Slimhole Drilling: The Story So Far...

Reducing the diameter of a borehole can significantly cut drilling costs. A slimhole rig weighs about one fifth of a

open new frontiers by making economic exploration in environmentally sensitive or remote areas. If slimhole

drilling could be safely applied offshore where well costs multiply, savings are likely to be huge. Nevertheless, wide

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At the end of the 1950s, the oil exploration industry began to investigate the practicability of a novel and specialized form of drilling. Its proponents argued that conquering the technical challenges would be rewarded by significant cost savings. At the time, these challenges proved too difficult, and few believed this novel drilling technique would ever materialize. Twenty-five years later, most of the obstacles were surmounted and horizontal drilling came of age. Will slimhole drilling similarly confound the skeptics?

Slimhole drilling means different things to different people. Some companies use the
conventional rig and its small size can

spread acceptance of small diameter wellbores remains in doubt. This article summarizes the current state of play.

expression when they design production wells with a reduced number of casing strings. This eliminates the need for a second set of blowout preventers, reduces the volume of rock drilled and requires less mud and cement. In its North Sea Forth field, British Petroleum (BP) Exploration Co. eliminated the 20-inch [508-millimeter (mm)] casing string, resulting in cost savings of 30 to 40 percent over the 15-well program. These wells were drilled and completed using conventional equipment.

Other definitions of a slim hole include small diameter boreholes drilled at the end of conventional wells. This occurs either as a result of problems which necessitate setting an extra string of casing or after a well has been reentered and an additional slimhole drilled, often horizontally.

Alternatively, a slim hole can be defined as a well in which 90 percent or more of the length has an openhole diameter of 7 inches.

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In this article Formation MicroScanner is a mark of Schlumberger; SLIM 1 is a mark of Anadrill.

at less than half the cost of a conventional well drilled nearby. \(^5\) Subsequently, in 1977 to 1981, the Swedish exploration group Olje- \(\text{sp} \) prospecting AB drilled 93 slim holes at Gotland Island, Sweden. These had a diameter of approximately 2\(\frac{1}{2}\) inches [63 mm] and recorded a 75-percent saving over conventional drilling methods. \(^6\)

These savings accrue from many sources: less site preparation, easier equipment mobilization, a reduction in the amount of consumables, less cutting to dispose of and smaller equipment. In 1986, in a six-well evaluation program on its onshore Plunger field, England, BP recorded savings of 70 percent in site preparation and estimated that the time spent rigging up and down the smaller equipment reduced transportation costs by 60 to 70 percent. \(^7\)

Savings that result from a reduction in consumables such as rock bits, muds, cement and fuel oil can also be significant. The annual volume of a slimhole well can be as little as 6 barrels (bbl) per 1000 feet [3 liters/meter] compared with conventional volumes generally an order of magnitude greater. In one application, a sixfold decrease in formation cuttings volume was recorded, with a concomitant reduction in disposal cost.

There are advantages besides cost savings. The scaled-down equipment makes operations particularly suitable for sites demanding a low impact on the environment.

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compactness of slimhole drilling rigs significantly reduces the drillsite area, in some cases to less than 7,500 square feet [700 square meters]—a conventional rig capable of drilling to 18,000 feet [5500 meters] requires at least four times the area (see “Comparison of Typical Rigs With 5000-Foot [1500-Meter] Drilling Capability,” right). This is particularly advantageous when drilling near residential areas. Noise is also less than from conventional rigs.

Société Nationale Elf Aquitaine has employed two slimhole drilling rigs in the densely populated Paris basin. By the end of 1989, the two rigs had drilled about 60 vertical and directional slim holes—a total of 400,000 feet [120,000 meters].

