SUGAR LAND LEARNING CENTER

Stuck Pipe Prevention

SELF - LEARNING COURSE

USEFUL PRE-REQUISITES

“A Primer of Oilwell Drilling”
**Introduction to self-learning:**

Self-learning enables you to learn at your pace, in your time and in your way. This course book provides the content, structure and organization of your learning which would otherwise be managed by an instructor in a class. It also asks you questions to help you to confirm your understanding (as the instructor probably would). You will also find a recap section that will be useful for you to review the important points stressed in this book after your training. At the end is a glossary containing the key-words relating to the subject, and the answers to the questions.

**Structure:**

Each section contains:
- Explanation of the subject, illustrated as much as possible.
- Questions (the answers are in Appendix B).

**How to use the course book:**

- Try to do the course in a maximum of 2 hours, with a break.
- Set yourself in a suitable environment (no noise, no interruptions, etc...).
- After reading a section, use the self-test questions to confirm what you have understood. Write down the answers on a sheet of paper and check the answers at the end of the book. It is your responsibility to answer honestly. If you get an answer wrong, go back to the section indicated and review the subject.
- A few days later, or at any moment, use the recap section and the glossary to refresh your knowledge of the subject.

**Remember:**

Learning is your responsibility. This book provides you with a good preparation before the seminar to the Sugar Land Learning Center and gives you a chance to learn more by not struggling with the basics.
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Introduction

Welcome to the Stuck Pipe Prevention self learning course. Stuck pipe is one of the most important problems you will find in the oil-industry. This book will introduce you to stuck pipe, explain the different mechanisms and how to prevent stuck pipe. After completion of this self-learning course, you will find more information in the IWOB self-learning package, relating to SPIN. Also refer to the Sedco Forex “Driller’s Stuck Pipe Handbook”.

Figure 1

T1 and T2, tension: the drill pipe is always in tension when drilling.
S, side force: when 2 surfaces are in contact with a perpendicular side force acting between them, any attempt to move one surface relative to the other will result in a friction force resisting the motion.
B, buoyant weight: apparent weight of the element in the mud.

Figure 1
1. What is a “Stuck Pipe”?

Drilling a well requires a drill string (pipe & collars) to transmit the torque provided at the surface to rotate the bit, and to transmit the weight necessary to drill the formation. The driller and the directional driller steer the well by adjusting the torque, pulling and rotating the drill string.

When the drill string is no longer free to move up, down, or rotate as the driller wants it to, the drill pipe is stuck. Sticking can occur while drilling, making a connection, logging, testing, or during any kind of operation which involves leaving the equipment in the hole.

We can define:

MO, maximum overpull: the max. force that the derrick, hoisting system, or drill pipe can stand, choosing the smallest one.
BF, background friction: the amount of friction force created by the side force in the well.
FBHA: The force exerted by the sticking mechanism on the BHA (Bottom Hole Assembly)

The drill string is stuck if  \( BF + FBHA > MO \)

In other words, the drill string is stuck when the static force necessary to make it move exceeds the capabilities of the rig or the tensile strength of the drill pipe. Stuck pipe can result in breaking a part of the drill string in the hole, thus losing tools in the hole.

A few variables must be taken into account when dealing with stuck pipe: pore pressure of the formation, mud system, and the depth versus time (the longer in the hole without action, the more likely to get stuck).

The consequences of a stuck pipe are very costly. They include:

- Lost drilling time when freeing the pipe.
- Time and cost of fishing: trying to pull out of the hole the broken part of the BHA.
- Abandon the tool in the hole because it is very difficult or too expensive to remove it.
  In that case the oil company pays Anadrill to replace the tool.

To give you an idea, an average cost per well of sticking pipe is about $50 000 US. Our service is to avoid the costly loss of the BHA (bottom hole assembly) to the client. Our responsibility is to protect the Anadrill tools contained in the BHA.

**Question 1**: What is a stuck pipe?
2. Mechanisms
2.1 Differential Sticking

Differential sticking is one of the most common causes of pipe sticking. It is due to a higher pressure in the mud than in the formation fluid. Differential sticking happens when the drill collar rests against the borehole wall, sinking into the mudcake. The area of the drill collar that is embedded into the mudcake has a pressure equal to the formation pressure acting on it. The area of the drill collar that is not embedded has a pressure acting on it that is equal to the hydrostatic pressure in the drilling mud. This is shown in Fig. 2. When the hydrostatic pressure \( P_h \) in the well bore is higher than the formation pressure \( P_f \) there will be a net force pushing the collar towards the borehole wall.

Overpull due to differential pressure sticking can be calculated from the product of the differential pressure force times the friction factor:

\[
\text{Overpull} = F_{dp} f
\]

where \( F_{dp} \) = differential pressure force [psi/in\(^2\)] and \( f \) = friction factor.

The differential pressure force is the difference in hydrostatic force and the formation force acting on the drill collar. The hydrostatic force is the hydrostatic pressure times the cross sectional area that is in the borehole and the formation force is the formation pressure times the cross sectional area that the mud cake is in contact with. This is shown in Fig. 3. Note that the cross-section area is used to calculate the force but not the surface area of the drill collar. The differential pressure force is defined:

\[
F_{dp} = \left(144 \text{ in}^2 / \text{ft}^2\right) A_{mc} (P_h - P_f)
\]

where \( F_{dp} \) = differential pressure force [lbf], \( A_{mc} \) = cross section embedded in mud cake [ft\(^2\)], \( P_h \) = hydrostatic pressure [psi], and \( P_f \) = formation pressure [psi].

The friction factor depends on the formation and the drill collar surface. It varies from 0.15 to 0.50.

