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Drilling and Completion of horizontal wells

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Introduction

Horizontal drilling is the process of steering a drill bit to follow horizontal path oriented approximately 90° from vertical through the reservoir rock. The interest in drilling horizontal wells can be attributed to the following major reasons:

- Enhancement in primary production.
- Enhancement in secondary production.
- Enhancement in ultimate recovery of hydrocarbon in place.
- Significant reduction in number of wells to develop as entire field.
- Significant increase in production.

Horizontal well drilling coupled with multilateral and extended – reach drilling, has unveiled many opportunities for the oil and gas industry to economically recover hydrocarbon reserves from fields that otherwise would not have been feasible. In addition to the economic gains, reducing foodsteps in the area has a very significant positive impact on the environment.the success in drilling and completing horizontal wells has been attributed to significant technologcal breakthroughs, innovation and design approaches, effective team work, utilization of the learning process, effective planning, proper program implementation,real – time field monitoring of drilling data, and updating of program designs.

Whether drilling vertical or directional (including horizontal) wells to exploit underground hydrocarbons, the same elements are needed to drill the well successfully and economically, they differ only in terms of requirements. These elements include

- Downward force on drill bit.
- Drill bit rotation.
- Fluid circulation.

Force. in vertical well drilling, WOB (force) is provided by the heavy drill collars located directly above the bit, with practically no weight loss due to sliding friction. However, in directional well drilling, there is inherent contact between the drill string and the walls of the wellbore; consequently, considerable friction force (drag) can be encountered, reducing the amount of weight needed to be transferred to the bit. This means that tubulars placed above the bit should be of a weight variation such that their contribution to drag forces will be minimized and their contribution to WOB will be maximized.

Rotation. drill bit rotation maybe induced at the surface, through the conventional Rotary table or top – drive motor, or at the bottom, through the use of downhole mud motors. In vertical well drilling, the major source of torque in the drill bit, with an almost negligible torque contribution from drill string friction forces. However, in the directional will drilling, rotation is induced at surface, and the portion of the drill string that is in contact with the walls of the wellbore will cause friction torque, in addition to bit torque, that can be five to ten times the friction torque encountered when drilling vertical wells. As hole angle increases from vertical to horizontal, the drag and torque due to friction forces will likewise increase. And horizontal section of the wellbore, the total weight of that part of drilling string will cause friction torque and drag, which is an undesirable situation. Excessive torque may limit a rig's available Rotary power; by contrast, when there is excessive drag, advancement of the bit may become the limiting factor in reaching the desired target.

Circulation.flow rate requirements and directional (including horizontal) drilling can be two or four times higher than the flow rate requirements in vertical well drilling. This is due to the proven need of higher annular fluid velocities for the effective removal of drill cuttings from the annulus to the surface. Higher flow rates cause high friction pressure losses and, therefore, higher rig hydrolytic horsepower requirements.

Historical overview

While the use of directional (or horizontal) drilling technology has increased dramatically since the mid-1980's, the technology itself dates back to 1891, when the first patent was granted for equipment to place a horizontal hole from a vertical well. In 1929, the first truly horizontal wells were drilled at Texon, Texas and many horizontal wells were drilled in the USSR and China during the 1950's and 1960's, with limited success. Weakening of oil prices, coupled with the need to reduce finding costs and the development of new downhole devices, resurrected horizontal drilling technology in the late 1970's and early 1980's.

The main sections of horizontal well

- Vertical section.
- Kick-off point (KOP).
- First build section.
- Radius of curvature R.
- Second build section.

