POLITECNICO DI TORINO

DIPARTIMENTO DI AMBIENTE E TERRITORIO

CORSO DI LAUREA IN:

PETROLEUM ENGINEERING

Innovative drilling technology

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TORINO

ACCADEMIC YEAR 2019/2020

JULY 2020

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1. Introduction

The first wells used to search for oil were drilled more than 150 years ago. Since that time on, various innovations have been adopted to drill deeper and deeper wells thanks to which we are now able to reach oil and gas reserves located also at 12 kilometres into the earth.

We have met several challenges over the years, but, because drill bits and rigs are constantly evolving by seeking new ways of getting the bit down to the depth required in a safe manner, our industry has allowed billions of barrels of oil and trillions of cubic feet of gas to be produced for industrial growth and development. Indeed, the history of drilling is rich with innovations that have fundamentally changed the world.

1.1. Aim of the work

The aim of this thesis is to show the most important innovations in drilling and completion techniques and technologies in comparison with the traditional ones.

This research briefly outlines the oil and gas drilling techniques from the beginning of the petroleum history and follows the trend to today's methods describing the relative components of which they are composed.

A portion of the work will be used to point out also completion techniques and part of the innovations in that field, knowing that their variety is immense and in continuos developing.

The work displays general caracteristics of innovative drilling methods as Directional drilling, Multilateral drilling, Extended Reach Drilling, Automatic drilling and Laser drilling;
furthermore, Intelligent Well Completion, Through tubing drilling and completion, Well matrix stimulation without HCl and Unconventional stimulation according to the innovative completion technology.

Notice that the units used in this report could be not the standard ones, thus, to avoid confusion and misunderstanding, here are the conversion factors to S.I unit:

- 1 foot = 0.3048 meters
- 1 inch = 0.0254 meters
- 1 ppg = 119.83 kg/m3
- 1 psi = 6898.93 Pa
- 1 bbl = 42 GAL = 158.98 dm^3
- 1 lb = 0.4536 kg

2. Drilling techniques

The term drilling indicates all the set of operations necessary to build wells of circular section applying excavation techniques.

A successful well drilling, either on land or offshore, must be able to provide the following actions simultaneously:

- fracturing and penetrating through rock formations to reach petroleum and gas overcoming the resistance of the rock, crushing it into small particles in the order of millimeters;
- remove the rock particles, called cuttings, from the bore hole;
- maintain the stability preventing the walls of the bore hole from collapsing, especially for unconsolidated formations;
- prevent the formation fluids from entering into the well.

Over the years, many processes have been invented and modified.
Since the bamboo rigs used in China, to cable tool used in the 19th century, down to the rotary drilling and now up to the laser drilling, the challenge is still to look for the most effective process which optimizes cost, time and respects safety and environmental issues.

Oil and gas exploration makes use of several types of drilling methods and platforms based on the type of formations, geographic location, soil type, depth of the hole.

Here there are the most common drilling methods used for extracting oil and gas from beneath the earth:

- Percussion or Cable Drilling
- Dual-Wall Reverse-Circulation Drilling
- Electro-Drilling
- Rotary Drilling

2.1 Cable Tool Drilling Technique

The technique is also known as cable drilling and it is an efficient way to wrench shallow but precise holes into the earth’s crust. This technique is the best option for holes around 40-50 meters deep, nevertheless, it can also be utilized to dig boreholes down to 300 meters.

Percussion drilling works by repeatedly raising and dropping a large hammer bit on the borehole causing the fracture of the soil. The hammer is attached to a powered cable system which lifts and drops the bit.

The water mixes with the crushed rock particles and settles at the bottom of the bore hole. As the drilling goes on, the mixture accumulates to a quantity that begins to reduce the penetration to an unaccepted level: at this point drilling is stopped and the slurry is removed by a bailer. The bit is reinstalled into the hole and drilling continues until the target is reached.

In air percussion drilling the hammer will be driven by compressed air.

A steel casing helps prevent the hole from collapse and also protect the hole from corrosion caused by formation fluids.

This type of drilling is perfect for unconsolidated and consolidated formations including sand, silt, sandstone and even gravel.

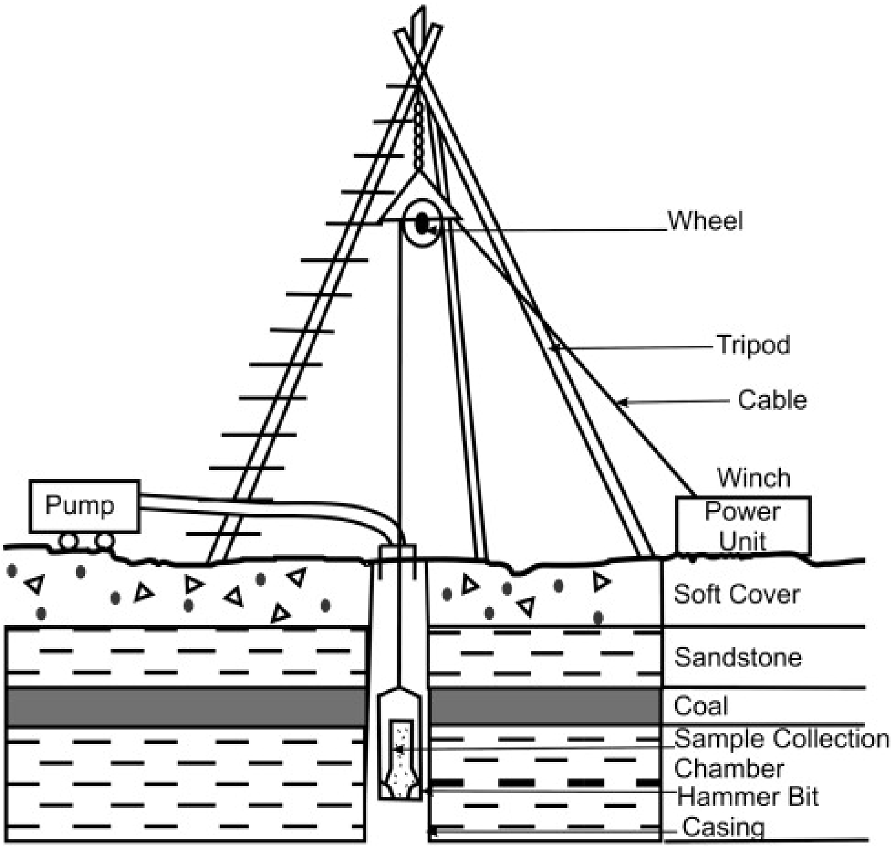


Figure 1: Schematic conceptual diagram of percussion drilling procedure. [https://ars.els-cdn.com/content/image/3-s2.0-B9780124160057000076-f07-01-9780124160057.jpg?_]

2.1.1 Cable Tool Drilling String Components

A cable tool string has four basic components:

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

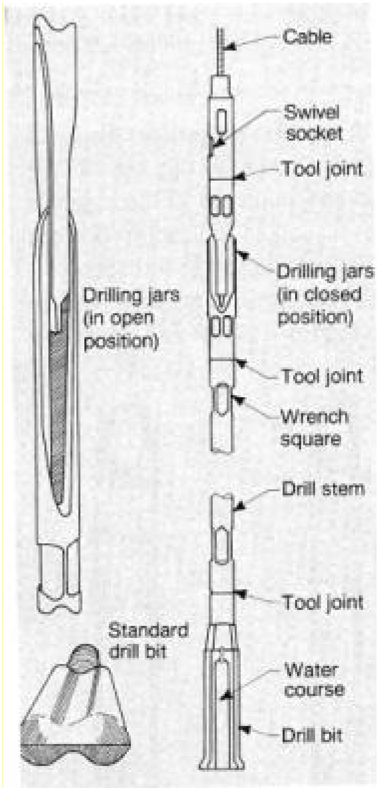


Figure 2: Cable Tool Drilling String Components [http://www.doc-developpement-durable.org/file/eau/creusement-forage-puits/Drilling-Methods.pdf]

2.1.2 Advantages of Cable Tool Drilling

Cable tool drilling has the following advantages:

- A relatively cheaper drilling method compared with rotary drilling.

- Efficient use of personnel: cable tool rigs are often operated by one or two people.

- Suitable for water poor areas and remote settings due to the fact that the cable tool drilling requires little amount of water.

- Low fuel consumption.

- Reliable qualitative and quantitative data with the possibility to retrieve information while drilling.

2.1.3 Disadvantages of Cable Tool Drilling

Cable tool drilling has the following disadvantages:

- Directional drilling is impossible with this method.
- 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 is low compared to rotary drilling with similar formation.
- Lack of experienced personnel: a cable-tool driller with a wide range of experience is hard to find.

2.2 Dual-wall reverse-circulation drilling

Dual-wall reverse-circulation, or RC drilling, is a method of drilling which uses two concentric drill pipes to create a controlled flow. The drilling fluid is pumped through an outer swivel to reach the bottom of the bit, and then ricochets upward into the main pipe. All cuttings are carried upward through an internal pipe and with the help of surface swivel.
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.
A cyclone separator is used to separate air from water and cuttings mixture.
The method also allows for geologic sample collection, with samples usually delivered through the cyclone created at the surface.

The method is applicable for all types of geologic formations and does not require surface casing, too.

Good sample recovery is one of the main strengths of this method.

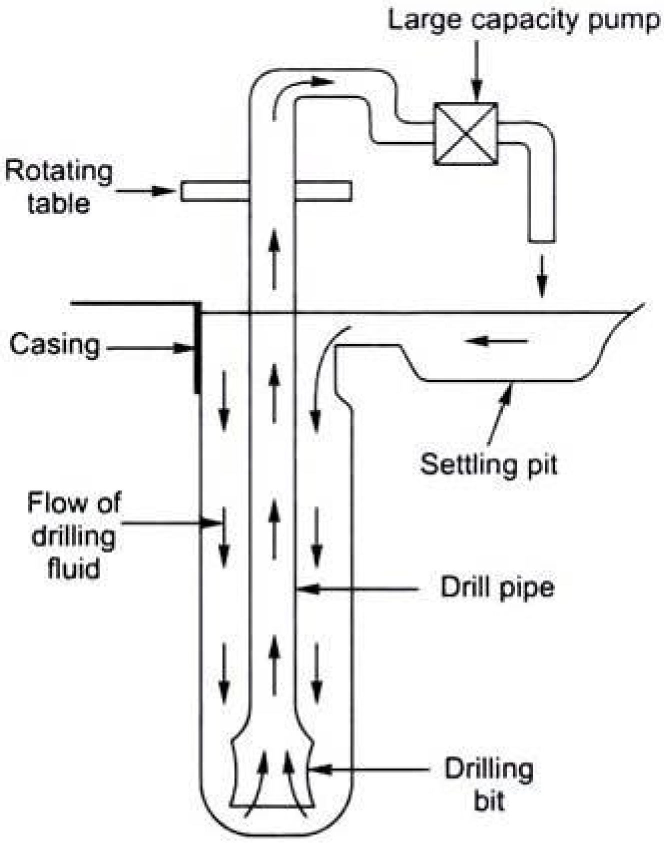


Fig. 9.14 Reverse rotary boring method.

*Figure 3**:** Reverse Circulation Drilling [http://www.agricultureinindia.net/wp-content/uploads/2017/06/clip_image010_thumb-9.jpg]*

2.2.1 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 less time lags to the surface and less mixing of cuttings which enhances sampling quality. Sample velocity through the inner tube can reach speeds of 250 m/sec, making the retrieval of drill cuttings a rapid but safe method.

There is less possibility for formation damage by mud invasion because water or very thin light mud is used.

Samples obtained via RC drilling are free of contaminants and they are sent directly to the lab to be assessed. RC sampling requires less handling than other methods resulting in cost and time reduction. Cost reduction is especially noticeable in geologically challenging locations since it is more resilient in harsh environments.

RC drilling is fairly straightforward and requires far less water than diamond drilling, making it ideal in places where water may be scarce or costly.

2.2.2 Disadvantages of the reverse circulation

Under-pressured geothermal fluids are prevented from entering the hole for temperature or chemistry change detection since the annulus fluid level is at the surface.

The sounds of constant hammering of drill bits into rock combined with the use of loud air compressors may cause hearing loss. That’s why occupational health and safety laws require workers to wear some sort of hearing loss protection as well as all other appropriate personal protective equipment.

2.3 Electro-Drilling

Basically this method is very similar to the rotary drilling one except for few differences.

The rotary tables, which let the drill pipes rotate, are driven by electric motors which lead to better flexibility in operations along with remote-controlled drilling.

These drills are new methods of oil and gas exploration, as they provide more direct power to the drill bit by connecting the motor above the bit.

The electro-drilling system has been successful in complex geological conditions in which it is necessary to use weighted mud or mud mixtures to boost savings in energy and material usage.

Combining the advantages of rotary and hydraulic-motor methods, electro drilling technique involves a big range of drill-bit rotational speeds. This method can also implement controlled drilling of deviated boreholes with the possibility to use different borehole cleaning agents.

2.4 Rotary Drilling Technique

Rotary drilling is the most common well boring method used today especially for digging up exploratory and production wells, which boast of depths that exceed five miles below the ground.
Although the idea of using a rotary drill bit to make holes is not new, it is only in the early XX century that a standard application of this method has had success for production in commercial quantity of petroleum and gas.
It still remains the most effective method of well drilling in petroleum and gas industries today.

The fundamental principle behind this technique is the use of a sharp, rotating drill bit which is able to drill down through the earth crust. Following constant technological innovations, the actual mechanism of today's rotary rigs is quite complicated, but it follows a general pathway like its precursors.

Rotary drilling rig

The drilling rig consists of a set of equipment and machinery located on the so-called drilling site.

The equipment is mounted on a platform with a 40-meter-high derrick, that consists of a rotary table, a handy engine, mud mixer and an efficient injector pump. It also includes a winch and 27-meter long pipe sections. The rotary table then directs the kelly, which is connected to the drilling pipe. The mud swivel on the pipe is subsequently connected to blowout preventers.
The pipe rotates at a velocity of 40 to 250 rpm. A drag bit is useful in this scenario to penetrate unconsolidated sediments, while the roller bit can drill through consolidated rock. The overall rotation speed of can be increased or decreased depending on the hardness of formation material.
Cuttings are then removed by fluid circulation up from the annulus.
The most important items of drilling site are shown in the figure below.

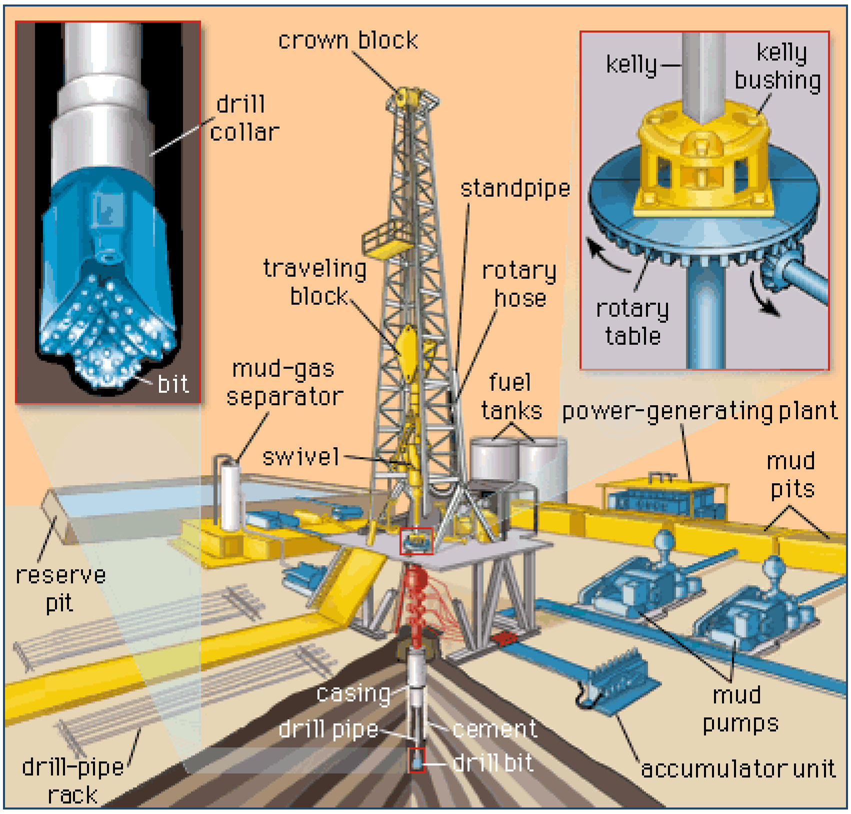


Figure 4: Basic Land Base Rotary Drilling Rig [http://158.196.10.120/DRILLING/drilling/theory/theory_html_m2f645251.jpg]

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

- The prime mover – which supplies power.
- The hoisting system – that raises and lowers the drill strings.

- The rotating system – that rotates the drill string and the drill bit.

- The circulating system – that pumps drilling mud down the hole.

- The blowout preventer (BOP) – used for safety reasons.

