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Drilling Well Problems Study of Well Problems in India

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Abstract: Oil and gas industry is experiencing a revolutionary improvement in the past few decades. Petroleum engineers have harnessed technology to improve oil and gas industry by all means to ensure an efficient, safe and cost effective operations, starting from exploration, passing by drilling, production treatment and refining. This paper concerns drilling operations which is a very critical stage as it is obstructed by many challenges that require precision, knowledge and wisdom to be carefully dealt with. Problems encountered during drilling are discussed with particulars in order to give a better understanding to the complications involved with the operation. And for progress, more effective solutions should be offered using latest technological methods.

In this paper, we're discussing the most occurring and common drilling problems, mentioning their reasons, conventional practices to solve and prevent them.

A. INTRODUCTION

Drilling operation is the first and the most costly phase in petroleum industry as, according to API (1991), it represents nearly one fourth of the total oil-field expenditure and its efficiency is mandatory as it will affect the whole investment technically and financially. An efficient, well-designed and well-operated drill job must ensure maximum safety for operating engineers and workers, minimum damage for the formation, lowest costs and shortest time for the operations.

Drilling operation maybe subjected to multiple factors that consequently cause major or minor drilling problems which could expose the crew to hazards and danger, cause pollution to the environment, cause damage to the tools and equipment or simply cause non-productive time (NPT). While there are various reasons for drilling problems, mostly they are linked to the drilling fluid which its characteristics and its optimization can help in preventing/mitigating several problems that could encounter during drilling saving a lot of money and avoiding or decreasing NPT. Average cost of drilling fluids in well drilling will range between 15% and 18% of the total drilling cost. Drilling fluids have witnessed a major evolution since its use in the first drilling process in USA. Its revolution from a simple water and clay mixture to more complex combination of various types of organic and inorganic additives has enhanced fluid's rheological properties and filtration capabilities (Ahmed Noah, Reduction of Formation Damage and Fluid Loss using Nano-sized Silica Drilling Fluids, 2014).

1. Drilling well problems

Pipe sticking

Pipe sticking is one of the most common problems faced during drilling that causes a lot of nonproductive time (NPT). Pipe is considered stuck if it cannot be freed and dragged out of hole without damaging the pipe or surpassing the maximum allowed hook load (Azar, 2006). Basically, there are two types of pipe sticking.

Differential pressure pipe sticking

In this event, a portion of the drill pipe becomes embedded in the mud cake. This happens when there is high pressure difference between wellbore and formation pressures.

$$F_p = f \Delta p A_c$$

The pull force, F*p*, required to free the stuck pipe is a function of the differential pressure, Δ*p*; The coefficient of friction, *f*; And the area of contact, *Ac*, between the pipe and mudcake surfaces.

$$A_c = 2L_{ep}\left\{\left(D_h/2 - h_{mc}\right)^2 - \left[D_h/2 - h_{mc}\left(D_h - h_{mc}\right)/\left(D_h - D_{op}\right)\right]^2\right\}^{0.5},$$

Lep is the length of the permeable zone, *Dop* is the outside diameter of the pipe,
Dh is the diameter of the hole, and *hmc* is the mudcake thickness.
Several parameters will promote differential pressure stuck pipe, this include;

- High differential pressure
- Thick mud cake
- Low lubricity mud cake
- Excessive embedded pipe length in mud cake
- Shape of drill collars

Indicators of differential pressure sticking are;

- Increase in torque and drag forces
- Inability to reciprocate drill string
- Uninterrupted drilling fluid circulation

Several precautions are considered during

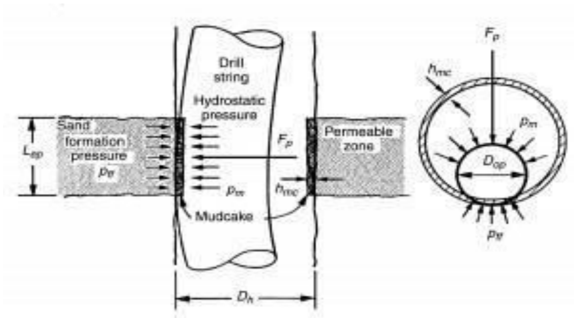


Figure 1- Differential pressure pipe sticking

drilling operation in order to decrease the possibility of sticking. Methods of applying these precautions can vary depending on the type of the drilling fluid, wellbore features and the degree of sticking (Bonar MARBUN, 2016). They include;

- Maintain lowest continues fluid loss
- Keep up the lowest solid content in the mud system or removing all solids if applicable
- Using lowest differential pressure
- Adjusting the drilling fluid in order to yield a smooth mud cake
- If possible, keep the drill trig rotating all the time

And, if the event of sticking is already presented, we can free the pipe by different methods that include

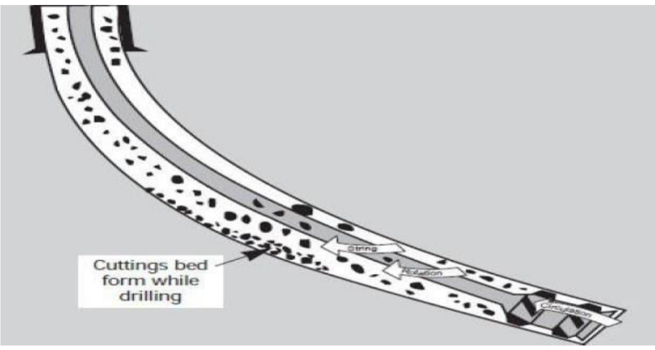
- Oil-spotting around the stuck section of the drill string
- Washing over the stuck pipe
- Reducing mud hydrostatic pressure

(This can be done by dilution, gasifying with nitrogen or placing a packer above the stuck point)

Mechanical pipe sticking

Three different causes can lead to mechanical pipe sticking. For every cause there are different reasons, indicators and solutions to mitigate the problem (Santoso Effendi 2011).

i. Inadequate removal of drilling cuttings
Inadequate removal of drilling cutting can cause cutting to accumulate in the annular space at the bottom of the wellbore resulting in a stuck pipe. In directional drilling,