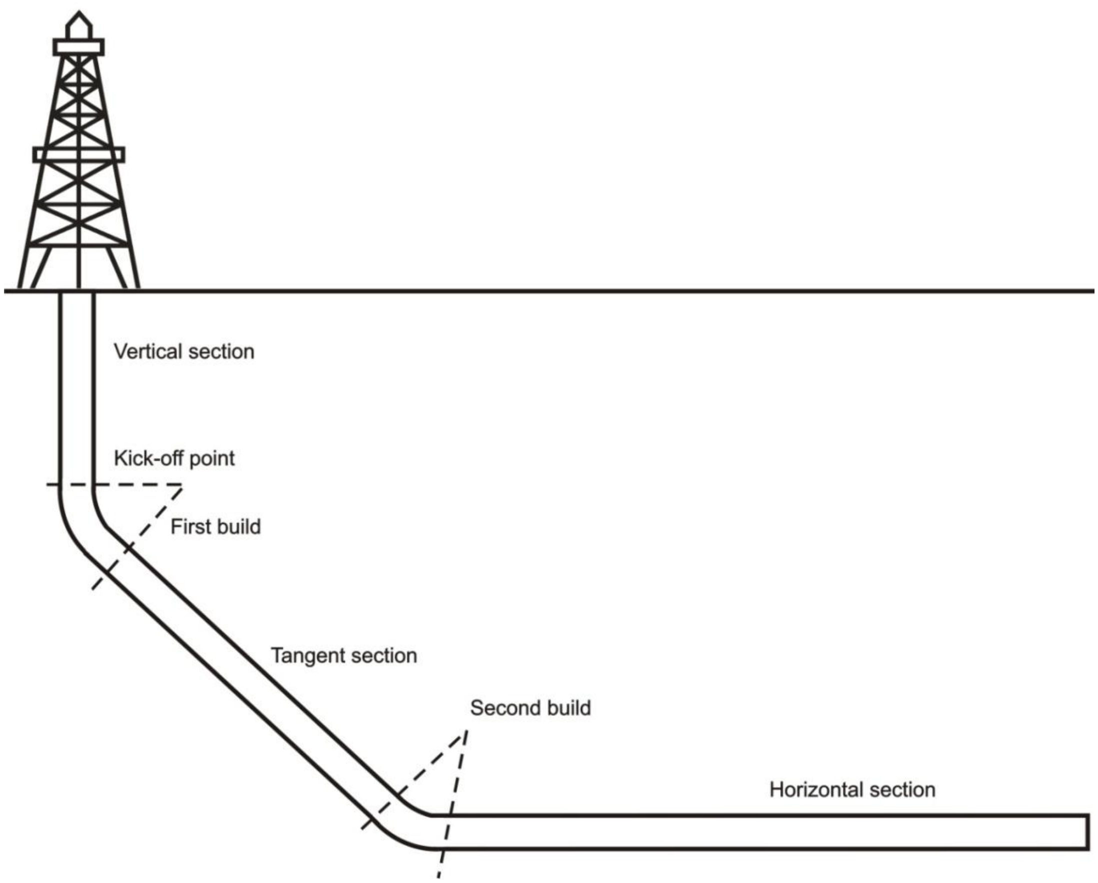


figure 1.shows the main sections of horizontal well

Horizontal well patterns

Horizontal drilling start subsurface location with a vertical section, followed by a deviated section at some preselected KOP, starting 0° from vertical and ending approximately at 90° add the entry point into the reservoir.the following methods are used to drill the deviated build sections to reach the entry point into the reservoir:

- Long – radius (LR).
- Medium – radius (MR).
- Short – radius (SR).
- Ultrashort – radius (USR).

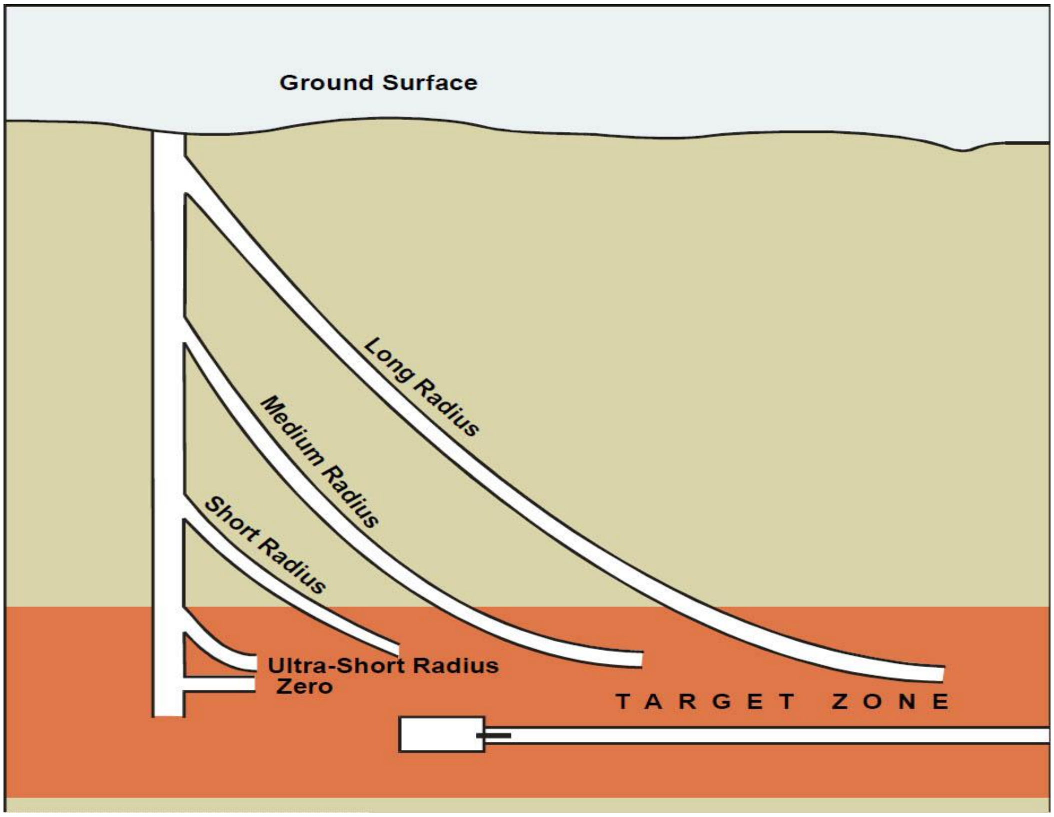


figure 2. different patterns of horizontal wells

Application of Horizontal Drilling

The reservoirs that maybe considered as possible candidates for horizontal drilling are

- Reservoirs that may have potential water/gas-coning problems
- Tight reservoirs (permeability << 1 millidarcies [md])
- Natural vertically fractured reservoirs.
- Economically inaccessible reservoirs.
- Heavy oil reservoirs.
- Channel and reef sand reservoirs.
- Coal bed methane reservoirs.
- Thin reservoirs.
- Layered reservoirs with high dip angle.
- Partially depleted reservoirs.

In Naturally fractured reservoirs, horizontal wells have been used to intersect fractures and drain them.