Slimhole drilling rigs are ideal for remote areas. In 1964, Standard Oil Company (Indiana) affiliate Pan American Indonesia drilled four wells with a slimhole rig mounted on nine skids 27 feet long, 6 feet wide and 3 feet deep [8 meters, 2 meters and 1 meter respectively]. These were capable of maneuvering across a swampy 13,500-square-mile [35,000-square kilometer] concession in central Sumatra, Indonesia.

Portability also played a key role in a 12-well drilling program in 1985 by Conoco Indonesia and Westburne Drilling Co. in the difficult Irian Jaya area, Indonesia. The wells were located over a wide area and often in swamps. Its purpose-built slimhole rig was designed to be carried to the drillsite by a Sikorsky S-58T helicopter in 4,000-lb [1,800-kilogram] sections and assembled without assistance from a crane, bulldozer or forklift truck (previous page, left).

About 100 airlifts were required to move the rig, excluding consumables and personnel. By comparison, moving a conventional 18,000-foot heli rig requires 330 airlifts (plus a further 220 to move the rig camp and tubulars). To minimize transportation costs, Conoco employed shallow-draft tugs and cargo barges (measuring only 40 feet by 75 feet [12 meters by 23 meters]) to transport the rig as close as possible to the drilling site.

The plan envisaged moving the slimhole rig in 4 to 7 days and drilling each well in 7 to 10 days. By the end of the program, Conoco Indonesia had achieved significantly quicker times. For at least three of the wells the rig was moved and the well drilled in only 7 days (right).

<table>
<thead>
<tr>
<th>Type of rig</th>
<th>Conventional</th>
<th>Slimhole</th>
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<tbody>
<tr>
<td>Hole diameter—in</td>
<td>8‌1/2</td>
<td>3 to 4</td>
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<tr>
<td>[mm]</td>
<td>[216]</td>
<td>[75 to 102]</td>
</tr>
<tr>
<td>Drilling weight—metric tons</td>
<td>40</td>
<td>5 to 7</td>
</tr>
<tr>
<td>Rig weight—metric tons</td>
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<td>12</td>
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<tr>
<td>Drillsite area—%</td>
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<tr>
<td>Installed power—kW</td>
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<td>75 to 100</td>
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<tr>
<td>Mud pump power—kW</td>
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<td>45 to 90</td>
</tr>
<tr>
<td>Mud tank capacity—bbl [m³]</td>
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<td>30</td>
</tr>
<tr>
<td>[litera/m]</td>
<td>[75]</td>
<td>[5]</td>
</tr>
<tr>
<td>Hole volume—bbl/1,000 ft</td>
<td>60</td>
<td>6 to 12</td>
</tr>
<tr>
<td>[litera/m]</td>
<td>[31]</td>
<td>[3 to 6]</td>
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</table>

Beating the schedule. In Conoco’s drilling program at Irian Jaya, Indonesia, twelve wells were drilled in less than five months, four months faster than planned.
Today, slimhole drilling falls into two distinct categories each requiring its own drilling hardware. First there are wells that are drilled using small bits. These tend to have diameters 6 inches [152 mm] to 4½ inches [114 mm] and can be both exploration and production wells. The rigs for this are scaled-down versions of conventional equipment evolved from the oil field.

Then there is a continuous coring system borrowed from the mining industry. Wells drilled in this way are almost exclusively for exploration and have a diameter of as little as 3 inches [76 mm] (below, left).

Typical of the scaled-down, purpose-designed equipment is Microdrill AB’s MD-5 Britta rig that drilled BP’s Plungar field and more than 250 wells in Turkey, Tunisia and Europe (left). It has a 36-foot [11-meter] mast compared with around 130 feet [40 meters] for a conventional land rig (next page). Maximum drilling depth is 4900 feet [1500 meters].

Instead of a conventional kelly bushing, the system uses a hydraulic rotating torque head mounted on the mast. This allows simultaneous rotation and tripping of drillpipe. Mud is pumped into the string via a swivel above the torque head.

