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A newly drilled well lined with cemented casing

A reservoir can take many shapes.

A rock is porous when it has many tiny spaces, or pores.

A rock is permeable when the pores are connected.

Reservoir fluids usually separate into layers of gas, oil, and water within porous rock.

Artesian effect; water in the reservoir seeks its own level.

In a water-drive reservoir, water underneath the oil pushes it to the surface.

Eventually, the water level rises to fill the majority of the reservoir.

In a dissolved-gas drive reservoir, gas comes out of the oil, expands, and lifts oil to the surface.

In a gas-cap drive reservoir, free gas in the cap expands and pushes down on the oil to move it to the surface.

In a gravity drainage reservoir, oil may flow downhill to the well.

The rotary drilling rig is a collection of equipment and machinery that drills a well.

The rig's hoisting system works like an old-fashioned windlass.

The hoisting system works like an old-fashioned windlass.

Concentric strings of casing line the drilled hole.

An open-hole completion allows reservoir fluids to flow into the uncased hole.

A jet perforating gun creates holes, or perforations, in the casing and into the surrounding formation.

A shaped charge blasts a high-energy jet stream through the casing, the cement, and into the formation.

A production liner is run inside a previously run string of casing.

A wire-wrapped screen, or screen liner, is often combined with a gravel pack inside perforated casing.

The slotted liner is a pipe with holes in it.

Specially shaped wire wraps around the slotted liner.

A gravel pack installation hangs tubing and seals the casing-tubing annulus.

The sealing element of a packer is made of dense synthetic rubber.

The slips grip casing to hold the packer in place.

The wellhead.

A casinghead.

Three casing strings hanging from two casingheads.

The tubing string hangs from a tubing head.

The Christmas tree is mounted on top of the tubing head.

Washing in the well replaces the drilling mud with salt water.

Injecting a high-pressure gas will often start the well flowing.
3.1 The beam pumping unit is a familiar sight in oil country.

3.2 Gears transfer power from the prime mover and slow the fast rotating motion of the prime mover to a more correct pumping speed.

3.3 A steel sucker rod has a flat section where a wrench can grip it and a threaded pin on each end.

3.4 A sucker rod coupling connects the rod pins to make up a string of sucker rods.

3.5 A sucker rod pump at the bottom of the sucker rod string lifts the reservoir fluids to the surface.

3.6 A soft-packed plunger has rubber or fabric rings around a metal mandrel.

3.7 Plunger movement in a sucker rod pump

3.8 A gas anchor is attached to the bottom of a sucker rod pump.

3.9 Insert and tubing pumps

3.10 Single-stage electric submersible pump

3.11 Impeller blades in a submersible pump

3.12 An open hydraulic system has surface and downhole components.

3.13 A downhole hydraulic pump

3.14 Gas lift valves are installed in the tubing at various depths.

4.1 A drill stem test tool records pressure and samples the formation fluid.

4.2 A driller's log

4.3 A core is a cylinder of rock a few inches in diameter drilled from deep in the earth.

4.4 An acoustic log is a curved line that moves horizontally to show the speed of the sound waves and vertically to show depth.