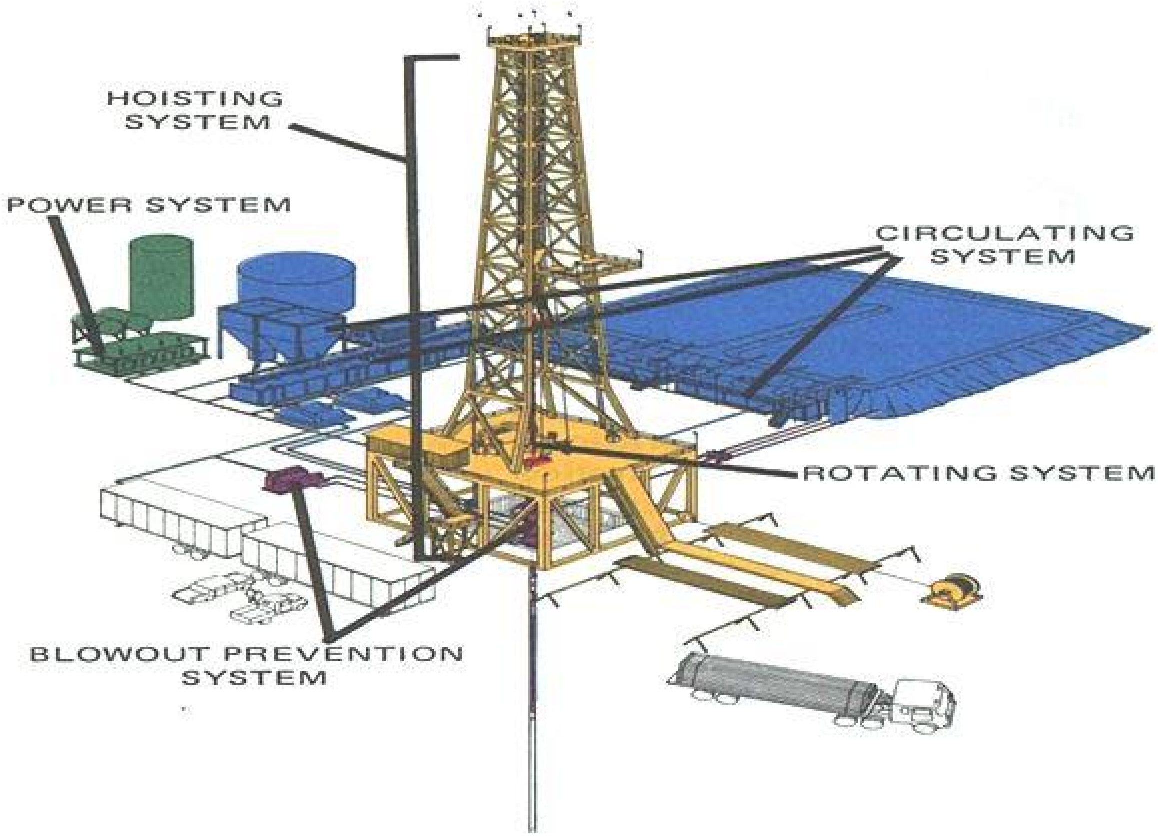


Figure 5: Drilling Rig Systems [http://www.oil-gasportal.com/wp-content/uploads/2015/03/drilling-system.jpg]

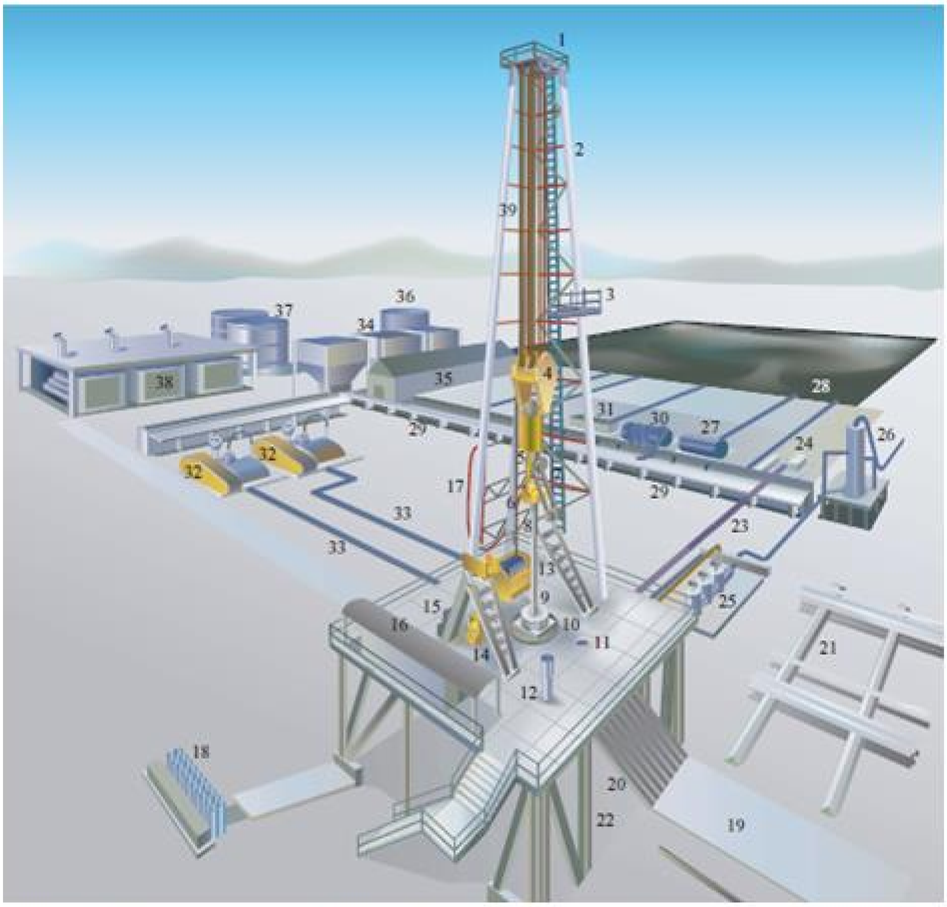


Figure 6: Drilling site equipments [http://www.oil-gasportal.com/wp-content/uploads/2015/03/Immagine32.png]

2.4.1 The Prime Movers

The prime movers are the power providers of the entire equipment in the rig.
Steam engines were used for the early rigs but today's rigs are provided by gas, diesel or diesel-electric engines.

Power is transferred from the engines to the different rig systems by belts, chains, and drive shafts on a mechanical rig, or by generated DC electrical power on an electric rig. Then it is distributed to the rotary table and to the mud pumps and to the drawworks.

Figure 7: *Drilling Rig Power Generation System [http://www.oil-gasportal.com/wp-content/uploads/2015/03/Drilling-rig-power.jpg]*

2.4.2 The hosting system

The hoisting equipment consists of tools used to raise and lower whatever other equipment that is in 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 drilling lines, draw works and to hold the monkey board in place.
The hoisting equipment is able to raise long drill pipes, that extend from the surface down to the drill bit, drill bits and drill collars in case a problem occurs that would require the need to change the drill bit.

If the derrick is tall enough, multiple sets of drill pipes (stand) may be removed at once for saving time.

The substructure is the supporting base for the derrick, the drawworks and the rotary table, and constitutes the working floor for operations, or drilling floor.

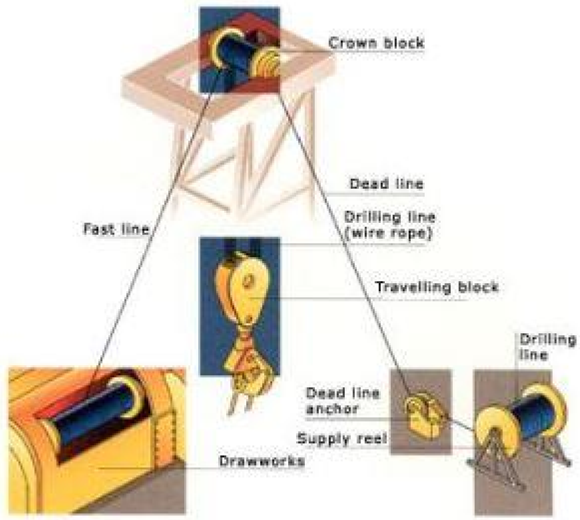


Figure 8: The Hosting System [http://www.oil-gasportal.com/wp-content/uploads/2015/03/hosting-system.jpg]

Figure 9: The Derrick Types

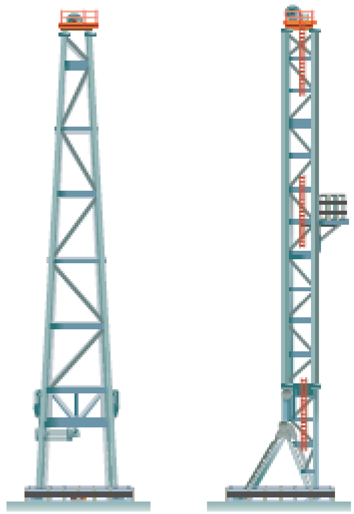


Figure 10: The Mast Types

[http://www.oil-gasportal.com/wp-content/uploads/2015/03/Immagine51.png]

2.4.3 The rotating system

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 rotating system allow the rotation of the drill string, and it consists of the rotary table, the kelly and the swivel.

The prime mover transfers power to the rotary table which is connected to the drill pipe and as it turns, the drill bit turns as well due to its connection.

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.

In modern rigs, a *top drive* groups together the functions of the above three items of equipment.

Drill collars stay between the drill bit and the drill pipe. They are heavier and thicker than drill pipes and are used to add weight to the drill string to provide enough downward pressure needed for the drill bit to crush through hard rock formations.

Figure 11: The Kelly System *Figure 12:* The Top Drive System

[http://www.oil-gasportal.com/wp-content/uploads/2015/03/kelly-system1.jpg]

2.4.4 The circulation system

It is a closed hydraulic circuit which allows the mud to flow from the surface to the bottom of the hole inside the drill string, and subsequently back to the surface, in the drillstring borehole annulus.

The equipment needed for the circulation system includes mud pumps, compressors, distribution lines, accumulation system, related plumbing fixtures, special injectors for the addition of additives to the fluid, and separators (mud tank, pits or cyclone type separator).

The main functions of the circulating system are:

- Removal of cuttings from the bottom of the hole up to the surface. This makes possible the analysis of the available cuttings and samples to study geological properties of rocks penetrated and to find the indication of oil and gas in the formation.

- Well hydraulic pressure control to prevent collapse of the well and unwanted formation fluid entrance by adjusting the density of the mud.

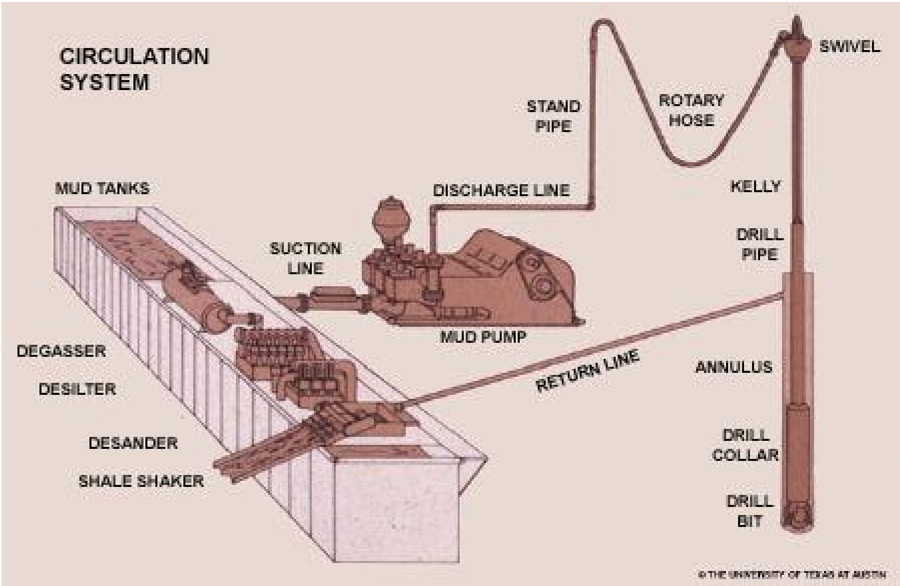


Figure 13: The Circulating System [http://www.oil-gasportal.com/wp-content/uploads/2015/03/The-circulation-system.png]

Drilling Fluids

Careful analysis should be made for selecting what drilling fluid best suits the local drilling conditions: both the engineer and the driller must be aware of the possible consequences of this selection and maintenance. The choice of the drilling fluid is dictated mainly by the characteristics of the formations to be drilled, and by the problems of disposal of the waste fluid.

Drilling fluids have many functions to perform including:

- *The removal and the transport to the surface of the cuttings produced by the bit;*
- *The control of the subsurface pressure;*
- *The prevention of caving and collapse of the borehole walls;*
- *The suspension of the cuttings when circulation stops;*
- *The cooling and lubrication of the drilling equipment;*

- *The sources of geological and stratigraphic information.*

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

- Damage to the subsurface formation.
- Reduction of penetration rate.
- Swab problems.
- Loss of circulation.
- Erosion of the borehole.
- Swelling of the sidewalls of the borehole.
- Sticking of the drill pipes against the walls of the hole.
- Retention of undesirable solids in the drilling fluid.

A good drilling fluid has the following characteristics:
Lubricity, Viscosity, Density, Gel Strength, Filtrate control

Drilling fluids are subdivided into three major classes:

- Water based muds;
- Oil based muds;
- Air -based muds.

In today‟s petroleum drilling, mud is the most commonly used drilling fluid because it possesses most of the characteristics listed above.

Modern drilling mud is a mixtures of bentonite 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 the water, an increase in the density and viscosity is caused.

Additives, such as organic polymers, dispersants, wetting agents, weighting agents, thinner and lubricants, are added to improve gelation, lubricity, filtration and other properties, thus making it a suitable drilling fluid.

As the mud is used, it gradually looses its standard physical properties, as it carries cuttings from the hole.

Mud density, or mud weight, usually is expressed in pounds per gallon (ppg).
An increase in density results in relative increase in cutting carrying capacity, an increase in borehole pressure reducing caving in and formation fluid flow into the hole; on the other hand, the density increment decreases settling rate in the mud pit and may result in loss of circulation (flow of drilling mud into the formation).

Density can be increased by the addition of barite – a weighting agent.

Mud viscosity is adjusted by varying the amount of bentonite and water or by adding polymers to thicken or phosphate to lighten the fluid.

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

The desired maximum limit is 2% by volume. Regular measurement pays out on the long run.

Gelling is a property of the mud that allows it to be fluid when under stress, but solid when left to stand.
Gelling can be used to stop loss circulation by adding more bentonite and pumping it down hole.

Lost circulation is the loss of drilling fluid from the borehole through cracks or porous formations. When circulation is lost, it is obvious that the drilling fluid can no longer perform its transporting cuttings up the well function, resulting in stuck pipe, cementation problems, loss of drilling time and possibility to loose the bit, drill collars, or part of the string or maybe even the entire hole.

Proper planning and rig operations are fundamental in order to prevent the occurrence of circulation loss: carefully planning the hole and casing program, treating the well bore gently, maintaining fluid velocity in the annulus at the lowest rate, making frequent measurements of mud properties to maintain minimum weight, viscosity and filtration.

Air-Based mud

Like the name, this is drilling with air. The lifting capacity of air and the volume requirement are two very important factors to consider.

The need to increment velocity to compensate for the increased weight of the cuttings, as going deeper into the hole, can lead to erosion of softer formations and thus air loss, resulting in all the problems already described for circulation loss.

Air drilling is the best choise when drilling on consolidated formations because it eliminates the danger of caving.

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 resulting by adding little amount of water plus wetting agents that help remove mud rings and controls dusts.

FOAM DRILLING

Drilling foam is composed of a small amount of water and large amount of air. 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.

Air-based fluid in rotary drilling has the following advantages in comparison with 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 disadvantages of air based fluids are the higher cost of equipment and fuel cost for driving compressors, dust occurrence, and excessive noise due to compressor's work.

Polymer Fluids

Polymer fluids are the third class of drilling fluid. They can be either natu-ral or synthetic. Organic synthetic polymers are not very encouraged as they are not environmentally friendly causing pollution.

Polymers have no gel strength but they possess high viscosity thanks to which they can carry cuttings up to the hole and drop them in the mud pit effectively.

However, the major setback with the use of polymer drilling fluids is 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 linking the molecules.

The drill string

The drill string is an assemblage of hollow pipes of circular section, extending from the surface to the bottom of the hole.

It has three functions:

- it brings the drilling bit to the bottom of the hole while transmitting its rotation and its vertical load to it;
- it permits the circulation of the drilling fluid to the bottom of the hole;
- it guides and controls the trajectory of the hole.

Starting from the surface, drill string consists of a kelly, drill pipes, intermediate pipes, drill collars and a number of accessory items of equipment (stabilizers, reamers, jars, shock absorbers, downhole motors, etc.), and it ends with the bit.

The bit is connected to the end of the drill string: it is the tool that bores the rock, transforming it into fragments called *cuttings*, which are then transported to the surface by the drilling fluid.

The choice of the type of bit depends on the hardness, abrasiveness and drillability of the rock formation.

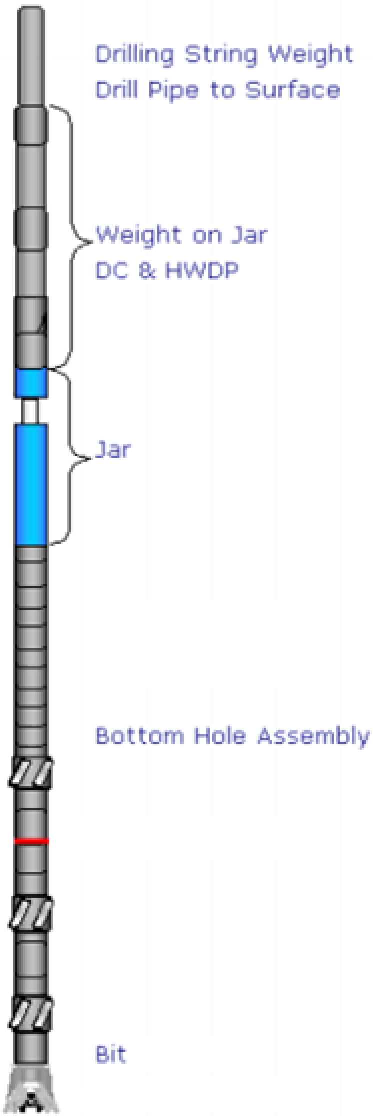


Figure 14: *Main Components of a Drill String [http://www.oil-gasportal.com/wp-content/uploads/2015/03/Immagine111.png]*

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 destroying anything it encounters during drilling.