At a connection, as with normal drilling, the drillstring is raised until the pipe joint reaches the level of the table, and the hydraulic slips are engaged. The rotating head then breaks the connection. The next joint of pipe, just 10 feet [3 meters] long, is then positioned by hand and screwed into the top of the drillstring. Torque is applied using the rotating head, the hydraulic slips are released and drilling continues.

Slimhole drillpipe comes in 3.3- to 19.7-foot [1- to 6-meter] lengths—rather than the 30-foot [9-meter] joints of conventional drillpipe—and has externally flush connections, which reduce drag particularly in deviated wells. To allow sufficient torque to be applied to the string, reduce leaks at connections and limit fluid friction losses in the annulus, upsets are placed internally (as opposed to internally flush/external upsets of normal drillpipe). Outside diameter ranges from 1 inch [25 mm] to 5 inches [127 mm].

The reduced weight of slimhole drillpipe may reduce wall abrasion, but may also
make the drillstring mechanically weaker than its conventional equivalent. Buckling of the smaller diameter pipe is partially ameliorated by support from the hole wall, which typically may have an annular clearance of only 1/2 inch [1.3 mm].

Bottomhole assemblies (BHAs) are very sensitive to weight on bit (WOB)—too much and the bit can be damaged. This is a particular problem when drilling from a floating rig where heave can vary WOB. Because of this, the rig's motion compensators and the shock absorbers in the BHA require careful attention.

Thin tubulars may also be more susceptible to twist off, particularly in deep, nonvertical wells. This can be obviated by keeping the wells as near vertical as possible and by using mud motors. These mud motors must be designed to take into account the high bottomhole temperatures caused by the depth, the speed of rotation and the small volume of mud cooling the BHA.

Downhole motors with a diameter as small as 2½ inches [72 mm] have been used. A typical drilling assembly for a directional well consists of a side-cutting, high-speed bit, a downhole motor, a fixed/moveable bent motor guidance system, wireline steering tools and nonmagnetic and regular drill collars.  

In slimhole drilling, fixed-cutter bits are generally preferred because they can withstand high rotational speeds (up to 1,000 rpm compared to a maximum of 200 rpm in conventional drilling).  

While polycrystalline diamond compact (PDC) and thermally stable polycrystalline (TSP) technology have been successfully used, traditional diamond bits often produce smaller cuttings that are easier to remove.  

The second slimhole drilling technique, continuous coring, offers the potential to extract large quantities of geologic information from core samples. In the mining industry the technique is employed to verify that an ore body discovery contains a sufficient mineralogical grade to justify full-scale mining. This commonly entails coring of up to 90 percent of a well. 

In the late 1950s, this technique began to be adapted to the oil industry. Using a string consisting of two concentric tubes welded together, Strato Drill Inc. recovered 100 percent of the core from a 1400-foot [420-meter] well in Texas, USA. During coring, fluid was pumped down the tubular annulus and reverse-circulated to the surface carry-


Environmental impact. This conventional rig drilling in Lincolnshire, England, was able to get a permit to drill—something environmental concerns make harder each year. Slimhole drilling reduces the environmental footprint.
ing core in 6-inch [152-mm] increments (below, right). But today cores are retrieved by pulling through the drillstring by wireline. A good example of a modern coring rig is the Longyear Co. rig PM 603. Last year it successfully cored to 9800 feet [3000 meters] in the Mallorquin field, Paraguay, for Texaco Inc. The well was drilled as a stratigraphic test. At total depth the hole diameter was 3 1/12 inches [77 mm] (next page, left). Like most such rigs the PM 603 has a topdrive and can pull down on the drillstring in the same way as snubbing units.