4.5 This acoustic sonde has one transmitter and two receivers.

4.6 An SP log and a resistivity log

4.7 Calipers measure the diameter of the open hole, tubing, or casing.

4.8 A dip meter survey shows where and how much the formation dips in relation to the wellbore.

4.9 A perforation depth control (PDC) log

4.10 Gas-cap drive

4.11 Gas-cap drive

4.12 Water can bypass oil in the reservoir by fingering.

4.13 Several reservoirs may be stacked.

5.1 A small, light-duty unit

5.2 A medium-duty unit

5.3 A large, heavy-duty unit

5.4 The mast is in the horizontal, or headache, position while being transported.

5.5 A hydraulic ram raises the mast to the vertical position.

5.6 A doubles rig is tall and strong enough for stands of two joints screwed together.

5.7 Guy lines from mast to carrier and from mast to anchors in the ground stabilize the mast.

5.8 A pole mast and a structural mast

5.9 A truck-mounted rig

5.10 A tractor pulls a trailer rig carrying prime movers.

5.11 A back-in carrier rig's cab is opposite the bottom of the mast.

5.12 A drive-in carrier unit's cab is on the same end as the bottom of the mast.

5.13 Rigs designed to be moved by helicopter can be broken down into component packages.

5.14 The mast on this slant-hole rig is tilted to 45°, its maximum tilt.

5.15 Offshore service and workover rig

5.16 This coiled tubing unit is mounted on a trailer.

5.17 Rope or chain wrapped around the catheads is attached to manual tongs.

5.18 A chain or a line from the cathead attaches to a long handle on manual tongs to make up and break out pipe.
6.19 Power tongs use a hydraulic motor.
6.20 The crew stores tubing joints on racks near the mast.
6.21 Sucker rods hang on a rod hanger in the mast.
6.22 A ram blowout preventer.
6.23 An annular blowout preventer uses a rubber seal to fit any size pipe.

7.1 Conventional electric log
7.2 Abrasion has damaged this coupling.
7.3 Overtightened pin and coupling.
7.4 A casing scraper.
7.5 Swabbing works like a syringe to lower pressure in the wellbore.
7.6 Swabs
7.7 Swab cups are made of or lined with natural or synthetic rubber.
7.8 The lubricator and oil saver.

8.1 Drill pipe stuck in a keyseat.
8.2 A spear.
8.3 An overshot.
8.4 A taper tap forms screw threads inside a hollow fish.
8.5 A die collar forms screw threads on the outside of a fish.
8.6 A washpipe with a rotary shoe on the bottom.
8.7 Various types of mills remove metal, cement, sand, or scale.
8.8 Internal cutters grip and cut a hollow fish from the inside.
8.9 External cutters cut a fish from the outside.
8.10 A jet cutter uses a disk-shaped charge inside a hollow fish.
8.11 A jet cut flares the end of the fish.
8.12 A chemical cutter blasts acid onto the fish to cut it.
8.13 Bumper jar.
8.14 A hydraulic jar.
8.15 A string-shot assembly.

9.1 Macaroni tubing fits inside the production tubing to wash sand out.
9.2 Coiled tubing washes sand up the annulus between production tubing and coiled tubing.
9.3 Sand is washed up the tubing when fluid is pumped down the casing-tubing annulus.
9.4 A washer pipe mills out packed sand around the tubing.
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9.17 Sidetracking drills around a fish that cannot be removed or other unreparable damage.
9.18 Horizontal drilling allows production from vertical reservoirs next to each other.
9.19 To sidetrack, the crew drills a window in the casing.
9.20 Whipstock.
9.21 In reverse circulation, the mud is pumped down the annulus and up the tubing.

10.1 Several powerful, truck-mounted pumps are arranged at the well site for a fracturing job.
10.2 High fluid loss creates shorter fractures.
10.3 Proppants hold the fracture open (A), but if they are harder than the rock, they embed in it and the fracture closes (B).
10.4 The crew can place a packer above the area to be fractured, set packers both above and below the area, or fracture with no packers.
10.5 Sealing balls seal off a fractured zone so that the fluid will fracture another zone. 121
10.6 This trailer-mounted fracturing unit carries a control panel, prime mover, transmission, and pump. 122

10.7 The blender mixes the fracturing fluid with the proping agent and additives. 122

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A newly drilled oilwell is not much more than a lined hole in the ground. When a drilling crew drills a well, they line it with large pipe called casing. They also cement the casing in the well (fig. 1.1). At this point in the well’s life, it usually cannot produce oil and gas (hydrocarbons). The company that owns the well—the operator, or operating company—has to complete it. The operating company completes the well by adding equipment and carrying out certain procedures that will allow the well to produce fluids (oil, gas, and water).