A conventional drill bit has three movable cones containing teeth made of different materials depending on the rock they are designed to cut through like tungsten carbide, steel, diamond etc.

Drill bits used in rotary drilling are classified as follows:

1. Roller bits (or roller-cone bits).
   - Steel tooth bits
   - Insert bits (or tungsten carbide insert bits)
2. 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 that has made it possible to use its shearing action for cutting through tough rocks quicker, reducing the cost of drilling. The choice of bit depends on the properties of the formations and drilling technique.

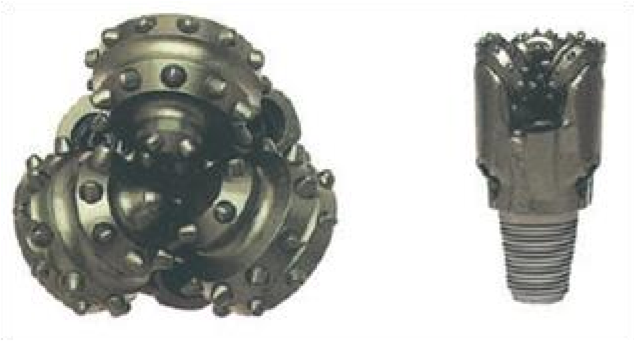


Figure 15: Insert Tricone Bit [http://www.oil-gasportal.com/wp-content/uploads/2015/03/Immagine121.png]

Figure 16: PDC Bit [http://www.oil-gasportal.com/wp-content/uploads/2015/03/Immagine13.png]

Casing

After a well has been drilled, it could eventually close in upon itself. Casing ensures that this will not happen while also protecting the wellstream from outside incumbents, like water or sand.

The casings consist of steel pipes that are joined together to make a continuous hollow tube covering all the well: starting from the surface and ending to the bottom of the hole.

It is rigidly connected to the rock formation using cement slurry, which also guarantees hydraulic insulation.

The casing supports the walls of the hole and prevents the migration of fluids from regions at high pressure to the ones at low pressure.

Furthermore, the casing protects the hole against damage caused by impacts and friction of the drill string, acts as an anchorage for the safety equipment (BOPs, Blow Out Preventers) and, in the case of a production well, also for the Christmas tree.

The dimensions of the tubes, types of thread and joints are standardized (API standards) and the functions and names of the various casings vary according to the depth.

The different levels of the well define what diameter of casing will be installed. Referred to as a casing program, the conductor pipe comes as first, then the surface casing and the intermediate casing, and finally the production casing.

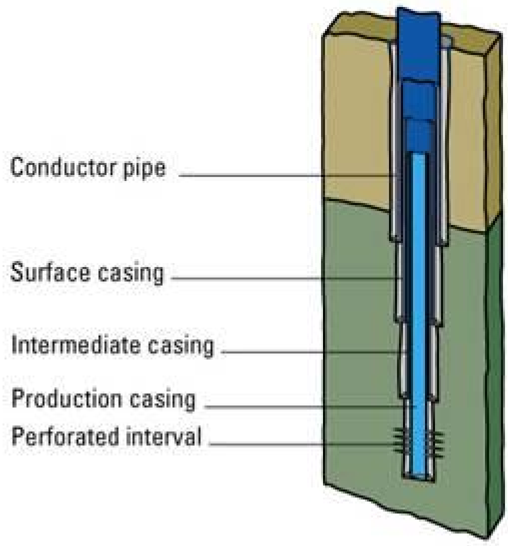


Figure 17: Casing Strings [http://www.oil-gasportal.com/wp-content/uploads/2015/03/Immagine14.jpg]

Cementing

Cementing is the operation of pumping a cement slurry between the casing and the formation to displace the existing drilling fluids and fill in the space between the casing and the actual sides of the drilled well.

Consisting of a special mixture of additives and cement, the slurry is left to harden, sealing the well from non hydrocarbons that might enter the wellstream, as well as permanently positioning the casing into place.

The primary cementing serves to rigidly connect the casing to the formation and to guarantee the hydraulic insulation of the various formations, preventing the migration of the fluids from different regions.

All other cementing operations carried out after the primary operation, either to correct a not effective cementing operation, or for other purposes (repair of a damaged casing, setting cement plugs, squeeze operations, and so on), are called secondary cementing.

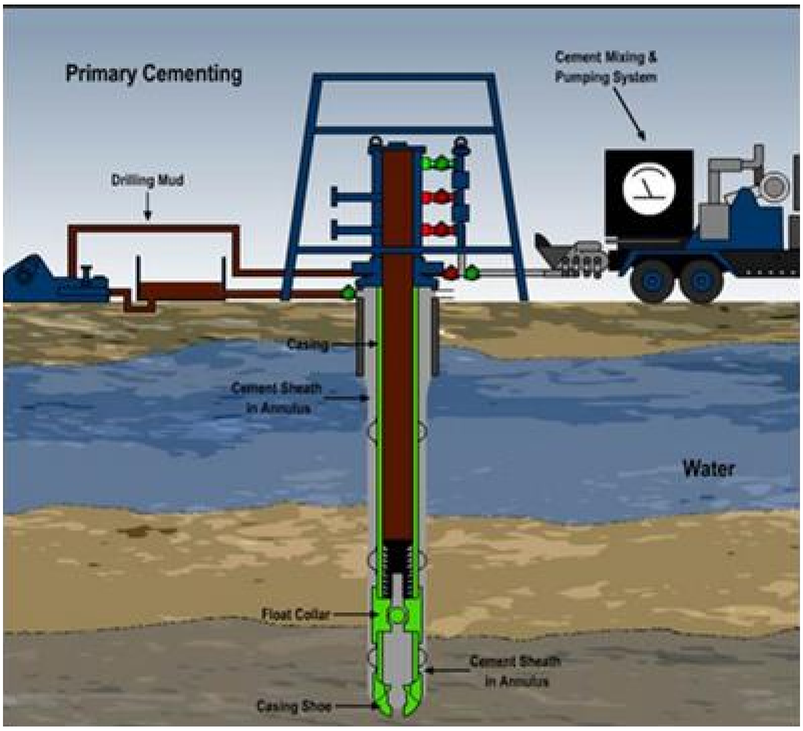


Figure 18: Primary cementing [http://www.oil-gasportal.com/wp-content/uploads/2015/03/Immagine15.png]

2.4.5 The Wellhead and safety equipment (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.

The wellhead and the safety equipment are the valve units that allow the well to be insulated from the environment outside.

In this way it is possible to control effectively and safely the pressures that develop in the well when it is in hydraulic communication with the subsurface formations.

The wellhead is a fixed unit that connects the various casings set inside the well. If it is a producing well, this unit remains there until the end of drilling, and is completed with the production head or Christmas tree.

The safety equipment, known as Blow Out Preventers (BOPs), are large valves located on the wellhead during drilling operations able to fully shut-in the well in case of need (Well control).

BOPs on onshore rigs and fixed offshore rigs (platforms, jack-ups) are installed on the surface wellhead, while for floating rigs they are located on the seabed, on the subsea wellhead.

The shut-in of the well is necessary when hydraulic control is lost, i.e. when the pressure of the underground fluids is greater than that of the bottomhole mud.

A blowout preventer is a large, specially designed valve that is mounted on top of the well during the drilling and completion stages of operation to stop the flow of oil or gas in case of emergency.

The Blowout Preventer, or BOP, is safety equipment designed to prevent uncontrolled flow of formation fluids during drilling and completion operations.

During drilling, mud is pumped down the drill string to equalize pressure in the well. If the well’s hydrostatic pressure falls below the formation’s pressure, a kick can occur, allowing gas, oil, and salt water fluids to enter the wellbore.

During a kick, these pressurized, combustible, hydrocarbons can be pushed up to the surface, where they may potentially blow out the well and ignite. The BOP has the capability to control this flow by sealing off the wellbore in several ways.

The BOP is attached to the steel casing that is cemented around the wellbore.

The Blowout Preventer is comprised of four main components, stacked one upon another. They are the annular preventer, blind ram, blind shear ram, and the pipe ram.

During a kick, the pipe ram is activated and creates a seal between the well bore and the outside of the drill string.

Afterward, it may become necessary to sacrifice the drill string to stop the flow of material inside the well bore. The blind shear ram performs this function by cutting, or shearing, the drill string, and sealing the well bore.

The blind ram is used to seal the well bore when there is no drill string in the well.

The annular preventer is a device that can seal around any object in the well bore, or upon itself. It is designed to create a seal, with or without the drill string present.

These multiple components provide redundancy, and are controlled by a device called the accumulator. This unit can be operated remotely, using a panel located on the rig floor, or by personnel on the ground, using duplicate controls on the accumulator itself.

Figure 19: Example of a Blowout Situation [https://www.ilcambiamento.it/data/articoli/orig/17/38/1794-3806.jpg]

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 in the well.

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

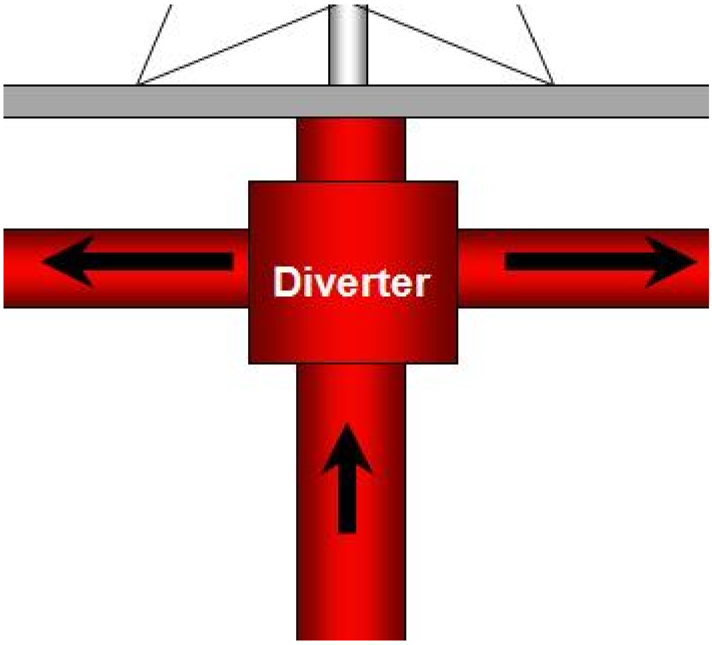


Figure 20: A Diverter System for Blowout Prevention [http://www.drillingformulas.com/wp-content/uploads/2012/08/140-Diverter-Systems-In-Well-Control-1.jpg]

2.4.6 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.

2.4.7 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.
- 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.
- Mud may plug aquifers and cause production decrease.
- 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.

3. Innovative drilling methods

Innovations in technology applied for well drilling and completion have enabled the energy industry to discover new resources, access to harsh and remote locations and the development of challenged reservoirs that previously were not economic to produce.

Advances in technologies will play a critical role in meeting rising energy demand around the world.

They also take into account the reduction of the environmental impact due to the energy production by allowing more oil and gas to be produced with fewer wells.

These types of drilling and completion technologies have also enabled the recent growth in production from shale and other unconventional oil and gas reservoirs in many parts of the world, using a combination of hydraulic fracturing and horizontal, extended reach drilling.

Some examples of advancements in drilling technology are presented below:

3.1 Directional Drilling

Directional drilling is the technique of deviating a well bore to reach a subsurface target whose location is at a given lateral distance from the vertical direction.

Directional drilling is actually an extension of the rotary drilling technique, which follows a curved path with the deepening of the hole.

Directional drilling is, therefore, a technique that makes it possible to reach deep targets even at a considerable horizontal distance from the location of the surface rig.

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

Directional drilling can help oil explorers reach deposits that cannot be extracted by vertical drilling. Reduced costs is the major advantage, as several wells can be drilled in all directions on a single platform.

Directional drilling is used in a great number of operational situations, the most recurrent of which are listed below:

Sidetracking, Inaccessible Locations, Salt Dome Drilling, Fault Controlling, Multiple Exploration Wells from a Single Wellbore, Offshore Multiwell Drilling, Relief Well, Horizontal Wells

Directional and horizontal wells are drilled on the basis of a design that follows precise technical criteria in order to obtain a regular and 'practicable' hole both at the drilling stage and during all of its subsequent productive life.

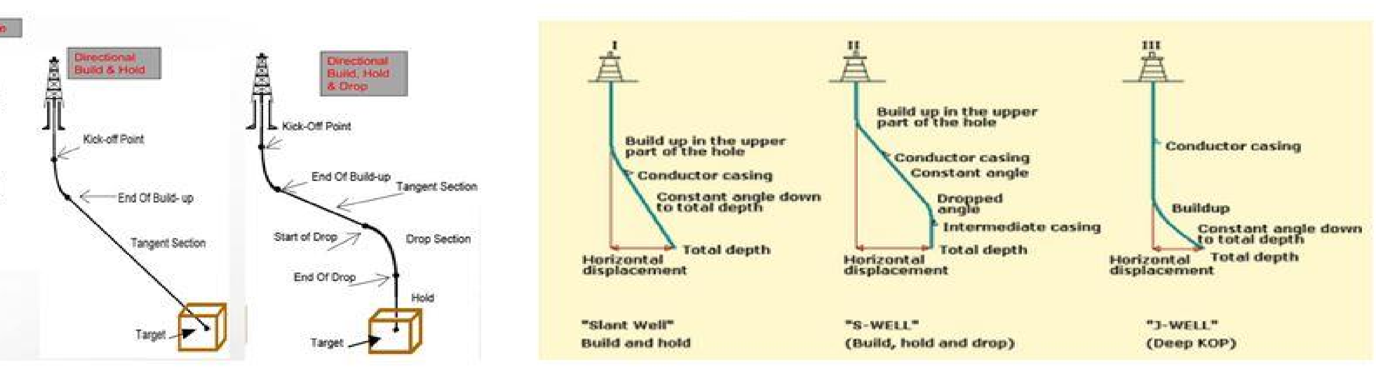


Figure 21: Typical Well Profiles and Terminology [http://www.oil-gasportal.com/wp-content/uploads/2015/03/typical-well-profile.jpg]

Some terminologies need to be defined to go further:

Kick off Point (KOP): The kick off point is defined as the point below the surface location from where the well is deflected from the vertical.

Build Up Rate (BUR): It is the rate of change (degrees/100 feet or degrees/30 meter) of the increasing angle in the hole.

Drop off: It is the act of reducing the inclination of the drilled hole with respect to the vertical.

Horizontal wells can be subdivided into three main categories according to the angular gradient with which the horizontal section is reached:

- *Long-radius wells* use standard technology to drill directional wells and the BUR may vary between 3° and 8° every 30 m and requires 2 or 3 sections.

- *Medium-radius wells use* standard equipment, although suitably modified to face the problems arising during horizontal drilling and the BUR increases significantly compared to the preceding case (between 8° and 20° every 30m);

- *Short-radius wells* make possible a build-up rates ranging between 30° and 60° every m and therefore has the possibility to arrive to the horizontal section in less than 3 m.

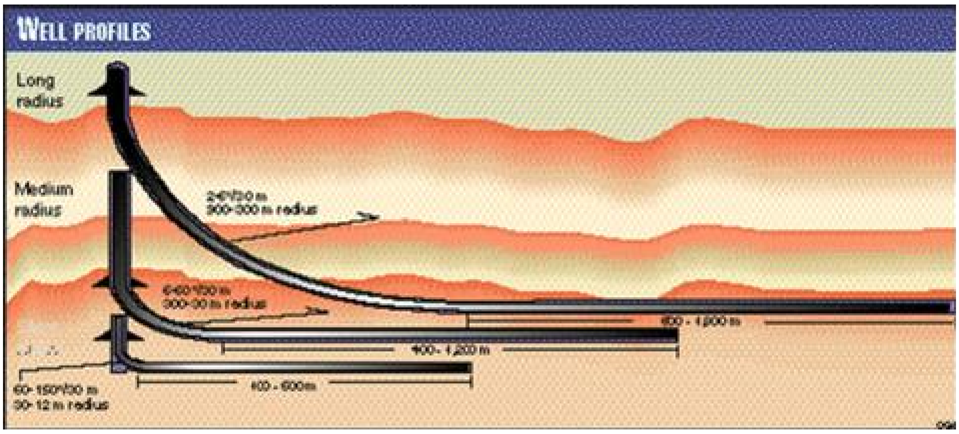


Figure 22: Typical Horizontal Wells Profiles [http://www.oil-gasportal.com/wp-content/uploads/2015/03/Immagine212.png]

The initial vertical portion of a horizontal well is typically drilled using the same rotary drilling technique that is used to drill most vertical wells.

From the kickoff point to the entry point the curved section of a horizontal well is drilled using a hydraulic motor, “steerable” downhole motor, mounted directly above the bit and powered by the drilling fluid.

Downhole instruments that transmit various sensor readings, as the azimuth (direction versus north), inclination (angle relative to vertical) of the drilling assembly and the position (x, y, and z coordinates) of the drill bit at any times, downhole environment (bottom hole temperature and pressure, weight on the bit, bit rotation speed, and rotational torque), are included in the drill string near the bit.

They may also provide any of several measures of physical characteristics of the surrounding rock such as natural radioactivity and electrical resistance, similar to those obtained by conventional wire line well logging methods, but in this case obtained in real time while drilling ahead.

The information is transmitted to the surface via small fluctuations in the pressure of the drilling fluid inside the drill pipe.

