

Introduction to Well Completions

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Once a well has been drilled to total depth (TD), evaluated, cased and cemented, engineers complete it by inserting equipment, designed to optimize production, into the hole. The driver behind every well completion strategy, whether for a complex or basic well, is to recover, at a reasonable cost, as large a percentage of the *original oil in place* (OOIP) as possible.

The decision to case and cement a well for production or plug and abandon it as a dry hole relies heavily on *formation evaluation* (FE) using open-hole logs. For the purposes of this article, completion refers to all operations following the placement of cement behind the production casing, which is performed after FE.

Once FE log analysis indicates the existence and depth of formations likely to produce commercial volumes of hydrocarbons, steel casing is run in the borehole and cement is pumped behind it. Completion engineers then displace the drilling mud in the well with a completion fluid. This may be a clear fluid or brine formulated to be nonreactive with the formation.

A primary reason to cement casing is to prevent communication between producing zones, thus engineers run a *cement bond log* (CBL) to ascertain

that the cement sheath between the casing and the borehole wall is without flaws (below left). If gaps exist, engineers remedy the problem by injecting cement through holes made in the casing at the appropriate depths. This is referred to as a *cement squeeze* job.

Engineers then *perforate* through the casing and cement sheath into sections of the formation where FE analysis indicates conditions are favorable for hydrocarbon flow. Perforations are holes made in the casing, usually using small, shaped charges fired from *perforating guns*. The guns may be lowered into the hole on wireline, tubing or coiled tubing.

Often, these operations leave debris in the well and in the perforations themselves, which may hamper the flow of formation fluids into the borehole. To reduce the impact of this debris, engineers may pump a weak acid solution downhole to the affected area to dissolve the debris.

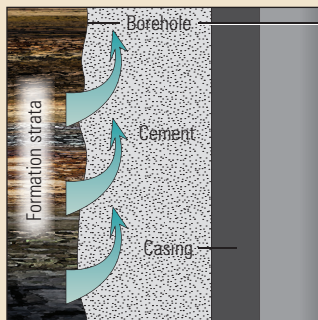
Depending on their knowledge of the formations being completed, operators may then perform a *well test*. In some instances this is carried out through a *drillstem test* (DST) valve attached to the bottom of a string of tubing or drillpipe called a workstring. The DST valve can be opened from the surface and the well fluids flowed through a *separator*—a device that separates the oil, gas, water and completion fluids at the surface. By measuring rates of water, gas and oil produced, operators gain information with which to make deductions about future well performance. Well tests also give operators extensive information about the character and extent of the reservoir.

Completion engineers may then consider several options, which are determined by formation characteristics. If the formation permeability is low, engineers may choose to create a *hydraulic fracture* by pumping water and sand or other materials—a *slurry*—through the perforations and into the formation at high pressure. Pump pressure builds against the unyielding formation until the rock yields and cracks open. The slurry is then pumped into the newly created formation fractures. When the pumps are turned off and the well opened, the water flows out, leaving behind the sand. This *prop-pant* holds open the newly created fractures. The result is a high-permeability pathway for the hydrocarbons to flow from the formation to the wellbore.

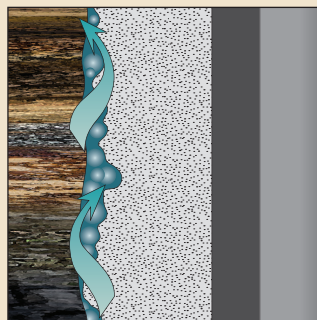
While oil and gas flow readily through permeable rocks, such formations may be unconsolidated and subject to breaking into small sand particles that may flow into the wellbore with produced fluids. These particles may plug perforation tunnels and stop fluids entering the well. To prevent the migration of these particles through the formation, engineers may inject chemicals into the formation to bind the sand grains together. To prevent sand from entering the wellbore, engineers may also opt for a sand control technique—or a combination of techniques—that includes various types of *sand screens* and *gravel packing* systems. Designed to block the migration of sand, these systems allow fluids to freely flow through them.