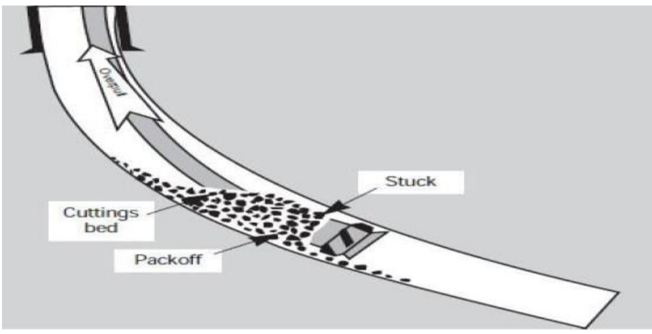


Figure 2 Mechanical pipe sticking 1

Increasing torque and drag forces and increase in circulating drill pipe pressure are the indicators for mechanical pipe sticking caused by cuttings accumulation. This problem could be mitigated by rotating and reciprocating the drill string and increasing the flow rate without exceeding the maximum allowed equivalent circulating density (ECD).

i. Borehole instabilities

In some cases, drilling through critical formations could lead to pipe sticking. Unstable wellbore may collapse, cave or slough (flow inward). These event mostly occur in plastic shale or salt sections or when using too low mud weight.

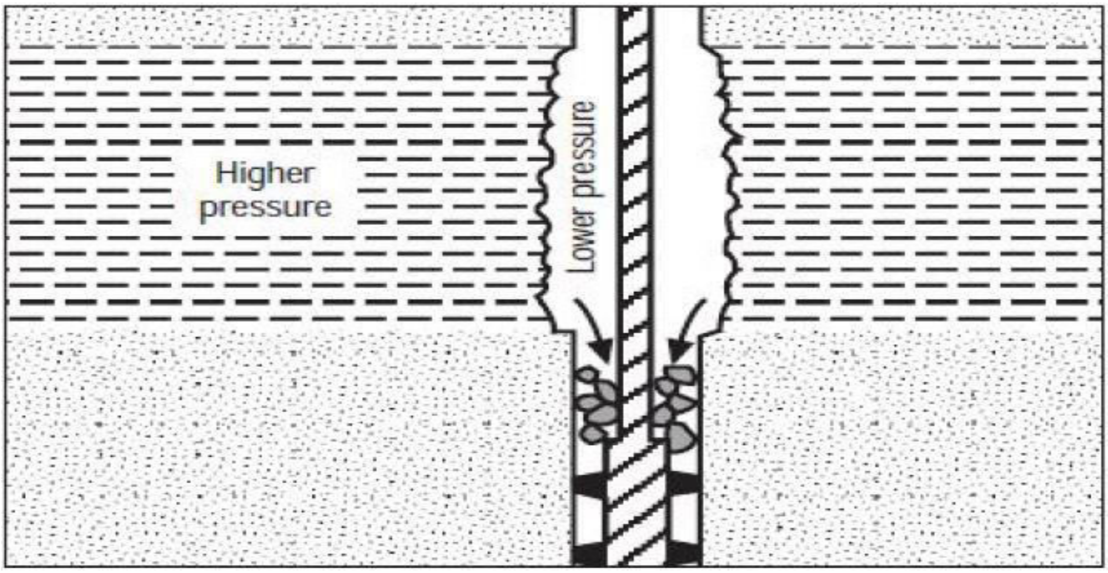


Figure 3 Mechanical pipe sticking 2

Indicators are;

- Rise in drill pipe circulating pressure
- Increase in torque
- No fluid return to surface

Preventions of mechanical sticking caused by wellbore instabilities is done by strengthening the wellbore and using a proper mud system that is compatible with the formation mechanically and chemically.
In case of hole narrowing, if it is a result of plastic shale, increasing mud weight would solve the problem. And if it is a reason of salt section, circulating fresh water is the solution.

ii. Key seating

In directional drilling, the drillstring rotating with side force (lateral force) acting on it will cause a small hole into the side of the wall (groove). These grooves are found at doglegs or in unnoticed ledges near washouts.

$$F_l = T \sin \theta_{dl}.$$

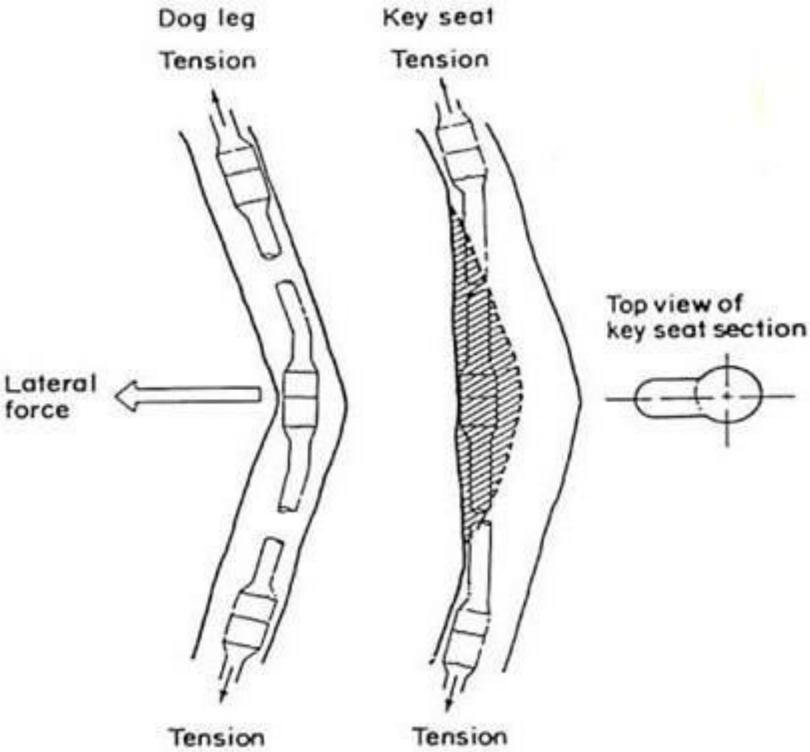


Figure 4 Mechanical pipe sticking 3

F_l is the lateral force, T is the tension in the drillstring just above the key•seat area, and Θ_dl is the abrupt change in hole angle (commonly referred to as dogleg angle)

Key seating is not a very common event, but it is indicated when several stand of pipe are pulled out normally, then suddenly the pipe is stuck.