The Mallorquin well was cored through a mixture of sedimentary and igneous formations but until recently, little research had been performed on continuous coring of sedimentary rock. In 1987, Amoco Production Co. started its stratigraphic high-speed advanced drilling system project (SHADS). This resulted in the continuous coring of more than 70,000 feet [21,335 meters] of sediments. More recently, Amoco and Elf conducted the Soft Rock Project to gain experience in continuous coring and drilling of soft formations. Four wells were drilled onshore through sedimentary lithologies in the Texas Gulf Coast, USA, (next page, middle). A total of 1670 feet [510 meters] of continuous core was extracted from Tertiary sediments.

Continuous coring differs from conventional oilfield coring. The core passes through the throat of the core bit into an inner barrel up to 90 feet [27 meters] long. Once the core barrel is full, a wireline overshot is lowered from the surface through the drillstring. The overshot connects with the inner barrel, which is then pulled through the tubulars to surface. Another inner barrel is then lowered downhole.

Core recovery rates of up to 100 percent are common in metasediments and volcanic lithologies. Although good recovery rates have been reported by Amoco, for younger coastal sediments recovery is often considerably less—typically around 40 percent. To maximize core recovery in soft sediments, a split sleeve may be used. This is a two-piece stainless steel cylinder inserted inside the inner barrel. The smooth stainless steel reduces friction experienced by the core as it enters the barrel. The split barrel protects the core when it is removed from the barrel at the surface because the extrusion force is applied to the tube and not to the core itself.

### Wireline Logging Tool Clearances

<table>
<thead>
<tr>
<th>Tool diameter</th>
<th>5 7/8</th>
<th>4 3/8</th>
<th>3 1/8</th>
<th>3 5/8</th>
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<tr>
<td>Dual Laterolog</td>
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<tr>
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<td>1.00</td>
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<tr>
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<tr>
<td>2 7/8</td>
<td>3.12</td>
<td>1.62</td>
<td>1.38</td>
<td>0.65</td>
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<tr>
<td>1 11/16</td>
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<tr>
<td>Induction</td>
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<td></td>
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<tr>
<td>3 3/8</td>
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<td>1.00</td>
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</tr>
<tr>
<td>2 7/8</td>
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<tr>
<td>4 3/4</td>
<td>1.12</td>
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<tr>
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<tr>
<td>Borehole Seismls</td>
<td>1 11/16</td>
<td>4.18</td>
<td>2.68</td>
<td>2.44</td>
</tr>
</tbody>
</table>

1. Clearance is difference between hole size and tool diameter.
2. Has been run successfully in 4 3/8-inch holes.

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**Specialized coring technique. Using a dual-concentric string, fluid is pumped down the tubular annulus and reverse-circulated to the surface carrying core in 6-inch [152-mm] increments.**
These improved techniques yield more than 80-percent core recovery.

In hard competent, uniform lithologies, the mining industry finds diamond-impregnated bits the most economical. These typically consist of small diamonds of 310 to 525 particles per carat embedded within a tungsten-carbide matrix. In adapting such mining techniques to the oil and gas drilling industry, different bit designs have been employed that are more suitable to the softer heterogeneous sedimentary lithologies (bottom).

Following a drilling program by Amoco on its Catoosa, Oklahoma, USA, experimental field, 30 bits were evaluated for bit life and penetration rates under coring conditions. By experimenting with bit profile, diamond concentration and placement and also with PDCs, Amoco was able to double the drilling rate.

Handling all the core from a whole well presents logistical problems. These have been partially solved by Amoco, using an onsite automated core processing system to clean, label, analyze and store core sections.

Despite having extensive availability of core, the desire for wireline logging is little reduced. Although the small diameter wellbores tend to restrict the logging suite that can be used, tools developed for the mining industry as well as oilfield logging equipment are available for slimhole service. The table (“Wireline Logging Tool Clearances” previous page, left) shows the Schlumberger equipment that can be run in slim holes. Two key services yet to be available are a dual induction tool and a forma-

tion testing tool. A 3½-inch (89-mm) testing tool is under development.