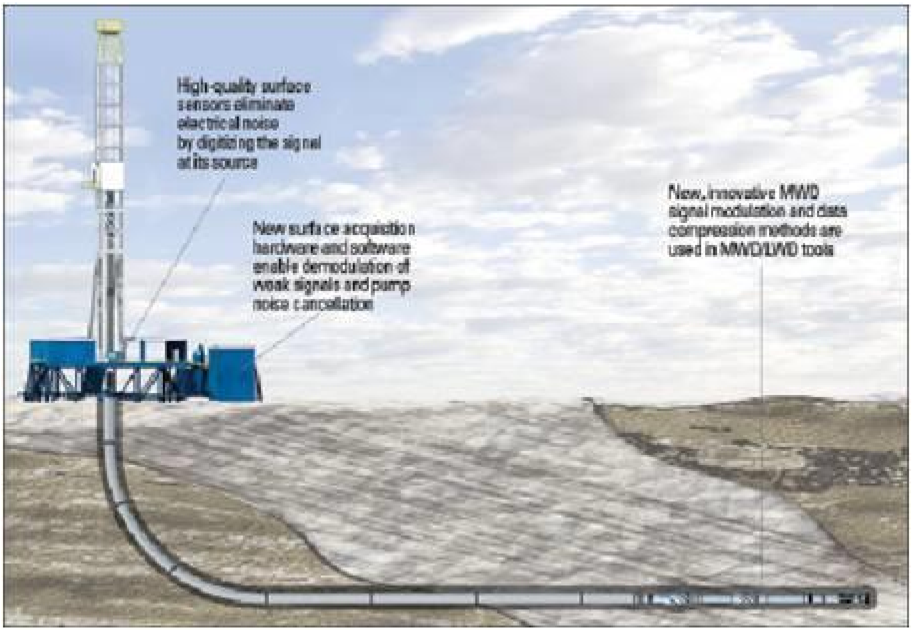


Figure 23: Horizontal Drilling Technology [http://www.oil-gasportal.com/wp-content/uploads/2015/03/Immagine1.jpg]

There are several systems to establish and carry out the deviation and some of them have been highly improved in recent times, from the application of the whipstock and jetting to the systematic use of bottomhole motors, steerable systems and geosteering.

In general, wellbore trajectory is controlled by the type of bottom hole assembly used and the weight on the bit.

A typical surface rotated bottomhole assembly (BHA) is made of stabilizers, drill collars and measurement while-drilling (MWD) equipment.

Assemblies can be designed to build angle, hold it steady or drop angle.

3.1.1 Steerable drilling system and geosteering

This technique makes it possible to navigate, in the true sense of the word, in the subsurface following the most suitable route to reach the prefixed targets.

Control of the wellbore azimuth is usually achieved with a downhole motor with a bent housing, which allows the rotation of the bit alone.

Downhole motors are hydraulic machines at the end of the string in which the entire mud flow goes through them and its pressure is converted into rotary motion and torque.

In this way, the rotation necessary for operating the bit is supplied by the downhole motor, while the whole drill string can remain stationary, or may be rotated, if necessary, with the rotary table or the top drive.

The use of such motors is essential both for directional drilling and for the application of modern techniques for controlling the vertical trajectory of wells.

Downhole motors, an integral part of the BHA, are axial-flow machines of tubular shape and are similar in size to a drill collar.

These motors are not part of the standard equipment of the rig, but are hired from service companies, which also supply the personnel specialized who look after their maintenance.

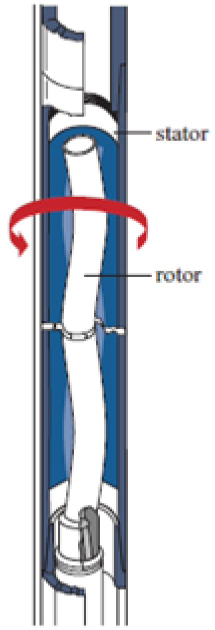


Figure 24: Schematic of a PDM Motor [http://www.oil-gasportal.com/wp-content/uploads/2015/03/Immagine22.png]

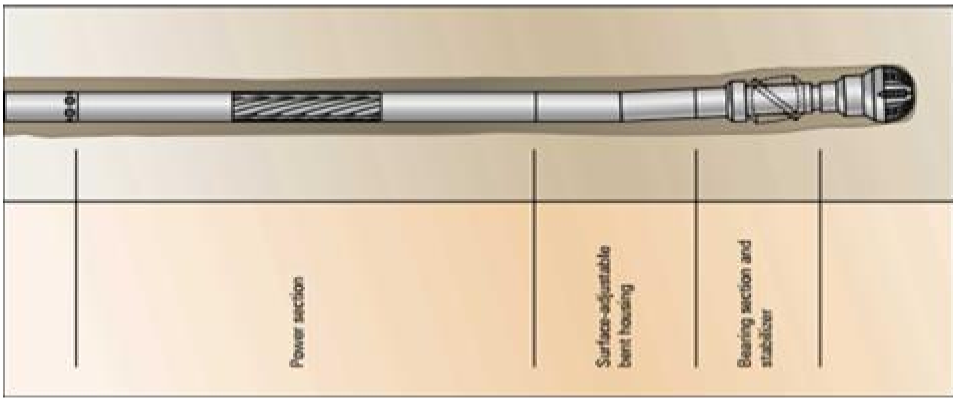


Figure 25: Steerable BHA [http://www.oil-gasportal.com/wp-content/uploads/2015/03/Immagine23.png]

A steerable drilling system is made up of a PDM (positive displacement motor), with a MWD (measuring while drilling) equipment, which provides in real time the data of interest for the driller (such as inclination, direction, pressure, temperature, real weight on the drill bit, torque stress, etc.) or the LWD (logging while drilling) equipment is installed.

The latter makes it possible to send to the surface, not only the information mentioned above, but also geological data (the gamma ray log, the resistivity, density and sonic logs, etc.).

The coupling of sensors providing information on the course of the well trajectory, in real time and in a continuous way, with logs characterizing the formations from a geological viewpoint, goes under the name of geosteering.

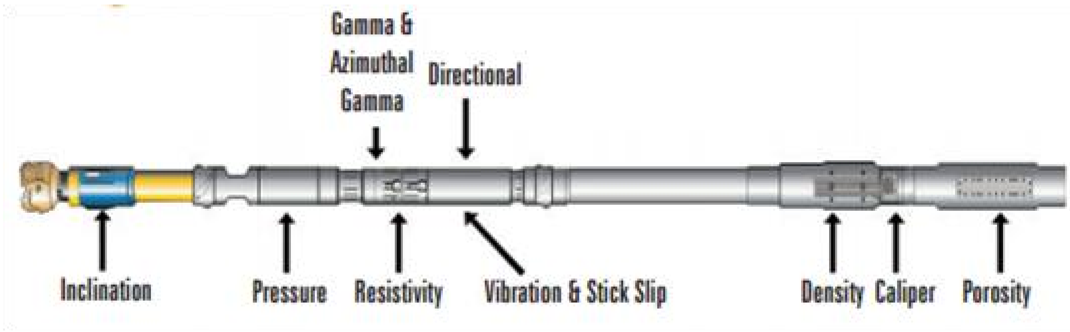


Figure 26: A Typical Geosteering BHA [http://www.oil-gasportal.com/wp-content/uploads/2015/03/Immagine24.png]

3.1.2 Rotary steereable system – RSS

Conventional directional drilling techniques require the use of bent housing downhole motors to be oriented in the borehole and "slid" along the borehole without rotation of the drillstring to achieve a change in the well's trajectory.

Rotary steerable drilling is a technology that enables full three dimensional directional drilling control to be performed while drilling with continuous drillstring rotation from surface (no "slide" drilling is needed).

This capability requires a special BHA component above the bit to direct the well path in the desired direction, maintaining the orientation of the drilling trajectory independent of the rotation of the BHA and drillpipe above it. This component is the rotary steering device.

This technology varies from relatively simple gravity-based orientation systems to more sophisticated flexure of internal drive shafts or flexure of the lower portion of the BHA by application of forces from pads against the borehole wall.

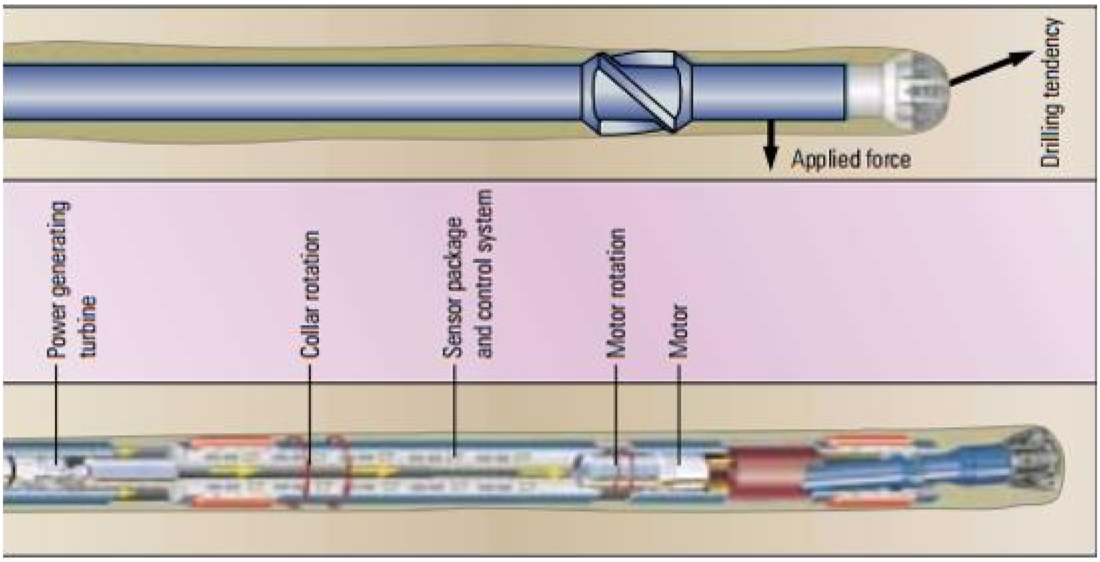


Figure 27: Rotary steerable system designs [http://www.oil-gasportal.com/wp-content/uploads/2015/03/Immagine25.png]

Some systems also employ automatic drilling modes where the wellbore is automatically steered using closed loop control systems programmed in the downhole tool.

These systems deliver significant benefits in wellbore placement and overall wellbore quality compared to non automated systems.

They combine the precise directional control of steerable motors with the high penetration rates, hole cleaning advantages, and reduced friction of rotary drilling techniques.

Efficient communication from surface results in significant time savings and a higher level of integration with MWD/LWD systems allows positioning of LWD sensors close to the bit while simultaneously minimizing BHA length and increasing reliability.

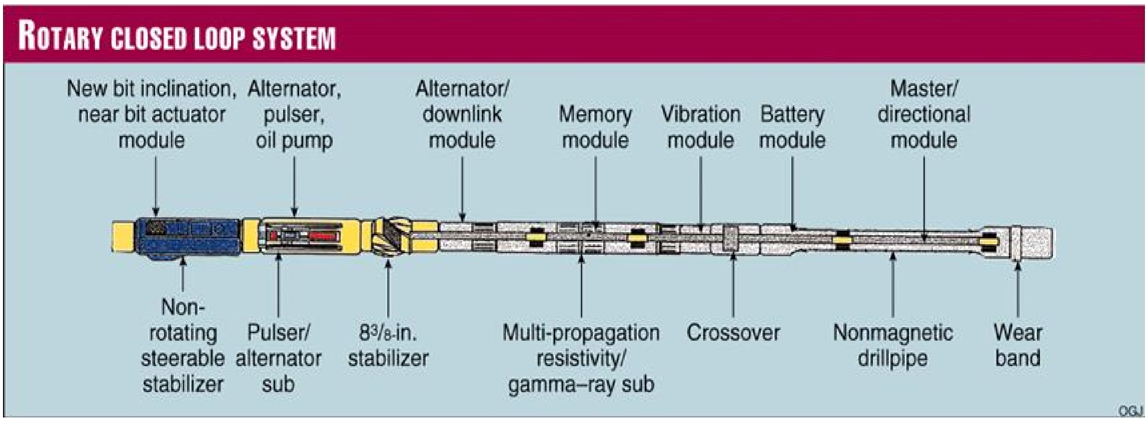


Figure 28: Example of Rotary Steerable Closed Loop System [http://www.oil-gasportal.com/wp-content/uploads/2015/03/Immagine26.png]

Horizontal drilling provides more contact to a reservoir formation and this fact enhance oil production and in some situations the improvement may be dramatic in respect with a vertical well.

There are many kinds of reservoir where the potential benefits of horizontal drilling are evident:

thin reservoirs; Reservoirs with natural vertical fractures; Reservoirs where water (and gas) coning will develop; thin layered reservoirs; heterogeneous reservoirs; shale gas/oil, tight gas/oil, CBM, heavy oil, oil sands, etc

3.2 Multilateral Drilling

Multilateral drilling is composed by a single well and one or more wellbore branches radiating from the main borehole.

When oil and natural gas reserves are located in separate layers underground, multilateral drilling allows producers to branch out from the main well to reach all the reservoirs at different depths simultaneously.

This increases production from a single well and reduces the number of wells drilled in a specific area.

General multi lateral configurations include:

- multibranched wells, forked wells, wells with several laterals branching from one horizontal main wellbore, wells with several laterals branching from one vertical main wellbore, wells with stacked laterals, and wells with dual-opposing laterals.

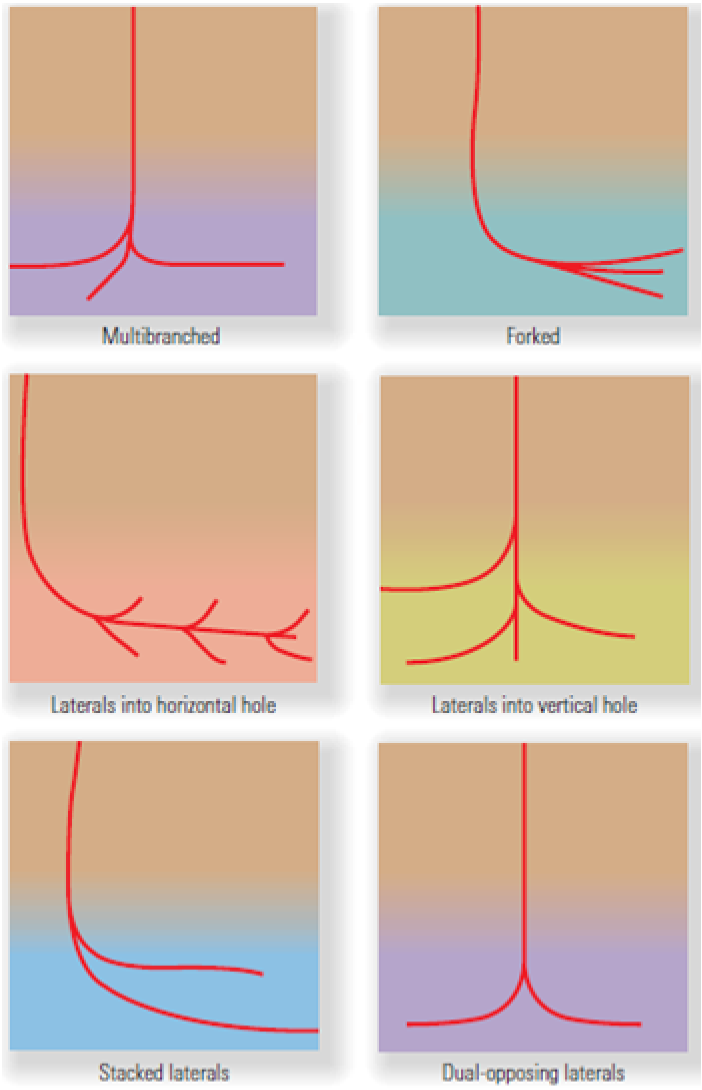


Figure 29: Multilateral Well Configurations [http://www.oil-gasportal.com/wp-content/uploads/2015/03/Immagine33.png]

In shallow or depleted reservoirs branched horizontal wellbores are often the most efficients, whereas in layered reservoirs, vertically stacked shape is usually the best.

A successful multilateral well that replaces several vertical wellbores reduces overall drilling and completion costs, increases production and provides more efficient drainage of a reservoir.

Furthermore, multilaterals can make reservoir management more efficient and help increase recoverable reserves.

Regardless of the level of complexity, multi lateral wells today are drilled with directional drilling technology.

Although there is always a certain risk which could derive from borehole instability, stuck pipe, overpressured zones and branching issues, advantages of multilateral systems are more evident than the disadvantages by far.

3.3 Extended Reach Drilling

True Vertical Depth (TVD) is measured vertically from the surface down to a certain target down hole.

Measured Depth (MD) is the total length of the wellbore measured along the actual well path.