The hydrostatic pressure is defined:

\[
P_h = TVD \cdot \gamma = TVD \cdot \rho \cdot \frac{0.433 \text{ psi} / \text{ft}}{8.33 \text{ ppg}}
\]

where \( P_h \) = hydrostatic pressure [psi], \( TVD \) = true vertical depth [ft], \( \gamma \) = pressure gradient of the mud [psi/ft], and \( \rho \) = mud weight [ppg]. Fresh water has a density of 8.33 ppg and...
a pressure gradient of 0.433 psi/ft. Formation brine in the Gulf of Mexico is 9 ppg, which is equal to 0.47 psi/ft.

**Figure 2**  Differential sticking. $P_h$ is hydrostatic pressure and $P_f$ is formation pressure.

**Figure 3**  Hydrostatic force and formation force that are acting on the drill collar.
The formation pressure is usually not known. There is no direct way of calculating it like the hydrostatic pressure. Usually, there is an estimation of the pressure gradient for the formation that is being drilled. That value can then be used to estimate the formation pressure.

The thickness of the filter cake is critical in differential sticking. The thicker the filter cake the bigger is the cross sectional area that the formation pressure acts on (see Fig. 3). Thus, the differential sticking force is higher when the mud cake is thicker. When the well bore pressure is higher than the formation pressure some of the mud filtrate (“mud filtrate” is the liquid phase of the drilling mud) will invade the formation if it is permeable and porous. Thus, a mud cake will build up on the surface of the well bore. The thickness of the mud cake depends on the mud properties and the porosity of the formation. At a certain point the mud cake will become thick enough to act as a barrier to stop further seeping of the mud filtrate into the formation and the mud cake will then stop growing. If the mud has a lot of drill solids then the filter cake will be more porous and permeable resulting in a thicker mud cake and faster growth. The ideal situation would be a thin, hard mud cake made up of mud solids only. The danger of differential sticking is usually present in a sand. Sand formations usually have high porosity and permeability and therefore a thick mud cake tends to build up.

**Stationary pipe**

If the drill pipe is not moved for a period of time the filter cake tends to build up around it and then add to the differential sticking force that is holding the drill collars. This is shown in Fig. 4. The mud cake forms a bridge between the drill collar and the mud cake in the hole.

**Filter Cake Erosion**

Filter cake erosion happens when the drill pipe rubs against the borehole wall. This only affects a small portion of the circumference of the wellbore. Wiper trip erosion happens when the stabilizers and the bit are pulled through the mud cake and a significant amount of it is scraped off. Most of the mud cake is removed when the hole is reamed. Filter cake erosion is shown in Fig. 5.
Figure 4  Bridging occurs when the drill collar is left stationary.

Figure 5  Three types of filter cake erosion: Drill pipe erosion, wiper trip erosion, and reaming erosion.
Warning Signs

Increasing overpull in long connections.
Overpull and torque increases when drillstring is stationary for some time.
Overpull decreases after reaming.

Identification

The pipe was stationary before it got stuck.
Full circulation is possible.
BHA adjacent to thick sand.
Hydrostatic pressure overbalance.

Preventive Action

Keep track of differential pressure in sands if possible.
Don’t stop too long for a survey. If necessary continue drilling after the precursor comes up.
Keep the mud weight under control.
Use a short BHA.
Make frequent wiper trips.
2.2 Inadequate Hole Cleaning

If the cuttings are not removed from the well properly, they will settle around the drill string, usually the BHA, causing the drill collars to become stuck. The problem is worse in overgauge hole sections where the annular velocity is lower. Cuttings will build up and eventually slump in the hole.

The cuttings are scraped by the stabilizers and the bit when the BHA is moved up the hole at a connection or a trip out. The cuttings accumulate in front of the bit and stabilizers as seen in Fig. 6. The overpull will increase until the cuttings will stick the BHA.

The hole cleaning differs with the inclination of the hole. The annular velocity required to clean the hole increases with inclination. Figure 7 shows the behavior in holes at different inclinations.

Warning Signs

Insufficient cuttings on shaker.
Excessive overpull at connections and trips.
Reduced overpull when pumping.
Increase in pump pressure and pressure spikes when hole momentarily plugs up.
Pump pressure much higher than predicted using hydraulics program.

Identification

Stuck shortly after pumps are shut off.
Circulation lost.

Preventive action

Circulate all cuttings out before tripping out.
If motor is used, rotate before tripping out of hole.
Keep the pumps running. Might be impossible to take survey at the moment.
The ROP can be lowered to reduce the amount of cuttings.
Check shale shakers to see if the cuttings are being removed.
Cuttings accumulate on the low side of the hole

Cuttings accumulate above bit and stabilizers when pulling out

**Figure 6** Cuttings collect around the BHA and increase the overpull.

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Annular velocity increasing

Inclination (Degrees)

Zone 1
Efficient hole cleaning

Zone 2
Good hole cleaning with moving cutting beds

Zone 3
Slow removal of cuttings

Zone 4
Some hole cleaning, cuttings bed formed

Zone 5
No hole cleaning

**Figure 7** Flow pattern of cuttings in deviated wells.
2.3 Chemically Active Formations

Different formations have a different degree of absorbing water. It is thus important for a field engineer to understand the characteristics of the formations that have and will be drilled. Some high clay content rocks absorb water and swell. The amount of swelling varies from highly reactive “gumbo” (fast absorption rate) to shales, which absorb water very slowly.

When drilling with water based mud, the water is absorbed into these types of formations (commonly shales), causing them to swell and weaken. As a result, chunks of shale will break-off and fall into the borehole. The water-absorbed (hydrated) shale tends to stick to the drill string and accumulate in sufficient quantities to fill the entire annulus around the BHA, causing it to become stuck.

Warning Signs

Large clumps of hydrated shale (gumbo) coming out of the hole.
Drilling rate is slower as less weight gets to the bit.
BHA packed off with gumbo (inspected at trips).
Increase in pump pressure.
Increase in torque as the hole size is reduced due to swelling.

