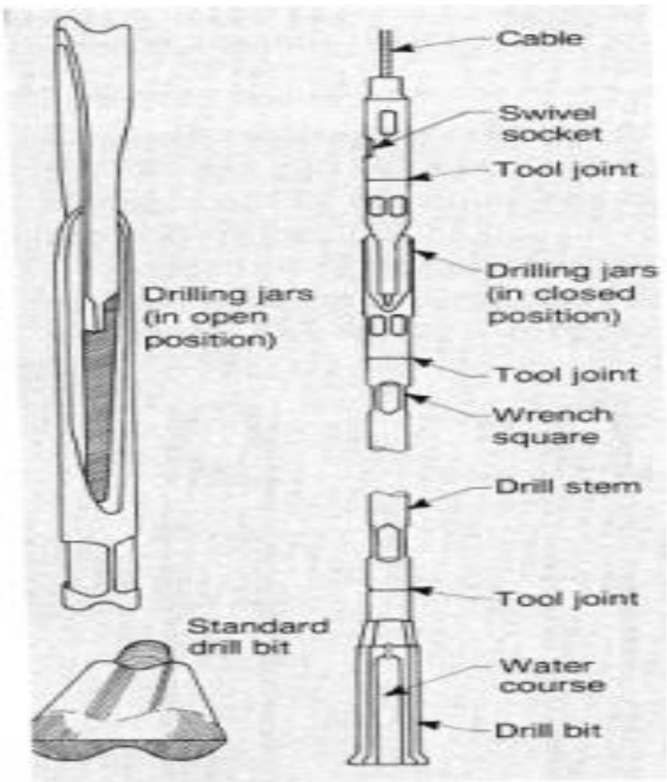


Figure 3: Cable Tool Drilling String Components

Drilling jars may be added to the drill string. They don't play any role in the drilling process per se, but depending on the formation, they may be needed to provide a hammering action that frees tools that become jammed.

8.1.2 Cable Tool Bailers

Bailers are metallic pipes with a one-way flapper valve on the lower end. They are attached to an eye in the end of a separate line called the bailing or sand line respectively. The drill string is removed from the hole and the sand line, carrying the bailer, is lowered in to remove the chips cut by the drill bit for drilling to proceed. Selection of the most suitable bailer depends on how well the slurry is mixed. Below are some common types.

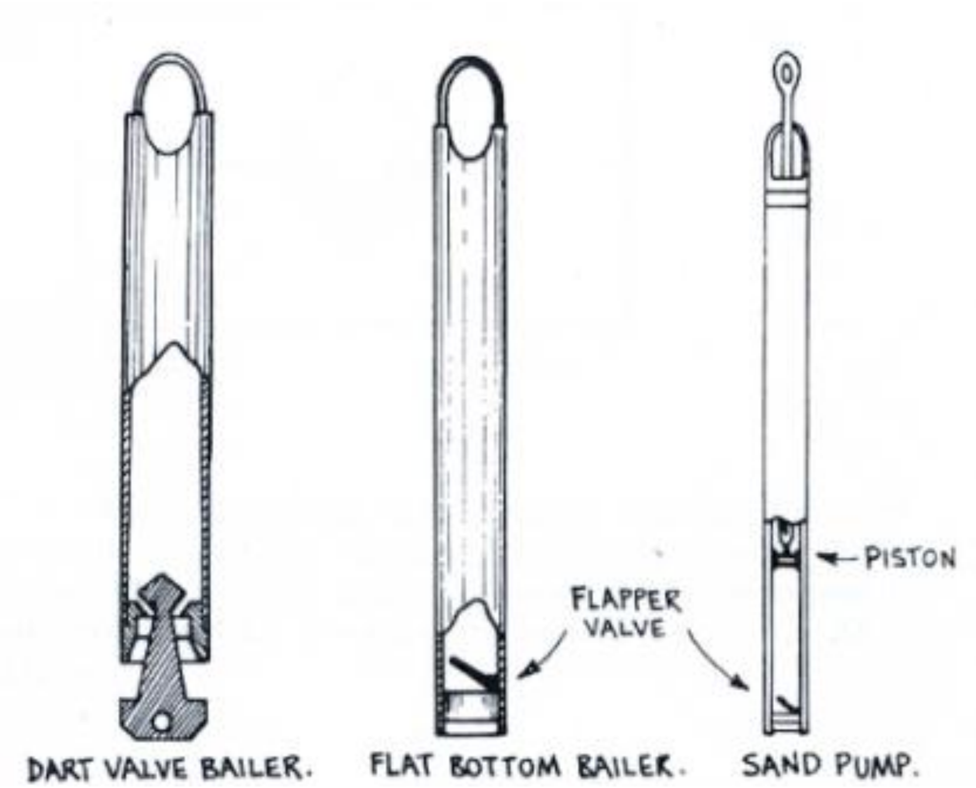


Figure 4: Cable Tool Bailers

8.1.3 Cable Tool Casing Driving Equipment

As pressure increase with depth of drilling, there is need for casing to protect caving in of the formation. The casing is driven down by a force provided by the drive clamp attached to the drill string. A wrench square is forged in the drill stem to allow for the attachment of the drive clamp.

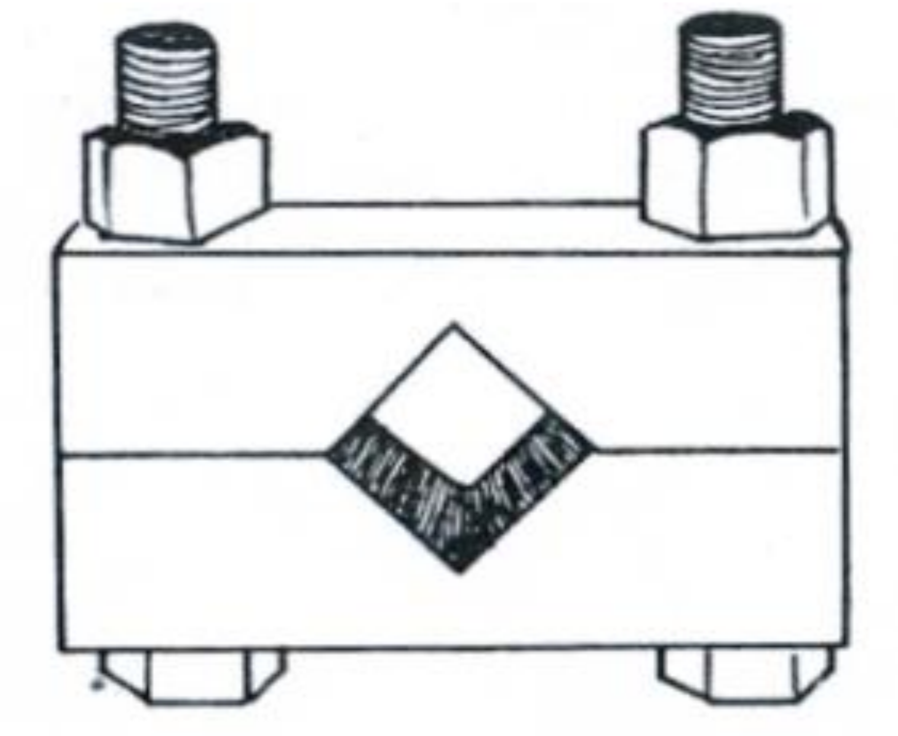


Figure 5: Cable Tool Drive Clamp.

A drive head is fitted or screwed to the top of the casing, to protect it from damage when being driven with impact loading.