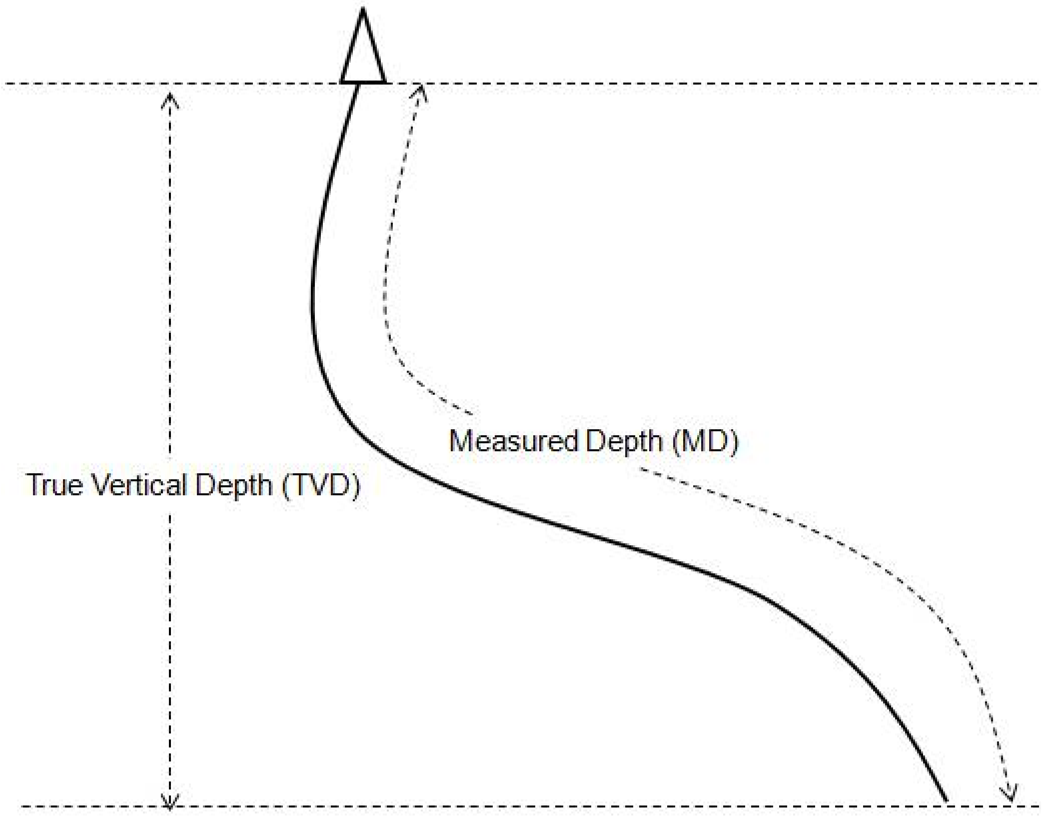


Figure 30: Difference between TVD and MD [http://www.drillingformulas.com/wp-content/uploads/2011/11/128-Difference-between-TVD-and-MD1.jpg]

An extended reach well is the one in which the ratio of the measured depth (MD) vs. the true vertical depth (TVD) is at least 2:1.

Extended Reach Drilling allows producers to reach deposits that are great distances away from the drilling rig in order to touch oil and natural gas deposits under surface areas where a vertical well cannot be drilled.

For example environmentally sensitive or under developed areas.

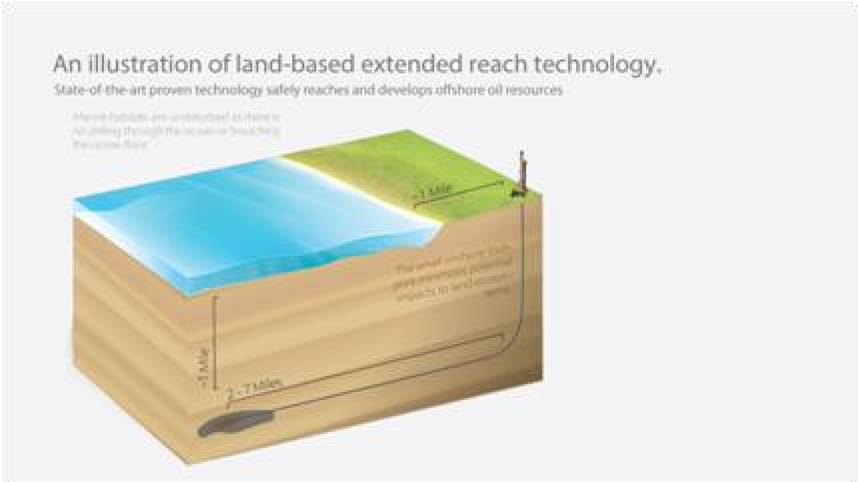


Figure 31: Example of ERW [http://www.oil-gasportal.com/wp-content/uploads/2015/03/Immagine53.png]

Directional control, hole cleaning, torque and drag, and casing flotation play a fundamental role with ERW.

Drilling in the sliding mode results in several inefficiencies that are compounded by extreme distances. The motor must be oriented and maintained in a particular direction while drilling to follow the desired path.

Geosteering is essential for this technique, in particular for the instrumented section and the fast wireless telemetry system that passes data to the MWD system higher up in the BHA for monitoring the pathway and retrieving information related to the surrounding rocks.

Inclinometers provide inclination data at the bit in a continuous mode.

Above the GeoSteering tool, a stabilizer with an adjustable gauge allows the directional driller to change the directional characteristic of the BHA in rotary mode.

Today, as the Horizontal Drilling, also the Extend Reach Drilling use the technology of the “RSS: Rotary Steerable System” that permit to steer an hole continuing the rotation of the drilling string with an improvement of the safety and the drilling efficiency.

The selection of a drilling fluid must balance a series of critical factors. The fluid must provide a proper lubricity and rheology in order to contrast differential sticking and lost circulation, minimize formation damage of productive intervals, reduce torque and drag and develop an effective cuttings transport.

Pipe rotation is another critical factor in hole cleaning.The objective of the hole cleaning program in ERW is to improve drilling performance by avoiding stuck pipe, avoiding tight hole on connections and trips, maximizing the footage drilled between wiper trips, eliminating backreaming trips prior to reaching the casing point and maximizing daily drilling progress.

Extended-reach wells are expensive and technically challenging, however, they can add value to drilling operations by making it possible to reduce costly subsea equipment and pipelines, by using satellite field development, by developing near-shore fields from onshore, and by reducing the environmental impact by developing fields from pads.

3.4 Automated drilling

Automated drilling is one of the oil industry's most important innovation targets.

Automated drilling would be faster, cheaper, more efficient, and safer, as it reduces the number of workers on site.

Through sensors mounted on the drill bit, the system monitors the trajectory of the drill and its performance as it travels through the site geology, and controls its path to ensure that it meets the top hole precisely.
Automating drilling takes in three stages of autonomy:

- The first is to mechanise the drilling equipment, such as the machinery which connects the drill pipes.
- The second is to monitor torque and weight on the drill bit to achieve optimum rate of penetration and the route of the bore-hole.
- The third level is to automate the entire process, including the speed of the pumps controlling drilling mud.

It can thus operate the rig machinery and monitor all aspects of the drilling process.

In fact, the monitored parameters serve as the feedback control for the rig machines. In this way the orientation of the borehole is constantly checked as it is being drilled, helping to ensure that the well is drilled efficiently and that it reaches its target.

In this R&D sector, Shell has developed an automated drilling system called SCADAdrill (SCADA being the acronym for supervisory control and data acquisition, a type of software used for automated factory and process control), and it is a component of a new well manufacturing system.

Figure 32: Shell's SCADAdrill System Pilote Test [http://www.oil-gasportal.com/wp-content/uploads/2015/03/Scada-drill-1.jpg]

The well manufacturing system uses three different types of drilling rigs mounted on trucks to construct the complex of wells.

One rig drills the 'top hole', the vertical upper portion of the well through which gas is extracted.

Two intermediate bores are then drilled, starting at an angle and proceeding horizontally to meet at the base of the top hole; these are used to dewater the rock and encourage the gas to flow.

The third type of rig installs the tubing and downhole pumps needed to operate the well.

The SCADAdrill system is used on the horizontal dewatering bores.

The SCADAdrill computer system connects the existing instruments and controls the whole drilling rig.

Although it is capable of working without human supervision, SCADAdrill allows well engineers to monitor the rig remotely. If necessary, control can be taken over from the machine.

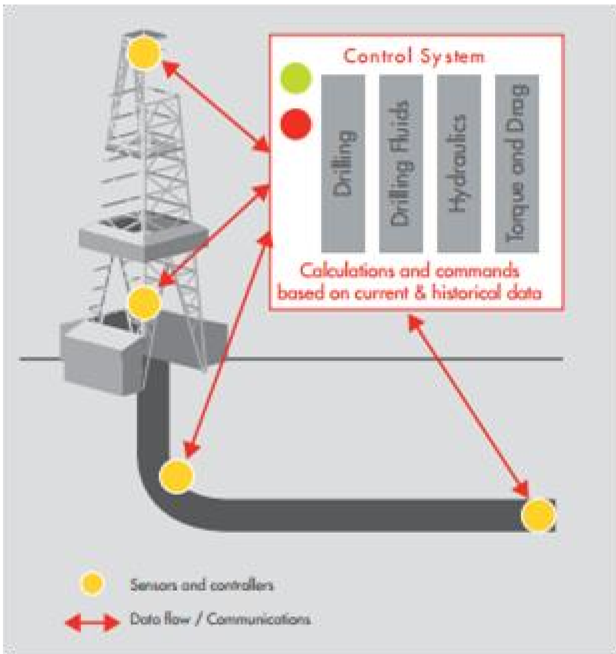


Figure 33: SCADA drill system [http://www.oil-gasportal.com/wp-content/uploads/2015/03/Immagine92.png]

Existing controls and sensors on rigs enable the computerised system to regulate mud pumps and manipulate top drives and hoists.

3.5 Laser Drilling Technique

Although the use of laser technology in petroleum well drilling is only a fairly recent development, the improvement has shown that it is feasible.

There are now available lasers that can destroy or drill through any kind of rock formation relatively fast.

However, experiments should be conducted to outline specific changes to reservoir characteristics, like porosity and permeability, caused by the application of this innovative technique.
Furthermore, also laser tools response should be inspected after the impact against the solid-fluid phase present in reservoir rocks.

A very important aspect of this technique is the simplicity in pointing the laser towards the spot to be drilled. As the hole depth increases, all that is needed is a corresponding increase in the length of the drill pipes in order to get the laser head closer, and pointed it to the uncut surface at the bottom of the well for continuing the drilling.

However, just like there is no rotary drilling technique without a circulating system with 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 them into the fractures to seal both the molten rock and the wall to the wellbore.

Reflection, scattering and absorption characterize the transfer of radiant energy (laser) to solid rocks in order to destroy them. Scattering and reflection represent energy that is not absorbed by the rock, so the energy loss in the system.

Major advantages of laser drilling over conventional drilling include:

- It drills 100 times faster
- It makes more precise holes
- 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

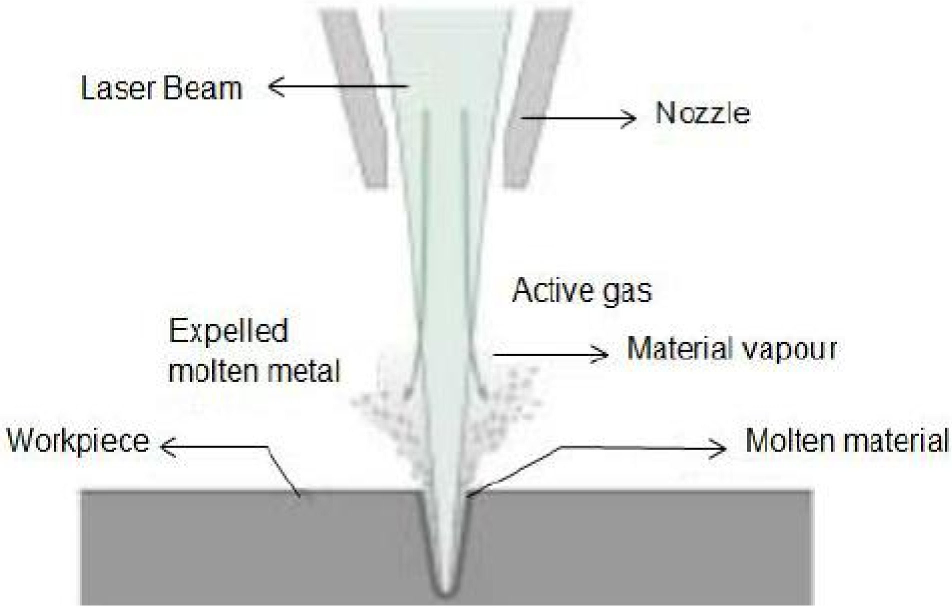


Figure 34: Schematic of a laser drilling process

[https://www.researchgate.net/profile/Dimitrios_Chantzis/publication/279187966/figure/fig1/AS:294437986029573@1447210895041/Schematic-diagram-of-a-laser-drilling-process.png]

This entire section is based on recent experiments with the aim of applying laser technology for drilling oil and gas wells.

Different rock types were exposed to lasers for a certain time interval, and results will be shown regarding the effect of lasers on permeability of the formation appling different rate of penetration (ROP) and specific energy (SE).

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.
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 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 of radius far.

The experiment has determined an inverse proportionality relationship between SE and ROP for all the five rock specimens. As the SE increases, the ROP decreases.

In addition, Graves et al. (1999) took into account 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 the vapour contamination in the wellbore on the ROP.
It was found that the greater the irradiation time, the greater the SE.
They concluded that an increase in exposure time consumes more laser energy as the development of melted rock increases due to the fact that it acts like a barrier between the laser and the uncut formation.

In conventional drilling system there are many factors that influence the rate at which the borehole is drilled like: weight-on-bit (WOB), mud circulation rate, rotary speed, hydraulic horsepower bit design and hole 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.

4. Completion techniques

Well completion is the process of making a well ready for production (or injection) after drilling operations.

After drilling an oil or gas well, the company evaluates the presence of hydrocarbons in place. If the reservoir is commercially valuable, the well can be turned into production.

Well completion includes the steps taken to transform a drilled well into a producing one through the installation of a downhole equipment so that oil and gas can be efficiently and safely extracted from the well.

The steps are casing, cementing, perforating, gravel packing and installing a production tree.

Oil and gas well completions should obtain the following results in order to be successful:

- Connect the reservoir to the production tubing so that oil and gas can flow through the pipe to the surface, or fluids can be injected into the reservoir.
- Isolate the oil and gas reservoirs to protect the producing zones from non-producing ones in order to avoid interference.
- Protect the reservoir's integrity and reduce damage to the formation.
- Help reduce the resistance to oil and gas flow.
- Resists corrosion and creep and does not collapse.
- Detect and assess changes in the reservoir conditions and hydrocarbon flow rate by well tests.

Well completion varies depending on the type of reservoir, the design of the well, the geology in the area of interest, volumes of oil and gas to be produced, the type of fluids that will be pumped, temperatures at the surface and downhole, the depth of the production zone, the rate of production, the expected pressure, the location of the well, the surrounding landscape and environment, and the economy of the investment. The choice, design, and installation of pipes and equipment have significant impact on the productivity of an oil and gas well, therefore, engineers must ensure that the well completion is as safe and efficient as it can be.

Whatever well completion strategy a company chooses, the key goal which drives every action is to ensure the recovery of the maximum possible volumes of oil at a reasonable cost.

Depending on these variables above mentioned, oil and gas well completions are divided into **lower completion,** or *downhole completion*, and **upper completion**.
The *lower completion* connects the oil and gas formation with the wellbore.
The *upper completion* is the link between the lower completion and the surface.

4.1 Lower completion

At the reservoir level there are two main types of well completion: the *open-hole completion* where there is no casing placed across the reservoir, and *cased completions, or liner completions* in which casings or liners are run and cemented across the reservoir zone.

If the well is completed in an open-hole completion manner, the drilling company does not need to perforate the well to produce hydrocarbons. If the driller places a casing, it will be needed to perforate the well to connect the tubing with the reservoir rock.

4.1.1 Open-hole completions

Open-hole completion is the simplest and cheapest type of oil and gas completion. Also called ***barefoot completion***, it does not have any casing or liner across the reservoir formation.

In open-hole completions, the production casing is set just above the reservoir's pay zone, the one that contains economically producible oil and/or gas.
The bottom of the pay zone is left uncased: this allows the hydrocarbons to flow directly into the wellbore.

Open-hole completion is the easiest and cheapest type of completion, nevertheless, it has some drawbacks which limit its use.

Open-hole completions make difficult the well control expecially for gas and may require frequent clean outs. Also the portion can not be selectively stimulated.

Moreover, the sandface, the physical interface between the formation and the wellbore, is not supported and could collapse.

Production enhancement and well stimulation are more difficult to actuate in an open-hole completion.

It is not suitable for weak formations which might require sand control, nor for formations requiring selective isolation of oil, gas and water intervals.

This type of completion would be generally used for reservoirs that are estimated to have little chance of producing unwanted fluids or sand.

Although it is a really basic method, it can be a good option for hard rock formations, multi-laterals and underbalance drilling.

It is also used to reduce the cost of casing where the reservoir is solid and well-known.

Moreover, the well can be deepened with no difficulties and it is easily converted to screen and liner.

There have been many recent developments that have boosted the success of openhole completions, and they also tend to be popular in horizontal wells, where cemented installations are more expensive and technically more difficult.

Openhole completions (in comparison with cemented pipe) require better understanding of formation damage, wellbore clean-up and fluid loss control.

There are a huge number of new ideas entering into the market to promote the use of openhole completions; for example, electronics can be used to actuate a self-opening or self-closing liner valve. This might be used in an openhole completion to improve clean-up, by bringing the well onto production from the toe-end for 100 days, then self-opening the heel-end.

Inflow control devices and intelligent completions are also installed as openhole completions.

Pre-holed liner may provide some basic control of solids production but it is not typically regarded as a sand control completion.

There are many variants of openhole sand control, the three popular options are stand-alone screens, openhole gravel packs (also known as external gravel packs, where a sized sand 'gravel' is placed as an annulus around the sand control screen) and expandable screens.

Horizontal open hole completion is the most common open hole completion used today. It is basically the same described on the vertical open hole completion but on a horizontal well.

It enlarges significantly the contact with the reservoir, increasing the production or injection rates of the well.

Sand control on a horizontal well is completely different from a vertical well. We can no longer rely on the gravity for the gravel placement.

Most service companies uses an alpha and beta wave design to cover the total length of the horizontal well with gravel.

4.1.2 Cased-hole completions

Cased-hole completions refer to the well completion method in which casing goes through the pay zone and is subsequently cemented across the reservoir zone.

This involves running casing or a liner down through the production zone, and cementing it in place. Drillers ensure the connection between the wellbore and the reservoir by perforation.

Because perforation intervals can be precisely positioned and isolated from the different zones in the reservoir and properly stimulated in a multi-layer reservoir, this type of completion affords good control of fluid flow, although it relies on the quality of the cement to prevent fluid flow behind the liner.

It is the most common form of completion.

Gas and water are easily controlled as the sand.

