Optimising Cementing

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Purpose

To ensure minimal operational time and risk exposure to personnel, process, production and equipment during cementing operations

The following operational cementing procedures are to that optimum cementing results are obtained.

To best meet procedures defined within this document, specific rig and well related guidelines and other relevant documents should also be followed.

Responsibilities

It will be the responsibility of the Operators drilling representative and senior contractor drilling personnel to ensure that others with duties relating to cementing control operations contained within this document are aware of their roles and responsibilities during cementing operations.

Scope

These procedures shall apply to all drilling personnel.

Further References

Drilling contractor's, service companies, and Operator's mutually agreed specific Cementing procedures and guidelines.

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Introduction

Engineering and Cementing Design Practices

Normal design practices involve the preparation of a draft cementing programme by the Onshore cementing engineering personnel, once the finalised drilling programme is available.

A typical cementing programme would include:

- recommended slurries,
- spacer compositions,
- and placement procedures.
- Setting and strengthening times.

Preliminary designs are based on general good oil field practices and experience of those operating in similar well/down-hole situations and circumstances.

As drilling progresses the slurry design and placement technique must then be further optimised and tailored to meet the actual well conditions to achieve cementing requirements. Special reference would be made to design aspects such as to BHST, hole caliper, mud and formation properties, lost circulation, over pressurised zones, permeable or salt formations etc.

Computerised simulations are then performed. Normal practices verifying that the cement slurry properties to be used will meet necessary requirements and if not would then be adjusted by laboratory testing using location samples of cement, additives and mixing water. This testing would be completed in the cementing companies laboratory.

Well Conditions

Well conditions would initially be based on the information taken from the Oil Operating company's preliminary well design information received from the drilling and well design documentation. The following additional assumptions would then have to be made in preparation of this cementing programme.

BHST estimations:

Bottom hole static temperatures (BHST) of xx Deg.C at cement depth(s) are required and would be measured from the operators predicted temperature profile.

BHCT estimations:

Bottom hole circulating temperatures, (BHCT) temperatures are based upon modified API recommendations and design lab simulations.

Excess volumes

Cement volumes and estimates on material usage would be based on the bit size and typical excesses recommended are for those typically run.

General Technical discussion

The Cementing Process

The three principal objectives of the primary cementing process are:

1. To *isolate* formations restricting fluid movement and sealing-off lost circulation or thief zones;
2. To *support* and bond the casing to the formation;
3. To *protect* the casing from corrosion and reinforce it against the shock loads in drilling deeper.

Derived from these three principal objectives, other more specific objectives for a well could be:

1. Minimise WOC time and avoid a top-up job;
2. Obtain a good casing shoe and a sufficient FIT for further drilling;
3. Bring cement top to the planned depth;
4. Successfully pressure test the liner top and obtain a good CBL over a certain interval;
5. Design economical slurries

In order to effectively achieve these objectives, constraints and potential problems need to be identified, fluids must be designed to meet hole conditions, jobs should be executed accurately with maximum mixing rates and avoiding stoppages, and, finally, the cement must be properly displaced. This last issue, cement placement, appears to be a frequent cause of the cementing process not achieving its objectives.

Displacement Practices

One of the most important factors in obtaining a good primary cement job is properly displacing the drilling fluid. If the mud is not properly displaced, channels and/or pockets of mud may be left in the cemented annulus, which can lead to defeat of any of the primary objectives. Many oil and service companies have studied the process of mud displacement at length. The basic, generally agreed-upon factors affecting mud displacement and some of the latest technology that has been developed to aid in this process are listed below:

Basic Mud Displacement Factors

Most researchers agree that the following factors affect the process of mud displacement:

Mud Conditioning. Studies reveal that as the viscosity of the drilling fluid decreases the displacement efficiency increases. More energy and higher pressures would be required to displace viscous rather than thin mud. The drilling fluid removal is affected by two major downhole conditions, namely, the gel strength of the drilling fluid and its filter cake deposition. For a successful cement job, conditioning of the mud prior to the cement job is an absolute requirement. The conditioning mud should have the lowest PV/YP acceptable for that mud system, a flat and a low 10s/10m gel and a low fluid loss value. Note that static periods after mud conditioning and prior to the cement job must be avoided.