Identification

Cannot circulate mud.
Sticking can occur during any operation while in open hole.

Preventive Action

Minimize time in open hole.
Maintain mud inhibitors at high enough levels.
Minimize length of BHA and open hole sections.
Avoid additional open hole operation such as wireline logging, survey runs, etc.
Figure 8  Migration of water into the formation, causing the swelled shale to collapse and accumulate around the BHA.
2.4 Mechanical Stability

It can be difficult to determine whether swelling shale is primarily due to a chemical imbalance or mechanical stability, or even a little bit of both.

Before the drill bit enters a section of the hole, the rock supports three unequal stresses in four different directions. These are:

1. Vertical Stresses: At depths greater than 1,500 feet, the largest stress on a rock formation is usually the stress imposed on it from the weight of all material above it, which acts in the vertical direction. A typical value of these stresses are 1.0 psi/ft.
2. Side Stresses: The side stresses which act in the horizontal component in both directions. A typical value of these stresses is 0.75 psi/ft.

The drilling process effectively replaces the cylinder of rock with mud. Usually, the mud weight is balanced to the pore pressure of the formation, however in some instances the mud weight cannot totally support the borehole pressure. The rock around the borehole is forced to act as extra support.

If the formation is strong, then there will be no problem. However, in younger formations, where the rock is not strong, the rock will not be able to support this extra stress. The rock will deform and the wellbore will begin to contract in a small amount.

Warning Signs

Large cuttings, low shale strength.
Tight hole over long sections during trip.
Large overpulls due to cavings.
Increase in pump pressure due to cavings in borehole.
Slower drilling rate.

Identification

Circulation restricted or impossible.
Sticking can occur during any operation while in open hole.

Preventive Action

Gradually increase mud weight.
Follow hole cleaning procedures.
Complete each hole section fast, therefore minimize time in hole.
Figure 9  Insufficient mud weight to keep the hole from contracting
2.5 Fractured/Faulted Formation.

A natural fracture system in the rock can often be found near faults. Rock near faults can be broken into large or small pieces. If they are loose they can fall into the well bore and jam the string in the hole (Fig. 10). Even if the pieces are bonded together, impacts from the BHA due to drill string vibration can cause the formation to fall into the well bore. This type of sticking is particularly unusual in that stuck pipe can occur while drilling. When this has happened in the past, the first sign of a problem has been the string torquing up and sticking. There is a risk of sticking in fractured/faulted formation when drilling through a fault and when drilling through fractured limestone formations.

Warning Signs

Hole fill on connections.
Possible losses or gains.
Fault damaged cavings at shakers.
Increase in pump pressure.

Identification

Sticking can be instantaneous.
Circulation restricted or impossible.

Preventative Action

Minimise drill string vibration. Choose an alternative RPM or change the BHA configuration if high shock vibrations are observed.
Slow the trip speed before the BHA enters a suspected fractured/faulted area.
Generally, fractured formations require time to stabilise. Be prepared to spend time when initially drilling and reaming prior to making significant further progress.
Circulate the hole clean before drilling ahead
Start/stop the drill string slowly to avoid pressure surges to the well bore.
Anticipate reaming during trips. Ream fractured zones cautiously.
Figure 10 Fractured/Faulted Formation.
2.6 Overpressured Formations

A different type of instability occurs when the formation pressure exceeds the mud hydrostatic pressure. In this case the rock is able to support the extra stresses when the drill bit has passed. An additional stress is applied to the rock if the hydrostatic pressure is less than the formation pore pressure. The formation in this case will tend to "pop" or "heave" into the wellbore. The shale pieces can sufficiently accumulate to pack off the BHA and cause sticking.

The heaving shale condition occur only when no permeable sand is present, since permeable sand with a higher pore pressure than mud pressure would cause a kick.

Warning Signs

Large, brittle, concave shaped carvings.
Recently crossed a fault.
Absence of permeable formations.
Large overpulls at connections.
Restricted circulation due to cavings loading the annulus.
Torque may increase.

Identification

Circulation restricted or impossible.
Stuck shortly after pumps off.

Preventative Action

Monitor all cuttings, be on a lookout for large concave shale pieces.
Monitor Rate of Penetration (ROP - Drilling Rate).
Follow hole cleaning procedures.
Figure 11  Heaving shale due to pressure in the formation being higher than in the mud.
2.7 High Dip Sloughing

Highly fractured shale section in areas with steeply dipping beds can cause sloughing problems. In a formation where there is little or no dip, the clay platelets lie horizontally. The shear direction for these platelets are also on a horizontal plane also. Gravity and mud flow will act in a perpendicular direction to the shear plane, which means that these platelets are less likely to break free and slough into the hole.

With a high dip (>60°), the forces of gravity and mud flow will have a significant component in the shear direction. In areas where the shale is not very strong, these forces can be large enough to cause significant sloughing.

Warning Signs

Hole fill after trips.
Large increase in overpull when pumps are off.
Large, fat cutting.
Increase in pump pressure.
Presence of large faults.
Torque may increase.

Identification

Cannot circulate mud.
Stuck shortly after pumps are turned off.

Preventative Action

Ask geologist what the dip angle is for the upcoming well.
Minimize time in open hole.
Minimize length of BHA and open hole section.
Figure 12  Comparison of a high and low dip with regard to hole sloughing.
2.8 Unconsolidated Formations

Loosely compacted sands and gravel can sometime collapse into the wellbore forming a bridge (Fig. 13).

Warning Signs

Large overpulls at connections.
Unconsolidated, uncemented sand in sample.
Increase in pump pressure.

Stuck Identification

Circulation restricted or impossible.
Stuck shortly after pumps are turned off.