Using a stiff BHAs will minimize the occurrence of doglegs. But if the problem is already found, the solution is to back off below the key-seat section and going back into the hole with an opener to drill out the key section. A fishing operation is needed later to retrieve the fish.

The operating company have the decision on how long to attempt to free the stuck pipe or backing off and side track as it is considered an economical issue.

Field practices to free a stuck pipe

Primary actions to free a stuck pipe *(Rabia, 2001)*

- Pump mud with maximum flow rate without exceeding the maximum allowable ECD.
- Apply highest torque on drill string and work it down to the depth of sticking to increase the chance to free the pipe.
- Release the weight of string to increase the down weight.

- Jar down with maximum trip load while using torque, as jarring down is more effective in freeing the pipe than jarring up.
- Reducing mud hydrostatic pressure would be an option is the problem still exists.
- Process and procedure of freeing a pipe takes a while so personnel must be patient.

After the string have been freed, hole cleaning must be assured and mud properties should be adjusted in order to prevent the reoccurring of the problem (Bonar MARBUN, 2016).

Fishing operation

Numerous problem may arise during drilling a well. Whether drill string sticking or breaks and drops to the bottom of the borehole or other accidents including tools that may fall from into the well from the rig. Those tools and equipment are called fish and mostly it is not possible to drill through it. In this incidence, fishing is necessary to retrieve it.

Figure 5 Fishing tools

With the intention of doing a fishing operation, drilling must be stopped and special fishing tools are applied. Every tool is specified to perform a certain job or retrieve a certain type of fish. Most of fishing tools are attached to the end of a fishing string which is similar to drill pipe and lowered down the hole.

Fishing tools

1. Spear;
    - Fits within the pipe then clasps the pipe from the inside, carry it up to the rig.
2. Overshoot

- Surrounds the pipe then clasps the pipe from the outer side, carry it up to the rig.

3. Washover pipe
   - Tool with a wider diameter than that of the fish
   - It has a cutting surface at its tip that toils the fish to a smooth surface
   - Drilling fluid is pumped to remove fragments
   - Another tool is lowered to pick up the rest of fish
4. Junk mill and boot basket
   - Junk mill is lowered into the wellbore and grinds the fish into smaller pieces
   - Boot basket is later lowered and drilling fluid is being pumped to circulate the grinded fragments from the bottom and raise them into the boot basket
   - The boot basket is raisin to the surface carrying the grinded fish parts
5. Tapered mill reamer
   - Used to recover collapsed casing parts and irregular fish shapes
6. Permanent and magnetic magnets for magnetic fish
7. Wireline spear
   - Uses hooks and barb to clasp broken wire line
8. Explosives
   - Break fish into smaller pieces to be retrieved by boot basket
9. Impression block

Helps professionals determining the suitable tool for the fishing job by giving an impression about the fish

Fishing operation may need up to days to be successfully completed resulting in a lot of nonproductive time (NPT) and additional costs for the operator. However, some contractors offer fishing insurance so that the operator is not responsible for the additional fees.

Spotting fluids *(Spotting Fluids to Free Stuck Pipe, 2016)*
In worse cases of differential pressure sticking, puling and working the string may not be effective to free it. That's when spotting fluids are used to eliminate the reasons of sticking in the mud cake.
Spotting fluids are designed to break down mud cake in order to weaken the bond between cake and pipe (reduce contact area and embedded length), hence reducing its severity.
Severity of sticking increases by time so it is important to make actions as soon as possible after the occurrence. Noting that spotting take up to 12 hours to effectively diminish.

Loss of circulation

Loss of circulation is the undesirable flow of portion or whole mud into the formation. There are two types of circulation loss (Azar, 2006) , it's either;

1. Partial loss, at which only portion of the mud flow into the formation and the rest flows to the surface.
2. Total loss, at which the whole mud flows into the formation with no return to the surface.

Loss of circulation is definitely a wide problem as its severity could initiate other problems like

1. Formation damage
2. Wellbore instability
3. Insufficient hole cleaning
4. Extra costs

Despite, it is an option to continue the operation while losing fluids, what is called Blind Drilling. Blind drilling is only acceptable if;

1. Fluid is clear water
2. Formation above thief zone is mechanically stable
3. No production
4. Economically feasible and safe

Lost circulation zones, referred as thief zones, are located at

1. Inherently fractured formations, the fractures are found in it before drilling and usually developed during composition or as a result of earth quakes.
2. Cavernous formations, caving could be inherent or new phenomenon as a result of well bore instability. Cavernous formation are often limestone. In this formation the circulation loss is quick, total and most difficult to seal.
3. High permeability formations, as shallow sand with permeability greater than 10 darcies.

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4. Induced fractured formation, fractures may be induced as result of excessive downhole pressure. Induced fractures here are mostly horizontal at shallow depths and vertical in depths greater than 25,000 ft.

Prevention of circulation loss

- Maintaining proper mud weight
- Minimize annular-friction pressure losses during drilling and tripping in
- Sufficient hole cleaning
- Avoiding restrictions in the annular space
- Setting casing to protect upper weaker sections of the formation
- Updating log and drilling data periodically for pore pressure and fracture gradients

If thief zones are foreseen, loss of circulation materials are used.

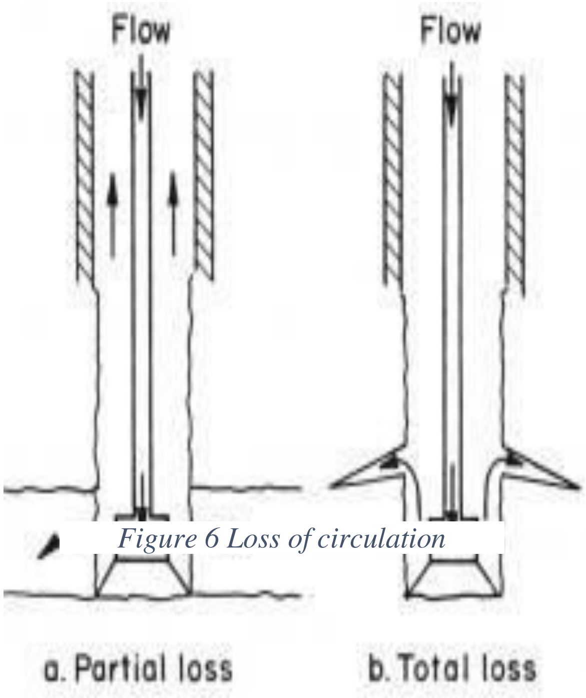

Figure 6 Loss of circulation

Hole deviation

Hole deviation is defined as the unintentional departure of the path of the drill bit from the preselected one (Robert F. Mitchell 2006). Several factors are responsible for the deviation including;