The formation can be selectively stimulated and the well can be deepened. This selection is adaptable to other completion configurations and logs are available to assist casing decisions.

The perforating cost can be very high.

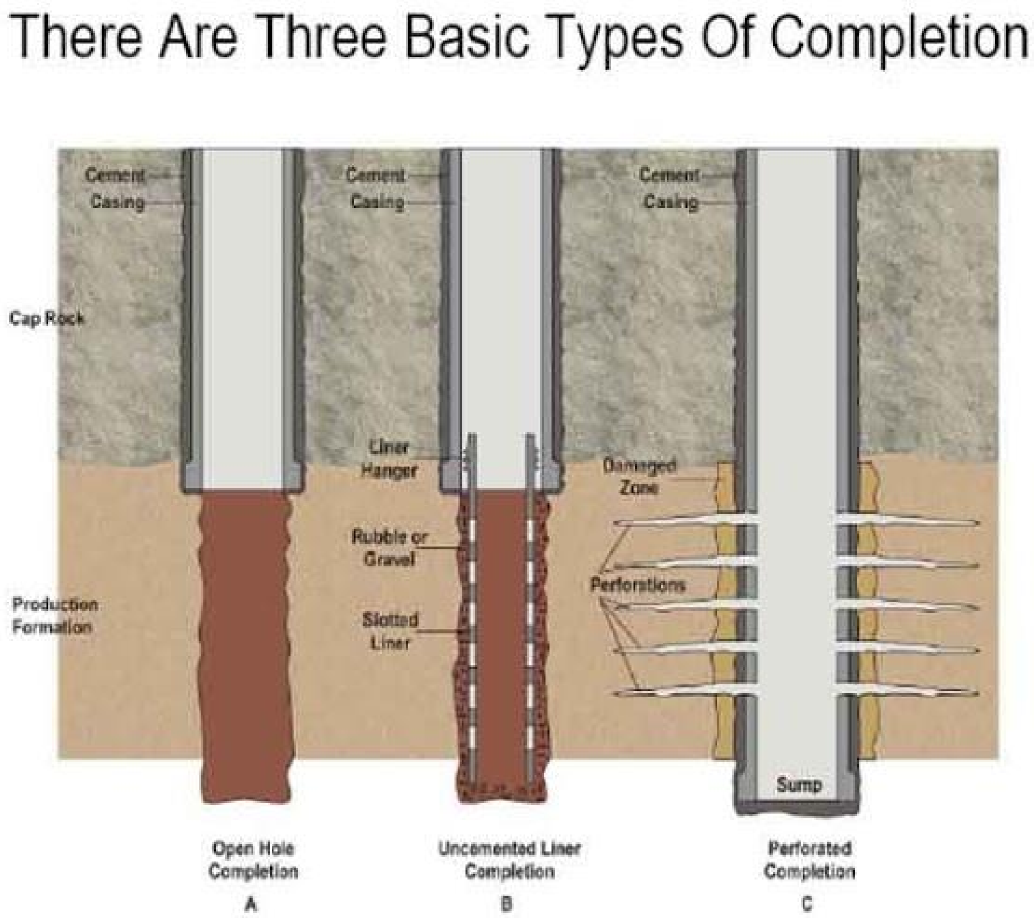


Figure 35: Main types of completion [https://2.bp.blogspot.com/-dgqablcp5Xk/WHGw32CfzOI/AAAAAAAACc4/Y0Uy7VHd1WgBQP_431gGwEsQqKbJApRjACK4B/w600/1349514925.jpg]

4.1.3 Liner completions

A liner is a type of casing in which the top is suspended from the inside and does not go all the way to the surface. The liner is hung from a liner hanger.

Because the liner does not extend to the surface, it allows for more flexibility in the completion design of the upper wellbore by increasing, for example, the diameter if the characteristics of the fluids and flow rates call for larger diameters at the upper end of the wellbore.

Casing is set above the producing zone, the zone is drilled and the liner casing is cemented in place. The liner is then perforated for production.

In this case the casing is set above the primary zone. An uncemented screen and liner assembly is installed across the pay section. This technique minimizes formation damage and gives the ability to control sand. It also makes cleanout easy.

Perforating expense is also low to non-existent. However gas and water build up is difficult to control and selective stimulation is not possible.

Furthermore, the well can't be easily deepened and additional rig time may be needed.

Also log interpretation is critical and it may be difficult to obtain good quality cement jobs.

The design of many conventional wells includes a production liner set across the reservoir zone.
The most commonly used types of liner completions in well completions include a:

- slotted liner completion,
- screen and liner completion,
- cemented liner completion.

A slotted liner refers to a liner in which slots have been prefabricated.
A screen is a liner in which holes have been pre-milled.
When placed across the reservoir zone, the slotted liner and the screen do not require additional perforations in order to access the oil or gas formation.

A cemented liner completion has many of the advantages of the cased and perforated completion because it also allows for precise selective perforation at particular intervals. In this way, the driller isolates the layers and can control production in the intervals where the cemented liner is perforated, as well as the injection of fluids into those differentiated zones.

The cemented liner makes the initial cementing job more difficult, but if the cementing is properly done, then the cemented liner completion has a lot of the characteristics of the perforated casing completion.
The cemented liner completion is typically a lower-cost well completion method than the cased and perforated completion.

Drillers may also use gravel pack completions in order to prevent the movement of sand from the reservoir into the wellbore or the area near the wellbore. Gravel packing is the typical method of installation of equipment or application of techniques to control sand movement to the wellbore. As part of the gravel packing, a steel screen is inserted in the wellbore, while the surrounding space is packed with gravel so that sand cannot pass into the wellbore.
The key goal of the gravel pack method is to stabilize the reservoir formation with the least possible impact on the oil or gas well productivity.

4.2 Completion Components

The upper completion refers to all the components from the bottom of the production tubing upwards.

Proper design of the "completion string" is essential to ensure that the formation fluids flow properly and to permit any operations necessary for enhancing production and safety.

Oil and gas well completions require not only a good well design, but also many components and different types of equipment to ensure the safe and efficient flow of oil and gas from the reservoir to the surface.

The primary completion components, the main elements of a completed oil or gas well, ensure that a type of well completion works the way it was designed to.
The type of well completion determines the completion components that will be used in an oil or gas well.

One of the most important components is the production tubing, which is the pipe used to collect formation fluids from the reservoir or to inject surface fluids into the reservoir.
It runs from the tubing hanger at the top of the wellhead down to a point generally just above the top of the production zone.
The characteristics of the production tubing will depend on the size and geometry of the wellbore, on the type of fluids in the reservoir, and on the production characteristics.
The tubing, assembled with other completion components, builds up the production string, the primary conduit through which oil is brought to the surface.

Another very important component which is present in almost every well completion is the packer. The packer is a downhole device typically placed just above the production zone in order to isolate the annulus and to drive the reservoir fluids inside the production string.
The production packer also helps to anchor and secure the bottom of the production tubing string. Production packers protect the casing from bursting under high pressures and against corrosion

from fluids. They prevent the movement of fluids between productive zones in multiple reservoir zones.
Depending on their application, the method of setting, and the possibility to be run and retrieved, packers can have different characteristics. They can be:

- retrievable mechanical packers
- permanent packers
- rotation-set packers
- hydraulic-set production packers
- inflatable packers
- compression-set packers
- tension-set packers

Apart from the production packer, the downhole completion equipment may also include downhole gauges to measure and record the pressure and temperature downhole.

This is an electronic or fiberoptic sensor to provide continuous monitoring of downhole pressure and temperature. Gauges either use tubing string to provide an electrical or fiberoptic communication to surface, or transmit measured data to surface by acoustic signal in the tubing wall. The information obtained from these monitoring devices can be used to model reservoirs or predict the life or problems in a specific wellbore.

The downhole safety valve (DSV) is fundamental for every oil and gas well and acts as a reliable closure when an emergency occurs or in case of an equipment failure on the surface. This component is intended as a last-resort method of protecting the surface from the uncontrolled release of hydrocarbons. It is a cylindrical valve with either a ball or flapper closing mechanism.

This valve allows fluids to pass up or be pumped down the production tubing. When closed the DHSV forms a barrier in the direction of hydrocarbon flow, but fluids can still be pumped down for well kill operations.

DSV are typically subject to rigorous requirements at local, regional, and national levels.

Most completions also include landing nipples placed at strategic predetermined intervals along the completion string to allow the placing of various devices for flow control.

It is a completion component with a short section of heavy wall tubular with a machined internal surface that provides a seal area and a locking profile. Landing nipples are included in most completions at predetermined intervals to enable the installation of flow-control devices, such as plugs and chokes. Three basic types of landing nipple are commonly used: no-go nipples, selective-landing nipples and ported or safety-valve nipples.

Tubing hanger is the component, which sits on top of the wellhead and serves as the main support for the production tubing.

On wells with gas lift capability, many operators consider it prudent to install a valve, called Annular safety valve, which will isolate the annulus for the same reasons a DSV may be needed to isolate the production tubing in order to prevent the natural gas downhole from becoming a hazard.

The side pocket mandrel is designed to contain gas lift valve, which allows flow of high pressure gas into the tubing by reducing the tubing pressure and allowing the hydrocarbons to move upwards. The design of a side-pocket mandrel is such that the installed components do not obstruct the production flow path, enabling access to the wellbore and completion components below.

The Electrical submersible pump is used for artificial lift to provide additional energy to drive hydrocarbons to surface if reservoir pressure is insufficient.

The sliding sleeve is hydraulically or mechanically activated to allow communication between the tubing and the annulus. They are often used in multiple reservoir wells to regulate flow to and from the zones.

Perforated joint is a part of tubing with holes punched into it. If used, it will normally be positioned below the packer and will offer an alternative entry path for reservoir fluids into the tubing in case the shoe is stuck.

In highly deviated wells, centralizer may be included towards the steps of the completion. It consists of a large collar, which keeps the completion string centralised within the hole while cementing.

Wireline entry guide is often installed at the end of the tubing, or at "the shoe". It is intended to pull out wireline tools easier by offering a guiding surface for the toolstring to reenter the tubing without getting caught on the side of the shoe.

In the last step of completion, a wellhead is installed at the surface of the well. Many times called production tree or Christmas tree, the wellhead device includes casingheads and a tubing head combined to provide surface control of the subsurface conditions of the well.

Christmas tree is the main assembly of valves, pressure gauges, spools, and chokes at the wellhead that controls flow from the well to the process plant (or the other way round for injection wells) and allows access for chemical squeezes and well interventions.

The Christmas tree, which is the surface end of the wellbore, contains the main equipment to control production and shut in the wellbore, as well as equipment for safe access for well intervention operations.

While both onshore and offshore wells are completed by production trees, offshore wells can be completed by two different types of trees: dry and wet trees. Similar to onshore production trees, dry trees are installed above the water's surface on the deck of a platform or facility and are attached to the well below the water. Wet trees, on the other hand, are installed on the seabed and encased in a solid steel box to protect the valves and gages from the elements. The subsea wet tree is then connected via electronic or hydraulic settings that can be manipulated from the surface or via ROVs.

Additionally, wells may have production flowing from multiple reservoir levels. These wells require multiple completions, which keep the production separate. Double-wing trees are installed on multiple reservoir levels.

Furthermore, completions have evolved to incorporate downhole sensors that measure flow properties, such as rate, pressure and gas-to-oil ratio. Known as intelligent wells or smart wells, these completions help to achieve optimum production rates.

4.3 Conventional completions

This is a list describing all the conventional completion methods:

- Casing flow: means that the producing fluid flows following the path to the surface through the casing.
- Casing and tubing flow: means that there is tubing within the casing that allows fluid to reach the surface.
- Pumping flow: the tubing and pump are run to a depth beneath the working fluid. The pump and rod string are installed concentrically within the tubing. A tubing anchor prevents tubing movement while pumping.
- Tubing flow: a tubing string and a production packer are installed. The packer means that all the flow goes through the tubing. Within the tubing you can mount a combination of tools that will help to control fluid flow through the tubing.
- Gas lift well: gas is fed into valves installed in the tubing strip. The hydrostatic head is lowered and the fluid is gas lifted to the surface.
- Single-well alternate completions: in this instance there is a well with two zones. In order to produce from both, the zones are isolated with packers. Blast joints (thicker wall

near perforation zone to resist at the perforation) may be used on the tubing within the region of the perforations. These are thick walled subs that can withstand the fluid abrasion from the producing zone.

- Single-well concentric kill string: within the well a small diameter concentric kill string is used to circulate kill fluids (mud of sufficient density to control the well) when needed.

- Single-well 2-tubing completion: in this instance 2 tubing strings are inserted down 1 well. They are connected at the lower end by a circulating head. Chemicals can be circulated down one tube and production can continue up the other.

4.3.1 Perforating

In cased hole completions once the completion string is in place, the final stage is to make a connection between the wellbore and the formation. In order to achieve production, the casing and cement are perforated to allow the hydrocarbons to enter the wellstream.

This is done by running perforation guns to blast holes in the casing or liner to make a connection.

This process involves running a perforation gun and a reservoir locating device into the wellbore, many times via wireline, slickline or coiled tubing.

Modern perforations are made using shaped explosive charges, similar to the armor-penetrating charge used on antitank rockets (bazookas).

Once the reservoir level has been reached, the gun then shoots holes in the sides of the well to allow the hydrocarbons to enter the wellstream. The perforations can either be accomplished via firing bullets into the sides of the casing or by discharging jets, or shaped charges, into the casing.

While the perforation locations have been previously defined by drilling logs, those intervals cannot be easily located through the casing and cement. To overcome this challenge, a gamma ray-collar correlation log is typically implemented to correlate with the initial log run on the well and define the locations where perforation is required.

4.4 Production Optimization

Production Optimization refers to the various activities of measuring, analyzing, modelling, prioritizing and implementing actions to enhance productivity of a field.

Production Optimization is a fundamental practice to ensure recovery of developed reserves while maximizing returns.

Production Optimization activities include:

- **Near-wellbore profile management**
  - gas–water coning and fingering,
  - near-wellbore conformance management
- **Removal of near-wellbore damage**
  - matrix stimulation or acidizing
- **Maximize the productivity index**
  - hydraulic fracturing
  - maximum-reservoir-contact well with multilateral completion
- **Prevention of organic and inorganic solid deposition in the near-wellbore/completion/pipeline**
- **Well integrity**
  - prevention and remediation of casing and cement failure
- **Design of well completion**

   - optimization of artificial lift performance at field and well level
   - sand control management
- **Efficiency of oil and gas transport**
- **Design of surface facilities and fluid handling capacity**
- **Production system debottlenecking**

Key factor in production optimization is the capability to mitigate formation damage during well construction and production routine operations.

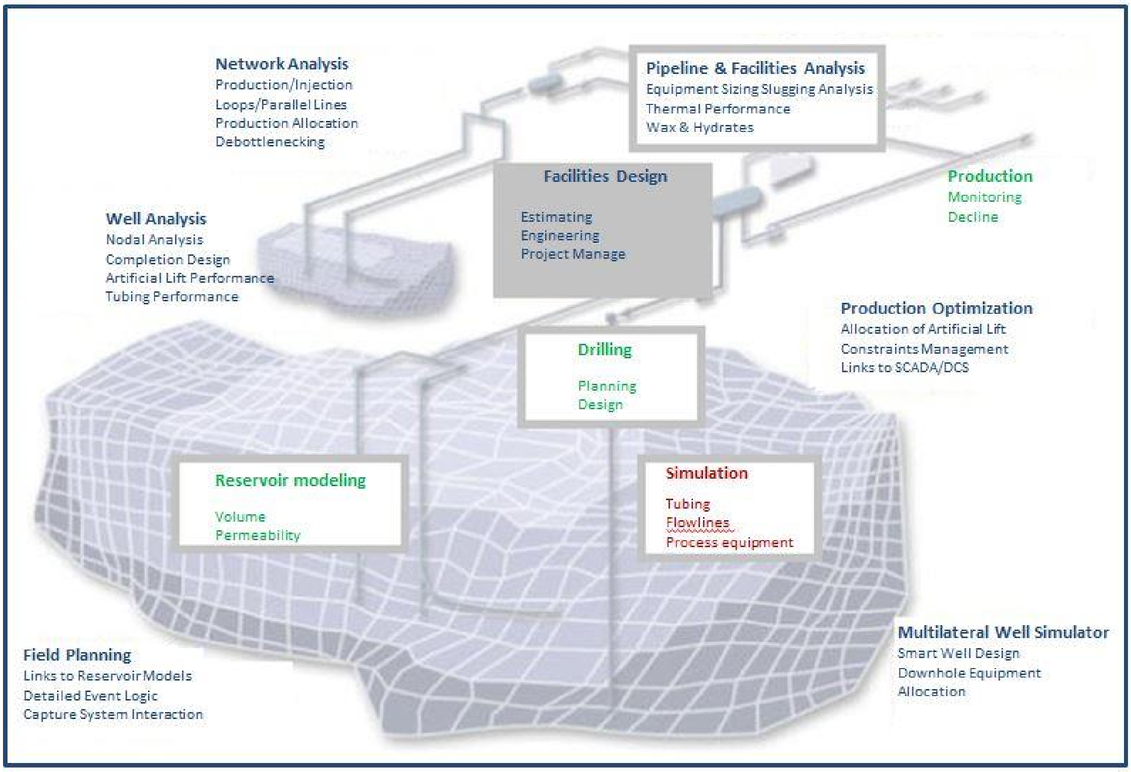


Figure 36: Various approaches to petroleum system production optimization [http://www.oil-gasportal.com/wp-content/uploads/2015/01/fig.1fundamental.jpg]

Well productivity

An ideal well productivity is the final goal of Production Optimization. “Nodal Analysis” is an approach applied to analyze the performance of systems composed of interacting components.