Preventive Actions

Identify sand or porous formations.
Maintain a high gel mud in the slug tank.
Monitor pump pressure and drill cuttings.
Pick off bottom and circulate.
Figure 13  Unconsolidated Formations
2.9 Mobile Formations

A salt or wet shale can extrude or “flow” into the wellbore and bridge off the annulus causing a stuck drillstring. The overburden stress from the rock above will tend to squeeze the salt out into the wellbore like toothpaste from a tube (Fig .14).

Warning Signs

Increase in mud chlorides.
Large overpulls at connections.
Pump pressure increase.

Stuck Identification

Stuck shortly after pumps are turned off.
Rotation may be possible but with high torque.

Preventive Actions

Identify salt dome.
Monitor mud chlorides and mud resistivity.
Trip in slowly and ream.
Figure 14 Mobile Formations
2.10 Undergauge Hole

Undergauge hole occurs when the gauge protection on the bit has become ineffective through drilling long sections of abrasive formations. If care is not taken when tripping in the new bit, it can become jammed in the undergauge hole (Fig. 15).

Warning Signs

Undergauged bit and stabilizers.
Low ROP.

Stuck Identification

Stuck while tripping into hole.
Circulation unrestricted.

Preventive Actions

Identify abrasive, hard formations.
Trip in slowly.
Ream the hole.
Figure 15  Undergauge Hole
2.11 Key Seating

A key seat is caused by the drill string rubbing against the formation in doglegs. The body and tool joints of drill pipe wear a groove in the rock about the same diameter as the tool joints (Fig. 16). During a trip out of the hole, the BHA may be pulled into one of these grooves, which may be too small for it to pass through. This type of sticking is likely to happen in a soft formation while dropping angle. Anyway, it is not the only possibility.

Warning Signs

Large doglegs.
Erratic overpull.

Stuck Identification

Stuck while tripping out.
Circulation unaffected.

Preventive Actions

Avoid severe doglegs.
Incorporate key seat wiper into BHA.
Figure 16  Key Seating
2.12 Wellbore Geometry

**Ledge**: The well bore passes through rock of varying types and ledges develop at the interfaces between layers of differing hardness (Fig. 17).

**Doglegs**: While drilling a well bore, the characteristics of the rock cause the bit to be deflected and can result in a change in direction. Likewise when drilling with a directional BHA, sudden changes in angle can cause a kink in the well bore direction. Sharp deviations in wellbore direction are called doglegs. High doglegs can result in drilling assemblies becoming stuck, especially if they are locked up.

**Warning Signs**

Sudden erratic overpull or setdown.
Problems are at fixed depths.
Prognosed hard soft interbedded formations.

**Stuck Identification**

Full circulation is possible.
Stuck after a change in BHA.
Stuck while POOH.

**Preventive Actions**

Ledging will be reduced by running a packed hole assembly.
Minimise direction changes in the well bore.
Minimise BHA configuration changes when in formations likely to produce ledges.
Consider reaming trips.
Make a log of depths of ledges and other anomalies. It can help to get a large scale log from the mud loggers or MWD engineer and to draw a scale BHA on a separate piece of paper. The paper BHA can be positioned at the depth of any overpulls and it is easy to see if any of the stabilisers are hanging up at the same point. By using this technique it is simple to keep track of multiple problem zones and to communicate expected problem depths clearly to the driller.
Survey with sufficient frequency. Increasing the well bore survey frequency will:
- assist in evaluating/reducing well bore tortuosity.
- reduce the number of BHA changes.
Slow trip speeds before BHA enters the suspected ledge zone or dog leg.
Avoid prolonged circulation across soft interbedded formations. Limit initial setdown weight to less than 50% of down drag to minimise momentum effects when running into a tight zone. Do not start angle building operations too close to the shoe (start at least 30m below old hole TD).

Figure 17  Ledges formed at formation boundaries.

Figure 18  High doglegs stick the BHA while POOH.
2.13 Junk

Debris that has fallen into the hole from surface or from downhole equipment, which falls down the well bore and jams the drill string. This mechanism usually occurs:
- Due to poor housekeeping on the rig floor.
- Due to the hole cover not being installed.
- Downhole equipment failure.

Warning Signs

Repair/maintenance work recently performed on the rig floor.
Missing hand tools / equipment.
Metal shavings at shaker.
Sudden erratic torque.
Inability to make hole.

Stuck Identification

Circulation unrestricted.
Stuck shortly after downhole equipment failure.

Preventive Actions

Encourage good housekeeping on the rig floor and regular inspection of handling equipment.
Keep the hole covered at all times.
Inspect downhole equipment before it is run in the hole and again as it is being run through the rotary table.
Inspect slip and tong dies regularly.
Install drill string wiper rubber as quickly as possible.
2.14 Collapsed Casing

Casing collapses either if pressure conditions exceed its original rated collapse pressure or the original collapse pressure rating of the casing is no longer valid due to casing wear and/or corrosion. Casing wear due to friction or corrosion decreases the effective collapse pressure rating of the casing, through decreased wall thickness. Collapse is often discovered when the BHA is run into the hole and hangs up inside the casing.

This mechanism can occur when:
· The collapse pressure of the casing is exceeded during a pressure test where an annulus leak is occurring. The collapse pressure of the casing may be less than expected, due to casing wear.
· The casing fluid is evacuated, causing the casing to collapse.
· The casing is buckled due to aggressive running procedures.

Warning Signs

BHA hangs up when RIH.
Caliper log shows collapsed casing.

Stuck Identification

Stuck while tripping through casing.

Preventive Actions

Avoid casing wear, refer to casing wear guidelines.
Good cementing practices should be used. Cement to surface or as high as possible.
Use corrosion inhibitors in fluids.
2.15 Cement related

2.15.1 Cement Blocks
The drill string becomes jammed in the hole by cement blocks falling around the string. This mechanism normally occurs when hard cement becomes unstable around the casing shoe, open hole squeeze plugs and kick-off plugs.