- Heterogeneity of the formation
- Bottom hole assembly characteristics
- Stabilizers

- Weight on bit
- Hole inclination angle
- Drill bit type and design
- Hydraulics of the bit
- Improper hole cleaning

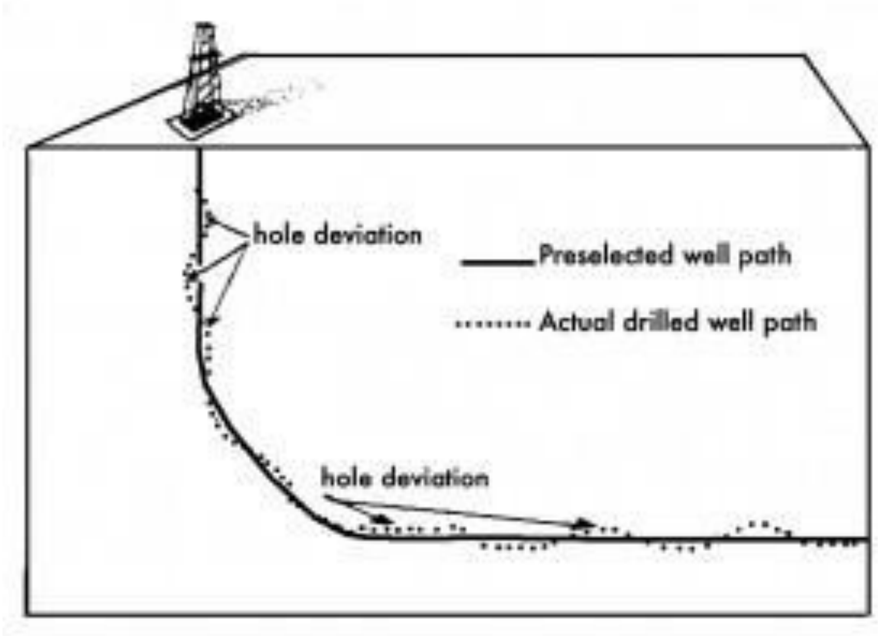

Figure 7 Hole deviation

One of major causes of hole deviation is BHA buckling, as buckling it misaligns the axis of drill bit with that of the intended hole path. Henceforth the deviation. BHA is a flexible, elastic structure that may buckles under compressive forces. So considering its stiffness and length would manage the buckling behavior. In addition to installing stabilizers with the right number and outer diameter.

Drill pipe failures

Drill pipe failure is a serious problem that is commonly encounter during drilling. Its main root may develop initially as a result of improper storing, transporting or installing (Ludivine Laurent, IADC - Drill String, 2012).

Figure 8 Drill pipe failure, Twist off

Drillpipe failures has four categories;

1. **Twistoff**; which is a result of the induced shear stress caused by extreme torques that may surpass the material's maximum shear stress. It's not very common in vertical drilling but it could found in extended reach and directional drilling as torques may exceed 80,000 Ib-ft.
2. **Prating**; caused by induced tensile stresses that exceeds the material's ultimate tensile stress. Its conditions arises when there's an over pull on a stuck pipe in addition to the effective weight of suspended string above the stuck point.
3. **Burst and collapse**; a very rare failure case that is a result of very high mud weight and complete loss of circulation. The high differential pressure between the pipe and the annulus may cause the pipe to burst.

Figure 9 Drill pipe failure, Burst

4. **Fatigue**; fatigue is the initiation of micro cracks and their propagation into macro cracks as a consequence of constant application of applied stresses. Corrosion is another factor that exhibit fatigue failure as it weakens the structure and reduce its ability to withstand applied forces and stresses.

Figure 10 Drill pipe failure, Fatigue

Drill pipe failure is the most common and expensive type of encountered drilling problems, specially while drilling deep well and in HPHT drilling. The combination of different stresses and the resultant forces applied on a drill pipe could cause the failure. The improper selection of the used materials and equipment is another factor, In addition to the contributed formation to be drilled and its characteristics.

Pipe failure could not be totally prevented, so in order to decrease the hazards of pipe failure of any means, these steps should be strictly followed;

1. The proper selection of drill string components depending on the applied stresses and formation characteristics
2. Proper storing of equipment and safety checks before every use
3. Fatigue failures can be alleviated by reducing induced cyclic stresses to the minimum and assuring a noncorrosive atmosphere during drilling
4. Cyclic stresses can be mitigated by controlling dogleg harshness and drill string vibrations
5. Corrosion may be avoided by using corrosive scavengers, proper insulation in corrosive environments and monitoring the mud pH
6. The appropriate handling and inspection of the components of drill string on a routine basis are the best remedy to prevent failures

Borehole instability

(Rabia, 2001) Discussed borehole instability and its parameters indicating that it is geo-mechanical issue that is related to hydraulic and chemical factors. Borehole instability in petroleum is well defined as the undesirable condition of an open hole interval that does not maintain its gauge size, shape or structural integrity, consequently driving the drilling operation into major problems and difficulties that will lead to additional costs and nonproductive time which increases with its severity.