To complete a well, a crew usually installs a string of relatively small pipe—tubing—inside the well. Near the bottom of the tubing, crewmembers usually install a special sealing device called a packer and connect valves and metering devices on top of the well to control flow. Sometimes, crewmembers add a pump or another device to lift the oil out of the ground.

As wells produce over time, equipment fails and the rocks holding the hydrocarbons—the reservoir—cause problems. When problems with equipment and the reservoir occur, flow from the well either slows down or stops altogether. When this happens, the operator also has to repair and work on the well to bring it back to full production. The industry calls such repair and work well servicing and workover. The operating company customarily hires a well servicing and workover company, or contractor, to do well repair and other remedial work.

Well servicing is maintenance work. It usually involves repairing equipment, but a servicing contractor may also add new equipment to restore the well’s ability to produce hydrocarbons.

Workover includes any of several operations on a well to restore or increase production when a reservoir stops producing at the rate it should. Many workover jobs involve treating the reservoir rock rather than the equipment in the well.

Well servicing and workover are important because oil is the most heavily used energy source throughout the world. The U.S. Geological Survey has estimated that 70 percent of all hydrocarbons on earth have been discovered. Of these, 32 percent have been produced and consumed. The undiscovered 30 percent is most likely in small fields in difficult environments like the polar regions and under the seas and oceans. These environments are extremely expensive to drill in.
After a drilling crew has drilled a hole to the reservoir and lined the hole with pipe, it may or may not do the additional work needed to get the well into production. Sometimes crewmembers move on to drill another well, and a well servicing crew comes in to add the equipment needed to start the hydrocarbons flowing, or to complete the well.

Completion begins with installing tubing inside the casing to provide a flow path for oil and gas. The completion crew sets a seal called a packer to seal off the space between the tubing and the casing and installs a well-head to control the flow of the reservoir fluids. Finally, the crew may install equipment such as a pump to lift oil to the surface, if natural drives cannot force it up.

**CASING**

Let's begin by reviewing the pipe, or casing, that lines the hole from the start of drilling to the end. Threaded couplings connect each joint of casing to form a *casing string*, which is the entire length of the casing. A cementing crew cements a string of casing in the hole as it is drilled; therefore, casing is not easily removable.

During drilling and completion, the crew runs several strings of casing into the hole. Each casing string fits inside the last, so each string is smaller in diameter than the one set before it (fig. 2.1). The first string is the *conductor casing*, a relatively short string (20 to 100 feet, or 6 to 30 metres) of large-diameter pipe that keeps the top part of the hole from caving in during drilling. The crew then drills below the conductor casing to just past the depth of the deepest fresh water in the formation.

*Figure 2.1. Concentric strings of casing line the drilled hole.*
After tubing has been run in, the packer set, and the well perforated, hydrocarbons usually flow to the surface immediately or after a crew swabs the well. When pressure from natural reservoir drive falls to the point where a well cannot produce on its own, however, an artificial method of lifting the hydrocarbons is necessary. Artificial lift is most commonly provided by some sort of pump or a method that involves injecting gas into the well.

BEAM PUMPING

By far the most common method of artificially pumping oil from the formation to the surface in land-based wells is beam pumping. A beam pumping unit sits on the surface (fig. 3.1).

It sends an up-and-down motion, called reciprocating action, to a string of rods called sucker rods. Sucker rods are solid, high-strength steel (or sometimes fiberglass) rods connected together. The top of a sucker rod string is attached to the front of a pumping unit, usually to a walking beam, and hangs down inside the tubing. At the end of the string, near the bottom of the well, is a sucker rod pump. The walking beam's reciprocating action moves the rod string up and down to operate the pump.

Figure 3.1. The beam pumping unit is a familiar sight in oil country.
Logging and testing wells occur during drilling, completion, service, and workover. Logging and testing specialists use many types of instruments and techniques to reveal information about the condition and location of the reservoir, formation fluids, wellbore, circulation fluids, and equipment in the hole. This chapter is an overview of some of the main types of logs and tests.