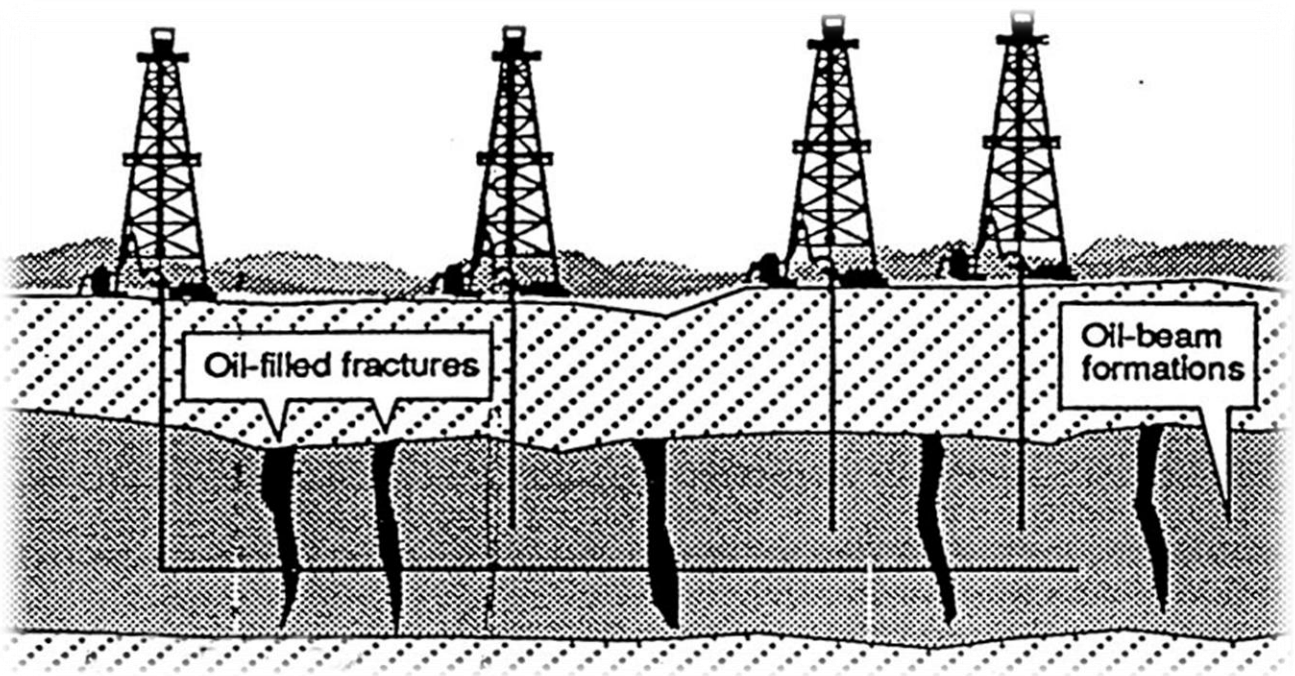


figure 3. Shows horizontal well & naturally fractured reservoir

In reservoirs with water and gas coning problems, horizontal wells have been used to minimize coning problems and enhance oil production.

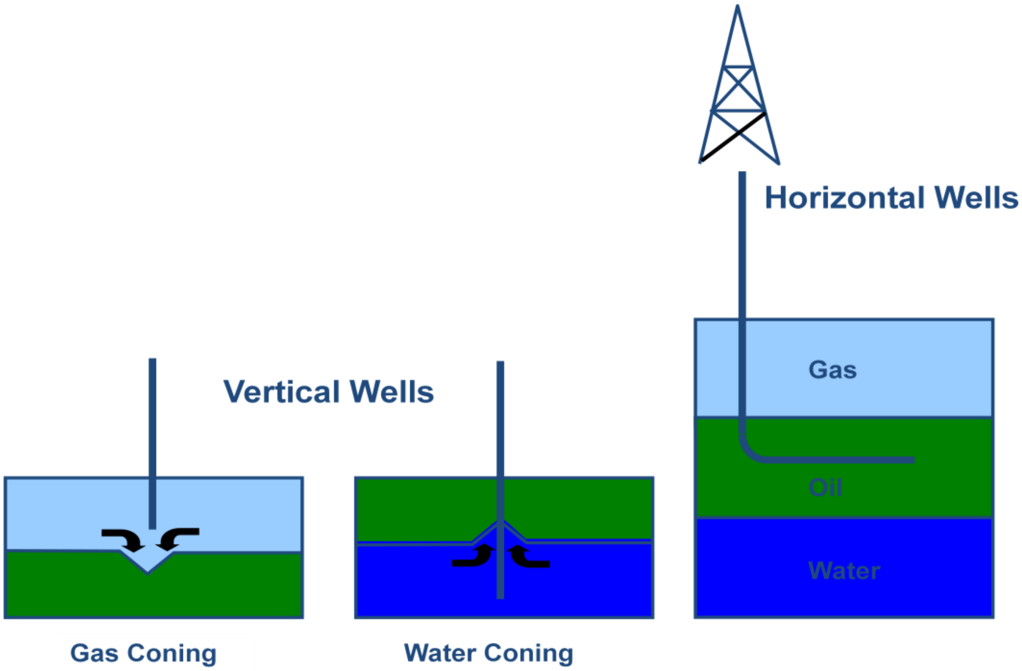


figure 4. Shows water and gas coning in the reservoir

In gas production, horizontal wells can be used in low – permeability as well as in high – permeability reservoirs. In low- permeability reservoirs horizontal wells can improve drainage area per well and reduce the number of Wells that are required to drain the reservoir. In high – permeability reservoirs, horizontal wells can be used to reduce Near – wellbore velocities. Thus, horizontal wells can be used to reduce near – well bore turbulence and improve Well deliverability in high – permeability reservoirs.

In EOR applications, especially in thermal EOR, horizontal wells have been used. A long horizontal well provides a large reservoir contact area and therefore enhances injectivity of an injection well. This is especially beneficial in EOR applications where injectivity is a problem. Horizontal wells have also been used as producers.