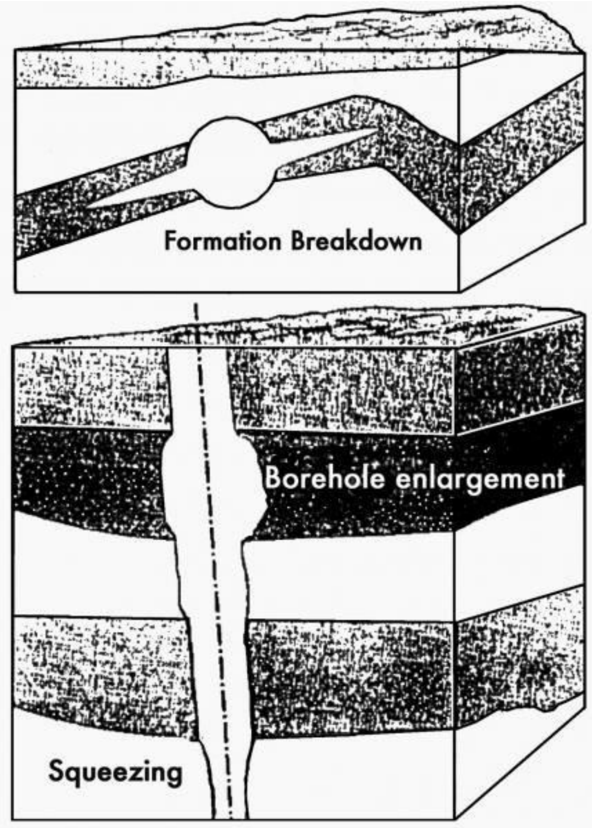

Figure 11 Borehole instability types

Principles of borehole instability

Before drilling, the drilled formation somehow have an equilibrium state between the rock strength and the in-situ stresses applied on it whether vertically from the overburden pressure or horizontally from the confining. However, drilling process disturbs this balance and weaken the mechanical stability. Furthermore introducing foreign fluids as drilling fluid will start an interaction with the formation rock and fluids (Larry W. Lake, 2006).

Borehole instability origins

Three origins for wellbore instability

1. Mechanical failure
   Resulted from the disturbance of in-situ stresses, typically proportional to mud weight and its hydrostatic pressure. Mechanical failure is either compressive failure caused by shear stresses as a result of too low mud weight (collapse, slough) or tensile failure caused by normal stresses as a result of too high mud weight (fracturing).
2. Erosion
   Caused by friction done by drilling fluid on the wall of the wellbore.
3. Chemical
   Resulted from the interaction between borehole fluids with formation rock and fluids which has an impact on the mechanical strength of the wellbore.

Borehole instability types

1. Hole closure (narrowing)
   Hole closure is a time-dependent process that decreases the wellbore's diameter. Hole closure generally occurs in plastic flowing shale and salt section with plastic behavior. Problems associated with hole closure are;
   - Increase in torque and drag
   - Difficulty in casing landing
   - Potential pipe sticking
2. Hole enlargement (washouts)
   Washouts are the unintentional increase in wellbore's diameter.

   Hole enlargement causes are;
   - Hydraulic erosion by drilling fluid circulation
   - Mechanical abrasion of drill string
   - Inherently sloughing shale

   Problems associated are;
   - Cementing difficulty
   - Hole cleaning difficulty
   - Problems with logging operation

- Increase potential of hole deviation

3. Fracturing
   High mud weight will introduce high hydrostatic pressure that may exceed formation's fracture pressure, henceforth fractures are induced.
   Formation fracturing, depending on its severity, will lead to circulation loss and a possible kick.

4. Collapse
   When drilling fluid's hydrostatic pressure is too low to maintain the structural integrity of the drilled hole, well may collapse.
   Associated problems are pipe sticking and, in extreme cases, loss of well is possible.

Pressures at the interface

1. Capillary pressure;

Capillary pressure occurs at the interface of pore throat where the borehole fluids contacts the native fluids in the reservoir.
High capillary pressure is required to prevent bore hole fluids from invading shale.
Capillary pressure can be increased by using oil based mud or low polar mud system that achieves high interfacial tension at the interface.

$$p_{cap} = 2\sigma \cos \theta / r,$$

2. Osmotic pressure

Activity of drilling fluid is a function of its energy level and when its energy level is different from that of the native fluids; water movement may develop in either directions across a semi permeable membrane as a result of the developed osmotic pressure.
Adding electrolytes to the drilling fluid will decrease the water movement as it decrease the difference in energy levels between both fluids.

3. Pressure diffusion

It's the change in pressure near the wellbore caused by the compression of native pore fluids due to borehole fluids pressure and osmotic pressure.

4. Positive differential pressure

Borehole fluids invasion into formation is occurred as a result of high differential pressure between wellbore fluid pressure and formation pressure. Higher wellbore fluid pressures will increase the invasion.

Instability of shale

Shale is the most common formation introduced to instability as it is the most altered by the drilling fluid hydraulically and chemically.

In mechanical means, as any other formation type, instability of the wellbore maybe introduced if the mud density does not bring the rehabilitated stresses to their original state, though it needs more precision than other formation types.

While in chemical instabilities, the chemical incompatibility of drilling fluid with reservoir rock and fluids may affect the mechanical strength in the skin around the wellbore.

Borehole instability prevention

Expecting a total prevention of borehole instability is unrealistic as reinstating physical and chemical in-situ conditions of formation is impossible.

However, problems of borehole instabilities could be avoided by sticking to upright field practices, including;

1. Proper mud weight selection and maintenance
2. Proper hydraulics to control ECD
3. Proper hole trajectory selection
4. Using drilling fluids that are compatible with the formation

In addition to;

1. Minimizing time spent with an open hole
2. Using decent learning curve figured from the off-set data
3. Monitoring trend change in torque, circulating pressure, drag, fill in during tripping.

Mud contamination

Mud contamination is the unwanted alteration in mud properties, like density, viscosity and filtration, as a result of an alien material entering the mud system. Water-based mud is more subjected to contamination (Darley, 1991). Contamination is resulted either from over treatment for drilling fluid or from materials entering the system during drilling.

Common Contaminants, Sources, and Treatments

There are different tyes of materials that can alter mud properties, they are;

1. Carbonate/bicarbonate
2. Cement
3. Calcium sulphate
4. Salt

Carbonate/Bicarbonate

Carbonate and bicarbonate ions form one of the most unrecognized forms of contaminants as its gradual development will result in increasing yield point and gel strength. It might be falsely diagnosed as increased solids but the use of thinners will have no effect in treatment.

Source of carbonates

Various sources could afford carbonates for contamination such as

- Thermal degradation of organics present in mud
- Drilling carbonate rich formations
- Carbon dioxide
- Overtreatment with sodium bicarbonate

Diagnosis

Carbonates contamination is detected by mud alkalinity analysis which is carried out on routine basis. Analysis outcomes are in the form of Pf to Mf ratio.