A log is a permanent record of information about the formations a well has drilled through. There are many ways to log, or survey, a well. Some involve observations of the drilling conditions and rock, and others involve lowering a tool into the well that sends signals to an observer on the surface.

**DRILL STEM TEST**

The drilling crew runs a drill stem test (or DST) to test a formation it has just drilled into. The DST gives accurate data about a formation’s pressure and the composition of the fluids in it. A DST tool is run in on the end of the drill stem (fig. 4.1). It has one or two packers that isolate the zone to be tested. A perforated pipe between the two packers, or between one packer and the bottom of the hole, allows formation fluids to flow in. A pressure recorder inside the tool above the packer and another below the perforated pipe chart the pressure. When the pressure testing is finished, valves in the DST tool close to trap a fluid sample, the packer is released, and the tool is retrieved.

Analyzing the DST reveals reservoir pressure, average permeability, the presence and location of permeability changes, formation damage, production potential, and pressure depletion rate.

*Figure 4.1. A drill stem test tool records pressure and samples the formation fluid.*
ANALYZING A WELL

Working on an existing well to restore or increase oil and gas production is an important part of today’s petroleum industry. Oil companies decide whether to service or work over a well based on two main factors: supplies of oil and gas, and their prices in the marketplace.

When oil prices are high, oil companies invest in drilling new wells because they expect to recover the costs quickly. In 1979 through the early 1980s, for example, oil sold for about $35 a barrel, and an average of about 3,000 wells a month were being drilled in the United States. In 1986, the price had dropped to about $10 a barrel, and only about 800 wells were being drilled a month in the United States. Fewer new wells means the proportion of older wells increases, and older wells need service or workover.

REASONS FOR SERVICE OR WORKOVER

A well that needs service or workover is not producing at all or is producing hydrocarbons at a rate not up to full potential. Six general types of problems may call for a service or workover contractor: (1) excessive gas production, (2) excessive water production, (3) poor production rates, (4) production of sand, (5) equipment failure, or (6) depleted reservoirs.

Excessive Gas Production

In wells with a gas-cap drive, the natural gas expands as liquids flow out (fig. 5.1). Originally, perforations in the casing are well below the gas cap, but eventually the gas cap expands below the perforations. The well then starts producing a lot of gas with the liquids. Excessive gas production depletes the gas, driving the oil out of the reservoir.

Figure 5.1. As oil is produced, the gas cap expands and reaches the level of the perforations in the casing or liner.
Before the 1950s, rig builders usually built a permanent derrick at each well for drilling and maintenance of the well throughout its life. Now, however, the whole drilling rig is moved to a new site when drilling is finished. The well is left with only a wellhead and sometimes a pump, so service and workover companies must bring the equipment they need to work in the well.

The amount and type of equipment they need depends on the job. One job may require a light-duty rig and a couple of workers. The next well may need a somewhat larger rig with a tall mast and a crew of several workers. Another job may require extra crews to work around the clock and a rig capable of light drilling and heavy-duty hoisting.

**RIG EQUIPMENT**

Service and workover rigs, like drilling rigs, are machines for hoisting pipe, wireline, and tools into and out of a well. They have a derrick or mast, a drawworks, and a power source. Unlike drilling rigs, not all of them have circulation or rotary systems.

They come in a variety of sizes. In general, servicing jobs require smaller rigs than workover jobs. The smallest rigs raise and lower a wireline or conductor line. Oilfield workers sometimes call these wireline rigs (fig. 6.1).

![A small, light-duty unit](petroleumextension.uta.edu)
Wells require maintenance and repairs from time to time due to normal wear, age, and hazards of the environment to which the equipment is exposed. Downhole pumps, sucker rods, and gas-lift equipment all have moving parts, which wear out because of erosion from the fast-moving reservoir fluid, which may contain sand or particles of metal left from perforating, for example. Production tubing also corrodes. Both moving and stationary equipment can fail because of corrosion, scale, and paraffin deposits.

Lease operators are usually the first to notice abnormal conditions in the well that suggest the need for repair work. Routine tests and well reports on daily production, wellhead pressure, and percentage of water in the oil provide evidence of the need for maintenance or repair.