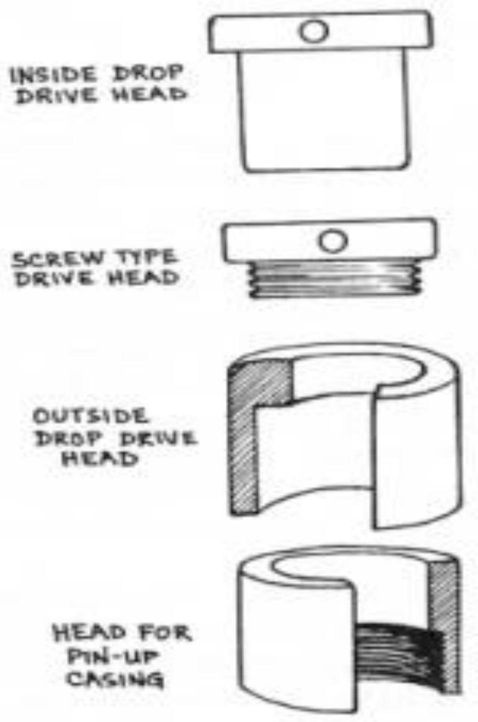


Figure 6: Cable Tool Drive Heads

At the opposite end, a drive shoe is attached to the bottom of the first casing to be driven and this paves the way down as subsequent casings are been added. The drive shoe is manufactured with a hardened cutting surface at the leading edge. This creates a seal on the walls of a consolidated formation when driven through.

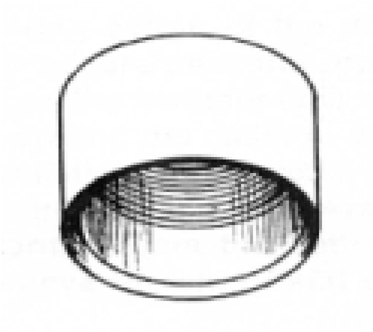


Figure 7: Cable Tool Drive Shoe

8.1.4 Advantages of Cable Tool Drilling

Cable tool drilling has the following advantages.

- A relatively cheaper drilling method. The capital cost of a new cable-tool rig and maintenance expenditure are relatively cheaper than that of a rotary drilling rig of similar capacities.
- Efficient use of personnel. Cable-tool rigs are often operated by one or two persons.
- Suitable for water poor areas and remote settings. This is due to the fact that the cable tool drilling requires little amount of water and identifies each water bearing formation penetrated in addition to its low fuel consumption and reliability.
- Qualitative and quantitative data; including good flow estimates, temperature, water chemistry measurement and static water level, can be obtained while drilling.

8.1.5 Disadvantages of Cable Tool Drilling

Cable tool drilling has the following disadvantages.

- Directional drilling is impossible as this method is limited to vertical holes.
- Depth and penetrating rates are very low, especially through hard rock formations.
- In unconsolidated formations, casing must be driven as drilling progresses. Collapsing or caving in of the formation is almost inevitable without immediate casing.
- Blowout preventers are not easily adapted.
- Productivity measured in hole produced per day is low compared to rotary drilling on similar formation.
- Lack of experienced personnel. With more abundant rotary drilling rigs today, a cable-tool driller with a wide range of experience is hard to find.

8.2 Rotary Drilling Technique

Rotary drilling, usually applied to make deep wells, is the most common well boring method used today by both water and geothermal well drilling. Although the idea of using a rotary drill bit to make holes is not new, it is only in the early 1900’s that a standard method of applying this technique found its way into making petroleum and gas wells for production in commercial quantity. It still remains the most effective method of well drilling in petroleum and gas industries today.

Much like a common hand held drill; the fundamental principle behind this technique is the use of a sharp, rotating drill bit with an applied force to drill down through the earth crust. Following constant technological advancements, the actual mechanics of today’s rotary rigs is quite complicated.

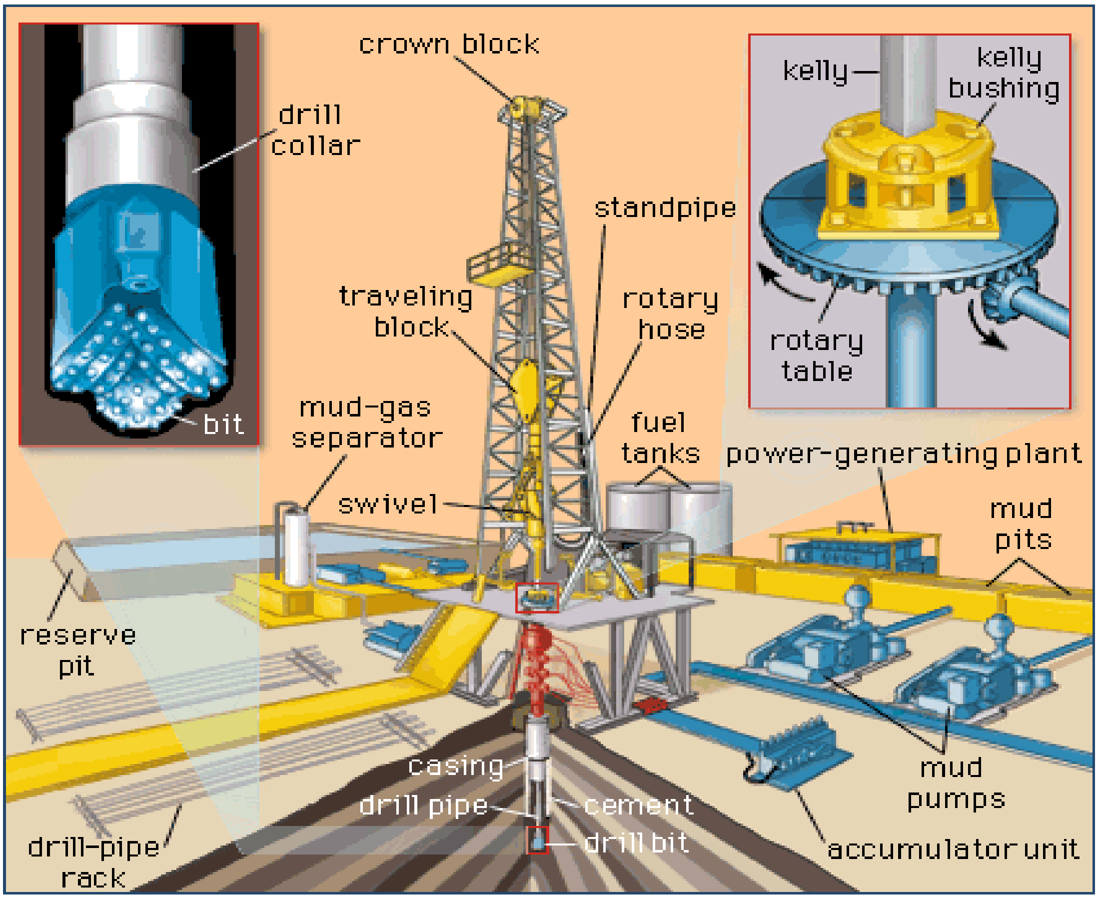


Figure 8: Basic Land Base Rotary Drilling Rig

Today's rotary drilling rig consists of multiple engines that can be split into five components:

- The prime mover – that suppliers power
- The hoisting equipment – that raises and lowers the drill strings (drill pipe)
- The rotating equipment – that rotates (turns) the drill strings and the drill bit.
- The circulating equipment – that pumps drilling mud down the hole.
- The blowout preventer (BOP)

8.2.1 The Prime Movers

The prime movers are the power house of the entire rig, in that they provide the energy needed to power the entire equipment in the rig. Steam engines used to be popular with the early rigs but today's rigs make more use of gas or diesel engines. In addition to the hoisting, rotating and circulating equipment it powers, are compressors and provision of incident lighting that are not directly related with drilling.

8.2.2 Hoisting Equipment

The hoisting equipment consists of tools used to raise and lower whatever other equipment that in and out of the well. It is composed of the draw works (pulleys), drilling lines, crown block, travelling block and the hook. The derrick is the most visible part of the hoisting equipment and it serves as support for the cables (drilling lines), draw works as well as to hold the monkey board in place.

