Causes, Detection and Prevention

It costs the oil industry between $200 and $500 million each year, occurs in 15% of wells, and in many cases is preventable. Stuck pipe remains a major headache that demands and is getting industry-wide attention.

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The following fictionalized conversation describes events that actually occurred on a rig drilling offshore in the Gulf of Mexico. It is noon on a Monday and drilling is at 3470 feet. The mud logger has just joined the driller on the rig floor.

**Mud Logger:** We've drilled three feet into a break. Better pick up and check for flow.

**Driller:** One flow check coming up.

A flow check tells whether a kick is in progress. This is a routine performed after a drilling break, a sudden increase in penetration rate, usually indicative of permeable formation. The mud logger returns to his unit. A short time later, the driller phones.

**Driller:** We've shut down for five minutes and there hasn't been any flow. We're going back to drilling.

**Mud Logger:** OK.

Before recommencing drilling, the driller picks up a little to work the pipe—and then calls the toolpusher.

**Driller:** The hook load shot way up when I picked up after the flow check. We must have had 100 kip of overpull for a couple of seconds there.

**Toolpusher:** How does it look now?

**Driller:** Everything's fine.

**Toolpusher:** Keep an eye on it. I'll go talk to the company man.
Fifteen minutes later, the measurement-while-drilling (MWD) engineer appears on the drill floor.

**MWD Engineer:** Did you notice the overpull when you picked up?

**Driller:** Sure did. It was over 100 kbl. What are we drilling down there?

**MWD Engineer:** The gamma ray shows a clean sand, and it looks like there might be something in it too.

Thirty minutes later, in the mud logging unit:

**Mud Logger:** How’s the mud doing?

**Mud Engineer:** Lousy. The mud cleaner and desander take turns breaking down. The company man is upset about the high water loss, and the mud weight keeps increasing. I’m stuck between a rock and a hard place.

**Mud Logger:** I bet the mudstone we drilled earlier is feeding the mud system. That stuff was soft—it practically dissolved in water.

**Mud Engineer:** That must be it. The drill solids are steadily increasing. It must be coming from the open hole somewhere.

High water loss and increasing drill solids produce thick, soft mudcake, a primary cause of differential sticking. Fifteen minutes later, at the mud pits:

**Company Man:** When are we going to reduce this water loss?

**Mud Engineer:** I’m trying everything I know, but the mud cleaner is down and that mudstone we drilled is putting a lot of solids into the system. We need to get it fixed and the desander needs work too.

**Company Man:** The rental company says they won’t have a man out for another day at the earliest. We’ll just have to make do, at least until the crew change tomorrow morning.

**One hour later, in the company man’s office:**

**MWD Engineer:** Pore pressure is still at 8.7 ppg. Is there any reason the mud weight has been increased to 9.4 ppg?

**Company Man:** Yeah, we can’t keep the solids control equipment running. The weight is creeping up.

**MWD Engineer:** When we shut down for the flow check in that sand, we had 100-klb overpull. We could be getting some differential sticking.

**Company Man:** Maybe you’re right. I’ll call the drill floor and have them keep the pipe moving. Let me know when we get out of the sand.

The next morning, the mud cleaning equipment is still malfunctioning, but drilling proceeds. Meanwhile a helicopter arrives with a new company man.

**Arriving Company Man:** How’s everything going?

**Leaving Company Man:** Pretty good. But yesterday, we had a 100-klb overpull after a flow check. We haven’t seen anything since.

**Arriving Company Man:** What do you think it was?

**Leaving Company Man:** I think it was differential. We’d been having problems with the mud cleaners. Everything is in the reports. I’d better get going, the helicopter’s waiting. See you in two weeks.

**Arriving Company Man:** Have a good time off.

Later that evening, total depth (TD) is reached. The driller calls the new company man.

**Driller:** We just reached TD and are going to pull out. You want me to rotate when breaking connections?

**Company Man:** No, let’s not waste any time. We’ve got a long logging program and we’re behind schedule.

**Driller:** OK.
They pull five stands and then cannot raise the pipe after a connection. The bottomhole assembly (BHA) happens to be opposite the sand where the drilling break occurred and has become differentially stuck—pressured against the permeable sand so hard that no force on earth can move it. It is a driller’s nightmare that is less common than ten years ago, but still common enough. In most cases, getting stuck is preventable and the main reason it happens is that warning signs come sporadically over days or even weeks. This pipe got stuck because warning signs were poorly communicated and eventually forgotten. If the mud cleaning equipment had been working, if the pipe had been kept moving while pulling out, if the rig had had the advantage of the latest information-system technology, then perhaps the incident would have been averted. Poor communication is often the main culprit behind stuck pipe, with the many players—from company man to shaker handler—not pooling their observations and failing to arrive at a collective decision at the right moment.