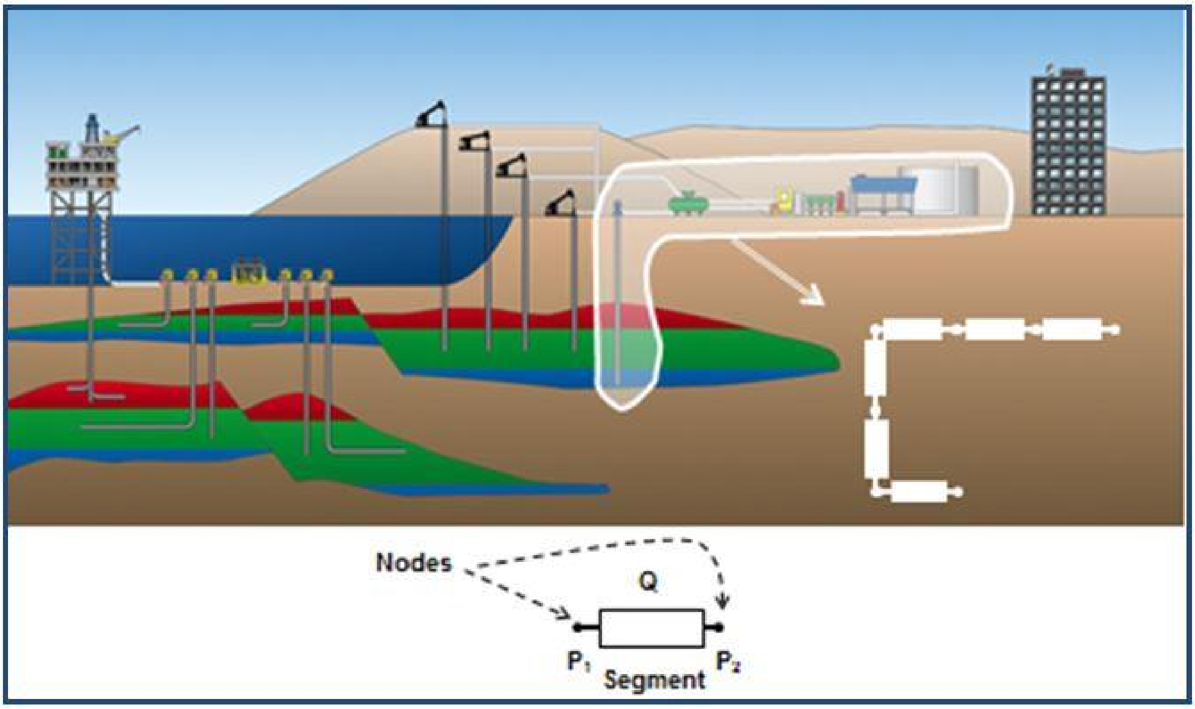


Figure 37: Well Performance Analysis [http://www.oil-gasportal.com/wp-content/uploads/2015/01/fig.3tech.jpg]

Productivity Index (PI or J) expresses the ability of a reservoir to deliver fluids to the wellbore. Optimal well productivity is achieved by the use of an integrated approach of disciplines and operations.

Well stimulation

Sometimes once the well is fully completed, further stimulation is necessary to achieve the planned productivity.

Well stimulation is a term describing a variety of operations performed on a well to improve its productivity.

Stimulation operations can be focused on the wellbore or on the reservoir. They can be conducted on old wells and new wells and they can be also designed for remedial purposes.

There are two main types of stimulation operations: matrix stimulation and hydraulic fracturing.

Matrix stimulation is performed below the reservoir fracture pressure to restore the natural permeability of the reservoir rock. Well matrix stimulation is achieved by pumping acid mixtures (acidizing) into the near-wellbore area to dissolve the limestone and dolomite formations or the formation damage particles between the sediment grains of the sandstone rocks.

This involves the injection of chemicals to eat away any skin damage, "cleaning up" the formation, thereby improving the flow of reservoir fluids.

A strong acid (usually hydrochloric acid) is used to dissolve rock formations, but this acid does not react with the Hydrocarbons.

Hydraulic fracturing means instead the process of creating and extending fractures from the perforation tunnels deeper into the formation, increasing the surface area for formation fluids to flow into the well.

This may be done by injecting fluids at high pressure (hydraulic fracturing), injecting fluids mixed with round granular material (proppant fracturing), or using explosives to generate a high pressure and high speed gas flow.

It is the most common mechanism for increasing well productivity.

Sometimes, productivity may be inhibited by the residue of completion fluids, as heavy brines, in the wellbore.

This is particularly a problem in gas wells. In these cases, coiled tubing may be used to pump nitrogen at high pressure into the bottom of the borehole to circulate out the brine.

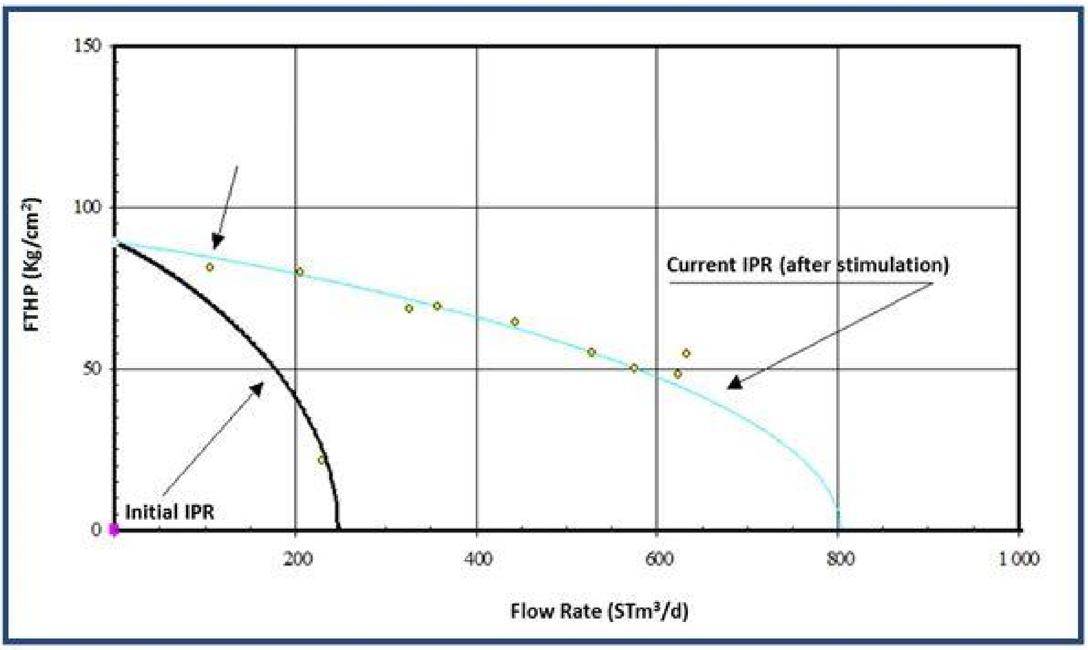


Figure 38: Graphical representation of IPR under different conditions [http://www.oil-gasportal.com/wp-content/uploads/2015/01/fig.5tech.jpg]

Sand control management

When oil is produced from relatively weak reservoir rocks, small particles and sand grains are dislodged and carried along with the flow. This sand production can create erosion in flowlines and other equipment.

Some wells require filtration systems in order to keep the wellstream clear of sand. In addition to running a casing with a liner, gravel packing is used to prevent sand from entering the wellstream.

More complicated than cementing a well, gravel packing requires a slurry of appropriately sized pieces of coarse sand, or gravel, to be pumped into the well between the slotted liner of the casing and the sides of the wellbore. The wire screens of the liner and the gravel pack work together to filter out the sand that might have otherwise entered the wellstream with the hydrocarbons.

Sand management can be considered as a key issues in field development in most of world's oil and gas fields.

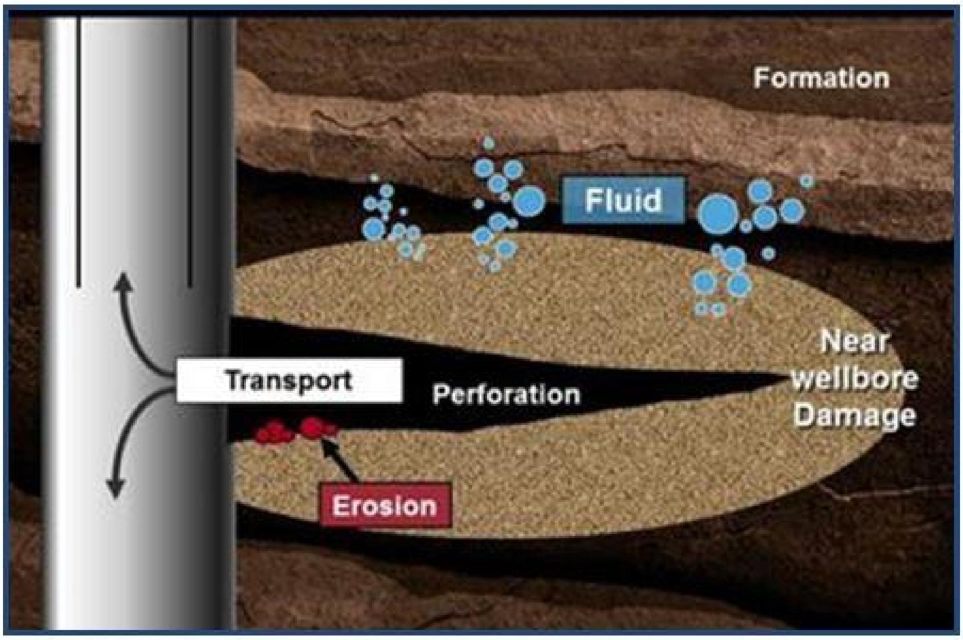


Figure 39: Step process for sanding [http://www.oil-gasportal.com/wp-content/uploads/2015/01/fig.6tech.jpg]

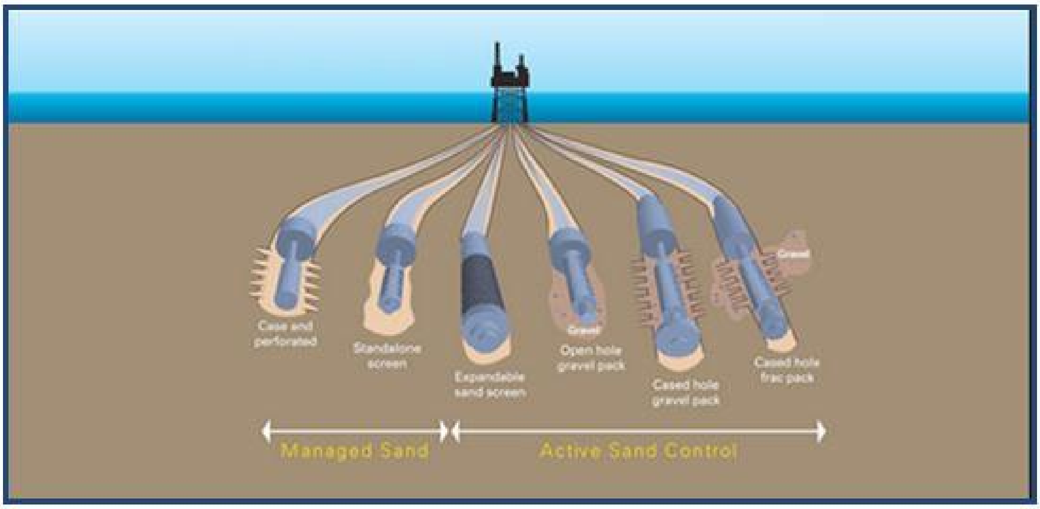


Figure 40: *Methods of sand control [http://www.oil-gasportal.com/wp-content/uploads/2015/01/fig.7tech.jpg]*

5. Innovative completion Technologies

Production optimization requires advanced and intelligent well completions.

5.1 Intelligent Well Completion

An Intelligent (Smart) completion is a well that contains a "Remotely Operated Adaptive Completion System" which provides real-time data and the capability to re-configure the well architecture without well interventions.

The system is able to collect, transmit, and analyze reservoir production data to better control reservoir, well, and production processes.

Their primary objectives are to maximize or optimize production/recovery, minimize operating costs, and improve safety.

Intelligent completions incorporate permanent downhole sensors and surface-controlled downhole flow control valves, enabling you to monitor, evaluate, and actively manage production (or injection) in real time without any well interventions.

Data is transmitted to surface for local or remote monitoring in the digital well platform.

Initially used in deepwater wells, where intervention is expensive and highly risky, intelligent completions have since the beginning proven their value in managing production from multilateral wells, horizontal wells with multiple zones, wells in heterogeneous reservoirs, and mature reservoirs.

All systems include temperature and pressure monitoring, communication and control lines, and intuitive surface systems to help you manage your wells.

Each system is fully integrated to maximize production control, reduce costs, simplify well planning, and increase downhole control for a targeted well type.

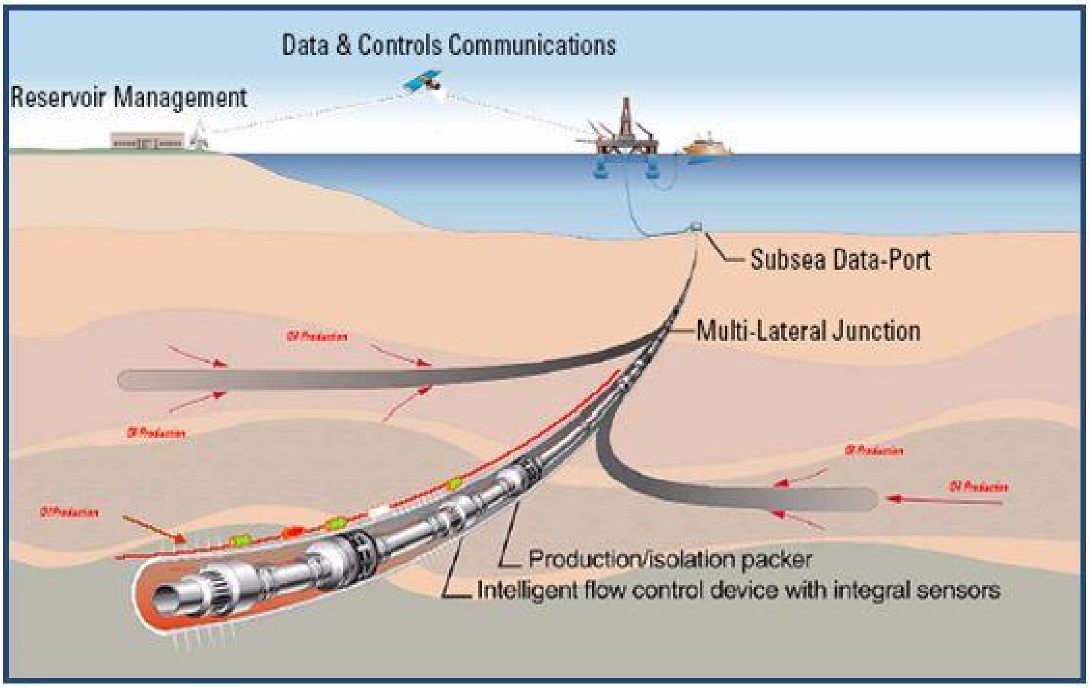


Figure 41: Intelligent well completion system [http://www.oil-gasportal.com/wp-content/uploads/2015/01/fig.1tech.jpg]

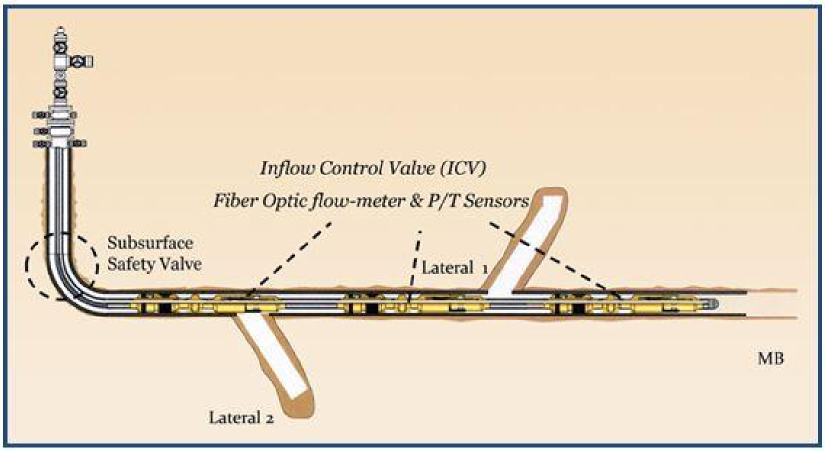


Figure 42: Intelligent completion for a multi lateral well [http://www.oil-gasportal.com/wp-content/uploads/2015/01/fig.2tech.jpg]

5.2 Through tubing drilling and completion

When planning an enhancement of an existing wellbore using multi-lateral completion technology, consideration must be given to the existing completion hardware. If it is functioning properly and/or if removal is not economical, a thru-tubing lateral drilled with state-of-the-art coiled tubing drilling techniques can be considered. Thru-tubing drilling with coiled tubing provides an economical means of increasing reservoir exposure by significantly reducing or eliminating the topside costs associated with rig utilization.

Through-tubing drilling and completion is a cost effective technology for increasing production and recovery.

TTDC is a generic term for drilling sidetracks in existing producers and injectors. The main advantage of the technology is that new reservoir sections can be reached without having to remove the existing christmas tree, the completion or the production casing, thereby reducing operational time significantly compared to a “standard” slot recovery or side-track.

TTDC- wells are particularly useful for accessing pockets of isolated oil and gas in mature fields. Due to the deep side-tracks achieved with this technique it is possible to minimize borehole lengths and avoid drilling problems in overlying formations.

Two significant advances in current casing exit technology have made thru-tubing re-entry possible.

- A whipstock that can be deployed through the tubing, exit out the tailpipe, and set and oriented in the larger diameter casing allows for easy access to the reservoir
- Recent tests have shown that it is possible to exit through the tubing and the casing.