Because well are drilled with long strings of pipes (drill pipes) that extend from the surface down to the drill bit, there is need to raise them all out and lower them back in if there is problem that would require the need to change the drill bit. The combine weight of the drill pipes, drill bits and drill collars are in excess of thousands of pounds in deep wells. The hoisting equipment is used to raise all of this to the surface should the need arise.

The height of the derrick can give a clue as to how deep a well is. Normally, drill pipes come in single units of 1.83 – 3.66 feet each. This means that even if the well is 182.88 feet deep, the drill string will be taken out in bits of 1.83 – 3.66 feet sections. However, if the derrick is tall enough, multiple sets of drill pipes may be removed at once and saving time.

8.2.3 The Rotating Equipment

The rotating equipment consists of components that receives power from the prime mover and transfers it down to the drill bit for it to crush or drill ahead. The prime mover transfers power to the rotary table. The rotary table is connected to the drill pipe and as it turns the drill pipe, the drill bit turns respectively as it is connected to the drill pipe. A component called the swivel, which is attached to the hoisting equipment, carries the entire weight of the drill string, but allows it to turn freely.

Drill collars come between the drill bit and the drill pipe. They are heavier, thicker and stronger than drill pipes and are used to add weight to the drill string to provide enough downward pressure needed for the drill bit to drill through hard rock formations. The down hole condition experienced while drilling determines the number and nature of drill collars needed on any particular rotary rig. This can be altered appropriately.

- Rotary Drill Bits

On the rotary drilling rig assembly, the drill bit is located at the bottom end of the drill string and is responsible for the actual cutting process as well as dislodging rock, sediments and anything else encountered during drilling. A conventional drill bit has three movable cones containing teeth made of materials, like tungsten carbide, steel, diamond etc, tougher and harder than the rock they are designed to cut through.

Drill bits used in rotary drilling are classified as follows:

- Roller bits (or roller-cone bits).
    - Steel tooth bits
    - Insert bits (or tungsten carbide insert bits)
- Fixed cutter drill bits.
    - Polycrystalline Diamond Compacts (PDC) bits
    - Thermally Stable Polycrystalline (TSP) bits
    - Natural diamond bits

Whereas the roller bits are mostly applicable to water wells, diamond-cutter bits are the most predominant nowadays in the petroleum business. This is due to the extreme resistance of diamond to abrasive wear that has made it possible to use shearing action of cutters for drilling. Hence, it can cut through tough rocks quicker, reducing the cost of drilling for energy resources.

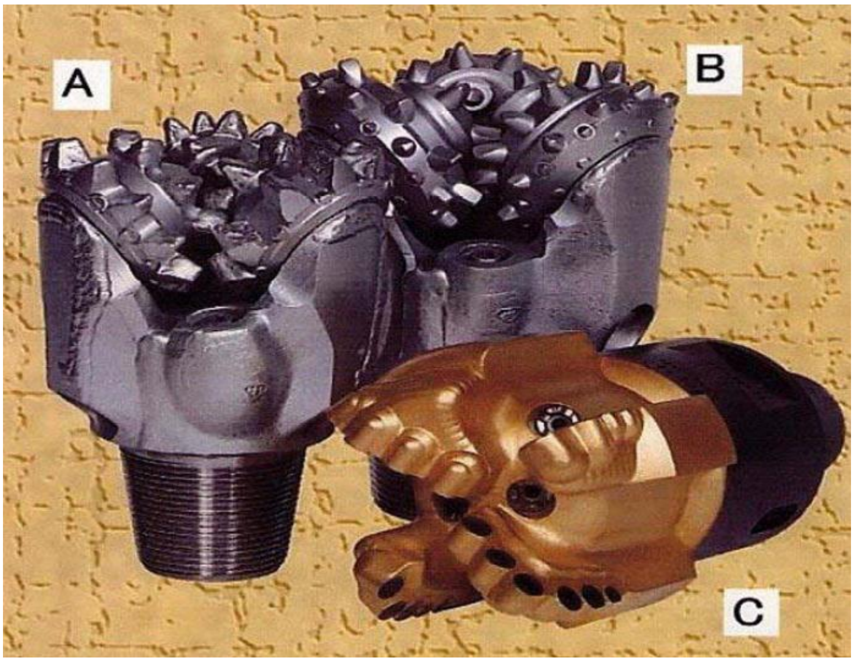


Figure 9: Three Types of Bits used in Rotary Drilling

A – Steel tooth bit

B – Insert bit

C – Fishtail Polycrystalline Diamond Compact (PDC) bit

The choice of bit depends on the properties of the formations and drilling technique.

8.2.4 The Circulating System

The circulating system is a continuous circulation of drilling fluid (mud) down through the well throughout the drilling process. The rotary drilling technique is designed to drill continuously without down time, hence the need to get rock cutting off the well bore for the drill bit to have a clear surface to drill on is just as important. The equipment needed for this cy-clic system include; drilling fluid pumps, compressors, related plumbing fixtures, specialty injectors for the addition of additives to the fluid flow stream, and separators (e.g. mud tank, pits or cyclone-type separator).

The main functions of the circulating system are:

- Removal of cuttings from the bottom of the hole to the surface. This exposes the drill bit to the uncut rock formations for drilling to proceed as well as makes available cuttings and samples for analysis to study geological properties of rocks penetrated and to find the indication of oil and gas in the formations.

- Controlling hydraulic pressure in the hole by adjusting the density of the mud to control formation fluids and to prevent collapse of the well.

- To cool and lubricate the working bit and drill stem.

In a reverse circulation system, the fluid is pumped down the annulus and carries the cuttings up through the drill pipe to the surface where it is cleaned of debris and pumped back. However, an air pipe is installed in the drill pipe to provide the necessary lift for the fluid and cutting mixture, as well as a cyclone separator to separate air from water and cuttings mixture.

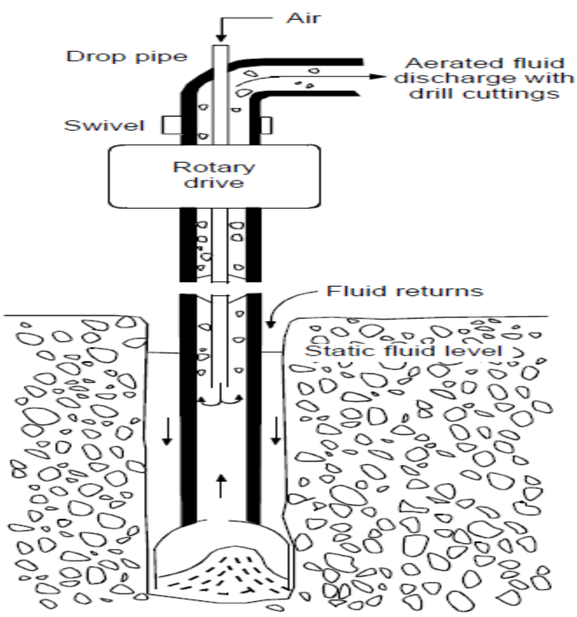


Figure 10: Reverse Circulation Drilling

Whereas in a conventional circulation system, the pumps force the drilling fluid through the drilling pipe down and out through the drill bit. The fluid (with cuttings) then flows up through the annulus to the surface of the ground where it is cleaned of debris and pumped back down the hole.

The major difference between these two circulation systems is the entrance and exit points of drilling fluid respectively that are directly opposite. However, either of both circulation system is an endless cycle that is maintained as long as the drill bit is turning in the hole.

Advantages of the reverse circulation:

- The reduction of velocity in the annulus reduces the possibility of wall erosion.
- The increase in velocity up the drill pipe provided fewer time lags to the surface and less mixing of cuttings which enhance sampling.
- There is less possibility for formation damage by mud invasion because water or very thin light mud is used.