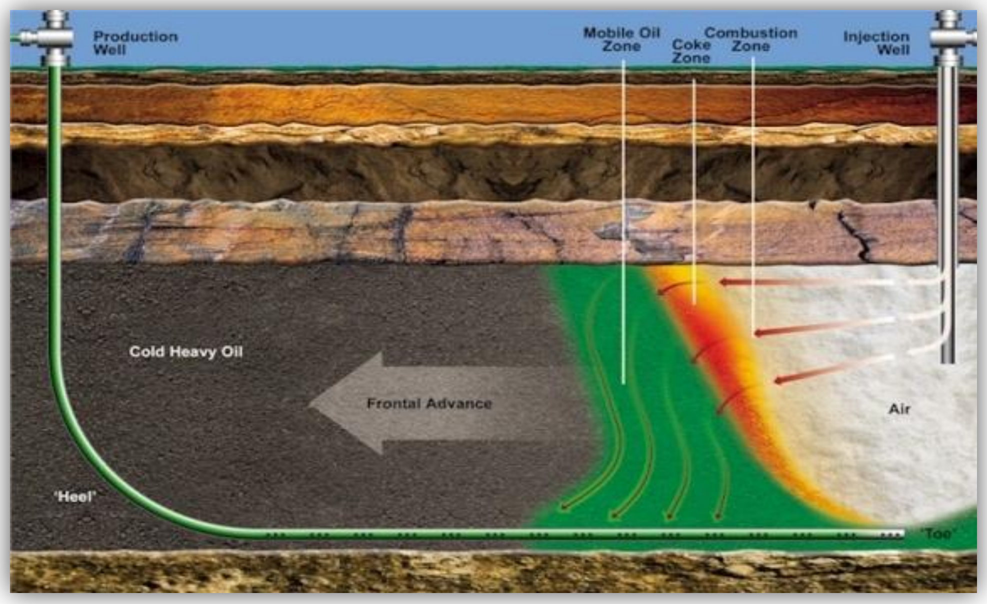


figure 5. Shows thermal recovery of heavy oil

Although several reservoir types maybe candidates for horizontal drilling applications, the ultimate deciding factor is economics–that is, the best return on investments. Overall well cost comparison between drilling a vertical or drilling a horizontal well should be based not on dollars per foot ($/ft) cost but rather on dollars per potential produced barrels of oil ($/BBL).

Other applications of horizontal drilling

- ✓ Horizontal drilling is highly applicable to existing cased vertical and directional wells with larger diameter casing and under favorable conditions.
- ✓ Horizontal drilling increases injectivity, improve sweep efficiencies, and reduce the number ofwells needed for waterflooding and steam injection for recovering heavy oils.
- ✓ horizontal drilling places pipelines underneath areas where conventional methods cannot be used. These locations include roads, rivers, ship channels, and industrial areas.
- ✓ Horizontal wells are efficient at producing methane gas from shallow coal beds in the western United States.

Drilling techniques

Before discussing various drilling techniques, it is important to define the terms: horizontal well and drainhole.

- Horizontal well: a horizontal well is a new well drilled from the surface the length usually varies from 1000 to 4500 ft.
- Drainhole: drainholes, which are also called laterals, are normally drilling from an existing well. That length usually varies from 100 to 700 ft.

The drilling techniques to drilling horizontal wells and drainholes are classified into four categories, depending upon their turning radius. Turning radius is the radius that is required to turn from the vertical to the horizontal direction. The four drilling categories are:

1. **Ultrashort:** turning radius is 1 to 2 ft, build angle is 45° to 60°/ft in this technique, 100 to 200 ft long drainholes are drilled using water jets, the drainholes are drilled through a 7 to 10 foot long,under - reamed zone, which is approximately two feet in diameter. The drainhole tubing diameter varies from 1 ¼ to 2 ½ inches, depending upon the drilling system used. After drilling, the tubing is perforated or gravel – backed. Then the tubing is Severed and the next drainhole is drilled at the same elevation.it is possible to drill several drainholes, like bicycle spokes, at given elevation.

2. **Short:** turning radius is 20 to 40 ft. Build angle is 2° to 5°/ft. In this technique, drainholes are drilled either through a cased or through an uncased vertical will. In cased holes, a window, about 20 ft long, is milled to kick – off laterally. The earlier drilling system versions used surface Rotary drilling to drill holes. In addition to surface rotation. Flexible drill collars joints (as shown in figure) are used to facilitate drilling. Normally, and angle build – up assembly is used to drill off the whipstock into the formation up to about 85°, a second stabilized assembly drills the rest of the hole.

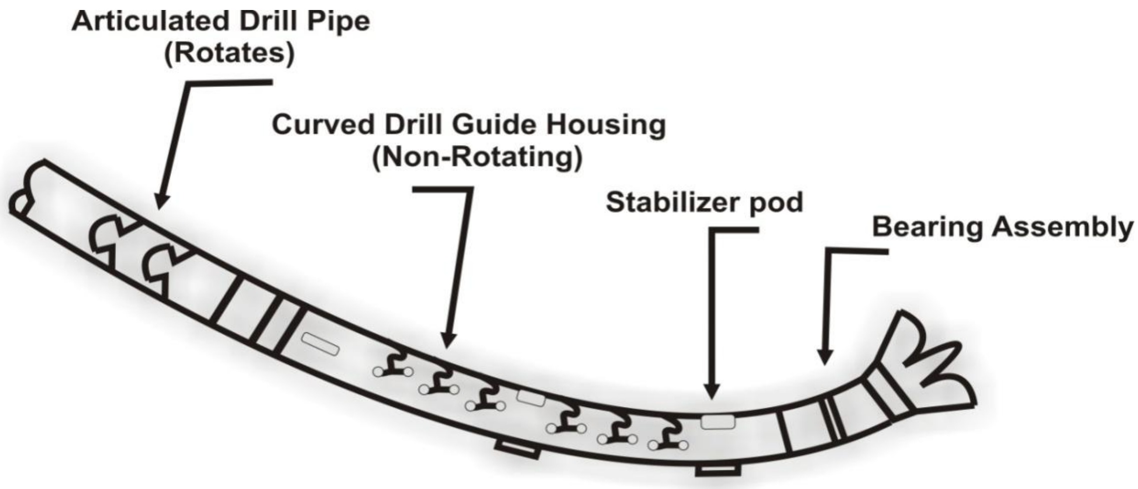


Figure 6.Shows SR- Drilling angle - Build assembly

3. **Medium:** turn in radius is 300 to 800 ft, build angle is 6° to 20°/100 ft. This is becoming a predominant method to drill horizontal wells. Because of the generous turning radius, it is possible to use most of the conventional oil field tools in the hole.specially designed downhole mud motors are used to drill horizontal wells. An angle - build motor is used to build angle and an aangle – hold motor is used to drill the horizontal well section. It is possible to drill very long, 2000 to 4000 ft long wells. Additionally, it is possible to complete them as open hole, with slotted liners, with liner and external casing Packers, or it is possible to cement and perforate these wells. These types of wells have been cored, and it is possible to fracture stimulate them.