Warning Signs
Large cement fragments at shakers.

Stuck Identification
Circulation unrestricted.
Rotation and downward movement may be possible.
Erratic torque.

Preventive Actions
Allow sufficient curing time for cement before attempting to kick off or drillout.
Ream casing shoe and open hole plugs thoroughly before drilling ahead.
Limit casing rathole length to minimise a source of cement blocks.
Slow the trip speed down before the BHA enters the casing shoe or the plug depth.
Use of fibre additives to the cement can increase its integrity.
Maintain sufficient distance between the paths of platform wells to reduce the possibility of cement blocks from adjacent well bores.
2.15.2 Green Cement
When the drill string is inadvertently run into cement, the cement can flashset. The top of the cement may be higher than prognosed. The increase in pressure generated by the surge of the BHA causes the cement to flash set. Circulation is attempted with the bottom of the drill string in soft cement. The increase in pressure causes the cement to flash set. A high penetration rate is used when cleaning out recently set cement, below which is un-set cement which flash sets.

Warning Signs

Increase in pump pressure leading to inability to circulate.
Loss of string weight.
Sudden decrease in torque.
Green cement in mud returns, discoloration of mud.

Stuck Identification

Stuck while running into the hole to dress off cement.

Preventive Actions

Do not rely solely on surface samples. Know the cement setting time, but do not assume it will be set when you trip in to the hole.
Know the calculated top of cement (TOC) before tripping in hole but always expect it to be higher. Do not rely on the weight indicator to find the top of the cement. If the cement is not set you may not see any indication on the weight indicator when you run into it. In large hole sizes begin washing down two stands above the theoretical top of the cement. Consider starting to ‘wash through’ 3-4 stands above the theoretical cement top in small hole sizes. If set down weight is observed when tripping in hole after a cement operation, pull back 2 stands before attempting circulation.
Control drill when cleaning out soft cement.
Consider pre-treating the mud system with chemicals prior to drilling out the cement.
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Questions: Mechanisms

**Question 2:** What is the pressure gradient and the hydrostatic pressure at TVD 8,000 ft and mud weight of 12 ppg?

**Question 3:** Drill collar has embedded into the mud cake in a 60 ft thick sand formation at 14,000 ft depth. The drill pipe was left stationary for some time and bridging occurred. The diameter of the drill collars is 7 in and 60° of the collars is embedded. The mud weight is 12.6 ppg and the estimated formation pressure in the sand is 8,700 psi. The friction factor is 0.2. Calculate the hydrostatic pressure at this depth and the overpull needed to free the pipe.

**Question 4:** If a pipe is not moved for a while, would that make the differential sticking more serious.

**Question 5:** Name the three types of filter cake erosion.

**Question 6:** How do you expect the mud characteristic to change when you are drilling with water based mud in a swelling shale zone?

**Question 7:** What type of mud would you recommend when dealing with swelling shale formations?

**Question 8:** Knowing that the Vertical Stress due to the weight of rock at depths greater than 1,500 feet is 1.0 psi/ft, and the corresponding side stress is 0.75 psi/ft, (a) complete the following diagram for vertical and horizontal wells, and (b) in which section of hole would you need the heavier mud?

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Revised: December 1999
Question 9: From analyzing the type of cuttings and material which are coming out of the borehole, how can you tell the difference between stuck pipe that is caused by chemically active formation, mechanical instability, or overpressured formations?

Question 10: What happens when you penetrate a permeable sand layer when the pore pressure is greater than the mud pressure?

Question 11: What can be done to prevent stuck pipe when drilling through a formation with a high dip (>60°)?

Question 12: When are the “Unconsolidated Formations” and “Mobile Formations Stuck” likely to happen?

Question 13: Is circulation useful for “Key Seating Stuck”?
3. Prevention
3.1 Planning

Currently, Anadrill has little involvement in the planning stage of the well unless directional drilling services are provided. As a result, many of the recommendations presented here may be difficult to fully implement.

3.1.1 Data from offset wells

Before planning the well, all persons involved in the process should collect data from offset wells. An offset well is a well drilled in the vicinity of other wells. They offer a wealth of information that can be used for correlation with the current planning of the new well.

For that purpose, the following should be noted:

- The permeable, unconsolidated formations and salt zones. The depth and thickness of these sticky formations should be noted along with the mud properties used.
- Record of key seating along with associated dogleg severity and ROP through the section.
- Formations that caused circulation problems and the mud weights used.
- Record of any hole cleaning problems with associated solutions.

3.1.2 Planning

- When planning in addition of the data provided by offset wells, the following should be applied.
- Identification of the potential troublesome formations and any special procedures adopted through these zones.
- A top drive is recommended for known sticking areas since top drives have been very successful in reducing tight holes problems (back reaming is possible).
- Careful BHA design with special attention to keeping the BHA length short and the OD (outside diameter) of the BHA collars to a minimum.
- Careful mud design and planned mud weight help to keep the hole in optimum condition.
- A hydraulic program should be run for the planned BHAs and hole sizes.
- Choose properly the depth for setting casing according to formations.
3.1.3 Rig operating guidelines

These are some useful practices that can prevent stuck pipe:

- Keep the drill string moving as much as possible in open hole.
- Forcing the string through a tight spot may lead to the string becoming stuck.
- Minimize the time spent in the hole. Any rig repair should be done with the drillstring inside the casing.
- Wiper trips should be made regularly according to predetermined procedures as the hole conditions dictates.
- On floating rigs, the motion compensator should be well maintained to prevent sudden movements of the drill string.

3.2 Monitoring at the Well site

There are several measurements which can be monitored by the drilling team to avoid stuck pipe. It is the responsibility of Anadrill engineers to confirm a sticking condition. They have to be able to communicate in a clear and simple way.