Disadvantages of the reverse circulation:

- Under-pressured geothermal fluids are prevented from entering the hole for detection by temperature or chemistry change since the annulus fluid level is at the surface.
- The chemistry of geothermal fluid might be changed if they find no space to enter the hole. Large amount of air usually scrubs out carbon dioxide (CO_2) and hydrogen sulphide (H_2S).
- Large amount of water can be required because there is very little or no filter cake to prevent losses to permeable zones.

8.2.5 Blowout Preventers (BOP)

Blowout is the term used for a situation where the control of formation fluid flow in the well is lost. Adequate prevention systems need to be in place as its occurrence is always catastrophic, often leading to losses of lives, property and environment.

Figure 11: Example of a Blowout Situation.

However, is it not complete doom for oil well drillers as efficient blow-out prevention (BOP) systems exist. Below is some efficient prevention systems used nowadays.

- The diverter system – which is employed to divert an uncontrolled flow of formation fluid away from the drilling rig and personnel.

- The well control system – which is used to circulate formation fluid by finding a balance between pressures at the under well.

However, the diverter system is used to handle kicks from shallow formations encountered prior to setting surface casing. After setting surface casing, the well control system can be used.

- The Diverter System

A basic diverter system is a large vent line which diverts formation fluid flow away from the rig and rig personnel in a downwind direction. Normally, more than one vent should be available to assure the downwind diversion and the vent line should be large enough to prevent significant pressure build-up in the well.

The diverter system consists of four components:

- The annular preventer (diverter) – this stops the upward flow and diverts it into the vent lines.
- The vent or diverter line – they are 4-in to 6-in diameter steel pipes connected to the spool. They carry fluids away from the rig.
- Associated valves and controls – which close the system during a normal drilling operation.
- The conductor casing – which determines the size of the annular preventer that can be used.

These all are shown in the figure below.

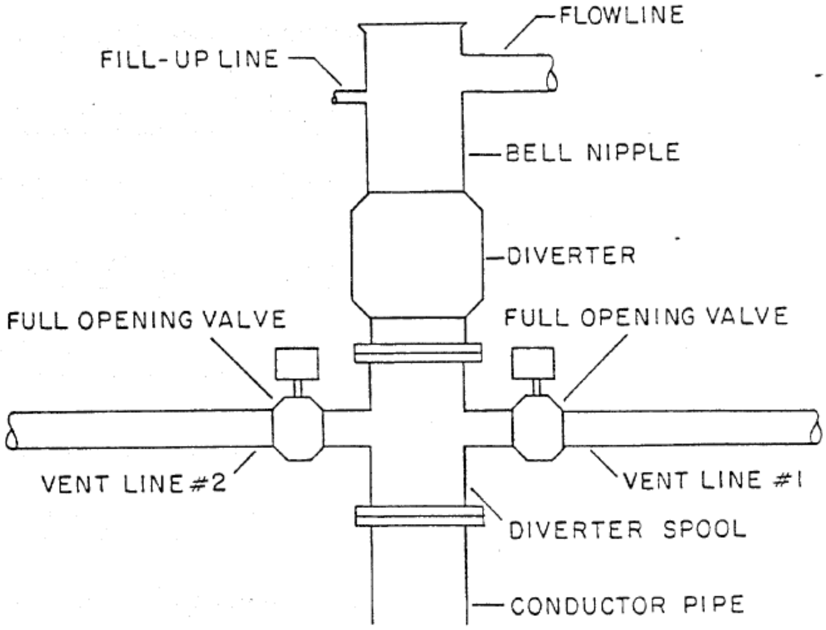


Figure 12: A Diversion System for Blowout Prevention.

- The Well Control System

Like many other aspects of drilling operations, the problem of blowout prevention increases in complexity especially nowadays that we have more wells in deep waters; requiring the use of floating drilling vessels. Well control problems associated with greatly reduced fracture gradient, and the use of long subsea choke and kill lines in these deep water drilling operations have to be managed.

For example, because of the relatively lengthy vertical subsea choke and kill lines extending from the BOP stack at the sea floor, an increase circulating frictional pressure loss results. This can cause a significant increase in the overall pressure occurring in the well bore. In addition to that, is a problem that results from rapid drop in hydrostatic pressure, especially when circulating a gas kicks. When gas exits the large casing to a relatively smaller diameter choke line, the hydrostatic pressure drops rapidly and in order to maintain the bottom hole pressure, a corresponding increase in surface choke pressure is needed. Choke manipulation and control becomes difficult during these periods and even much more difficult with increase in well depth.

In such wells in deep waters, a relatively complex casing program, although extremely more expensive than comparable land wells, are required to manage the pressure in the well bore and hence maintain a significant differential between formation pore pressure and fracture gradient.

The Figure below is an example of such well casing program.