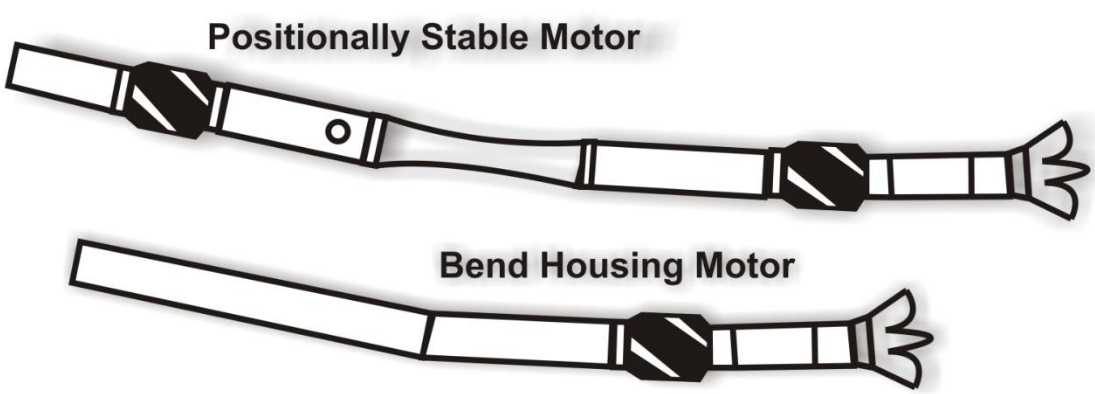


Figure 7.Shows MR- Drilling angle - Build assembly

4. **Long radius:** turning radius is 1000 to 3000 ft, build angle is 2° to 6°/100 ft.this technique uses a combination of Rotary drilling and downhole mud motors to drill these wells. Similar to conventional directional drilling, bent subs are used to kick – off and build angle. The Horizontal position is drilled using downhole mud motors. Very long wells can be drilled using this technique. It is possible to core these wells. In addition,several compilation options are also available at these holes.

Completion techniques

As noted earlier, it is possible to complete horizontal wells as open hole, with slotted liners, liners with external casing Packers (ECPS), and cemented and perforated liners. The choice of completion method can have a significant influence on well performance. The various completion options and their advantages and disadvantages are summarized below. Additionally various issues that need to be considered before choosing completions are also briefly discussed:

1. **Open hole:** open-hole completion is inexpensive but is limited to competent rock formation. Additionally, it is difficult to stimulate open – hole wells and control either injection or production along the well length. A few early horizontal wells have been completed open hole but the present trend is away from using open hole completions, except in formations such as Austin chalk.

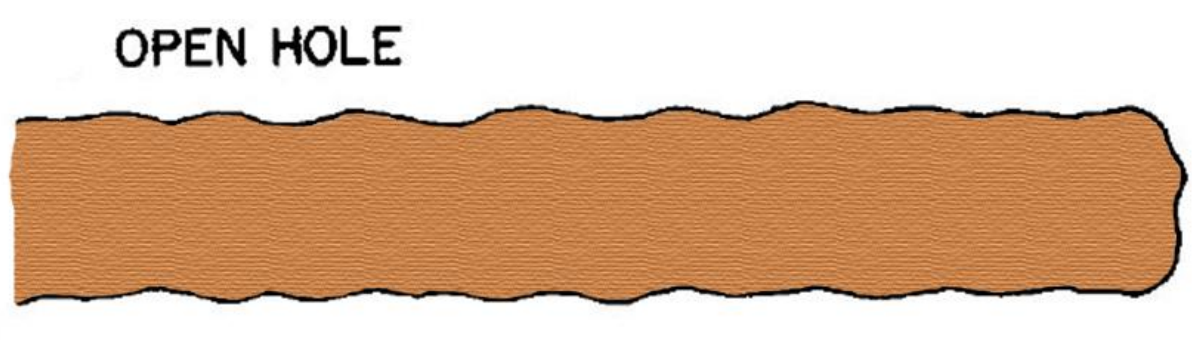


Figure 8.Shows open-hole completion

2. **Slotted liner completion:** the main purpose of inserting a slotted liner in a horizontal well is to guard against hole collapse. Additionally, a liner provides a convenient path to insert various tools such as coiled tubing in Horizontal well. Three types of liner have been used:
   a. Perforated liners, where holes are drilled in the liner.
   b. slotted liner, where slots of various width and depth are milled along the liner length.
   c. Prepacked liners.

Slotted liners provide limited sand control by selecting hole sizes and slot width sizes. However, these liners are susceptible to plugging. In unconsolidated formations, wire warped slotted liners have been used effectively to control sand. Recent literature indicates the successful use of gravel packing for effective sand control in horizontal wells.the main disadvantage of the slotted liner is that effective well stimulation can be difficult, due to the open annular space between the liner and the well. Similarly, selective production and injection is difficult.

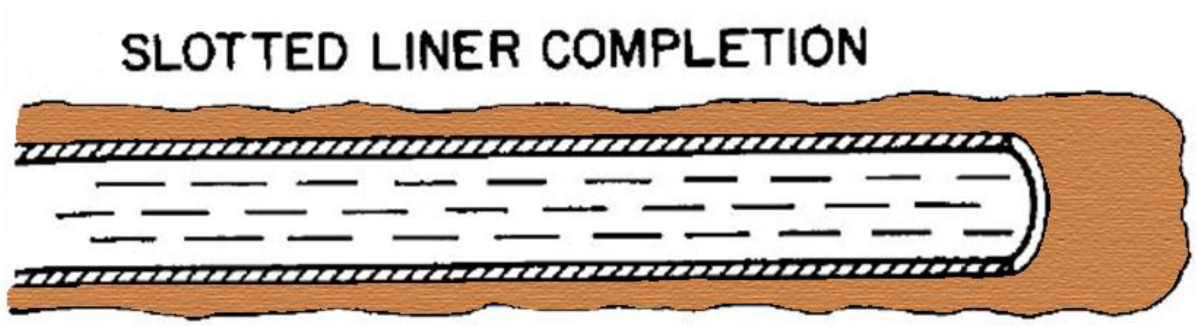


Figure 9.Shows slotted liner completion

3. **Liner with partial isolation:** recently external casing Packers (ECPS) have been installed outside the slotted liner to divide a long horizontal wellbore into several small sections (as shown in figure). This method provides limited zone isolation, which can be used for stimulation or production control along the well length.