Displacement Rates. Displacement rates should be maximised because higher flow rates would apply higher shear forces to a drilling fluid. The higher the shear force, the more gelled drilling fluid would be broken free and circulated out of the annulus. Research studies have concluded that an annular velocity of 260 ft/min would be required to effectively displace the mud. The limiting factor to pumping rates would be the formation strength (fracture gradient). It is recommended to perform computer simulations to determine the ECD throughout the job thus ensuring that the fracture gradient is not exceeded.

Casing Movement. Both casing reciprocation and rotation during mud conditioning and cement placement have proven to improve mud displacement efficiency. Pipe rotation appears to be more beneficial when the casing is severely decentralised.

Casing Centralisation. The importance of pipe centralisation has been recognised since the first cementing studies were published in 1940. Pipe centralisation helps to create a uniform annular flow area and thereby equalises the pressure distribution around the pipe; thus the flow resistance is also evenly distributed. Therefore in an eccentric annulus the cement slurry will tend to flow and thus displace the drilling fluid on the wide side of the annulus while bypassing the mud on the narrow annulus. A casing standoff of 80% is recognised as an industry standard for maximum displacement efficiency. Especially nowadays with most wells being drilled under high inclinations or horizontal, inadequate centralisation will result in the pipe resting on the low side making it impossible to obtain a uniform cement sheath around the pipe, and may lead to the build-up of cuttings beds due to inadequate circulation. Computer simulations incorporating centraliser data and actual well profile could be run to determine the number of Centralisers needed for optimum standoff.

Spacer Fluids. Spacers are needed to isolate unlike fluids and help prevent potential contamination problems. A good spacer fluid should (1) adequately separate and be compatible with all well fluids in contact with the spacer, (2) remove efficiently mud or gelled up mud, and (3) not adversely affect the properties of the cement slurry or the mud. Spacers and flushes can be formulated with other beneficial properties, e.g. to enhance displacement efficiency and improve cement bonding. To combat the incompatibility of the OBM or SOBM with water base fluids and to change the pipe wetting from oil to water wet, surfactants will need to be included in the spacer system. The weight of the spacer should be designed at midpoint between the mud and the cement and the volume of the spacer should typically be equivalent to 10 minutes contact time.

All of the above factors need to be given careful consideration as they are interactive and vary as a function of the hole conditions and drilling fluid properties. The quality of a cement bond evaluation would be proportional to the attention given to the above factors. Halliburton has recently developed a computer simulation based on the latest technology which uses erodibility data. This model determines the optimum spacer & cement rheology for effective mud removal.

New Mud Displacement Concepts

Erodibility Technology

Another recently developed cement displacement technology that can greatly aid in achieving a good cement job is the Erodibility Technology. The Erodibility Technology provides a means to determine how fast a given fluid (spacer) must be pumped to “erode” drilling fluid, in its various forms, from the annulus. While drilling fluid is typically characterized by density and rheological properties, it can exist downhole as whole, gelled, partially dehydrated gelled, and filtercake. Eroding whole drilling fluid from an annulus by circulation is usually much easier than eroding the same drilling fluid that has gelled (because of sitting static for some time) or has partially dehydrated (because of fluid loss to the formation). Erodibility Technology provides a means of quantifying the force needed to erode a gelled up mud, considering the geometry and centralization of a casing string. Knowing the force needed to erode that drilling fluid, provides a means of calculating how fast a given fluid, with specific plastic viscosity and yield point, should be pumped to erode the drilling fluid. If the specific rate cannot be achieved, then the fluid properties will need to be altered to improve mud removal efficiency.

The following examples should aid in understanding how this technology is applied.