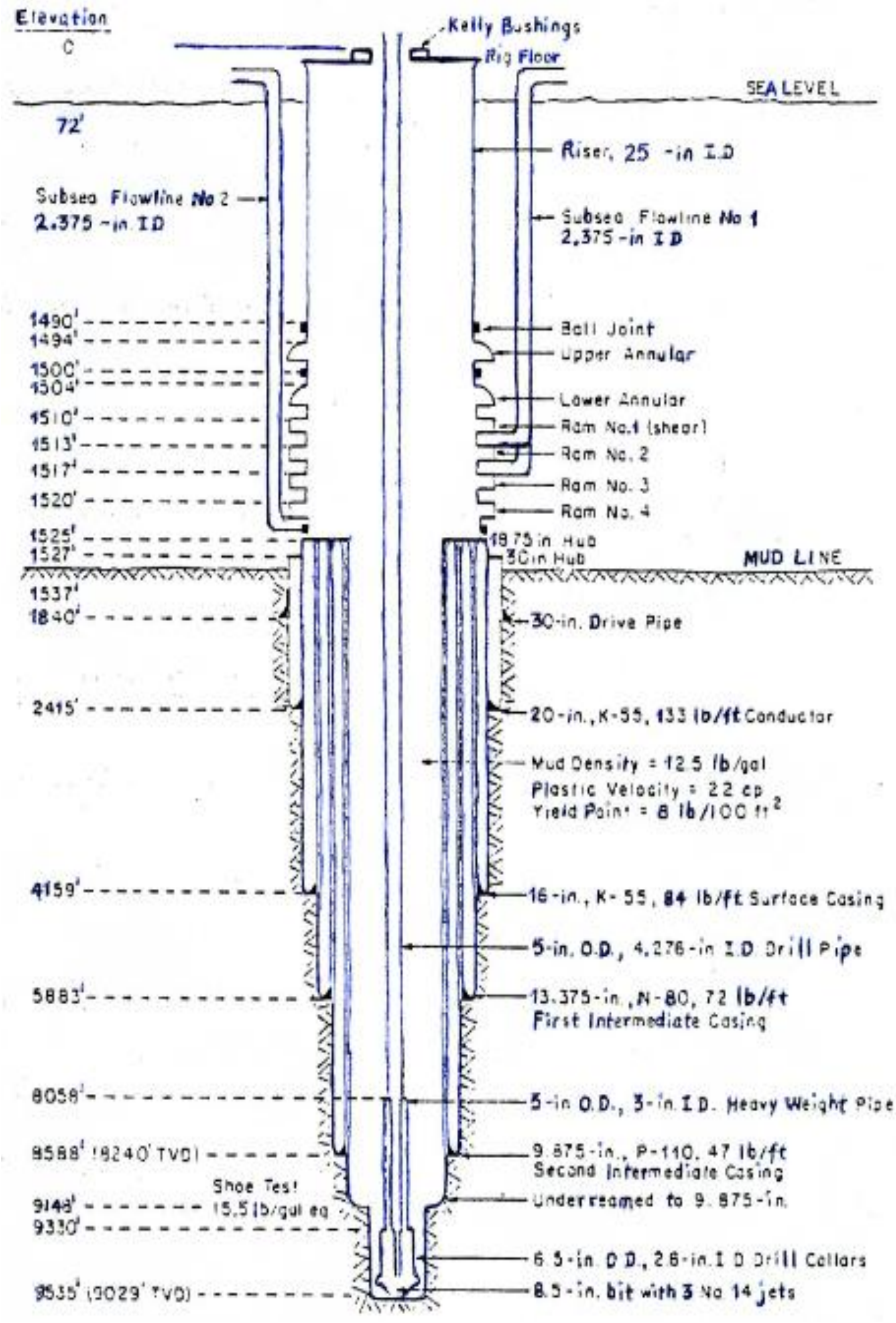


Figure 13: Example of Casing Program for Deep Water Well

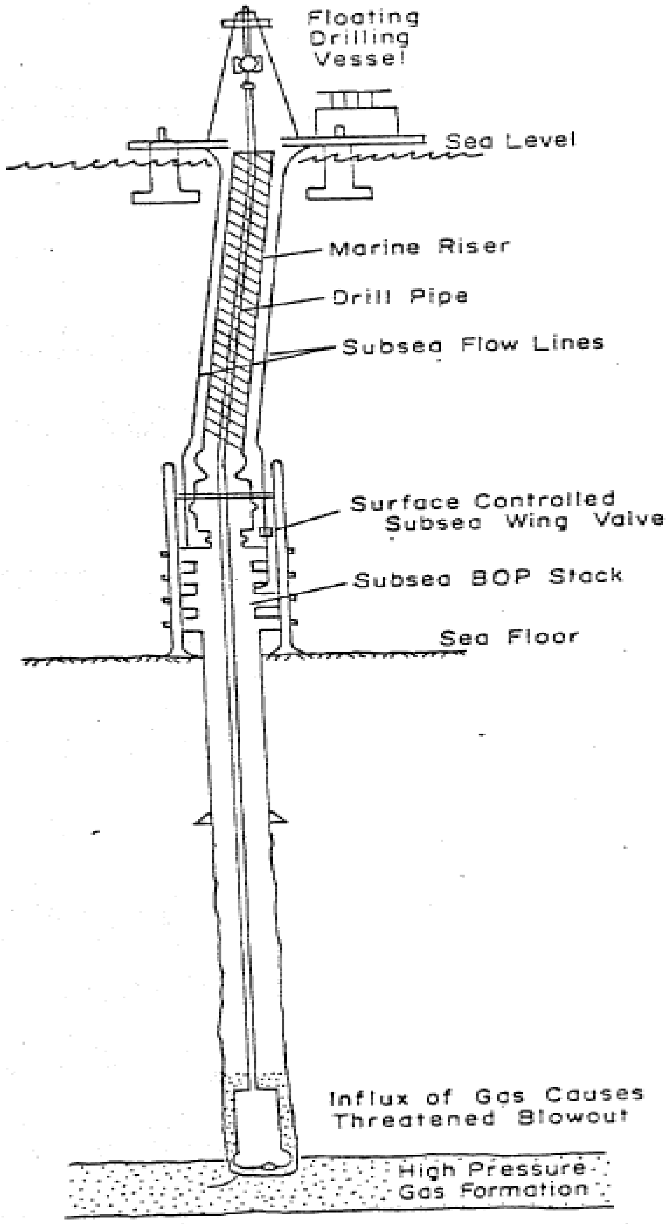


Figure 14: Well Control Operation Design Showing BOP Stack.

8.2.6 Directional Drilling

Directional drilling simply means drilling towards a target that is located at some horizontal distance offset from the drilling rig or well site. Otherwise normally, wells are drilled as straight and plumb as reasonably possible. Well completion and pump installation are much more difficult with directional drilled wells, but it might be the best options in situations where:

- Several wells are to be drilled from a single drill pad often used in geothermal electrical generation reservoir

- To sidetrack or bypass a junk that cannot be fished off a hole. For example, a twisted off drill pipe that cannot be fished off a hole.
- To intersect a fault for increased production.
- To drill parallel in close proximity to a fault to reduce the possibility of fault movement shearing off a casing.

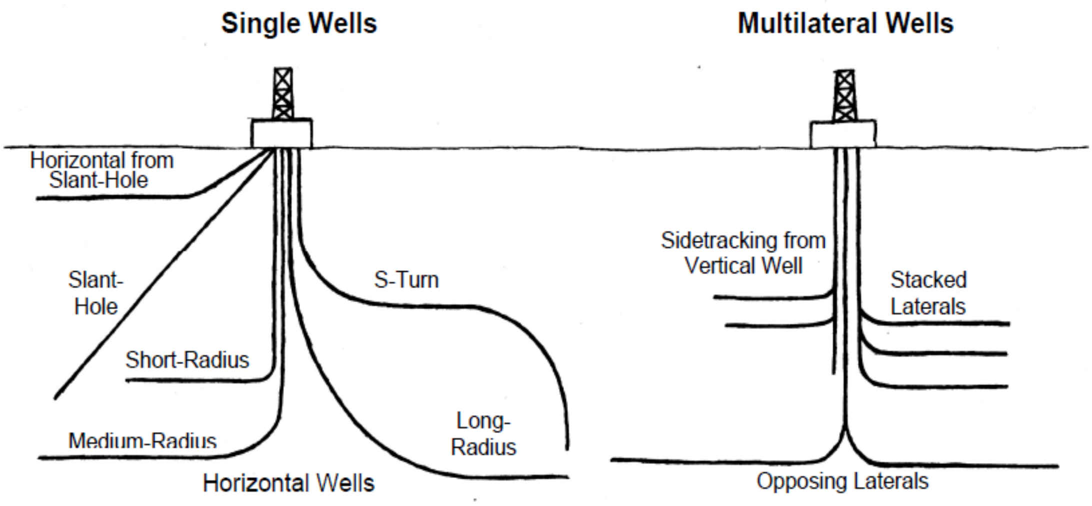


Figure 15: Different types of directional wells.

The different types of directional drilling have been around for ages, but it is only in the last couple of decades this technique gained broad acceptance and widespread application.

> *Modern controlled directional drilling is accomplished by using a downhole motor driven by drilling fluid pumped down the drill string. The motor is attached to the string by a bent sub and anon-magnetic sub. The drill string and subs do not rotate. The bent sub is angled one to three degrees and is oriented to guide the drill motor and bit in the desired direction. Periodic surveys using plumb bobs and magnetic compasses with cameras to record their readings allow the directional drilling engineer to plot the course of the well and make changes to direct the hole in the desired direction.* (Gene, n.d.).

8.2.7 Drilling Fluids

In rotary drilling, drilling fluid is circulated through the system to remove cuttings from the hole and performs several other functions. Because locations differ in local conditions, careful analysis should be made before selecting what drilling fluid best suits what local drilling conditions, bearing the maintenance of the drilling fluid in mind. Both the engineer and the driller must be aware of the possible consequences of this selection and maintenance.

The functions of drilling fluids include:

- Cool and lubricate the bit and the drill string.
- Clean the bottom of the hole beneath the bit.
- Transport cuttings to the surface.
- Suspend drill cuttings in the annulus when circulation is stopped.
- Support the walls of the bore hole.
- Control subsurface pressure.
- Stabilize the bore hole.

To achieve these functions, the following side effects should be minimized.

- Damage to subsurface formation, especially those that may be productive.
- Reduction of penetration rate.
- Swab and circulate pressure problems.
- Loss of circulation.
- Erosion of the borehole.
- Swelling of the sidewalls of the borehole creating tight spots and/or hole swelling shut.