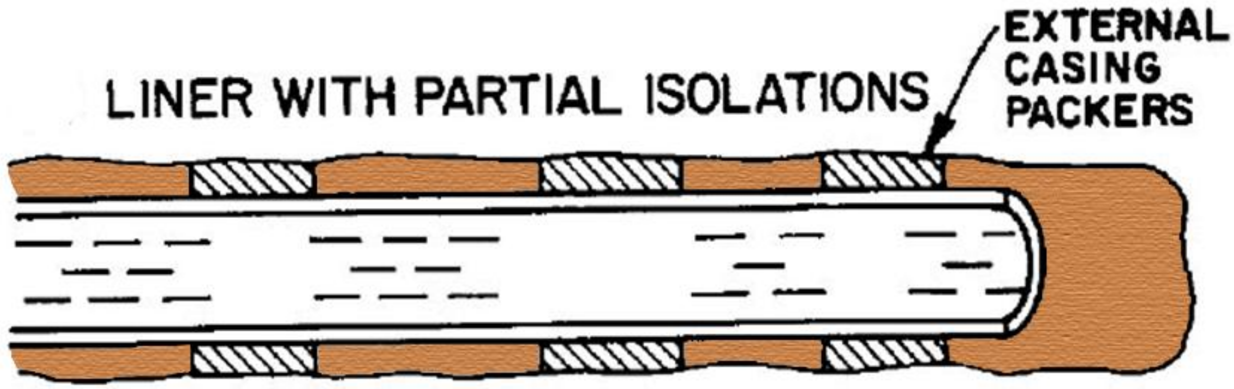


Figure 10.Shows liner with partial isolation completion

4. **Cemented and perforated liner:** it is possible to cement and perforate medium and long radius wells. At the present time it is not economically possible to cement short radius wells. Cement using horizontal well completion should have significantly less free water content than that used for vertical well cementing. This is because in a horizontal well, due to gravity, free Water segregates near the top portion of the well and heavier cement settles at the bottom. This results in a poor cement job. To avoid this it is important to conduct a free water test for cement at least 45° in addition to or instead of, the conventional API free water test, which is conducted in the vertical position.

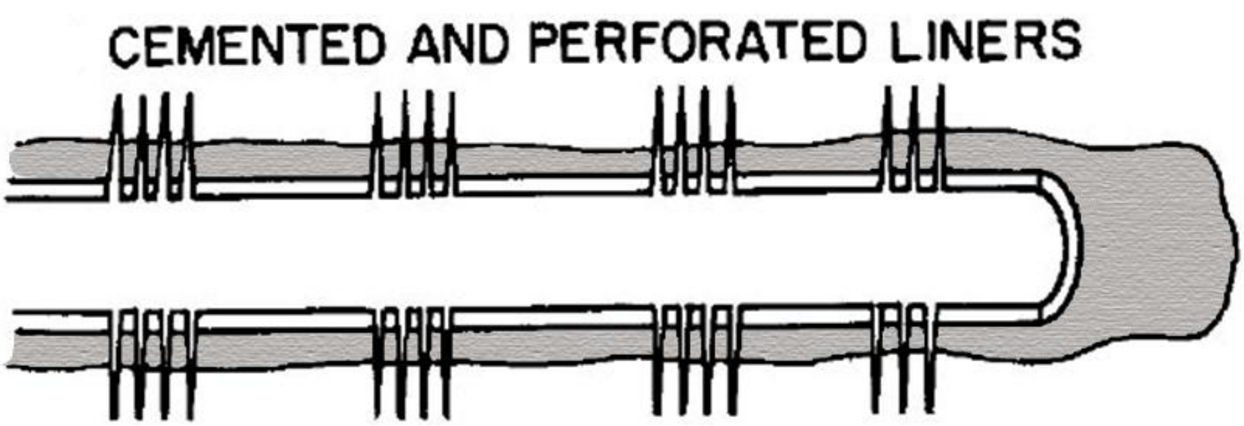


Figure 11.Shows cemented and perforated liners completion

Completion summary

Proper well completion is essential to ensure a successful horizontal well project. Based on the completion needs, one can choose an appropriate drilling technique.for example, if the well to be cemented, ultrashort and short – radius drilling techniques cannot be used. In contrast, medium and long radius wells can be cemented and perforated. Table 1. Includes a summary of possible completion options and logging options for difficult drilling methods.

Table1.Drilling Method & Their Completion Technique

Method	Completion	Logging
Ultrashort radius	Perforated tubing or gravel pack	No
Short radius	Open hole or slotted liner	No
Medium radius	Open hole, slotted liner or cemented and perforated liner	Yes
Long radius	Slotted liner or selective completion using cementing perforation	Yes

Advantages of horizontal drilling

1. Intersect many fractures in a hydrocarbon containing formation. Very popular in limestone and some shale formations.
2. Avoid drilling into water below (or gas above) hydrocarbon or perforating adjacent to water or gas. Either are thought to promote gas and water coning. Popular in formations containing relatively thin oil zones as compared with the underlying water zone.
3. Increase both the drainage area of the well in the reservoir and the lateral surface area of the wellbore. The first is thought to increase the cumulative hydrocarbon production, while the second enhances the hydrocarbon production rate. Popular in formations containing heavy oil. These holes may be thought of as drain holes in some cases.
4. Intersect layered reservoirs at high dip angles.
5. Improved coal gas production (degasification).

6. Improve injection of water, gas, steam, chemical, and polymer into formations.

Disadvantages of horizontal drilling

1. **Hole cleaning.** As the drillstring lies on the low side of the hole,beds of cuttings build up around the bottom of edge of the drillstring. These can be very hard to shift.