3.2.1 Primary Sticking Measurement.

OVERPULL: Over pull is a primary measurement of sticking. It is the maximum tensile strength of the drill pipe. It means that if the force necessary to free the drill string exceeds this force, we are STUCK.

\[
OVERPULL = \text{Hookload while moving the Drillstring up} + \text{Total Hookload}
\]

So it is very important to monitor this measurement. However, we must take in consideration the fluctuation, as well as the magnitude. The next 2 log examples are from a 20 deg slant well. They show how overpull can be monitored while drilling. The overpull of the drill string was 200 klbs.

The first example show how increasing overpull at connection results in stuck pipe. Between section c300 and c650 ft, the over pull was averaged at 90 klbs which is high for this section. At 650 ft the over pull increased to 130 klbs and stayed at this level until the drill string become sticking at 750 ft. By monitoring this measurement in real time, we could have start taking preventive action when we reached 90 klbs.

Notice that the average overpull of 130 klbs was significantly less than the maximum overpull of the drill string.

The second example shows how overpull can be monitored while tripping out of the hole to detect sticking.
OVERPULL = Hookload With Drillstring Moving Up -Theoretical Hookload \hspace{1cm} (5)

The theoretical hookload is the weight of the drillstring in the current wellbore. The trip out of the hole began at d250 ft; the overpull increased at 475 ft but fluctuated after around 100 klbs until c950 ft where it rose to 140 klbs and got stuck. As you can see, by monitoring in real time this measurement we can avoid getting stuck.
TORQUE: Torque is a primary measure of sticking. It increases gradually with depth. A sudden increase in torque can mean a severe dogleg or abnormal sticking forces on the BHA, but don’t forget that it can mean other down hole status such as changes in formation, increase in weight or a cone locking.

The next example is also from the same 20° slant well. At 850 ft, an increase from 7.5 to 8.5 klbs is noticed in surface torque. This is due to increased surface weight which probably induced an increase in bit torque. The drillstring then slid for 60 ft. When rotating again, the surface torque remains the same in the range of 8.5 to 9 kft lbs for the remainder of the bit run. At e100 the drillstring got stuck when attempting to wiper trip.

Running DWOB sub or IWOB permits to calculate $\Delta$-torque which helps us to eliminate bit effects and focus on BHA sticking.

$$\Delta \text{TORQUE} = \text{SURFACE TORQUE} - \text{DOWNHOLE TORQUE} \quad (6)$$

We can see on the $\Delta$-torque log, that from d950 to e100 ft $\Delta$torque is higher than previously, indicating abnormal sticking forces on the BHA.

The Anadrill engineer can help preventing sticking situation by running SPIN which provides both DRAG and FRIC factors any time the drillstring is moving, encompassing all drilling operations.
Questions: Prevention

**Question 14:** What is an offset well?

**Question 15:** What are the data to look for in offsets wells when planning a well?

**Question 16:** List 3 parameters to consider when planning a well.

**Question 17:** List 3 useful practices that can prevent stuck pipe.
4. Recap section


4.1 Summary

**Question:** When is pipe considered stuck?

**Answer:** When it is restricted to move up, down or rotate as the driller wants it to do, and this can occur during ANY TIME during the drilling process.

**Major Variables:**
- pore pressure of the formation
- mud systems
- depth versus time in the hole

**Consequences:**
- lost drilling time to free the pipe
- time and cost to fish the pipe
- tool abandonment in the hole due to difficult and expensive fishing operations

**Responsibility:**
- avoid a costly loss of a BHA to the client by using a BHA design that is simple and effective, and not complicated if it does not need to be
- avoid costs and lost time by implementing preventative methods when the signs of sticking do appear at the rigsite

**Question:** How can the problem be solved before it has a chance to occur?

**Answer:** By simply implementing good planning objectives by:
- looking at data from offset wells such as formations encountered, records of previous sticking and other hole problems
- careful design of the drilling program such as BHA design and mud systems
- preventative practices on the rig such as wiper trips, reaming and minimal time spent in the hole
- careful monitoring of drilling operations such as cuttings, torque and pump pressure increases

The following is a simplified table of stuck pipe and their respective prevention’s. This should only be used as a reference, and not as a true justification for you to identify stuck pipe as experience with stuck pipe also plays an important role in the identification and prevention process.
### Table 4.1

#### 4.1.1 Differential Sticking

<table>
<thead>
<tr>
<th>WARNING SIGNS/CONDITIONS</th>
<th>PREVENTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>-increasing overpull at connections</td>
<td>-if stationary continue drilling as soon as possible</td>
</tr>
<tr>
<td>-circulation possible</td>
<td>-frequent wiper trips</td>
</tr>
<tr>
<td>-increase in torque</td>
<td>-controlled mud weight</td>
</tr>
<tr>
<td>-decreasing overpull after reaming</td>
<td>-minimal length BHA’s</td>
</tr>
<tr>
<td>-overbalanced conditions</td>
<td></td>
</tr>
<tr>
<td>-stationary pipe before sticking</td>
<td></td>
</tr>
<tr>
<td>-BHA adjacent to a thick sand</td>
<td></td>
</tr>
</tbody>
</table>

#### 4.1.2 Inadequate Hole Cleaning

<table>
<thead>
<tr>
<th>WARNING SIGNS/CONDITIONS</th>
<th>PREVENTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>-increase in pump pressure/pressure spikes</td>
<td>-with motors, rotate before tripping out of the hole</td>
</tr>
<tr>
<td>-reduced overall pull when pumping</td>
<td>-circulate bottoms up</td>
</tr>
<tr>
<td>-insufficient cuttings on shaker</td>
<td>-keep the pumps running</td>
</tr>
<tr>
<td>-excessive overpull on connections and trips</td>
<td>-lower the ROP-less cuttings</td>
</tr>
<tr>
<td>-lost circulation</td>
<td>-removal of cuttings from the shaker</td>
</tr>
<tr>
<td>-stuck shortly after pumps off</td>
<td></td>
</tr>
</tbody>
</table>