Pm, Pf and Mf are values indicating the alkalinity of drilling mud and the following is meaning of each value (Andy Philips, 2012).

Pm

Pm stands for “phenolphthalein end point of the mud” and it specifies extents of Potassium Hydroxide (KOH), caustic soda and cement in the water base mud. The Pm states to the amount of acid needed to decrease the pH of mud to

The Pm test comprises the effect of both dissolved and non-dissolved alkalis and salts in drilling fluid.

Pf

Pf stands for the phenolphthalein alkalinity of the mud filtrate. Pf is unlike the Pm as it tests the effect of only dissolved bases and salts. However, Pm includes the effect of both dissolved and non-dissolved alkalies and salts in drilling mud. **Mf**

Mf stands for the methyl orange alkalinity end point of mud filtrate and the definition of the methyl orange alkalinity is the amount acid used to reduce the pH to 4.3. According to the API test, Pm, Pf and Mf are shown in a daily mud report and all the figures are reported in cubic centimeters of 0.02N sulfuric acid per cubic centimeter of drilling fluid sample.

Pf and Mf are based on the mud filtrate tests that will help people know about ions in the drilling mud.

There are three cases regarding Pf and Mf.

- **First case**: Pf and Mf are similar in value to each other. It indicates that the ions (hydroxyl ions) are the main contributor to the mud alkalinity.

- **Second case**: If Pf is low but the Mf is high, it indicates that bicarbonate ions are in the mud.
- **Third case**: if both figures (Pf and Mf) are high, it means that carbonate ions are in the mud system.

Treatment

Add caustic soda to increase pH to the range 9.5 to 10, later add lime and gypsum to overcome contamination.

Cement contamination

Cement is the most occurring type of contamination as it is found in every drilling process. Calcium hydroxide is the source of contamination and it may cause higher fluid loss, higher PH and thickening of bentonite based drilling fluid (flocculation of the bentonite clay).

Pre-treatment level determines the severity of the problem as following;

- Lignosulphocate high treated system, viscosity will drop as clay will not be dispersed rather it will be flocculated state.
- In polymer treated mud system, precipitation of polymers will occur due to the increase of pH and calcium concentration caused by the contamination.

Sources of contamination

- Drilling green cement rich section
- Adopting poor placement job

Diagnosis

Main indications will be

- Higher pH
- Increased calcium concentration

Treatment

- Pretreating mud with sodium bicarbonate with concentration of 1.0 lb/bbl
- In severe cases of contamination, we use sodium bicarbonate at rate of 0.15 lb/bbl for each 100 ppm calcium.
- In some cases it's economically beneficial to displace contaminated mud with new mud. This is familiar when drilling formation which contains high quantities of cement.
- Using sea water to drill cement section is offshore rigs could be an option as well as using formation water in onshore sites.

Calcium sulphate

Flocculation of bentonite based mud will be resulted from the contamination causing an increase in fluid penetration to the formation and increasing yield point.

Sources of contamination

Mostly while drilling Anhydrite

Diagnosis

- Increase in calcium filtration
- Decreased pH

Treatment

- Add soda ash with rate 0.116lb/bbl for every 100ppm calcium
- Lignosulphonate treatment might be needed to control viscosity and filtration.

Salt

High salt content in bentonite based fluid may cause high gel strength and fluid loss
Polymer systems can overcome salt contamination. However, polymer concentration will depend on that of salt.

Sources of salt

- Salt dome
- Salt water aquifers

Diagnosis Increased chlorides Decreased pH

Treatment

In most cases, the only treatment for salt contamination is dilution with water.

Hole cleaning

Inadequate hole cleaning during drilling has a high potential of causing problems that will lead to large amount of additional costs and increase NPT. It was demonstrated that a well with an inclination angle varies from 30 to 60° from vertical presents difficulties in removing drilled cuttings which are not observed in vertical wells (Rabia, 2001). Several factors and parameters should be implemented to assure an efficient hole cleaning .

Problems associated with poor hole cleaning

- Increasing torque and drag forces
- Low ROP
- Higher hydrostatic pressure
- Fracturing
- Mechanical pipe sticking
- Difficulties in logging, cementing and in casing landing

Most related problem associated with inadequate hole cleaning is excessive torque and drag forces that does not allow achieving require target in horizontal drilling and decreases ROP .

Hole cleaning in extend reach drilling operations

Proper selection of drilling mud and its maintenance is mandatory for a successful drilling operation in extended reach wells. In order to bypass formation damage and protect well integrity in extended reach wells (Cameron,

C. 2001), several challenges should be managed including;

- Maintain lowest differential pressure.
- Reducing torque and drag forces.
- Sticking to ECD.
- Handling well bore instabilities.
- Proper hole cleaning.

To overcome hole cleaning problems, the following parameters should be well managed;

- Annular velocities
- Drilling-fluid viscosity
- Pipe-rotation speed
- Pipe eccentricity

Factors effecting hole cleaning

i. Annular-fluid velocity

Flow rate is the most responsible for the efficiency of removing cuttings as increasing it will always be more effectual. However, flow rate intensity is restricted by;

- Maximum allowable ECD
- Vulnerability of hydraulic erosion to open-hole sections
- Rig hydraulic power

ii. Hole inclination angle

It was proven that increasing inclination angle of well from zero to 67° from horizontal increases the flow rate requirements, then it slightly decrease heading for horizontal. Moreover, at angles ranges between 25° to 45°, sudden stop in circulation can cause cuttings to settle towards the bottom and mechanical pipe sticking maybe evolved.

iii. Drillstring rotation

Whirling motion caused by rotation of drillstring plays a role in hole cleaning enhancement. This motion causes a mechanical agitation to the cuttings bed settled at the lower side of directional well allowing it to be exposed to higher fluid velocities at the upper side of the hole. Level of enhancement due to whirling motion is highly dependent on cuttings size, mud rheology, flow rate, pipe rotation and its dynamic behavior.
Pipe rotation is not always beneficial as it causes cyclic stresses that may accelerate pipe failure. In addition, in narrow holes, high speed pipe rotation will increase annular friction pressure loses leading to higher ECD.