- Sticking of the drill pipes against the walls of the hole.
- Retention of undesirable solids in the drilling fluid.
- Wear on the pump parts.

A good drilling fluid has the following characteristics:

- Lubricity
- Velocity
- Viscosity
- Density
- Gel Strength
- Filtrate control

Drilling fluids fall into one of three general classes:

- Water based
- Air based
- Oil based

In today's petroleum drilling, mud is the most commonly used drilling fluid because it possesses most of the characteristics listed above. It is classified under the water based class, as water that is re-circulated can be seen as very thin mud containing suspended particles of drilled cuttings. However, polymer fluids – classified under oil based, and foam – classified under air based are employed in some drilling conditions.

- Drilling Mud

Modern drilling mud is primarily mixtures of bentonite (sodium montmorillonite) and water plus special additives needed to modify its properties to meet changing hole conditions or counteract changes previously made by the driller. Normally, when bentonite is added to water, an increase in the density and viscosity is noticed. Additives, such as organic polymers, dispersants, wetting agents, weighting agents, thinner and lubricants, are then added to improve gelation, lubricity, filtration and other properties, thus making it a suitable drilling fluid.

As the mud is used, it gradually losses its standard physical properties, as it carries cuttings from the hole. Hence, regular measurements are needed to keep these properties in check in order to improve performance. Some of these properties include:

- DENSITY

  Mud density or mud weight usually expressed in pounds per gallon (ppg) is measured with a mud balance or a balance beam. An increase in density results in relative increase in cutting carrying capacity, as well as increase in borehole pressure and thus reduce caving in and formation fluid flow into the hole. Mud density increase, on the other hand, decreases settling rate in the mud pit and may result in loss of circulation as it increases the flow of drilling mud into the formation. Generally, 9ppg is the maximum recommended.

  Density can be increased by the addition of barite – a weighting agent. Hydrostatic pressure can be calculated with:

  $$P = 0.052ed \tag{1}$$

  Where

  P = hydrostatic pressure (psi)

  e = density (ppg)

  d = depth (ft)

- VISCOSITY

  Mud viscosity, expressed in seconds per quart (s/qt), is a measure of its ability to carry cuttings up the hole, drop them in the mud pit and to form a gel. In fields, it is measured by measuring the time it takes a measured amount of mud, usually one quart, to flow through a standard Marsh funnel. This is its funnel or apparent viscosity; different from its true viscosity. At 21^{o}C, water has a funnel viscosity of 26s/qt and 32 to 38s/qt is a very typical range for a good drilling mud.

Although viscosity is affected by density and the type of suspended solids, the true viscosity changes only a little compared with changes in its funnel viscosity. Mud viscosity is adjusted by varying the amount of bentonite and water or by adding polymers to thicken or phosphate to lighten the fluid.

- SAND CONTENT

The volume of sand in the drilling mud should be kept to its beeriest minimum as this affects mud density, viscosity, bit life, drilling rate and causes formation damage, wear of pumps, swivels and other equipment.

Sand content is measured by carefully washing a measured volume of mud on a 200 mesh screen and afterwards, pouring the materials held on the screen on a cone shaped graduated container. The desired maximum limit is 2% by volume. Regular measurement pays out on the long run.

- FILTER CAKE

Filter cakes are clay platelets built up on the formation to reduce fluid loss into the formation. Because the drilling mud in the annulus is under pressure, some water filters through these filter cakes in some occasions causing water loss. In extreme cases, the whole mud goes through resulting in mud loss.

A standard API filter press is used to measure filter cake thickness and water loss. A compressor supplies gas pressure of 100psi to a set up of filter paper supported in a mud filled standard cell. This is kept for 30minutes. Afterwards, the amount of water that passed through the filter paper is measured as well as the buildup of the filter cake in the paper. Desirable properties are $15cm^3/30min$ of water and 2/32in thickness of filter cake.

- GELLING

This is a property of a bentonite and water mixture that allows it to be fluid when stirred but when left to stand; it begins to stiffen or gels and becomes fluid again when stirred. This helps to suspend cuttings during non-circulation periods. Gel strength is progressive and can increase to a strength that becomes almost impossible to remove. What we do not want to happen is for our drilling mud to gel and set in a potential geothermal producing zone. It can be very undesirable in such situation.

For example, when a circulation is loss or reduced, the mud continues to flow into the formation until the hydrostatic and formation pressures regain its balance. Once these pressures are balanced and circulation is regained, the mud in the formation stops flowing and begins to gel. Except sufficiently diluted by formation water, the mud gels and sets to a strength that affects production if that were a productive zone.
Gelling can be used to stop loss circulation by adding more bentonite and pumping it down hole. With the bit pulled to a safe distance, the mud is allowed enough time to gel and set and drilling continues slowly afterwards. Problem is if this is a potential production zone, it is lost as it is almost impossible or very expensive to remove.

- LOST CIRCULATION AND LOST CIRCULATION MATERIALS (LCM)

Lost circulation, sometimes referred to as lost return, is the loss of drilling fluid from the borehole through cracks, crevices or porous formations. This can either be partial or complete if part or all the fluid, respectively, fail to return to the surface. When circulation is lost, it is obvious that the drilling fluid can no longer perform its transporting cuttings up the well function, leading to blind drilling. If these cuttings remain in the hole, they will pack around the drill string above the bit resulting in stuck pipe, and possibly loss of the bit, drill collars, part of the string or maybe the hole.
However, if the formation is very porous – with large cracks or crevices, the fluid may carry cuttings away with itself into the formation. None the less, the drillers have no assurance that this

is the case. On the other hand, a continuous loss of the fluid may reduce the fluid level below the surface, resulting in partial or complete loss of fluid pressure needed to stabilize the hole wall. This in turn can cause cave-ins, another cause of stuck pipe that can lead to loss of equipment in the hole.

Other problems associated with loss of circulation include:

- Loss of expensive fluid components
- Loss of drilling time
- Added cost of expensive lost circulation materials to keep losses from plugging possible production zones
- Cementation problem

Proper planning and rig operations are important in order to reduce the possibility of this occurring. Some of these techniques include:

- The use of nearby well logs and geological information and carefully planning the hole and casing program.
- Treating the well bore gently. This involves; raising and lowering of the drill strings and casing slowly without spudding, starting fluid pumps at slow rates and increase slowly, maintaining fluid velocity in the annulus at the lowest rate to assure cuttings removal, and avoiding too fast drilling to prevent overloading the annulus with cuttings.
- Making frequent measurements of mud properties to maintain minimum weight, viscosity and filtration.

Lost Circulation Materials (LCM) are materials used to bridge across openings or pores in the formation and provided a foundation for the building of filter cakes. Any piece of material can do this job including; groundnut shells, sawdust, hog hair, etc.

Although, organic materials can do a better job compared with inorganic materials – such as mica flakes, their use is prohibited because they promote undesired organic growth or degrade water quality or both. The best materials are thought to be a mixture of flake and fibre

.

- Air-Based Fluids

Like the name, this is drilling with air. The simplest form is the use of dry air. It becomes more complicated when there is the need to convert the dry air to either mist or foam in situations where water is encountered. The lifting capacity of air and the volume requirement are two very important factors to consider. Where the former is directly proportional to its density and annular velocity, the later is directly related to the well depth. As the hole depth increases, the air velocity is reduced because of increased weight of cuttings supported and pressure build-up due to friction. With the need to increase velocity to compensate for the loss, excessive velocity can lead to erosion of softer formations which in turn will require more air to maintain adequate velocity in the increased annular space. On the other hand, excessive air pressure can lead to air loss just like lost circulation in water-based drilling mud, resulting in stuck tools as cuttings pack around the drill stem above the bit.