#### 4.1.3 Chemically Active Formation

<table>
<thead>
<tr>
<th>WARNING SIGNS/CONDITIONS</th>
<th>PREVENTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>-large clumps of gumbo at surface</td>
<td>-minimize the time in the hole</td>
</tr>
<tr>
<td>-slower drilling due to less WOB</td>
<td>-mud inhibitor at high levels</td>
</tr>
<tr>
<td>-BHA packed off with gumbo</td>
<td>-minimal length BHA’s</td>
</tr>
<tr>
<td>-pump pressure increases</td>
<td>-minimal open hole sections</td>
</tr>
<tr>
<td>-torque increase due to smaller hole size as a result of swelling</td>
<td>-avoid other open hole operations</td>
</tr>
<tr>
<td>-circulation not possible</td>
<td></td>
</tr>
</tbody>
</table>
4.1.4 Mechanical Stability

<table>
<thead>
<tr>
<th>WARNING SIGNS/CONDITIONS</th>
<th>PREVENTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>-large cuttings, low shale strength</td>
<td>-gradually increase the mud weight</td>
</tr>
<tr>
<td>-tight hole over a long section</td>
<td>-hole cleaning procedures</td>
</tr>
<tr>
<td>-large overpull due to cave ins</td>
<td>-minimal time in open hole</td>
</tr>
<tr>
<td>-pump pressure increases</td>
<td></td>
</tr>
<tr>
<td>-slower drilling rates</td>
<td></td>
</tr>
<tr>
<td>-no circulation</td>
<td></td>
</tr>
</tbody>
</table>

4.1.5 Fractured/Faulted Formations

<table>
<thead>
<tr>
<th>WARNING SIGNS/CONDITIONS</th>
<th>PREVENTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>-large blocky cuttings</td>
<td>-minimise drillstring vibration</td>
</tr>
<tr>
<td>-hole fill on connections</td>
<td>-hole cleaning procedures</td>
</tr>
<tr>
<td>-possible losses or gains</td>
<td>-slow trip speed through suspected fractured/faulted zones</td>
</tr>
</tbody>
</table>

4.1.6 Overpressured Formations

<table>
<thead>
<tr>
<th>WARNING SIGNS/CONDITIONS</th>
<th>PREVENTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>-large, brittle, concave cuttings</td>
<td>-monitor cuttings and ROP</td>
</tr>
<tr>
<td>-large overpulls at connections</td>
<td>-hole cleaning procedures</td>
</tr>
<tr>
<td>-restricted/no circulation</td>
<td></td>
</tr>
<tr>
<td>-torque may increase</td>
<td></td>
</tr>
<tr>
<td>-stuck shortly after pumps are off</td>
<td></td>
</tr>
</tbody>
</table>
4.1.7 High Dip Sloughing

<table>
<thead>
<tr>
<th>WARNING SIGNS/CONDITIONS</th>
<th>PREVENTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>-hole fill after trips</td>
<td>-minimal BHA length</td>
</tr>
<tr>
<td>-increase in overpull when pumps off</td>
<td>-obtain geologist’s dip angle for the well</td>
</tr>
<tr>
<td>-large, fat cuttings</td>
<td>-minimal open hole sections</td>
</tr>
<tr>
<td>-increase in pump pressure</td>
<td>-minimal time in the hole</td>
</tr>
<tr>
<td>-torque may increase</td>
<td></td>
</tr>
<tr>
<td>-no circulation</td>
<td></td>
</tr>
<tr>
<td>-stuck shortly after pumps are off</td>
<td></td>
</tr>
</tbody>
</table>

4.1.8 Unconsolidated Formations

<table>
<thead>
<tr>
<th>WARNING SIGNS/CONDITIONS</th>
<th>PREVENTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>-large overpull at connections</td>
<td>-identify the formation</td>
</tr>
<tr>
<td>-increase in pump pressure</td>
<td>-monitor pressures and the cuttings</td>
</tr>
<tr>
<td>-stuck shortly after pumps off</td>
<td>-high gel mud</td>
</tr>
<tr>
<td>-unconsolidated, uncemented sands in samples, no circulation</td>
<td>-come off bottom and circulate</td>
</tr>
</tbody>
</table>

4.1.9 Mobile Formations

<table>
<thead>
<tr>
<th>WARNING SIGNS/CONDITIONS</th>
<th>PREVENTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>-mud chlorides increase</td>
<td>-identify salt domes</td>
</tr>
<tr>
<td>-large overpulls at connections</td>
<td>-monitor mud chlorides</td>
</tr>
<tr>
<td>-pump pressure increases</td>
<td>-monitor mud resistivity</td>
</tr>
<tr>
<td>-rotation possible, but high torque</td>
<td>-slow trips and reaming</td>
</tr>
<tr>
<td>-stuck shortly after pumps are off</td>
<td></td>
</tr>
</tbody>
</table>

4.1.10 Undergauge Holes
## 4.1.11 Key Seating

<table>
<thead>
<tr>
<th>WARNING SIGNS/CONDITIONS</th>
<th>PREVENTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>-large doglegs</td>
<td>-avoid severe hole deviation</td>
</tr>
<tr>
<td>-erratic overpull</td>
<td>-install key seat wipers in the BHA</td>
</tr>
<tr>
<td>-stuck while tripping in or out</td>
<td></td>
</tr>
<tr>
<td>-highly deviated wells</td>
<td></td>
</tr>
<tr>
<td>-circulation possible</td>
<td></td>
</tr>
</tbody>
</table>