iv. Hole/pipe eccentricity

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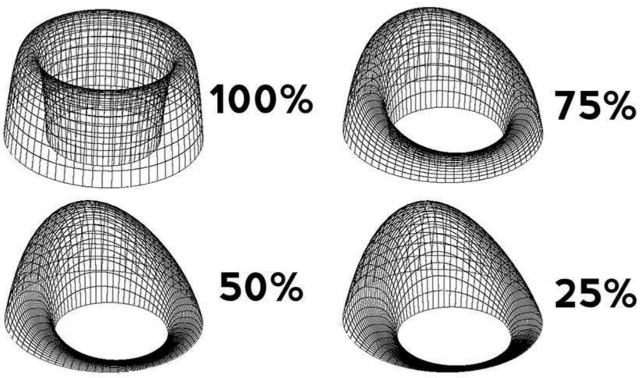
Due to gravity, pipe tends to rest on the lower side of hole in inclined sections of well. This slims the gap in the annulus lower section, reducing the fluid's velocity and impedes transportation of cuttings to the surface. This impact is mostly unavoidable .

Figure 12 Hole cleaning – pipe eccentricity percentage and fluid velocity profile



v. Rate of penetration

Higher rate of penetration will always produce larger amount of cuttings. Hence, a higher flow rate is needed to assure adequate hole cleaning. If that is not obtainable, reducing ROP is a must to avoid cuttings accumulation and associated problems of mechanical pipe sticking or excessive torque and drag.

vi. Mud properties

Density and viscosity are the two mud properties that have a direct effect on hole cleaning. Never the less, density cannot be adjusted to serve for hole cleaning as its purpose is to stabilize the mechanical structure of well and prevent invasion of formation fluids into wellbore. Excessive mud density will effect ROP and may cause fractures. Viscosity is modified to be capable of suspending weighting materials added and can be adjusted to serve hoe cleaning in vertical wells.

vii. Cuttings characteristics

Dynamic behavior of cuttings is impacted by their shape, size, distribution and specific gravity. While specific gravity of rocks is mostly 2.6, however, shape and size of cuttings are not controllable.

Drilling induced formation damage

Formation damage is defined as " The impairment of the unseen by the inevitable causing an unknown reduction in the unquantifiable " (J.J. azur , 2006). In other

words, formation damage spoils the permeability around the vicinity of the wellbore causing a reduction in the inherent productivity of the formation. Formation damage has a negative impact on both drilling and production operations which adversely affect the economics.
Though formation damage alters rock properties in the near well region (skin), its effect may extend shallower into the formation.

Damage mechanisms

Drilling induced formation damage could happen with different mechanisms, it is either mechanical or chemical (Faergestad, 2016).

Mechanical damage

Damage caused by direct interaction between equipment or fluids and the formation without any chemical alteration. Mechanical damage could be due to

.1 Fine migration: Induced fine grains of clay or sand are forced to move by high fluid shear rates causing pore throat resulting in reducing permeability.

.2 External solids entrainment: particles from external source (wellbore fluids) enters and plugs pore throats.

.3 Phase trapping and blocking: wellbore fluids invades formation and alter water saturation.

.4 Glazing and mashing: when drill bit and string cause damage to the formation at their interface with the formation.

Mainly, fine migration is found in clastic formation due to the high content of transportable materials. Stabilizers maybe used to reduce their mobility and limit their movement.

Chemical damage

Clay swelling: hydrophilic materials such as clay happen to expand and swell when hydrated with low salinity water causing flag in pore throats. High salinity mud systems are used in such formations containing clay.

Clay deflocculation: sudden changes in pH value or salinity can cause clay particles to dis-attach from each other as a result of disturbance of electrostatic forces flocculating then together. Deflocculation is bypassed by avoiding sudden changes in pH and salinity.

Emulsion and sludges: incompatibility of wellbore and formation fluids may result in forming sludges that will block pore throats and decrease permeability.

Wettability alteration: chemical mud additives can play a role in formation damage as some chemicals, like corrosion inhibitors may alter rock wettability and change it from water-wet to oil-wet leading to changing relative permeability of water to oil in order that rock's permeability to water will increase while that of oil will decrease. Adding surfactants to drilling fluid can overcome this problem and control wettability conditions.

Hydrogen sulfide bearing zones

Hydrogen-sulfide anticipated during drilling operations can involve a serious consequences for personnel and equipment (J. J. Azar, 2006). Exposure to a relatively low concentrations of H2S for a short period of time may cause health problems or even death to personnel in site, in addition to be very corrosive to equipment in presence of oxygen.
Level of danger of hydrogen-sulfide is dependent on H2S content of formation fluids, formation pressure and flow rate. These data are gathered to evaluate the risk and determine the treatment and safety procedures (Mills, W.G., Malone, M.J., and Graber, K., 2006).
Studies and planning

1. Geological and geographic information of the formation should be studied with precision in the advance of predicting bearing H2S zones. Depth, pressure, temperature and field conditions should be taken into considerations in a precise study.
2. Hydrogen-sulfide scavenger should be included in the mud program in order to protect drill string and other equipment expected to be in contact with the corrosive gas in order to protect them from corrosion and govern its processing before reaching the surface. Maintaining high pH of mud (10.5-11) is a common practice for mud treatment against H2S.
3. In kick situations, H2S scavengers are no longer effective to protect equipment as the hole maybe partially or fully displaced from drilling fluid and preventing its contact with the equipment. In this case, equipment should be plated with H2S resistant materials (zinc plated).
4. Former reaching the gas bearing zones, emergency equipment as the B.O.B. and degasser must be tested and confirm their performance.
5. Gas detectors should be periodically checked and maintained.