While thru-tubing re-entry multi-laterals are in their developmental infancy, the possibilities long term are enticing.

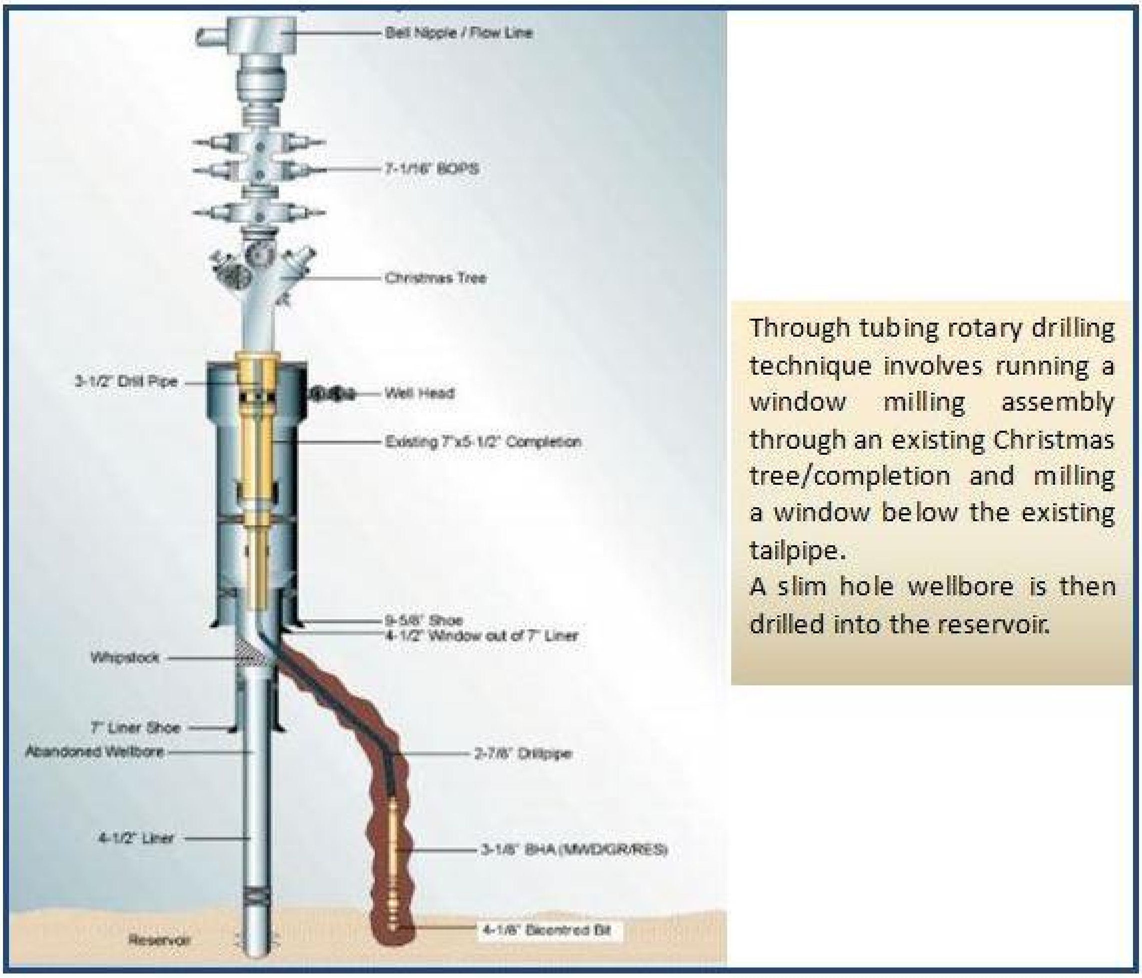


Figure 43: Through tubing rotary drilling [http://www.oil-gasportal.com/wp-content/uploads/2015/01/fig.1innovation.jpg]

5.3 Well matrix stimulation without HCl

Well acidizing is a common practices in the oil industry and hydrochloric acid (HCl) has been used as the main acid for limestone stimulation purposes.

There are several concerns with the use of HCl acids: health and safety of the field crew, corrosive nature of the acids for the flow lines and equipment, and environmental effects of the produced HCl.

A new product called FF-01 is an environmentally-friendly and equipment-friendly product. It is a conversion to an organic base to maintain very low pH as a vehicle for aggressiveness.

Low pH, slower reaction rates with limestone, small amount of residue after reaction, safety, minimum damage to equipment, and longevity are the properties of this product.

It will dissolve the same mass of rock if enough time is given, and it lasts longer during the course of reaction while leaving fewer residues.

HCl performs better in cleaning the near wellbore rock while FF-01 performs better in generating long wormholes and higher effective permeability compared to the cores that were treated using HCl.

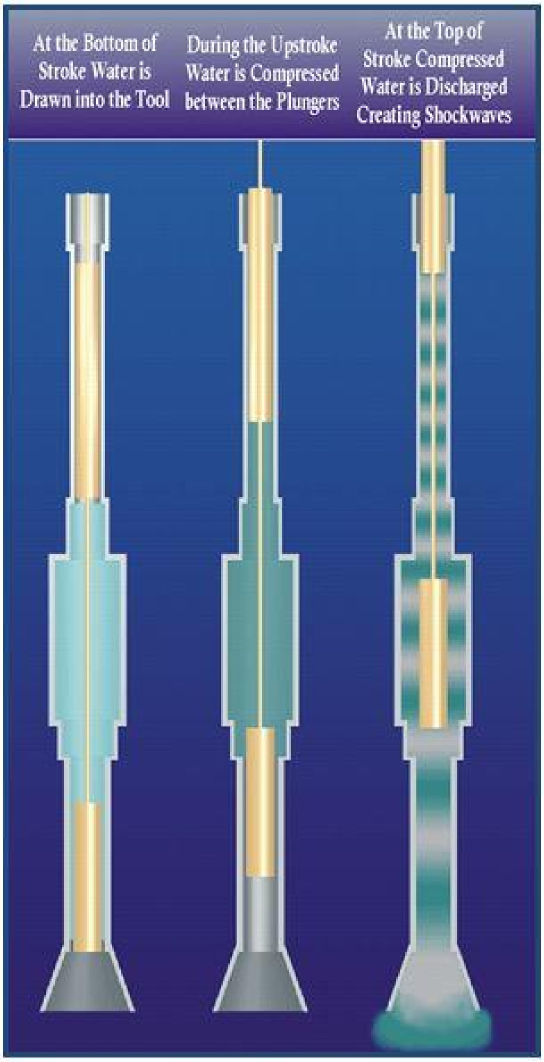
5.4 Unconventional stimulation

The acoustic stimulation technology has the potential to provide a low-cost procedure for enhancing oil recovery in mature fields.

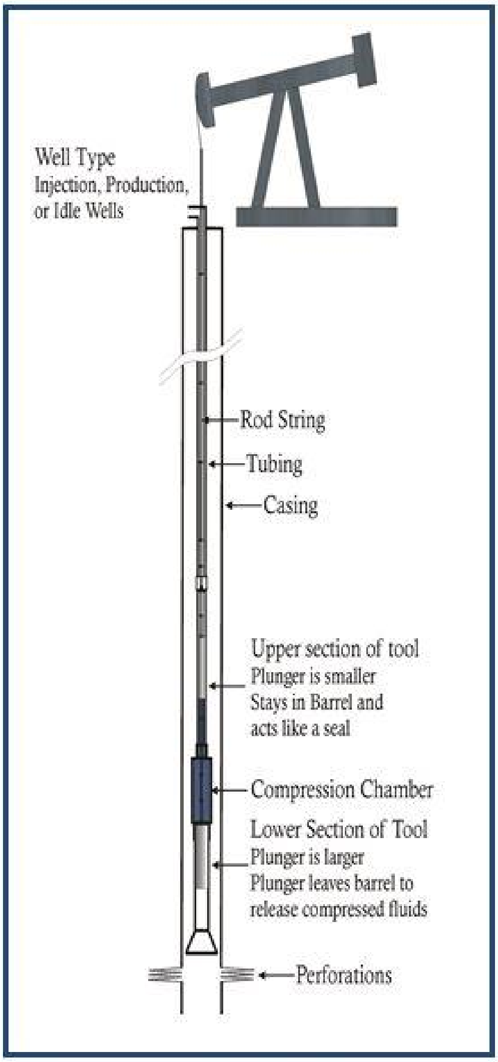
Low frequency shock waves produced downhole can increase oil production mobilizing immobile oil in ¾ mile range. Application of this technology well suits well/field having the following properties:

- Oil Viscosity less than 10 cP

- High water cut, ideally greater than 80%
- Low GOR, ~10 m3 per m3 of fluid produced is ideal
- Minimum spacing of 400 m between source wells with production wells spaced within 300 m radius “stimulation zone”, if multiple tools are run.



Particular and functioning of the compression tool



Schematic of the well including the compression tool

Figure 44: Acoustic stimulation technology

[http://www.oil-gasportal.com/wp-content/uploads/2015/01/fig.2innovation.jpg]

6. Conclusions

Oil well drilling is a complex operation and the drilling industry engages the services of personnel and a complicated array of machinery and materials to drill an oil/gas well to depths greater than 6000 meters.

When a drilling project is commenced, two goals must be achieved:

1. To drill and finish the well in a safe manner (personal injuries, technical problems) and according to its purpose;
2. To complete the project with minimum cost.

Rotary drilling is the most efficient technology applied in the oil and gas industry making possible to drill safely and efficiently the well.

The planning of a well is a fundamental part of the drilling process: it is the basis for making all the important technical choices, for assessing the costs and organizing the actual construction of the well in the most efficient way.

The great complexity of the drilling process, its high costs, the need to ensure the full efficiency of the rig and the respecting of safety and of the environment, call for a continuous optimizing of operations, which are achieved through the monitoring and processing of all available data, both geological and drilling.

The drilling industry has seen technological progress, however, these advances have not changed the fact that, besides the use of complicated machinery, successful drilling is a result of tremendous team effort. Numerous personnel from the operating company and several service companies work together to drill and complete an oil/gas well.

7. References

Dr. Brantly, J. E. 1971. History of Oil Well Drilling. Houston, London, Paris, To-kyo: Gulf Publishing Company.

Dr. Claude B. Reed. 2006. Laser Rock Drilling. History Channel. Interview. 1.5.2006 http://www.ne.anl.gov/facilities/lal/DemoMovies/laser_well_drilling/LRD_Hist_Channel.html. Referenced 15.12.2009

Dr. Claude B. Reed. 2009. Laser Oil and Gas Well Drilling. Argonne National La-boratory. http://www.ne.anl.gov/facilities/lal/laser_drilling.html. Referenced 02.12.2009

Dr. Reimer, P. 2009. World Petroleum Council. http://www.world-petroleum.org. Referenced 13.01.2010.

Erik M. Molvar, Dr. Rickey P., Walter K. Merschat. 2003. Drilling Smarter: Using Directional Drilling to Reduce Oil and Gas Impact in the Intermountain West http://www.voiceforthewild.org/blm/pubs/DirectionalDrilling1.pdf. Referenced 27.12.2009.

Foremost Industries LP. 2003. Benefits of Dual Rotary Drilling in Unstable Over-burden Formations. http://www.foremost.ca/pdf/en/dr_benefits.pdf. Referenced 07.01.2010

Gahan B. C., Richard A. Parker, Gas Technology Institute; Batarseh S., Colorado School of Mines; Humberto Figueroa, PDVSA-Intevep, S.A.; Claude B. Reed, Zhi-yue Xu, Argonne National Laboratory. 2001. SPE 71466. In: SPE Annual confer-ence and Exhibition. New Orleans, Louisiana, 30.09 – 3.10.2001.

Gene C. n.d. Drilling and Well Construction.
http://www.osti.gov/geothermal/servlets/purl/895127-cWjqee/895127.pdf. Refer-ence 20.01.2010.
Graves, R. M., and O'Brien, D. G. 1998. StarWars Laser Technology Applied to Drilling and Completing Gas Wells.
http://www.ne.anl.gov/facilities/lal/Publications/Laser%20well%20drilling/SPE%2049259.pdf. Referenced 08.02.2010
Graves, R. M., and O‟Brien, D. G., O‟Brien, E. A. 1999. StarWars Laser Technolo-gy for Gas Drilling and Completion in the 21st Century. SPE 56625-MS Journal.
Irfan K., Mohit K., Nakul M., Vickey C., Nikhil K., Anand S., SPE, Maharashtra Institute of Technology, Pune. 2009. SPE Annual Conference Exhibition, Offshore Europe. 8 – 11.09.2009.
John H. Berry. n.d. Drilling Fluids Properties & Functions.
http://www.cetco.com/CDP/Bentonite/Properties%20of%20a%20Drilling%20Fluid.pdf. Referenced 20.01.2010.
Kurts Prengling, DeGolyer, MacNaughton and McGhee, Eugene A. Stephenson, University of Kansas. 1940. In: Drilling and Production Practice. API 40-064 Journal.
Mustafiz, S., Bjorndalen, N. and Islam, M. R. 2004. Lasing into the Future: Poten-tials of Laser Drilling in the Petroleum Industry.
http://dx.doi.org/10.1081/LFT-200034067. Referenced 09.01.2010
Oliver Kuhn. n.d. Ancient Chinese Drilling.
http://www.cseg.ca/publications/recorder/2004/06jun/06jun-ancient-chinese-drilling.pdf . Referenced 20.12.2009
Petroleum 2009. Encyclopedia Britannica.

http://www.britannica.com/EBchecked/topic/454269/petroleum/50714/Oil-traps. Referenced 20.11.2009
Tanaka S., Okada Y. and Ichikawa Y. 2005. Offshore Drilling and Production Equipment. http://www.eolss.net/ebooks/Sample%20Chapters/C05/E6-37-06-04.pdf. Referenced 28.11.2009.
The American Oil & Gas Historical Society. 2006. Making Hole. http://www.aoghs.org/pdf/septwebsite.pdf. Referenced 01.12.2009

The Department of Environmental Protection, 2009. Oil and Gas Well Drilling and Production in Pennsylvania.

https://oilprice.com/Energy/Energy-General/The-Complete-Guide-To-Oil-Gas-Well-Completions.html

https://www.theseus.fi/bitstream/handle/10024/25352/Akpedeye_Kelvin.pdf?sequence=1&isAllowed=y

https://www.sciencedirect.com/topics/earth-and-planetary-sciences/percussion

https://www.nationaldriller.com/articles/90598-five-most-common-drilling-methods-used-in-oil-and-gas-exploration

http://www.oil-gasportal.com/drilling/introduction-to-oilgas-well-drilling/

https://www.machines4u.com.au/mag/diamond-core-rotary-percussion-drilling-whats-difference/

https://www.sciencedirect.com/topics/earth-and-planetary-sciences/percussion

https://www.machines4u.com.au/mag/diamond-core-rotary-percussion-drilling-whats-difference/

https://www.nationaldriller.com/articles/90598-five-most-common-drilling-methods-used-in-oil-and-gas-exploration

https://www.theseus.fi/bitstream/handle/10024/25352/Akpedeye_Kelvin.pdf?sequence=1&isAllowed=y
https://castledrill.com/an-introduction-to-reverse-circulation-drilling/

http://www.oil-gasportal.com/drilling/introduction-to-oilgas-well-drilling/

https://www.arescotx.com/photos-videos/what-is-a-blowout-preventer/

https://www.machines4u.com.au/mag/diamond-core-rotary-percussion-drilling-whats-difference/

https://www.nationaldriller.com/articles/90598-five-most-common-drilling-methods-used-in-oil-and-gas-exploration

http://www.oil-gasportal.com/drilling/introduction-to-oilgas-well-drilling/

https://www.theseus.fi/bitstream/handle/10024/25352/Akpedeye_Kelvin.pdf?sequence=1&isAllowed=y
https://www.nationaldriller.com/articles/90598-five-most-common-drilling-methods-used-in-oil-and-gas-exploration
http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-74407/5500-FS-DEP2018.pdf. Referenced 25.01.2010.
F. Sánchez, S. Houqani, M. Turki, and M. Cruz. 2012. Casing While Drilling (CwD): A New Approach to Drilling Fiqa Formation in the Sultanate of Oman—A Success Story. *SPE Drilling & Completion* 27 (2): 223-232. SPE- 136107-PA.
Wikipedia. 2012. *Semi-submersible* (28 November 2012 revision), http://en.wikipedia.org/wiki/Semi-submersible (accessed 28 November 2012).

http://www.oil-gasportal.com/drilling/new-technologies-innovations/

https://connect.spe.org/blogs/kon-deng/2017/01/28/directional-drilling#:~:text=Build%20Up%20Rate%20(BUR)%3A,with%20respect%20to%20the%20vertical.&text=An%20inclination%20(angle)%20greater%20than,the%20term%20%22drilling%20up%22.

https://www.nationaldriller.com/articles/90598-five-most-common-drilling-methods-used-in-oil-and-gas-exploration

https://www.theseus.fi/bitstream/handle/10024/25352/Akpedeye_Kelvin.pdf?sequence=1&isAllowed=y

http://www.drillingformulas.com/difference-between-true-vertical-depth-tvd-and-measured-depth-md/#:~:text=True%20Vertical%20Depth%20(TVD)%20is,along%20the%20actual%20well%20path.

https://www.rigzone.com/training/insight.asp?insight_id=326&c_id=

https://www.theseus.fi/bitstream/handle/10024/25352/Akpedeye_Kelvin.pdf?sequence=1&isAllowed=y

https://en.wikipedia.org/wiki/Completion_(oil_and_gas_wells)

http://www.oil-gasportal.com/drilling/introduction-to-oilgas-well-drilling/

https://www.slb.com/completions/well-completions/intelligent-completions

http://www.oil-gasportal.com/drilling/introduction-to-oilgas-well-drilling/