## 4.1.12 Wellbore Geometry

<table>
<thead>
<tr>
<th>WARNING SIGNS/CONDITIONS</th>
<th>PREVENTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>-sudden erratic overpull or setdown</td>
<td>-avoid severe hole deviation</td>
</tr>
<tr>
<td>-problems at fixed depths</td>
<td>-ream the hole</td>
</tr>
<tr>
<td>-stuck after BHA change</td>
<td>-minimise BHA configuration changes</td>
</tr>
<tr>
<td>-stuck while tripping out</td>
<td></td>
</tr>
</tbody>
</table>
4.1.13 Junk

<table>
<thead>
<tr>
<th>WARNING SIGNS/CONDITIONS</th>
<th>PREVENTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>missing handtools or equipment</td>
<td>-good rigfloor housekeeping</td>
</tr>
<tr>
<td>metal shavings at shakers</td>
<td>-inspect equipment before RIH</td>
</tr>
<tr>
<td>sudden erratic torque</td>
<td></td>
</tr>
<tr>
<td>stuck shortly after downhole equipment failure</td>
<td></td>
</tr>
</tbody>
</table>

4.1.14 Collapsed Casing

<table>
<thead>
<tr>
<th>WARNING SIGNS/CONDITIONS</th>
<th>PREVENTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>BHA hangs up when RIH</td>
<td>-avoid casing wear</td>
</tr>
<tr>
<td>caliper log shows collapsed casing</td>
<td>-good cementing practices</td>
</tr>
</tbody>
</table>

4.1.15 Cement Blocks

<table>
<thead>
<tr>
<th>WARNING SIGNS/CONDITIONS</th>
<th>PREVENTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>cement fragments at shakers</td>
<td>-allow sufficient curing time for cement</td>
</tr>
<tr>
<td>erratic torque</td>
<td>-good cementing practices</td>
</tr>
</tbody>
</table>

4.1.16 Green Cement

<table>
<thead>
<tr>
<th>WARNING SIGNS/CONDITIONS</th>
<th>PREVENTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>green cement in mud returns</td>
<td>-allow sufficient curing time for cement</td>
</tr>
<tr>
<td></td>
<td>-good cementing practices</td>
</tr>
</tbody>
</table>
Appendix A : Glossary

BHA : Bottom Hole Assembly.

Dogleg : bend of the well hole, measured in Deg/100 ft.

Gumbo : Highly reactive swelling shale.

Inhibitors : Chemical additives for changing mud properties, they include:
- Calcium based muds (lime, gypsum, or calcium chloride).
- Potassium based muds.
- Magnesium based muds.
- Polymer muds.
- Oil-based muds.

Kick : when formation fluids go into the mud because of a too low mud pressure. Uncontrolled, it can result in a blow-out.

Overpull : Hookload while moving the drillstring up - Total Hookload (force required to pull drillstring out of hole to overcome friction).

Sloughing : a condition wherein shale which has absorbed water from the drilling fluid expands, sloughs off and falls down the hole.

Unconsolidated : not consolidated, soft, loose.

Wet Shale : shale formation rich in water.
Appendix B : Answers to Questions

Question 1: The drill string is stuck when the static force necessary to make it move exceeds the capabilities of the rig or the tensile strength of the drill pipe.

Question 2: Hydrostatic pressure = (8,000 ft)(0.62 psi / ft) = 4,990 psi

Question 3: Using Eq. 2.3:

\[
\text{Hydrostatic pressure} = (14,000 \text{ ft})(12.6 \text{ ppg})\left(\frac{0.433 \text{ psi} / \text{ ft}}{8.33 \text{ ppg}}\right) = 9,169 \text{ psi}
\]

Width of cross section embedded = \(2\left(\frac{7 \text{ in}}{2}\right)\sin\left(\frac{60^\circ}{2}\right) = 3.5 \text{ in}\)

\[
F_{dp} = (3.5 \text{ in})(60 \text{ ft})(12 \text{ in} / \text{ ft})(9,169 \text{ psi} - 8,700 \text{ psi}) = 1182 \text{ kip}
\]

Overpull = 1182 kip * 0.2 = 236 kip

Question 4: Yes, because it gives time for the mudcake to build up and bridging will also increase the problem.

Question 5: Drill pipe erosion, wiper trip erosion, and reaming erosion.

Question 6: The return mud flow will be more viscous than the entering mud flow, as water from the mud is absorbed by the formation.

Question 7: Oil-Based Mud (OBM).

Question 8: Vertical Well - all 0.75 psi/ft; Horizontal Well - Side Stress = 0.75 psi/ft, Vertical Stress = 1.0 psi/ft; Horizontal section will need the heavier mud.

Question 9: Chemically active formations - large clumps of gumbo (sticky shale); Mechanical Instability - large cuttings, low shale strength; Overpressure - large brittle, concave shaped cavings.

Question 10: A kick will result.

Question 11: Minimize time in hole; Follow hole cleaning procedures; try increasing the mud weight in increments and observe cuttings; clean out excess fill before drilling ahead; plan on using mud additives such as blown asphalt and gilsonite to prevent shearing, since they invade the cracks and strengthen the formation.
Question 12: Shortly after pumps are turned off.

Question 13: No, circulation does not help.

Question 14: An offset a well drilled in the vicinity of other wells

Question 15:
- The permeable, unconsolidated formations and salt zones.
- Record of key seating along with associated dogleg severity and ROP through the section.
- Formations that caused circulation problems and the mud weights used.
- Record of any hole cleaning problems with associated solutions.

Question 16:
- Identification of the potential troublesome formations.
- A top drive is recommended for known sticking areas.
- Careful BHA design.
- Careful mud design and planned mud weight.
- Choose properly the depth for setting casing according formation.

Question 17:
- Keep the drill string moving as much as possible in open hole.
- Forcing the string through a tight spot may lead to the string becoming stuck.
- Minimize the time spent in the hole. Any rig repair should be done inside casing.