The industry’s interest in stuck pipe is currently going through a renaissance. Several operators are making determined efforts to codify the warning signs and to improve communication—not just for their own drillers, but for all on-site drilling and service company personnel. Meanwhile, better rig sensors and information systems are providing rig-floor “smart” alarms to help the driller recognize trouble before it gets out of hand.

The causes of stuck pipe have been known since drilling began (next page). Broadly, they are divided among differential sticking, formation-related sticking and mechanical sticking.1 Differential sticking occurs in permeable zones when drill collars, drillpipe or casing get embedded in mudcake and pinned to the borehole wall by the difference between the mud’s hydrostatic pressure and a lower formation pressure. Formation-related sticking occurs when unstable formation constricts the drillstring. This includes unconsolidated rock, swelling shale, flowing formations such as salt and plastic shale, and geopressed formations. Mechanical sticking covers numerous causes such as key seating—in which a groove cut in the borehole wall by drillpipe traps the larger-diameter hardware when tripping out—accumulation of cuttings due to poor hole cleaning, undergauge hole, doglegs, junk, collapsed casing, and fragmented cement.

The causes of sticking are more numerous than can be listed here, and it is a mistake to think that only one cause may be acting. Pipe stuck because of swelling shale may sooner or later also get stuck differentially at another point in the well. One of the results of the industry’s current attention is a better understanding of the events leading up to stuck pipe and their interpretation in terms of the causes of sticking. Knowing the causes is essential for taking correct remedial action.

**Differential sticking**

Research into differentially stuck pipe started in the 1950s.2 Simplicistically, the pressure differential between the mud and formation pushes the drill collars and drillpipe against the borehole wall, and the friction force required to move the string—the pinning force multiplied by a coefficient of friction—becomes too great for the rig drawworks to pull the pipe free (above). In the simplistic picture, pinning force equals the pressure differential multiplied by the contact area between drill collar and borehole (continued on page 18)
**Formation related**

**Unconsolidated formations**
Unconsolidated formations such as loosely compacted sands and gravels can collapse into the wellbore forming a bridge around the drillstring.

**Reactive formations**
Certain montmorillonitic and bentonitic shales hydrate and swell on contact with water-base mud, filling the borehole and creating clay balls that can block the wellbore and constrict the drillstring. Treating the mud with KCl and polymer can arrest hydration. Oil-base mud inhibits the process completely.

**Mobile formations**
Formations like salt and plastic shales literally flow into the wellbore when restraining stresses are removed, jamming the drillstring.

**Fractured/Faulted formation**
Formation that is naturally fissured or near a fault zone may break off in pieces into the borehole and jam the drillstring. Pieces can vary from small up to boulder size. Formations that commonly fracture are carbonates and shales.

**Geopressed formations**
Overpressured formations can blow apart when penetrated by the drill bit, filling the borehole with rock particles that can stick the drillstring.

**Undergauge hole**
Undergauge hole geometry occurs when the gauge protection on the bit becomes ineffective after drilling long sections of abrasive formations. Unless care is taken, a new bit can get jammed in an undergauge hole.

**Wellbore geometry**
Doglegs and ledges between hard and soft formations can stick the drillstring, particularly when tripping out. The drillstring is under less tension tripping in, more flexible and able to circumvent obstacles.
**Poor hole Cleaning**

Poor hole cleaning results in overloading the annulus with cuttings, potentially sticking the drillstring. This is most likely in washouts where annular velocity decreases and cuttings accumulate. In deviated wells, cuttings form beds on the low side of the hole and can migrate uphole like shifting sand dunes.

**Junk**

Junk is any object in the hole not meant to be there. Roller cones or even a PDC cutter are large enough to stick the string. Once the drillstring becomes free, junk must be flushed with a reverse-circulation junk basket or magnets.