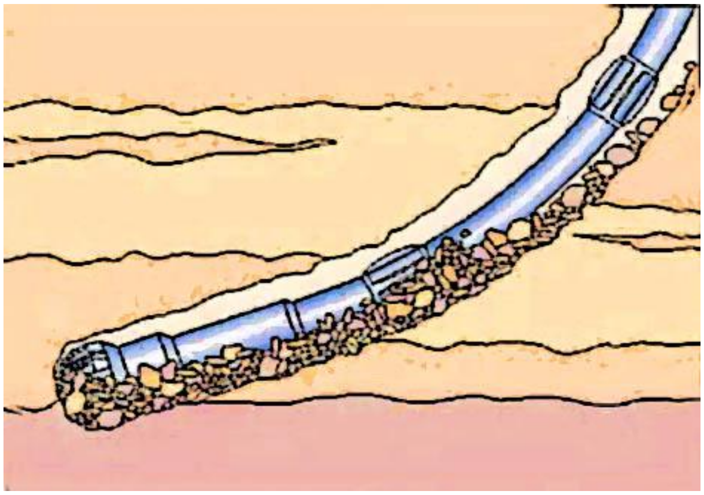


Figure 12.Shows poor hole cleaning

2. **Frictional forces.** The power needed to turn the drillstring or to pull it out of the hole are higher on horizontal well than on a normally deviated or vertical well.

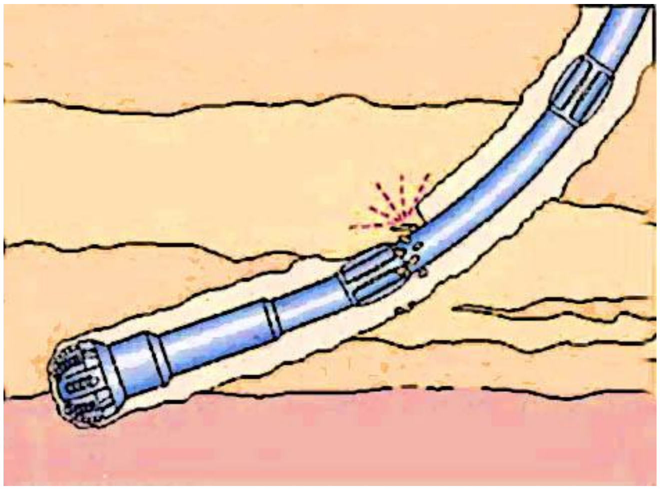


Figure 13.Shows friction force

3. **Accurate navigation in the reservoir**.navigation within the reservoir is relative the reservoir characteristics and not computed according to inclination and azimuth only.

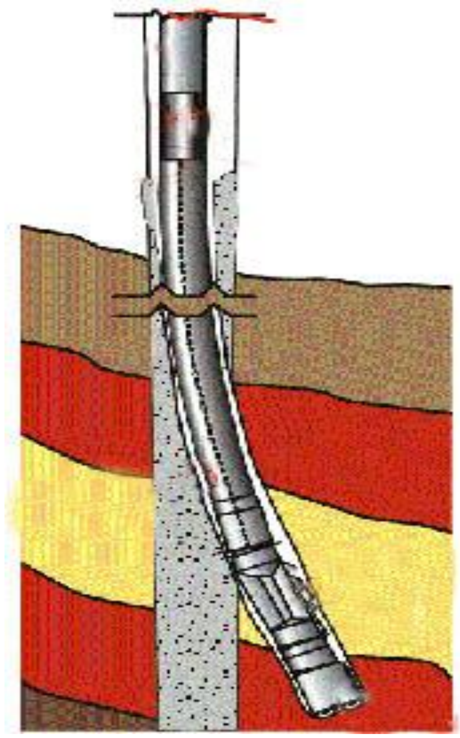


Figure 14.Shows navigation in the reservoir

Horizontal Well Costs

The cost of drilling a horizontal well depends on many factors, contingencies, and circumstances; however, the drilling costs may be reconciled into three sections of the hole:

1. The vertical section.
2. The build (s) section.
3. The horizontal section.

In comparison with vertical holes, horizontal holes most likely will have added costs in the following areas. These costs may be 120% of vertical well costs.

1. Surface location and surface equipment.

2. Casing and tubing.
3. Rig rental rate and tool rental.
4. BHA equipment rental (excluding directional tools and motors)
5. Mud and mud handling equipment.
6. Hole loss and fishing (or sidetracking).

The cost of drilling a horizontal well is given by the following equation:

Cost $ = Location + Casing + Mud + Tool Rental + Directional + Rig Rental + Drilling Time + Logging

Table 2. Comparative cost of wells

Event	Vertical	Horizontal
Surface, etc.	$80,000	$96,000
Drill to KOP	$326,000	$342,000
Drilled to tangent		$465,000
Drilled to lower build		$483,450
Drilled to horizontal		$495,750
Drilled to bottom of hole	$375, 364	$649, 500

Advances in horizontal drilling

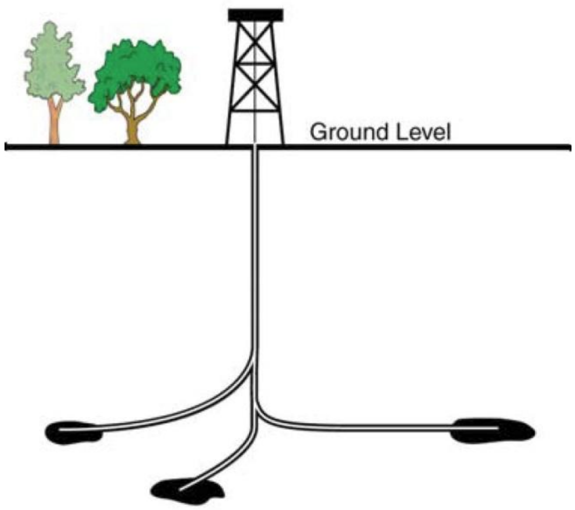
Multi-lateral Wells:

Over the last years re-entry and multilateral well applications have become more prevalent in our industry. To maximize reservoir access, multi- leg horizontal wells are drilled from a single leg horizontal well to ensure proper drainage without the additional cost of building another surface location. With proper planning and the experience of engineers and field staff, these directional drilling applications have become more common to the industry.