H2S emergency planning

1. If hydrogen-sulfide zone is anticipated during drilling, the following emergency plan should be considered to maintain safety and eliminate hazards
2. Informing personnel about risks of being exposed to hydrogen-sulfide or sulfer-dioxide.
3. Informing personnel about safety procedures and safety equipment to be used if in danger conditions and aware them with their responsibilities and duties in such events.
4. Setting evacuation plan
5. Notifying authorities in case of emergency
6. Availability of medical facilities

4. Drilling fluid and its role in preventing/mitigating drilling problems

Drilling fluid functions, properties and types

American petroleum institute defined drilling fluid according to its function as a circulating fluid engaged to control any or all responsibilities involved in drilling operations in rotary drilling (Awona, 2016). Responsibilities of drilling fluid include (Ludivine Laurent, IADC Drilling Manual, 2014)

• Well cleaning, removing drilled cuttings and circulating them to the surface;

• Tolerate wellbore's mechanical and chemical stability;

• Drive hydraulic energy to downhole tools and bit;

• Cooling and lubricating drilling bit and string;

• Help gathering more data about the nature of the drilled formation, formation evaluation;

• Afford a finalized wellbore ready for production;

• Suspend drilled cuttings and weighting materials in the downhole when circulation is stopped, allowing cuttings to be removed at surface facilities

• Forming a low permeable, thin and tough filter cake across high permeability sections of the formation

These present the principal functions of the drilling fluid at which, every single function, play a non-dispensable role in a successful drilling operation. A good mud design will have many challenges to achieve its goal and overcome expected problems and sometimes mitigating it. To achieve these fundamental functions, drilling fluid should retain a specific desired rheological properties that will impact its quality and behavior (Awona, 2016). These properties are

- Mud weight
- Plastic viscosity
- Yield point
- Gel strength
- Low-end rheology
- Mud filtrate and cake
- Resistivity

"Properties of drilling fluid have greatest impact on the quality of drilling operation and prevent problems during drilling. Undesirable alteration of mud properties during exposition to wellbore condition is the major concern of mud engineers. When mud properties change it cannot perform its functions properly, so it is necessary to control drilling fluid's properties continuously and keep them in proper range."

Adjusting the rheology, with respect to the formation properties and drilling plan, will deliver a safe and efficient drilling operation. Designing an efficient drilling mud is highly crucial for oil and gas formation requirements (Adel M. Salem 2016).

Challenges encounter during drilling operations in more complicated types of formations have contributed to the designing of different types of drilling fluids (Waleed tareq al-sallami, 2015). The primary ingredients of all drilling fluids are either water, oil or gas. So their general classification is Oil based mud, Water based mud and Gas based mud. The selection of the fluid type is dependent on the nature of the formation to be drilled. Shah et al. (2010) stated that the most used drilling fluid is water based mud (WBM), this is due to its low cost and availability. While Oil based mud (OBM) is rather used in shale formation to avoid shale swelling due to the absorption of water which may lead to a stuck pipe due. OBM is also used when high lubricity in the wellbore is needed and in HTHP formations (SPE 2015).

The rate of penetration is impacted by mud density and the properties of suspended solids (Ludivine Laurent, IADC Drilling Manual, 2014). Regular periodic tests are necessary to observe and monitor mud properties. Results of tests are interpreted and treatment is applied to maintain proper mud properties. This is essential to a successful drilling program.

Additives

Different types of mud additives are used to improve the main properties of the drilling mud. The most common types of additives used in water-based and oil based muds are (Rabia, 2001);

1) Weighting Materials, such as (Barite, Illmenite, Calcium Carbonate, and Siderite)
   - Also called densifers, they are solid material which will increase mud weight when dissolved in water. Mostly weighting materials are insoluble in water so a viscosfier is used to support their suspension in water. Most common viscosfier is clay.
2) Viscosifiers, such as (CMC, HEC, Xanthan gum)
   - Suspending drilled cutting and weighting material in a drilling fluid is a function of viscosity which is, if not sufficient, will cause all solids to settle to the bottom shortly after the circulation is stopped. There are many solids than can be added to oil or water to increase its viscosity till reaching the desired value.
3) Filtration Control Materials (PAC and CMC)
   - They are compounds added to drilling mud to reduce amount of fluid lost to the formation due to differential pressure between wellbore pressure and formation pressure. Bentonite, polymers and thinners can work as filtration control agents.
4) Rheology Control Materials (Thinners)
   - Added to drilling fluid when the control of gel strength and viscosity of the fluid cannot be achieved by adjusting viscosfier's concentrations. Thinners/ deflocculates cause a change is the interaction between solid or dissolved salts in a manner that will reduce the viscosity of the fluid.
5) Alkalinity and pH Control Materials (NaOH, KOH, Ca(OH)2, NaHCO3 and Mg(OH)2)
   - Substances which are used to achieve a particular pH value and maintain alkalinity of water based mud. Usually a pH value of 10.
6) Lost Circulation Control Materials (Flakes (mica and cellophane), Granular (nutshells, calcium carbonate and salt), and Fibrous (glass fibre, wood fibre and animal fibre)

7) Lubricating Materials (oil (diesel, mineral, animal, or vegetable oils), surfactants, graphite, asphalt, gilsonite, polymer and glass beads)
    - Used to reduce friction between drillstring and wellbore. Hencem reducing torque and drag.
8) Shale Stabilizing Materials (high molecular weight polymers, hydrocarbons, potassium and calcium salts (e.g. KCl) and glycols)
    - Shale stabilizing can be achieved by preventing water contacting open shale sections. Shale stabilizing materials either encapsulates shale or neutralizes its charge so that the water will not adhere or filtrate it.

Conventional drilling fluid limitations

In spite of different additives added to the traditional drilling fluid to improve it performance, it still faces several challenges that limits its ability to do the required duties and achieve a safe job (Waleed tareq al-sallami, 2015).

There are still limitations during use these traditional drilling fluids in spite of the chemicals added to improve the drilling fluid performance. The main limitations of water based drilling fluids are: the ability of WBM to dissolve salts which may result in an unwanted jump in density. Moreover, the WBM is capable of interfering with the flow of gas and oil through porous media. Other limitations are the ability of WBM to promote the disintegration and dispersion of clays and the inability of WBM to drill through water sensitive shale. As well as the ability of WBM to corrode iron such as drill pipes, drill collars and drill bits (Mellot, 2008). Just like water based mud, oil-based drilling fluids have limitations such as the fluids are very expensive from several aspects, as the constituents of this type of mud are very expensive and the high cost of treatment cuttings and disposal of it (Oakley et al., 1991). On the other hand, this type is not favourable to the surroundings because their disposal may result in the pollution of water bearing aquifers, pollution of lands, and the decimation of the coral reefs. Furthermore; this type of fluids is unsuitable for use in dry gas reservoirs (Apaleke et al., 2012).

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