The next stage in completion includes placing various pieces of hardware—referred to as jewelry—in the well; the jewelry is attached to *production tubing*. Tubing, the conduit between the producing formation and the surface, is the infrastructure upon which almost all completions are built. Its strength, material and size—weight/unit length and internal diameter—are chosen according to expected production rates, production types, pressures, depths, temperatures and corrosive potential of produced fluids.

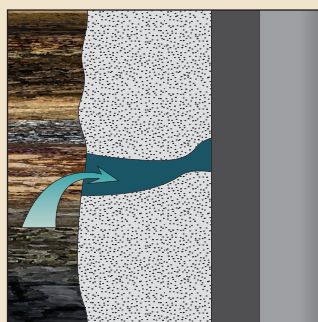
Incorrect Density



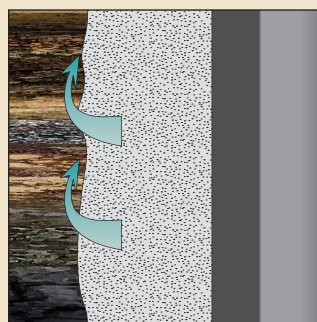
Poor Drilling Fluid Removal



Premature Gelation

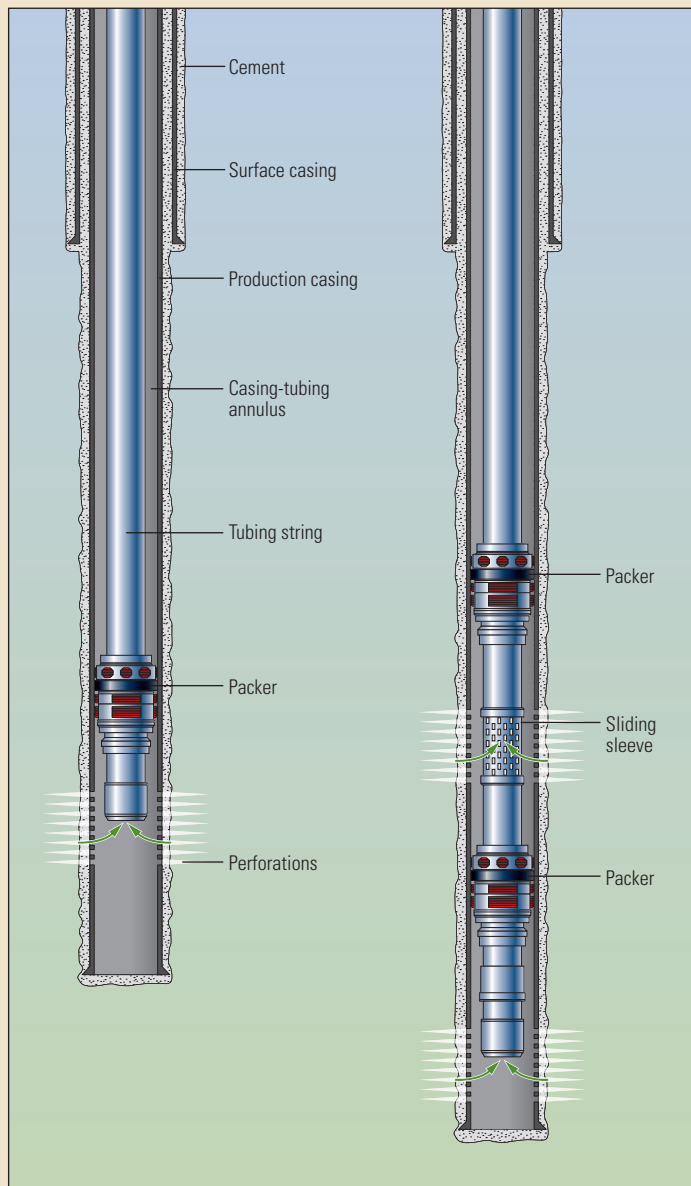


Excessive Fluid Loss



^ Cement sheath flaws. Cement bond logs can detect negative results from poor cementing practices or designs, which may allow fluid flow (blue arrows) from one zone to another or to the surface. Some causes of flaws include incorrect cement density (*top left*), poor drilling fluid removal (*top right*), premature gelation, or setting (*bottom left*), and excessive fluid loss from the cement slurry (*bottom right*).