Air drilling is at its best when drilling on consolidated formations. This is so because it eliminates the danger of caving, possibly resulting in stuck a tool that is common with its application on unconsolidated formations. Air loss to the formation, equally resulting in stuck tools, can also be as a result of the formation of mud rings in the drill pipe and hole wall, resulting in pressure build up and reduction in velocities. These mud rings are formed when small amounts of water mixes with cuttings and dusts especially with Shale.

Besides the use of dry air, air mist and foams are other fluids applicable to air-based drilling.

- AIR MIST DRILLING

  Air mist drilling is a technique developed to increase the density of air column, resulting in pressure increase at the bottom of the hole. Air mist is a drilling fluid gotten by adding little amount of water to the surface plus wetting agents that help remove mud rings and controls dusts. This technique is effective if the amount of water entering from the formation is kept as small as between 15 to 25 gpm.

- FOAM DRILLING

  In contrast to the general knowledge of foam composition, drilling foam is composed of a small amount of water and large amount of air. It is made by injecting water and additives into the air stream by a metering pump. Depending on drilling requirements, one of stable foam, stiff foam or wet foam can be used.

  Stable foam is made by adding surfactants and sometimes polymers and clay – to increase the viscosity and density. Surfactants are additives that:

  - Provides the ability to lift large volumes of water
  - Reduce air volume requirements
  - Provides greater solids carrying capacity
  - Reduced erosion of poorly consolidated formations.

  Stiff foam – made with polymers (3 to 6lb/100gal) or bentonite (30 to 50lb/100gal) and 1 to 2% surfactant, can be used with annular velocities as low as 50 to 100ft/min. However, with higher annular velocities of up to 1000ft/min, wet foam may be used. Wet foams are made with 0.25% surfactants only and no other additive.

  Air, being a compressible fluid, follows the ideal gas laws. This holds for the relationship between pressure (P), temperature (T) and Volume (V) for all types of air-based fluids drilling. Below is a figure showing these relationships and components of air rotary circulating system.

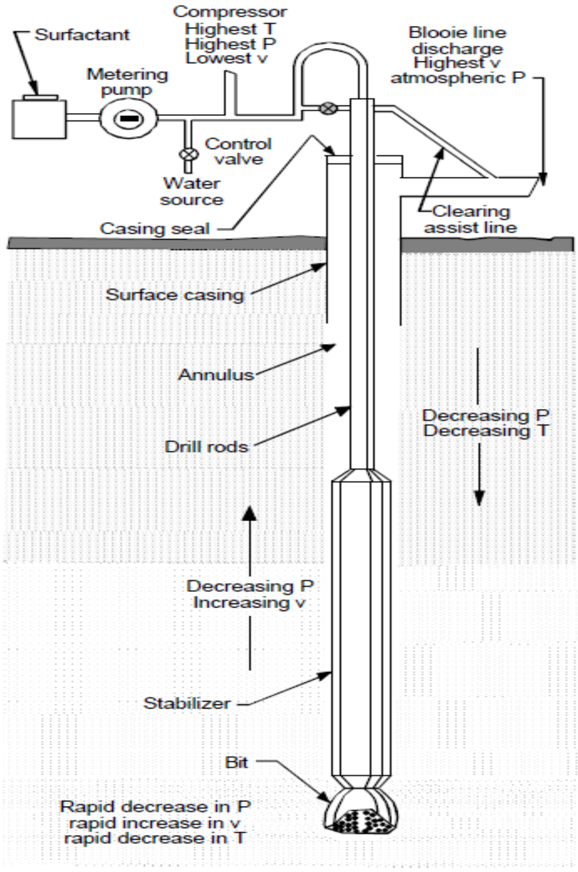


Figure 16: Air-based fluid rotary circulation system

Pressure and temperature are high and volume is low as the fluid goes into the air feed line and down through the drill pipe. At the bit, a rapid expansion occurs with a drop in pressure and temperature. Expansion continues until the pressure at the bit equals the pressure caused by resistance to flow in the presence of cuttings and water load.

Air-based fluid in rotary drilling has the following advantages over water-based fluids.

- Higher penetration rates, especially in hard rock.
- Easy detection of aquifers and estimation of potential flow rates.
- Reduced formation damage.
- Longer bit life.

- No water (or very little) required for drilling.
- Better formation samples.

On the other hand, the major disadvantage of air-based fluids is associated with the fact that all air-systems bring the water to the surface. This presents disposal problems and the danger of dealing with hot water. Other disadvantages include:

- Higher cost of equipment and fuel cost for driving compressors.
- Dust.
- Noise of compressors and blooie exhaust.

▪ Polymer Fluids

Polymer fluids are the third class of drilling fluid. They can be either natural or synthetic.

- Natural polymers – Most of them are biodegradable while others are broken down easily by oxidizers such as weak acids.
- Synthetic polymers – Inorganic or organic. Organic polymers are not very encouraged as they possess the potential of pollution.

Polymers have no gel strength but they provides high viscosity that is required to carry cuttings up the hole and drop them in the mud pit just as effective. To a very great extent, problems associated with bentonite, due to gelling, are eliminated in low-temperature geothermal wells with the application of polymer fluids. Fortunately, polymers lack of gelling is the reason for this.

However, a major setback with the use of polymer drilling fluids is due to the fact that they are easily broken down. Geothermal fluids normally contain chemicals and dissolved gases that may react with polymers, especially in high temperature regions. These reactions can either reduce viscosity by breaking the long polymeric molecule or form a thick gel by cross linking the molecules.

8.2.8 Advantages of Rotary Drilling

Rotary drilling has the following advantages.

- It can drill through most rock formations.
- Water and mud support unstable formations
- It has a high penetration rate.
- Operation is possible above and below the water-table.
- Possible to drill to depths of over 14,000ft
- Easier directional drilling.
- Possible to use compressed air flush.

8.2.9 Disadvantages of Rotary Drilling

Rotary drilling has the following disadvantages.

- It is capital intensive.
- Often requiring pumping water in large volume.
- Often requires mud mixing equipment and dug pits or metal tanks for circulation.
- It requires fundamental knowledge of bentonite and additives needed to achieve adequate penetration rates and stabilize formations.
- There can be problems with boulders.
- Rig requires careful operation and maintenance.
- It is more difficult to identify water bearing zones, especially in low flow operations.

- Loss circulation zones can cause aquifer contamination and dramatically increase bentonite cost.
- Mud may plug aquifers and cause decreased production.
- Disposal of mud after hole is drilled can be inconvenient and expensive.
- It is often difficult to work with mud in freezing temperatures.
- Driller still bears the risk of the hole collapse or swell, resulting in possible loss of drill string or jamming of casing during installation.

8.3 Laser Drilling Technique

The setting is not a complicated one, just like in laser welding. A very important aspect of this is the simplicity in pointing the laser head to the spot to be drilled. In petroleum and gas wells, as the hole depth increases, all that is needed is a corresponding increase in the length of drill pipes in order to get the laser head close and pointed to the uncut surface at the bottom of the well for boring to continue.

However, just like there is no rotary drilling technique without a circulating system and drilling fluids, a purging system plays a similar role in laser drilling technique. The purging system provides a transparent medium for the laser to pass through, cleans the hole of cuttings, and move molten rock into the fractures to seal them as well as sealing the wall of the wellbore.

Reflection, scattering and absorption characterize the transfer of radiant energy (laser) to solid rocks in order to destroy them. Amongst them, absorption is the process by which heat is collected by the rock; which eventually results in destroying it (Graves and O’Brien 1998). Scattering and reflection represent energy that is not absorbed by the rock or energy losses in the system. Therefore, for the feasibility of laser drilling,

Graves and O’Brien (1998) outlined the following criteria:

- Low reflectivity of rocks result in good coupling of laser radiation with rocks.
- Deep penetration of laser energy into rock resulting in volumetric absorption of laser energy.
- Low thermal conductivity of rocks resulting in effective heating.