The small diameter holes also restrict use of measurement-while-drilling (MWD) technology. However, directional MWD tools with external diameters of 2 inches [51 mm] and, more recently, 1¾ inches [44 mm], are now available. These are wireline retrievable and sit inside 4½-inch drill collars and can be used with a bit as small as 6 inches (right). There are plans to further reduce the size of MWD equipment.

A key development area in slimhole drilling is mud. Slim holes generally have an annular clearance of about ½ inch [13 mm], compared to 1½ to 9 inches [38 to 230 mm] in conventional wells. Because of small annuli, high annular velocities are generated at low pump rates which obviates the need for viscosity-building additives.

Another consideration is the drillstring rotation speed. When small diameter pipe is rotated at 500 to 1,000 rpm, it can act as a centrifuge causing mud solids to adhere to the internal surface of the drillstring. These solids gradually build up and impede fluid flow and prevent wireline retrieval of a core barrel. A solution is to use a brine-oil emulsion with weighting material or a gel-water system. A recent approach is to use highly inhibitive cationic polymer systems.

Restricting solids raises a challenge to slimhole drillers—attaining sufficient mud weight to prevent kicks. Amoco calculates that a 2-barrel [320-liter] kick taken at 8,000 feet [2440-meters] by a conventional well would occupy 40 feet [12 meters] of the annulus and reduce bottomhole hydrostatic pressure by 15 psi. A 2-barrel kick in a continuous-coring slimhole annulus would occupy 375 feet [114 meters] and reduce hydrostatic pressure by 120 psi. Not only does the small fluid increase make kick detection difficult to detect conventionally, but reaction time is reduced.

With conventional methods, a kick is detected by observing an increase in mud volume in the return pit or an increase in outflow. In slim holes, the pit gain could be too small for even the most sensitive float. Thus, new technology is required to provide improved accuracy. For instance, sensitive electromagnetic flowmeters have been employed by Amoco to measure mud inflow and outflow.

An acoustic outflow measurement has been developed by Anadrill. Another technique developed by Anadrill detects the presence of a gas influx by monitoring the round-trip travel time of mud pump pressure waves. Because these waves travel more slowly through gas than through mud, a sharp increase in travel time indicates a gas influx.

On floating rigs, slimhole kick detection will be even more difficult because mud outflow varies as the rig moves. Variations can be as much as 300 gal/min [1,135 liters/minute] compared to a pump rate of as little as 40 gal/min [150 liters/minute]. Shell UK Exploration and Production Co. estimates that at least two more years of development is required to enable the first slimhole high-pressure exploration well to be drilled from a semisubmersible. However, the calculated savings from this would be up to $1 million per well.

Once detected, a kick must be killed. This requires a precise knowledge of downhole pressures which is not calculated in the usual way. When mud circulates inside a wellbore, the hydrostatic head increases because of frictional forces caused by the mud moving in the annulus. This increases the apparent density of the mud, called the equivalent circulating density (ECD). This is generally not an important factor in conventional drilling because standard hole sizes and velocities are small. But in slim holes, particularly the very slim ones, ECD becomes significant.

Controlling ECD by varying pump rate—having taken into consideration hole diameter, depth, pipe size, mud rheology and pump performance—can help control a kick in what is called the dynamic kill. Because no weighting up of mud is needed to increase downhole pressure, response time can be very rapid. However, use of annular pressure loss to control downhole pressure can inadvertently cause lost circulation. This in turn can exacerbate the well control problem.

Although slimhole drilling activity is clearly increasing, it is concern about safety that is inhibiting a more rapid spread of slimhole projects. Amoco estimates that with no previous experience, an operator could assemble the equipment within three to six months to drill onshore slim holes safely to 6,000 feet [1829 meters]. Tougher applications, like deeper holes or offshore drilling, will not be so easily achieved. Furthermore, widescale use of slimhole drilling for new appraisal and development wells—as opposed to pure exploration wells and recompletions—will depend on how successfully the technique is applied over the next few years. —JH