Jewelry almost always includes *packers*, which seal against the inside of the casing. Packers isolate producing zones within the casing-tubing annulus in the same way cement does outside the casing. If the zone being produced is the deepest in the well, fluids flow from the formation below the packer and through the end of the tubing to the surface. In wells with multiple zones, a more common scenario, flow enters the well between an upper and lower packer and into the tubing through perforations or *sliding sleeves* (below). A sliding sleeve is a valve that is opened or closed mechanically; a



^ Single-zone and multizone well completions. In the single-zone completion (left), a packer, which forms a seal inside the production casing, hydraulically isolates the tubing string from the region above the packer, called the "backside." The backside contains completion fluid with corrosion inhibitors to prevent casing corrosion. The multizone completion (right) employs at least two packers that separate the producing zones. Fluids from all zones may be allowed to commingle during production, or production from the upper zone may be shut off by closing a sliding sleeve until operators have determined the fluids may be commingled. Alternatively, operators may choose to allow the lower zone to become depleted, then set a plug (not shown) above the lower zone and open the sliding sleeve to produce only from the upper zone.

specially designed tool on slickline or coiled tubing moves the valve's internal perforated sleeve up or down.

Nearly all completions also include *safety valves*. These come in a variety of forms but all are placed in the tubing within a few hundred feet of the surface. They are designed to automatically shut in the well when the surface control system is breached. They can also be closed manually to add an extra barrier between the well and the atmosphere when, for example, the well is being worked on or a platform is being evacuated in preparation for a storm.

With the basic jewelry deployed, many refinements are possible, depending on the specific needs of the field or well. For example, *intelligent completions* (ICs) are often used in situations or locations where entering the well to change downhole settings is costly or otherwise problematic. ICs include permanent, real-time remote pressure and temperature sensors and a remotely operable flow control valve deployed at each formation.

In other wells, the formation pressure is, or eventually becomes, insufficient to lift the formation fluids out of the well. These wells must be equipped with pumps or gas lift systems. *Electric submersible pumps* (ESPs) pump fluids to the surface using a rotor and stator. Pump rotor drives can be located on the surface. Reciprocating pumps, called pump jacks, may be used to lift the fluid to the surface through a reciprocating vertical motion.

Gas lift systems pump gas down the annulus between two casing strings. The gas enters the tubing at a depth below the top of the fluid column. This decreases the fluid density enough for buoyancy to lift the fluid out of the well. The amount of gas entering the well may be regulated through a sequence of valves located along the length of tubing, or it may be streamed in at one or more locations.

Also in low-pressure formations, water or gas may be injected down one well to push oil through the formation to producing wells. The producers may be fitted with *injection control devices* (ICDs) that regulate how much and where fluid enters the wellbore.

Before designing a completion, engineers take into consideration—for every well—the types and volumes of fluids to be produced, downhole and surface temperatures, production zone depths, production rates, well location and surrounding environment. Engineers must then choose from the most basic openhole completion that may not have even a production casing string, to highly complex *multilateral wells* that consist of numerous horizontal or high-angle wellbores drilled from a single main wellbore, each of which includes a discrete completion.

The indispensable underpinnings of the optimal completion are solid FE, data from nearby *offset wells* and flexibility. Armed with reliable knowledge of target zones, how nearby wells accessing those formations were completed and how they produced, engineers are often able to plan the basic completion before the well is drilled. But completion engineers know that not every well will behave as expected, so they include contingencies in their completion plans and are prepared to implement them. In the end, how a well is completed—the culmination of all the decisions about jewelry and processes—directly impacts the rate at which and how long hydrocarbons will be produced from that well.