The most common service and repair jobs include swabbing and repairing or replacing sucker rod pumps, sucker rods, production tubing, and packers. (The next chapter describes another type of servicing job, fishing.)

Another maintenance check is to assure that the cranks are correctly counterbalanced. Improper weight can cause damage to the gear teeth.

**Sucker Rods and Pumps**

Sucker rods, their couplings, and sucker rod pumps can fail because of corrosion and scale, erosion and wear, careless handling, or stress from the pump’s movement. Often, more than one of these factors is at work.

To service, repair, or replace the rods or pump, a crew pulls the sucker rod string out of the well. For a tubing pump crew, members must also pull the tubing, and for an insert pump they pull only the sucker rod string.
Oilfield workers have two names for pieces of metal lost or stuck in a well: fish and junk. A fish is a piece of equipment, pipe, or any other sizable piece of metal in the hole that should not be there. Junk is a smaller piece of metal, such as a broken bit tooth or a hand tool that a crewmember dropped in the well accidentally. Junk can interfere with workover or well service operations. When it does, the operation ceases, and crewmembers have to fish (remove) the junk from the well. Similarly, a large piece of equipment, part of the tubing string, or any other large fish impedes work and must be removed.

The operation to recover a fish or junk is a fishing job. Fishing often involves rotating a tool in the hole or circulation of a workover fluid, so it may require a larger service rig. However, many fishing operations can be done with wireline or coiled tubing run inside the production tubing.

**TYPES OF FISH**

Fish include drill pipe, drill collars, tubing, screen liners, packers, and sucker rods that are either stuck in the well or have broken off because of mechanical failure, corrosion, or abrasion.

**Drill Pipe**

Drill pipe or drill collars can get stuck in the hole for several reasons: (1) the hole can collapse around the pipe; (2) the pipe can get stuck in a keyseat, a small-diameter portion of the hole; or (3) pressure can hold the drill collars so securely to the wall of the hole that no amount of pulling can free the pipe.

The most common reason for the wall of the hole collapsing around the pipe is that, under certain conditions, salt water in pores of the rock can attract water in the drilling mud. If the formation consists of shale and the water in the mud is in contact with the water in the shale, the water in the mud has a tendency to transfer to the shale. Transferred water causes shale to expand; small sheets of shale then flake off into the hole, eventually fill it up, and the pipe sticks.

Pipe can also get stuck in a keyseat (fig. 8.1). A keyseat is caused by a dogleg, which is a severely crooked section of hole. (“It’s as crooked as a dog’s hind leg” is the expression that gives rise to the term.) The drill pipe tends to lean against the side of the dogleg and, as the pipe rotates, it digs out a new, smaller hole in the side of the main borehole.
Workover jobs may include cleaning sand out of the well and adding a means of preventing sand from entering it, replacing liners, plugging the well, repairing casing, drilling deeper, and drilling around obstructions in the well. Some workover jobs require only a wireline to lower tools, but others need to rotate tubing or drill pipe, so the workover rig has equipment to rotate the pipe string. Operations that need to circulate workover fluid into the well require pumps and storage tanks.

**SAND CLEANOUT**

In a wire-wrapped screen completion, fine sand eventually infiltrates the gravel pack and the screen and fills up the inside of the slotted liner. Sometimes, however, in spite of every attempt to exclude it, sand enters the well and causes trouble. When this happens, a workover crew cleans the well out.

The method of cleaning out the sand depends on where the sand is and how tightly it is packed. All methods use circulation of a fluid, usually salt water, to flush the sand out.

**Using a Macaroni Rig or Coiled Tubing**

One method uses either a macaroni rig (fig. 9.1) or coiled tubing (fig. 9.2). A macaroni rig is a relatively small rig that handles special lightweight, small-diameter pipe called macaroni. The crew leaves the production tubing and packers in place and lowers the macaroni string or coiled tubing, generally about 1 to 1 1/4 inches (about 25–30 mm) in diameter, inside the production tubing. Crew members lower the string until it just reaches the top of the sand. Then they circulate salt water down the tubing at a high velocity, lowering the string as the sand washes out. This high-velocity salt water forces the sand to the surface through the annulus between the production tubing and the macaroni or coiled tubing.