Major advantages of laser drilling over conventional drilling include:

- It drills 100 times faster
- It makes more precise holes
- Reduces downtime due to dull bits
- Eliminates waste created by drilling mud (cuttings vaporize)
- It creates a ceramic surface that seals the wall of the well
- It eliminates influx/out-flux of fluids hence formation damage is eliminated as well.
- It is much more economical both in saving time and reducing extra cost of employing, for example steel wall casing.

9 DISCUSSION

This entire section is based on recent experiment works undertaken with the aim of applying laser technology in drilling and perforating oil and gas wells. Different rocks types were exposed to lasers for certain time interval, and inferences were made on rate of penetration (ROP), specific energy (SE), and the effect of lasers on permeability on the formation.

Graves and O'Brien (1998) conducted an experiment to determine the feasibility of MIRACL (Mid Infrared Advanced Chemical Laser) for drilling and perforating wells. MIRACL is a US Army's continuous wave laser with a wavelength of 3.8µm and a power output of 5 – 12 kW. A 6-inch and a 2-inch diameter holes were drilled on two 12 by 12 by 3-inches samples of 9 Darcy dry Sandstone. On the first slab, the 6-inch diameter hole was drilled to determine the amount removed by a full laser beam, for drilling purpose. The laser was directly pointed at the slab and a 2.5-inch deep hole was produced after only 4.5s. This result is an equivalent rate of penetration (ROP) of 166ft/h. On the other slab, the 2-inch diameter hole was drilled horizontally with an output power of 500kW. This was to confirm the feasibility of laser for perforation purpose. The rock was exposed to the laser for 2s and a 6-inch deep hole was created; which is equivalent to a ROP of 450ft/h. Permeability tests were equally conducted on the slab before the experiment and around the hole after the experiment and no change was noticed.

Graves et al. (1999) conducted an experiment on Sandstone, Limestone, Shale, Salt and Granite with the use of COIL (Chemical Oxygen-Iodine Laser) with an aim to determine the least specific energy (SE) needed to destroy varying rock types. COIL is a US Air Force continuous wave, with power between 5 – 10kW and wavelength of 1.315µm, laser designed to track and destroy missiles at 31mile radius. Comparing that distance to a petroleum well that is approximately 3miles deep, it was a welcome candidate. 0.25-inch diameter holes were created on each specimen irradiated for 8s and the SE's were determined. For three different power levels (100, 50 & 35%), the SE determined for the rock specimen range from 10 – 40kJ/cm^3. However, the salt specimen used the lease SE at 100% power level whereas limestone used the least for other power levels. On the other hand, Shale consistently used the largest amount of SE. However, a more recent experiment showed that limestone SE is greater than shale. (Gahan et al, 2001). The explanation for this was due to the fact that a lighter coloured limestone was used and its reflective property was correspondingly higher resulting in less energy absorption. The relationship between SE and ROP was also determined for the five rock specimen. They are inversely proportional, i.e., as the SE increases, the ROP decreases. In addition, Graves et al. (1999) gave an account on the effect of fluid saturation on SE. Cores were saturated with fresh water, brine, oil, and gas and the test showed that a little increase in the SE was needed to penetrate the saturated cores.

Hole penetration limitation test was performed to determine the effect of hole depth and vapour contamination in the wellbore on the ROP (Graves et al. 1999). Rock specimen were lased for 3, 6, 9, 12, & 15s and it was found that the greater the irradiation time, the greater the SE. Gahan et al (2001) equally concluded on this direct proportion relation between exposure time and SE required when samples of rocks were lased for 0.5, 1.0, & 1.5s with Nd:YAG pulsed laser. Graves et al (1999) pointed that plasma screening perhaps is a factor. Plasma screening is the formation of liquid or gas that leads to a change in the atmospheric condition in the hole. They concluded that an increase in exposure time consumes laser energy as it allows for the development of melted rock that acts as a barrier between the laser and the uncut surface of the hole bottom (rock).

In conventional drilling system, there are many factors that determine the rate at which the borehole is drilled. They include; weight-on-bit (WOB), mud circulation rate, rotary speed, hydraulic horsepower bit design and hold size. With laser drilling, this rate may only depend on the delivered power and the hole size (Graves et al 1999) thus eliminating the complexity of the current drilling technique. Dr. Claude (May 10, 2006) in an interview on History Channel pointed out that in about ten years' time, laser drilling will probably replace all oil and gas well drilling technique. He explained that lasers can penetrate, melt and vaporize any rock material.

10 CONCLUSION

Although the use of applying laser technology in petroleum well drilling is only a fairly recent development, the improvement so far has shown that it is very feasible. The question of whether or not laser can drill rocks has been answered; as there are now available lasers that can destroy or drill through any kind of rock formation relatively fast. However, experiments to outline specific changes to reservoir characteristics – porosity and permeability changes, as well as to what extent will the rock fracture due to lasing should be conducted. Detailed experiments should also be conducted on the impact the varying kinds of solid-fluid phase and multiphase present in reservoir rocks have on lasing practice. In addition, a 3-D model describing the full laser petroleum well drilling process should be developed. With the pace at which researches in this subject are yielding positive results, a prototype that would mark a revolutionary change in four years' time will not be a surprise.

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Appendix 1

DEFINITION OF TERMS

ANNULUS	The space between the drill string and the wall of the wellbore.
AQUIFER	An underground layer of water-bearing permeable rock or unconsolidated material from which groundwater can be usefully extracted.
BAILER	A device used to remove a collection of substance from where they are packed.
BITS	This is the cutting tool that rotates while bearing down on the bottom of the well, thus gouging and chipping its way downward, as used in the rotary drilling technique.
BLOWOUT	This is an influx of fluid from the formation to the well bore caused by the formation pressure being greater than the hydrostatic pressure of the drilling mud.
CASING	Running pipe down the well bore to protect the hole from collapsing and creates a fine wall surface free of debris for clean production.
DERRICK	The tall tower-like structure that extends vertically from the well hole.
DRILLING MUD	A mixture of clay, usually bentonite, water and other additives used primarily to carry rock cuttings to the surface and also to lubricate and cool the drill bit. By its hydrostatic pressure, it prevents entry of formation fluids into the well, thereby preventing “blowouts”.
DRILL COLLARS	They join the drill bit to drill pipe and helps to add weight to the drill string.
DRILL PIPE	Are 20 – 40ft long sections of heavy steel pipes used to transfer power to the drill bit down the hole.
DRILL STRING	Drill pipes connected together forms drill string.
FISHING	A process of getting stuck tools out of the drilled hole.
FORMATION	The arrangement of the earth in layers makes up the formation.

FORMATION PORE PRESSURE

The pressure of fluids within pores of a reservoir.

FRACTURE GRADIENT

The pressure required to induce fractures in rock at a given depth.

HYDROSTATIC PRESSURE

Defines the pressure of the drilling fluid.

KICK
Unexpected influx of petroleum from the formation to the annulus.

LASER
(Light Amplification by Stimulated Emission of Radiation) This is a device that emits lights (electromagnetic radiations) through a process called stimulated emission. Basically, lasers convert different forms of energy to energy of light (intense photon). For example, a chemical laser converts chemical energy to light energy. Laser light is emitted in a narrow, low-divergence beam, or can be converted to one by the use of optical component such as lenses.

MONKEY BOARD

It is a moving floor stood upon to handle pipes up in the derrick.

RESERVOIR ROCKS

It is a place where oil migrates and it is held underground.

SLURRY
A watery mixture of something such as mud, animal waste or dust.

TRAP
This is a closed inverted container where oil finally collects. It can be of any shape in the form of porous and permeable reservoir rocks that is sealed above by a denser and relatively impermeable cap rocks.