**Cement related**

Cement-related sticking occurs when blocks of cement fall into the wellbore from casing ratholes or cement plugs, jamming drillstring. It also occurs when drillstring becomes planted in soft or "green" cement that flash sets when pressure is applied.

**Collapsed casing**

Collapsed casing occurs when formation forces exceed casing collapse pressure, such as when:

- casing is too light duty
- casing is old
- casing is landed with too much tension, reducing its collapse rating.

**Key seating**

Key seats, grooves in the borehole wall cut by rotating drillpipe, stick larger diameter collars and other hardware when tripping out. A key seat reamer placed higher in the string can open the key seat, allowing passage of collars.

**Differential Sticking**

Differential sticking occurs opposite permeable formations when drill collars get embedded in thick mudcake and are pinned to the borehole wall by the differential pressure between mud and formation.

Material compiled by the BP stuck pipe task force.
wall, an area that increases with mudcake thickness and length of BHA in contact with the formation.

According to this picture, preventing differential sticking depends on, among other things, careful mud design and conditioning. The mud must not be too heavy because that increases hydrostatic head and differential pressure. A recent survey by Chevron USA Inc. indicates the increasing probability of differential sticking with pressure and suggests a maximum of 2000 psi, although this obviously is subject to local conditions (below). The mud must also have good fluid loss properties to prevent excessive mudcake buildup. And the solids control equipment must be functioning correctly to prevent solids and cuttings from remaining in the mud and possibly accreting to the cake, building it up further.

Other preventive measures include always keeping the string in motion, particularly when adding pipe whiledrilling, the most likely moment for differential sticking. Wiper trips and reaming also help because they remove parts of the mudcake (above). Top drives, which permit rotation while raising pipe, contribute to decreasing the chances of getting stuck.

Preventive measures, though, must begin in the planning stages. The first step is selecting casing points. These are usually picked so that in each openhole section mud weight lies between a lower limit, below which the mud would no longer counterbalance pore pressure, and an upper limit, above which the mud would fracture or damage the formation causing lost circulation. If a maximum differential pressure is imposed to reduce the chances of differential sticking, for example opposite permeable depleted formations, the upper limit may have to be reduced and an additional casing point may be necessary. The extra cost of adding a casing string, however, must be weighed against the alternative of simply reducing mud weight and hoping the well will not kick—stuck pipe could be less expensive than a blowout.

Further well planning is necessary for deviated wells. The well trajectory should be designed to minimize drag. Use of steerable assemblies without rotation to steer the hole should be minimized—rotary drilling produces fewer doglegs.

A second planning step is careful BHA design—it is the large diameter drill collars that usually get stuck. The trend toward simpler BHAs, with only as many collars as are strictly necessary, has done much to reduce the incidence of sticking. Further reductions have resulted from using spiral collars, which present less surface area to the borehole wall, and stabilizers every second or third joint that keep the entire BHA away from the borehole wall.

A third way to avoid differential sticking is to use MWD measurements to provide a continuous record of direction and inclination. Obtaining these data the traditional way, by lowering instruments down the drillpipe, keeps the drillstring stationary for up to 30 minutes, time enough to get truly stuck. Fourth, spotting fluids circulated to free differentially stuck pipe should be premixed and available at all times.

Advances in preventing differential sticking currently rely on further research into the sticking mechanism, better understanding and codification of the telltale signs that precede sticking, improved monitoring of rig data through drilling information and alarm systems to detect those signs, and, most important of all, training of rig floor personnel that emphasizes the importance of communication.

Researchers seek answers to the most basic question: What exactly is the sticking mechanism? Is it the Coulomb friction force mentioned above, or is sticking not associated with the borehole wall but entirely with the mudcake? Perhaps the force needed to free the BHA must simply overcome the yield stress of the cake. Pursuing this line of thought, researchers are investigating in detail the properties of mudcakes (next page, below left).