![Figure 9.1. Macaroni tubing fits inside the production tubing to wash sand out.](image)
Well stimulation includes techniques for overcoming the problem of a tight formation, or one that has a low permeability. Remember that permeability is a measure of how well the pores that contain hydrocarbons are connected to each other. Extracting the hydrocarbons from tight reservoirs is difficult and slow. On the other hand, the natural permeability of the rock may be adequate, but the formation near the wellbore may be damaged in a way that restricts the flow channels in porous rock. Formation damage can occur during drilling, completion, workover, production, or injection.

Low permeability, whether natural or artificial, reduces productivity to a rate that is not economical. Well stimulation is successful enough that many wells are stimulated immediately after completion and then whenever production drops because of low permeability.

Well stimulation overcomes low permeability by creating new flow channels or enlarging old ones. There are three ways to do this. The oldest method is to use explosives. During the 1930s, acid stimulation, or acidizing, became commercially available. Hydraulic fracturing, the third stimulation method, was introduced in 1948.

EXPLOSIVES
As early as the 1860s, crews exploded nitroglycerin inside wells to improve their productivity. They simply lowered a nitro charge into the open hole on a conductor line and detonated it to fracture the formation. Nitro shooting was fairly routine until the advent of acidizing and hydraulic fracturing.

For a time in the 1960s, lease operators experimented with nuclear explosives in a limited number of gas wells. While this method increased production somewhat, the cost was prohibitive.

Oil companies are still interested in explosive techniques because certain kinds of tight formations do not respond readily to either acidizing or hydraulic fracturing. Research continues in an effort to find other techniques that might increase production, but fracturing and acidizing are currently the most effective well stimulation methods.
AFTER a well has used up the reservoir’s natural drives and all the hydrocarbons possible have been lifted by pumps or gas lift, statistics show that 25 to 95 percent of the oil in the reservoir may remain there. This amount of oil can be worth recovering if prices are high enough. The petroleum industry has developed several techniques to produce at least part of this remaining oil.

One thing to keep in mind about additional recovery techniques is that they are expensive and risky. They require special chemicals, equipment, and personnel. And there are no guarantees that a project will work. Of course, the potential rewards are high if a project does work out, but the risk is also high. In most cases, it takes years before a company actually starts recovering any oil from a project. Recovering oil from reservoirs beyond the initial production remains one of the great challenges facing the oil industry.

**WATERFLOODING**

When the wells drilled into one reservoir stop flowing, the company representative may hire a workover contractor to pump, or inject, water into some of them (fig. 11.1). The wells into which water is pumped become injection wells. This water kills the wells and then sweeps into the reservoir and moves some of the oil that remains in the rock toward other wells in the same reservoir. These producing wells then pump up the oil and water, often by means of a beam pumping unit. Several injection wells surround each producing well. This procedure is called waterflooding. Sometimes a crew injects a gas, such as natural gas, nitrogen, or flue gas, in alternating steps with water to improve recovery. In this case it is called gas injection.

*Figure 11.1. In waterflooding, water is injected into wells around the producing well. This is a five-spot pattern—four injection wells and one producer—but many other patterns can be used.*
The tens of thousands of wells producing all over the world cannot begin to produce or continue to do so efficiently without the efforts of completion, well servicing, and workover personnel. Using sophisticated techniques and equipment, these people start and keep oil and gas flowing, from tiny 10-barrel-a-day “stripper wells” to giant gas wells producing millions of cubic feet (cubic metres) of gas each day.

Whether using a simple truck-mounted swabbing unit or a complicated jackup offshore unit, well service and workover companies the world over keep one of our most vital resources—petroleum—available to us when and where we need it.
To obtain additional training materials, contact:

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