Assume a drilling fluid that requires 30 lb/100 ft^2 shear stress to be removed when the casing has a 70% standoff and the spacer has a PV of 15 and a YP of 7. The software determines that to remove 100% of the drilling fluid the flowrate should be 8.7 bbl/min. This increases to 9.5 bbl/min when the standoff is reduced to 60%. When the spacer viscosity is increased to provide a PV of 30 and a YP of 12, the flow rate required for 100% drilling fluid removal drops to 7.4 bbl/min. When the shear stress required to remove the mud is reduced from 30 to 20lb/100 ft^2, the flow rate required to remove the gelled mud greatly reduces to 3.3 bbl/min when the standoff is 70% and the spacer has a YP of 30.

To determine a drilling fluid’s shear stress value under downhole conditions, tests can be performed using the specially designed erodibility cell. An indication of the mud’s shear stress after prolonged static conditions (e.g. 24 hrs) can also be derived using the mini-macs apparatus.

Cement job simulation

General

The cement job simulator will model the effects of various cement job design parameters before the job is actually performed. Potential problems can be identified at the design phase and appropriate modifications can be made.

In order to ensure that the model reflects actual well conditions information such as expected mud properties, deviation data, fracture pressure and pore pressures need to be known.

Simulators can be used to:

- Optimise pump rates for maximum mud displacement efficiency by designing the highest allowable pump rates, without exceeding fracturing pressures.
- Predict circulating pressures (ECDs) at any location in the well at any specific time during the job, even during "freefall" when the well is on vacuum and surface pressure indication is zero.
- Evaluate job results by comparing the pre-job simulation to on-site recorded job data thus allowing you to optimise future designs, or analyse and pinpoint the probable cause of a "problem" job.

Six step process to a effective cement simulation

STEP I: Establish cement job objectives

Optimised cement job

• A cost effective design which meets all job objectives
For example centralisers should not be run in regions where a cement seal around the annulus is not required.

STEP II: Review offset well information

Best starting point

• The best starting point for a cement job design is a successful job on a previous well
Cement placement simulations should however still be used to establish whether changes in well conditions will reduce the likelihood of success on the current well.

If the last cement job was unsuccessful this will also provide valuable information. Cement placement simulators can thus be used to help identify the cause of the failure and so highlight what needs to be changed on the current well.

STEP III: Obtain Well Parameters

"Garbage in > Garbage out"

• Any computer simulation is at best only as good as the input information supplied and evaluated

Especially so for critical jobs *(e.g. isolating a known gas bearing zone)*, it is therefore important to take the time to ensure that the information is the best quality available.

- Also ensure mud properties are representative of those at the end of the hole section.
- If fracture gradient is limiting flow rate, ensure that the current best data are used.
- If the data is uncertain, build in an appropriate evaluated safety margin.

STEP IV: Model mud circulation

What to input

• Input well geometry information, a first guess at stand-off in regions requiring zonal isolation, and mud properties
Establish whether full mud removal can be achieved in zones of interest.
If not:

- Improve centralization if practical
- Reduce mud gel strength
- Mud must be treated prior to running casing
- Mud should be pilot tested and new properties run in cement simulations to ensure treatment will be effective. *(Reducing 10min gel can also change other mud properties)*

• Circulation rate is also important, but it depends on the hole geometry, the smaller the hole, the more important the flow rate.

STEP V: Model Cement Job

Variables on which to focus

• Concentrate on the variables most easily changed and most likely to have a major impact
These are **spacer properties** and **flow rate.**

Properties of mud and cement can be changed to a limited extent but too large a change may adversely affect their primary function. Spacer properties on the other hand can be varied greatly.

Spacers can be divided into two categories: **Laminar flow and turbulent flow spacers.** As a rule of thumb, if a weighted spacer can be effectively pumped in turbulent flow this will result in a better displacement than using a laminar flow spacer. However this is very often not achievable in the field because of hydraulic limitations.

There are a large number of variables which affect the success of cement placement. For example pipe movement is not modeled, but it will normally improve the situation. Modeling all possible variations would be a very time consuming task.