At a larger scale, several groups of experimenters have built wellbore simulators that offer insight into the friction forces that develop while drilling or sticking. None, though, has satisfactorily determined what factors contribute to the suddenness or intensity of the sticking pipe phenomenon. One more enigma for researchers is why spotting fluids are often successful at freeing pipe. Does the diesel-base fluid infiltrate

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**Probability of differential sticking versus differential pressure, established from analysis of 600 well histories in the Gulf of Mexico. An "acceptable" probability of 20% is achieved if differential pressure never exceeds 2000 psi. (From Weakley, reference 3.)**

**Three ways mudcake can be removed, diminishing the probability of differential sticking. While drilling, the rotating pipe wears one side of the borehole removing the cake. During a wiper trip, the stabilizers and bit remove a large portion of the cake. Reaming does the best job of removing cake, but it takes the most time.**
moving pipe from static

Drag trend increasing

Is circulation restricted?
  Yes
  No

Are known problem formations exposed?
  Yes
  No

Reactive, fractured/faulted, mobile, unconsolidated, or geopressed formations
  No

Is drag reduced when pumping?
  Yes
  No

Inadequate hole cleaning

Can drillstring be moved?
  Yes
  No

Differential sticking

Are permeable formations exposed?
  Yes
  No

Junk, cement blocks, string component failure, stabilizers hanging up on ledge

Flow diagram for diagnosing the cause of stuck pipe when encountering overpull after moving pipe from a static position—for example, after making or breaking connections during drilling, tripping or reaming.

This and other similar charts were compiled by the BP stuck pipe task force. Prevention of stuck pipe depends on speedily answering each query as it arises. This is being facilitated by increasingly sophisticated data provided by new MWD tools and better data analysis and alarms provided by computerized rig instrumentation. (Courtesy of BP Exploration.)


Laboratory evidence of the complexity of mudcake. In experiments at Schumberger Cambridge Research, Cambridge, England mudcake was developed in a filtration cell over three time periods—1 hour, 4 hours and 24 hours—and then dissected to determine cake void ratio versus distance from the filter paper. The void ratio varies dramatically. The cake is dense and nonporous adjacent to the filter paper and increasingly porous away from it. Given enough time (see the 24-hour data), the outer surface of the cake achieves a uniform void ratio. Researchers are analyzing the implications of this and other results for differential sticking. (From Sherwood et al., Journal of Chemical Society Faraday Transactions, reference 4.)

and destroy the cake? Or does it lubricate the drillstring, allowing more pulling force to reach the stuck BHA? If scientists can answer these questions, better methods for freeing stuck pipe may become available.

Meanwhile, the emphasis is on prevention. And that means watching the warning signs and knowing what combination of circumstances presages a stuck pipe incident. One of the aids produced by a recent BP stuck pipe task force is a flow diagram for each drilling operation—drilling, making connections, tripping in and out, reaming in and out, circulating and running casing. The diagrams show how events accumulate to make sticking increasingly probable. Differential sticking usually occurs when moving from a static position. The relevant flow diagram leads inexorably through the events, queries and answers that culminate in stuck pipe (above):

- Does drag increase when moving string from static position? Yes.
- Is circulation restricted? No.
- Are permeable formations exposed? Yes.
- Can drillstring be moved? No!

The BP chart not only forewarns of impending disaster, but also suggests what type of sticking should be expected. For example, if, after moving pipe from a static position, circulation had been restricted, we are led to the left part of the diagram toward forma-
A more complex diagnostic flow diagram for tripping out. (Courtesy of BP Exploration.)
tion-related sticking. A more complex chart provides an analysis of what may happen while tripping out (previous page). Possible sticking mechanisms include formation-related problems, key seating, cement-related problems, junk and wellbore geometry.

**Shale Sticking**

Differential sticking accounts for more than 70% of stuck pipe in areas where wells are drilled through depleted, highly permeable sands as in the Gulf of Mexico. But in other areas, such as the North Sea, where operators are obliged to drill through unstable tertiary shales to reach pay, shale-related sticking claims a similarly high percentage.

In the presence of water-base mud, shales frequently swell—particularly those containing abundant montmorillonite—constricting the borehole and finally gripping the drillstring. Others slough off small particles that fill the borehole and risk packing off the BHA or bit. Drillers are aware of shale-related drilling problems if they have encountered them in nearby wells, and they have several methods of dealing with them. The simplest is to weight up the mud, although this does not necessarily halt the chemical reactions between mud and shale that are responsible for shale's instability.

The simplest method of controlling chemically active shale is to use oil-base mud, a solution that transformed exploitation in the North Sea. By containing its water phase in small oil droplets, oil-base mud eliminates contact between the water and the formation, ensuring that the shale remains stable. In a wellbore simulator at Schlumberger Cambridge Research, Cambridge, England, oil-base mud was flowed through a one-inch borehole drilled in a block of Pierre shale—a highly unstable rock obtained from a near-surface site in Colorado, USA containing 30% clay, of which a third is montmorillonite. In the simulator, overburden, confining and mud pressures can be independently maintained up to 30 megaPascals (MPa) [4350 psi] (top, right). Throughout the experiment, the borehole remained on gauge and relatively smooth, indicating that as in real life, oil-base mud eliminates shale-related sticking problems (right).

