Avoiding Differential Sticking While Drilling Depleted Sands

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Introduction

More and more we have to drill depleted sands. Early production in fields was taken from the shallowest take points. Now, many years later, we have deeper targets that can only be accessed by penetrating the shallower, depleted sands. These are true hazards that should be avoided if it is possible to change the trajectory of the wellbore to somehow not penetrate the depleted sands. This paper will address the times that this isn't possible and we want to avoid differential sticking while drilling depleted sands.

Best Practices

First always keep the pipe moving. If not up and down then rotate. It seems as soon as a connection takes longer than normal; your stuck. If you have a rig available that can drill stands (top drive), use it because there will be fewer connections and less chance to get stuck. When not moving and pumping wall cake builds up and wall contact is possible. Note that if there is wall contact with moving pipe, the dynamic coefficient of friction is often less than half of the friction force of static pipe. Also because of rotation there is a layer of moving fluid always between the pipe/collars and the hole preventing contact, suction and pinning of the pipe to the wall. If there is a problem and work must stop, ROTATE or WORK THE PIPE UP and DOWN. If you leave it still it will be stuck.

Trying to touch on the keys to minimize differential sticking is decrease the wall contact area. This can be done by decreasing the OD of the BHA and/or increasing the size of the hole. Also the design of the BHA can be a design that minimizes contact. Spiral flex collars can have 25% of the contact of regular drill collars. This will mean 25% of the pinning force available to grab the pipe.

Decrease the filter cake. This can be done in various ways. Contact your drilling mud professional.

Decrease the amount of differential from the mud hydrostatic and the formation pressure. This means being prepared to drill with less overbalance if possible. Managed Pressure Drilling (MPD) or Underbalanced Drilling (UBD) accomplishes this.

Have the best methods to free pipe ready to use. Conventially the first thing to do upon being differentially stuck is to slump the pipe downward

and rotate (the natural thing for an inexperienced hand though is to pull up). Next, if well control and stability conditions allow, U-tube the pipe to take differential pressure off the stuck point. Next spot an agent downhole to eat at the wall cake and lubricate at the stuck point.
Have the jars configured correctly. If the mechanism most likely is differential sticking then design the jars position in the BHA to provide maximum impulse force that will mean movement that is needed to get the BHA off the side of the hole and the suction there.
Use the jars correctly. Some consider that putting torque and jarring down when differentially stuck is the best way to get free. If using combined loading (overpull or compression and torque) keep in mind that the tensile and compressional loading of the pipe are diminished. Use the correct combined loading equations carefully. These equations can be found in API RP 7 G.
Keep mud weights as light as possible (see #4).
Keep differential low with LCM that is designed properly and will plug in the pore throats and not make a thick wall cake. A thick wall cake is like a suction cup and you will be stuck.
There are two methods of losing mud: Darcy flow through the permeability of the sand and the pressure differential across the sand face AND actual fracture of the sand. Be aware that there are two different mechanisms and two different ways to cure this with LCM designs. Flow through the permeability of the sand with material that plugs of the flow paths and essentially lowers the permeability (k) of the sand near the wellbore and screening out a fracture tip are two different phenomenon. This first must be understood clearly in order to plan and strategize with operational tactics designed to solve TWO DIFFERENT ISSUES with one common surface manifestation; loss of drilling mud. The literature has numerous methods for plugging permeability and plugging tensile fractures. Know ahead of time which one of these is most likely or if both are likely be prepared to use dual methods. You can calculate how much depletion will cause how much loss from permeable flow using Darcy's equation. You will need the pressure differential of the mud hydrostatic and the current sand pressure and also permeability.

Look at Darcy's equation and remember that most of the time while drilling there is an overbalance and so Darcy Flow into sand is possible. Darcy's law is used extensively in petroleum engineering to determine the flow through permeable media - the most simple of which is for a one dimensional, homogeneous rock formation with a fluid of constant viscosity.

$$Q = \frac{kA}{\mu L}\left(\frac{\partial P}{\partial L}\right)$$

Where Q is the flowrate of the formation (in units of volume per unit time), k is the relative permeability of the formation (typically in millidarcies), A is the cross-sectional area of the formation, μ is the viscosity of the fluid (typically in units of centipoise, and L is the length of

the porous media the fluid will flow through.

$$\partial P/\partial L$$

represents the pressure change per unit length of the formation. This equation can also be solved for permeability, allowing for relative permeability to be calculated by forcing a fluid of known viscosity through a core of a known length and area, and measuring the pressure drop across the length of the core.

The reason losses stop is because of the filtrate and the wall cake that is formed causes the permeability on the wellbore wall to become so low as to disallow further flow. There must be some loss to create the "skin" that prevents further flow. A paper written long ago suggests that a critical differential exists at 3000 psi yet if you do the calculations you might find that the formation has less permeability and 3000 psi is too low or more permeability and 3000 psi is too high. Remember that the Fracture Gradient (tensile strength) of the rock is a function of pore pressure.

$S_h = [v/(1-v)] \cdot (S_v - P_o) + P_o$

If the sand is depleted the fracture pressure goes down as a function of pore pressure. If you want to know the exact amount that the fracture of the sand is decreased as a function of pore pressure we may re-arrange the above equation to yield the following relation: (1-2v)/(1-v) for every 1 ppg of depletion. v = Poisson's ratio and varies between .2 and .45 for sands so the FG will diminish by .75 - .18 respectively. This means that for brittle sands depletion has a big effect on Fracture Strength of the sand and for rubbery sands it has less effect. This makes sense. This equation is Eaton's formulation for fracture gradient according to law's of lateral constraint. They have been studied and debated for years and are now generally regarded as decently accurate. Now, if after calculating the "new" fracture strength of the sand after depletion yields a value lower than the expected mud hydrostatic you will need to drill the sand with then you will perhaps also need to "screen out" the fracture tip you will create in addition to plugging permeability. Usually this means getting LCM material to "dewater" and form a plugging bridge in the fracture. So if you're drilling and you stop the losses with plugging material that decreases the permeability and subsequently you raise the mud weight and loss mud again it might be the sand "fracturing" and the same smaller particle plugging material suddenly might not work and you might then need to pump different material that will get to the fracture tip and then dewater and form a bridging plug.

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The key is to be aware that there are 2 different phenomenons at work and that these can complicate surface indications and proscribed treatments that will be effective.

Summary for success

Keep the pipe moving and if the rig breaks down get the pipe out of the hole. Minimize mud weight, ECD's and EAD's (the amount of cuttings in the hole at any time meaning lower ROP). Keep the mud system loaded with LCM of broad spectrum of particle sizes designed to plug the formation of interest (get a professional to help you design this based on anything, logs, cores, that you know about the depleted sand). Minimize connection times. Don't take surveys. Run a gyro at the end of the well. Trust me on that probably the most common time to get stuck differentially is taking a survey. DON'T. Run an expensive, wireline retrievable (just in case!), digital survey tool that doesn't require that you stop moving pipe. It will be worth it.

Hope this is a good primer and look for more details on the points discussed.