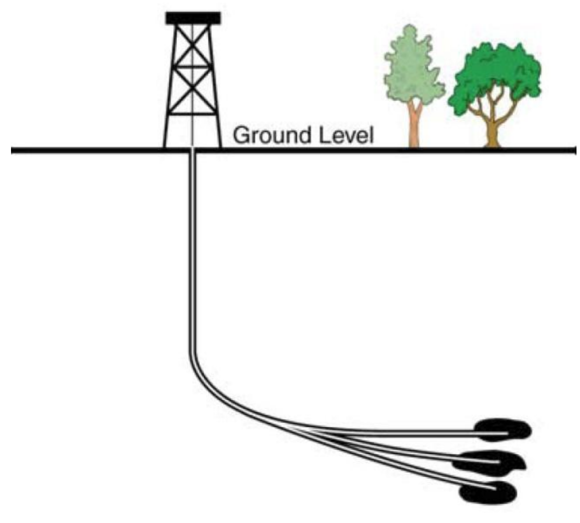
Use of multilateral technology can provide key benefits to operators

- Accelerated production that increases the net present value of a project.
- Access to additional reserves from productive wells to increase production and extend the well's productive life.
- A reduction in the number of offshore platform slots required and the number of wells to be drilled from the surface.
- Ability to make development of a marginal field viable by connecting multiple targets from what would otherwise be marginal wells.
- Reduction in uphole drilling and equipment costs by reducing the number of wells to be drilled from surface.
- Reservoir boundaries may be delineated by drilling probe wells, lease - line wells and performing reservoir characterization logging from a minimum number of surface locations.

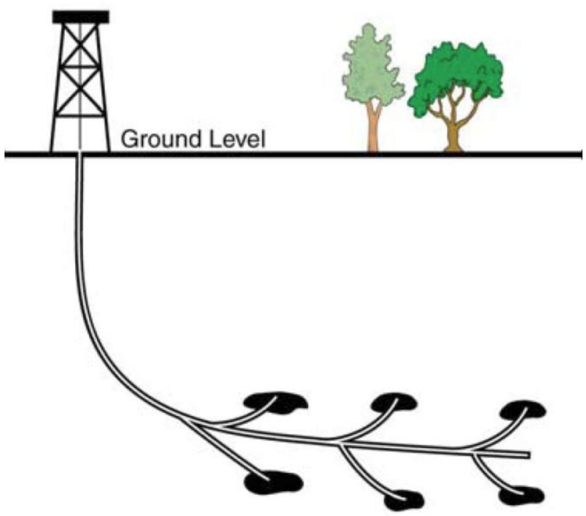
Multilateral Well Configurations



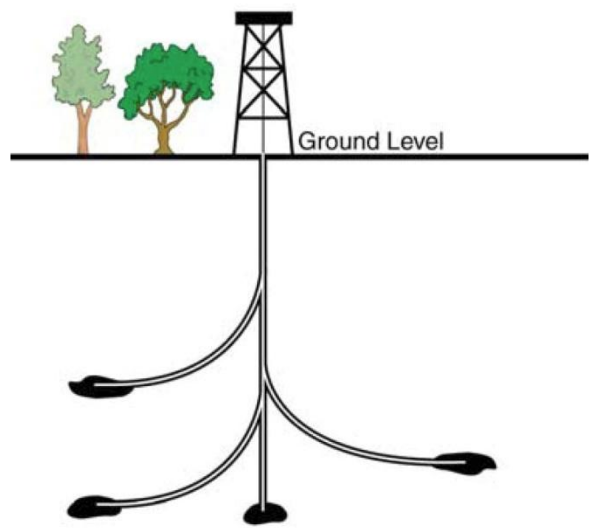
Multibranched



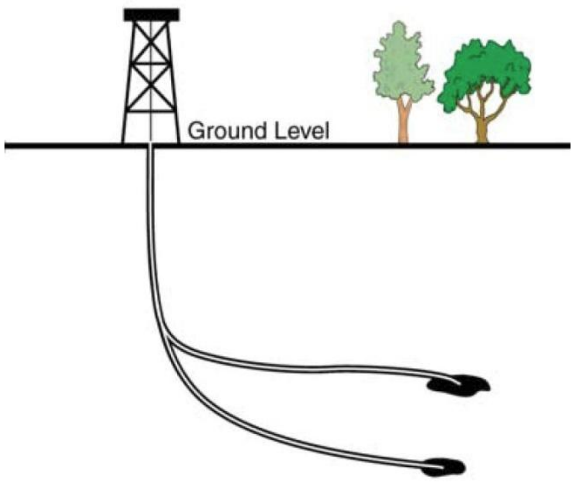
Forked



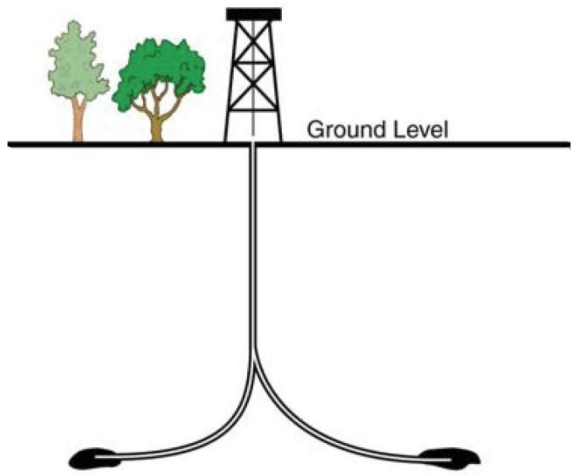
Laterals into horizontal hole



Laterals into vertical hole



Stacked laterals



Dual-opposing laterals

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