As environmental restrictions tighten, though, the toxicity of oil-base mud has thrown its future into question. This is spurring increased research on muds made with vegetable rather than petroleum oil or with polymers synthesized from petrochemicals. The latter, however, may be just as toxic as conventional oil-base mud. That leaves water-base mud.

The water-base solution for fighting unruly shales is generally a mix of potassium chloride (KCl) and polymer. The role of the polymer is poorly understood. Current joint research at Schlumberger Cambridge Research and Institut Français du Pétrole, Rueil-Malmaison, France suggests that it plays no role in arresting the chemical reactions that occur when shale meets water. Rather, its role is to prevent dispersion by physically encapsulating clay particles as the shale swells and disintegrates.

The role of KCl is better understood. The common denominator between mud and shale is water activity, a measure of the ability of water molecules to escape from a substance. By definition, pure water has a water activity of 1. Anything that gives up water vapor less easily, and shales usually fit this category, has an activity less than 1. When two substances are in contact, an equalizing

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7. Another wellbore simulator used to examine shale-related problems is described in:
process takes place in which the substance with the higher water activity loses water molecules to the substance with the lower activity. Thus, water-base mud tends to lose water to shales. In absorbing water, shales swell or break up.

To prevent this, a water activity balance must be achieved by 1) reducing water activity of the mud and/or 2) increasing activity of the shale. Mixing salts like KCl, sodium chloride (NaCl) or calcium chloride (CaCl₂) into the mud achieves the first goal, with KCl providing the least reduction and CaCl₂ providing the most. The second goal may be achieved when mud contacts the shale and the salt enters the shale with the absorbed water. As this occurs, the salt—potassium, sodium or calcium—replaces the original cations in the shale, which are predominantly sodium. Laboratory measurements have shown that if calcium replaces sodium, the shale activity decreases—a step in the wrong direction. Sodium cations replacing sodium-rich shale give practically no change, which does not help. But when potassium replaces sodium, activity increases. Thus KCl mud achieves the dual goal of decreasing mud activity and increasing shale activity.

Several laboratory techniques are routinely used to measure the activity of shales, shale swelling and the effectiveness of mud formulations in stabilizing shales. A simple relative humidity meter measures activity. Swelling is measured by compressing a paste of shale into a receptacle with a piston, exposing one end of the paste to the mud, and then measuring the outward displacement of the piston versus time once the compression pressure has been released. The failure or success of a particular mud in controlling shale dispersion is determined in a hot rolling oven. Small particles of shale are weighed, then placed with the mud in closed containers. The containers are rolled gently overnight in an oven, to enhance the mud-shale interaction at downhole temperature conditions. The next morning, the resulting soup is sieved to retrieve remaining particles, which are then dried and weighed. The goal is to have minimum loss of shale into the mud. A good inhibitive KCl-polymer mud will typically preserve 95 to 100% of the original shale. Using larger equipment such as the Schlumberger Cambridge Research small wellbore simulator, the effect of incorrect mud formulations can be directly observed; the results are often frightening.

Measuring shale activity in situ is a much harder challenge. Currently, the only hope is from geochemical logging measurements that can be interpreted to provide a sophisticated mineralogical analysis of the formation. If the activities of each mineral component are known, the analysis may then provide an estimate of formation activity. Logs either come after the well is drilled and the risk of sticking has passed, or from nearby wells. Ideally, the same technique would be used in real time with MWD data. Current MWD technology, however, fails to provide the necessary range of geochemical measurements.

**Real-time Prevention**

In other ways, MWD technology provides valuable data for preventing stuck pipe in real time. In the drilling mode, MWD measurements of downhole weight-on-bit and downhole torque can be compared with surface hook load and torque. Using a model of the well trajectory, also determined from MWD measurements, the comparison permits an estimate of pipe friction versus depth that can provide early warning of sticking. Anadrol's SPIN sticking pipe indicator works on this principle and provides both drag and rotating friction factors (next page). A recently introduced MWD wellbore caliper measurement provides another indication of sticking by directly showing how mobile formations and unstable shales affect wellbore diameter (page 24). The evolution of wellbore diameter can be monitored during each trip in and out of the hole. This new sensor promises easy identification of key seats.