Laminar flow design objective

• To achieve a value of (V *min* / V *av*) as close to 1 for all displacement of mud by spacer and spacer by cement

The following is a rough guide to the significance of V_{min}/V_{av} :

• 0 No flow on the narrow side of the annulus

• 0+ to 0.3 Severe channelling - some mud will be bypassed

• 0.3 to 0.95 Reasonable displacement but some mud channels likely

• 0.95 to 1 Excellent displacement, minimal channelling

Turbulent flow design

• To be fully effective

A turbulent flow spacer should be turbulent all around the annulus, *i.e. the percentage turbulence graph should be all green in regions of interest.*

Also V_{min}/V_{av} should be greater than 0 for weighted *spacers (it will always be 0 for flushes).*

STEP VI: Post-job analysis

Use all data

• All available data (bond logs, leak-off tests, etc.) should be used to quantify the success of the cement job

The actual cement job pumped should be compared to the job plan.
If there are major differences, the actual job should be simulated.
The objective is to get one or another of the graphs in the simulation very green (optimized) as opposed red (in-efficient).

Finally, post-job analysis is probably the most neglected area in cementing operations.

Optimising Cement plugs

Introduction

1.1 Cement testing should be carried out using samples of the actual materials to be used during the job. If this is not possible then materials of the same type should be used.

1.2 The minimum thickening time, to 70 Bc, should be the job time plus a safety factor of 1 to 2 hours.

1.3 General values for slurry rheology are: yield point greater than 5 lb/100 ft^2 with a 3 RPM reading of not less than 5 lb/100 ft^2.

1.4 Open hole slurry volume must be based on subsurface slurry losses that will occur due to the high permeability and porosity of the deepwater sediments e.g. A guideline excess volume is 50%.

1.5 If subsurface losses are occurring then set the cement plug in two stages *i.e. pump an initial small plug to act as a carrier for the second plug.*

1.6 Calculate the hydrostatic pressures throughout the job and check that the formation is never under balanced. *I.e. avoid displacing to seawater if gas bearing or shallow water flow zones have been identified. Weighted spacers or mud must be used to maintain primary well control at all times.*

String design

2.1 Wherever possible run a slim tubing stinger below the main pipe. The minimum stinger length should be the plug length plus 30m.

2.2 The natural tendency for cement slurry is to travel downwards when it leaves the string, since the slurry will generally be heavier than the completion fluid. For a good cement plug job the slurry needs to be encouraged to travel upwards. This can be achieved by:-

- Running a diverter sub below the cementing string. This sub will be a blanked off piece of tubing with holes cut in the sides to give a minimum total flow area equivalent to the tubing internal diameter.
- Spotting a pill of viscosified fluid below the plug setting interval.
- Generally a 100m long pill will be spotted.

Slurry mixing and placement

1. Pump a spacer ahead of the slurry to give a minimum separation of 100m.
2. Cement slurry should be batch mixed.
3. A slight under-displacement is required in order to pull a dry string.
4. Pump a spacer behind the slurry to give a minimum separation of 100m.
5. Displace at maximum rates
6. Do not reciprocate the string during the slurry displacement.

Clean up

4.1 Pull back slowly through the plug (maximum speed 20m/min to minimise disturbance to the plug) to a minimum of 100m or excess volume + a safety volume above calculated top of cement plug.

4.2 Do not stab back into the cement plug after pulling clear.

1.3 Once clear of the plug, circulate the well ensuring hydrostatic balance is maintained. Monitor returns for cement with ROV.

Test plugs

5.1 Wait on cement surface samples to set. *(place samples in anticipated downhole temperature conditions)*

5.2 Run in hole and confirm top of cement (TOC).
If confirmed pull out and make up next drilling assembly or run casing as required.

ROV will monitor wellhead to observe for any flow as cement sets and loses hydrostatic.

5.3 If drilling is to continue, RIH to above plug TOC, establish slow circulation and rotation. Ream down until circa 10,000 1bs has been drilled off. Record this depth as the top of cement.