Pipe friction in the tripping mode is one output of a trip monitoring program recently
Example of Anadrill's SPIN sticking pipe indicator analysis. From MWD downhole weight-on-bit and torque measurements, surface hook load and torque, and a model of the well trajectory, the analysis outputs both drag and rotary friction factors (tight track). As drilling proceeds, preventive action such as short wiper and reaming trips are made each time the friction factors increase beyond what experience deems safe limits. The MWD gamma ray data permit correlation of sticking events with permeable sands (low counts) and shales (high counts).

<table>
<thead>
<tr>
<th>Rate of penetration, ft/hr</th>
<th>Surface weight, kib</th>
<th>DWOB downhole weight, kib</th>
<th>BHA position</th>
<th>Depth, ft</th>
<th>Surface torque, kft-lb</th>
<th>DTOR downhole torque, kft-lb</th>
<th>Rotary friction factor, %</th>
<th>Drag friction factor, %</th>
<th>Interpretation</th>
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<tbody>
<tr>
<td>10</td>
<td>40</td>
<td>40</td>
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<td>0</td>
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<td>25</td>
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<td>ROP increases to 70 ft/hr. Rotary friction decreases only when stabilizers leave sand. Diagnosis: intermediate stabilizers hanging in sand at 310 ft.</td>
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<td>10</td>
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<td>Drag and rotary friction increase; ROP decreases from 80 to 15 ft/hr. Working and reaming hole has no success. Five-stand wiper trip decreases both frictions to normal levels. ROP increases to 50 ft/hr. Diagnosis: intermediate stabilizer digging in sand at 480.</td>
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<td>50</td>
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<td></td>
<td>Rotary friction increases sharply and drag increases slowly; ROP decreases from 60 to 10 ft/hr. Three-stand wiper trip decreases both drag and rotary friction; ROP increases to 80 ft/hr. Diagnosis: top stabilizer hanging in sand at 710 ft.</td>
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<td>100</td>
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<td></td>
<td>After a connection, hole was worked and reamed. Rotary friction decreases sharply.</td>
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<td>200</td>
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<td></td>
<td>Drag friction increases. Three-stand wiper trip brings it down. Diagnosis: top stabilizer hanging in sand at 880 ft.</td>
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</tbody>
</table>


A recent MWD innovation—ultrasonic sensors that measure standoff to the borehole. An estimate of borehole diameter is obtained by summing two standoff measurements made on opposite sides of the MWD collar and adding the diameter of the MWD tool. Transmitted to the surface, the data are accumulated over time and displayed in a distribution plot. This shows the range of borehole diameters encountered as the drillstring turns in the borehole. Small and large diameters are picked from the lower and upper end of the distribution and presented in log form versus depth.

Comparisons with wireline caliper logs run days later can reveal deteriorating borehole conditions that may presage the pipe getting stuck. Between X050 and X150 ft, a shale section is collapsing. The wireline calipers show that the hole has enlarged since the MWD calipers passed the zone and indicated the beginnings of a washout. In a permeable zone between X170 and X190 ft, the MWD data indicates the hole to be on gauge, while the wireline logs show undergauge hole. This difference is caused by mudcake development.

dveloped by Anadroll. As before, inputs to the friction calculation include hook load and well trajectory, but the program also takes into account mud buoyancy and BHA dimensions. Thus, the resulting friction factor is independent of drillstring configuration and mud, an important consideration if these are being adjusted to cope with a sticking situation. The friction factor is displayed on a rig floor monitor, providing an immediate indication of the onset of sticking.11

After MWD technology, the computerized collection of drilling data from surface sensors promises the greatest impact on fighting stuck pipe. The MDS information and alarm system being installed on Sedco Forex rigs displays all pertinent data on ruggedized rig-floor video screens for the driller and on workstations to other key decision makers on the rig, overcoming communications barriers. The system also addresses possible lack of communication during crew changes, because it allows arriving crews to easily review the previous days' data. But most important, the system alerts the driller to abnormal data trends and issues smart alarms so action can be taken to avert crises. An example in fighting stuck pipe is the hook load profile.12

During previous trips and drilling, hook load is stored and averaged in the system each time the drillstring hangs free or is moving within defined speed limits. Displayed versus depth or time, this average hook load profile represents the expected trend when there is no sticking. This is compared with the hook load trend recorded in real time during a trip. Any overpull is immediately apparent on the video screen, and in case a hook load increase goes unnoticed, a smart alarm automatically alerts all personnel on the rig (next page, above). Alarms raised on previous trips can be permanently displayed to warn of possible trouble to come. Further analysis can be performed on a workstation by comparing overpull sections to lithology, ROP and dogleg severity.

The full power of computerized information systems has yet to be realized, though, but a thorough analysis of data acquired during a recent sticking incident on a Sedco Forex rig drilling for TOTAL in offshore Borneo, Indonesia gives a flavor of the sophistication to be expected in the near future.

Around 2 P.M. on April 29, 1991, drilling had reached 2066 m (6778 ft) in a fairly
unstable claystone formation. Because penetration rate had dropped, it was decided to make a trip to replace the bit. After pulling one stand, the pipe stuck on slips despite an overpull of 75 klb (bottom, right). Using the rig’s topdrive, it was possible to ream out for half an hour although circulation was blocked. But then the torque required to ream exceeded the topdrive capability, and the drillstring became truly stuck. A few days were spent backing off and connecting high-shock jars to the stuck BHA. After considerable jarring, rotation and circulation were re-established and the string became free.

Detailed analysis of drilling data for the eight-hour period preceding this event gives some indication that friction is increasing, in this case probably caused by unstable formation that is falling into the hole and packing off the BHA (next page). One indication is the hook load overpull experienced while drilling each time a new stand of pipe is connected to the drillstring—connections are indicated by hook load going to zero as the string is hung in the slips. Instantaneous overpull averaged 34 klb and rose to 54 klb at 13:40 hours. Another indication of increasing friction is the sporadic spikes on the torque log, which occur more frequently near the end of the log.

Monitoring standpipe pressure and torque during the last 3.5 hours and comparing it with an earlier one-hour period yields further indications that borehole conditions are deteriorating. During the earlier period, both torque and standpipe pressure are reasonably uniform. But in the later period, there are several pressure pulses of up to 50 psi. These are thought to indicate temporary blocking of the annulus by sloughing formation. Sometimes the pulses correlate with spikes on the torque log indicating simultaneous grabbing of the BHA.

Expanded logs for the last ten minutes confirm that sticking is a likely problem. Before attempting to pull out of the hole, the driller pulled up the string over the length of a stand and then ran the string back in the hole. The difference in hook load between these two events gives a better estimate of


Analysis of a recent sticking event while pulling out of hole—Sedco Forex was drilling for TOTAL in offshore Borneo, Indonesia. Displays of hook load and elevator position versus time show two stands successfully pulled, and then the drillstring becoming stuck, with successive overpulls of over 90 klb failing to budge it. The rapid fall in hook load during the next few minutes results from the formation bearing progressively more of the weight of the BHA as it becomes trapped.

October 1991
Drilling data in the hours and minutes prior to the sticking event displayed in the previous figure. A detailed display for the last ten minutes indicates a 23-klb overpull caused by drag friction and large torsional oscillations caused by the BHA alternately sticking and slipping. Displays of standpipe pressure and torque for the period between 12.6 and 14 hours shows pressure pulses caused by temporary blocking of the annulus and torque spikes caused by the drillstring sticking. These events sometimes correlate. Compare with an earlier period, between 7 and 8 hours, when response is normal and no sticking is occurring.

Overpull than the increase in hook load experienced at connections. The difference is about 23 klb, still a considerable amount and indicative of large friction losses somewhere in the borehole. Two others signs of increasing friction come from the expanded torque log. One is the large oscillations near the beginning of the ten-minute period caused by the BHA alternately sticking and slipping. The other is the large torque at the end of the ten-minute period during which the drillstring was off bottom.

This analysis would have been impossible without the data gathering ability of a computerized information system. The challenge for researchers and engineers is to codify stuckpipe indications and manufacture more reliable alarms for the driller. This is an exciting time for such developments. Rig sensors are improving, rig-based information systems are becoming accepted and stuck pipe research continues. As these forces converge in the next few years, stuck pipe incidents may become rarer, ensuring more cost-effective drilling.

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