CEMENTING OPERATIONS

Prepared by
Functional Committee on “Cementing Operations”

Oil Industry Safety Directorate

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Preamble

Indian petroleum industry is the energy lifeline of the nation and its continuous performance is essential for sovereignty and prosperity of the country. As the industry essentially deals with inherently inflammable substances throughout its value chain – upstream, midstream and downstream – Safety is of paramount importance to this industry as only safe performance at all times can ensure optimum ROI of these national assets and resources including sustainability.

While statutory organizations were in place all along to oversee safety aspects of Indian petroleum industry, Oil Industry Safety Directorate (OISD) was set up in 1986 Ministry of Petroleum and Natural Gas, Government of India as a knowledge center for formulation of constantly updated world-scale standards for design, layout and operation of various equipment, facility and activities involved in this industry. Moreover, OISD was also given responsibility of monitoring implementation status of these standards through safety audits.

In more than 25 years of its existence, OISD has developed a rigorous, multi-layer, iterative and participative process of development of standards – starting with research by in-house experts and iterating through seeking & validating inputs from all stake-holders – operators, designers, national level knowledge authorities and public at large – with a feedback loop of constant updation based on ground level experience obtained through audits, incident analysis and environment scanning.

The participative process followed in standard formulation has resulted in excellent level of compliance by the industry culminating in a safer environment in the industry. OISD – except in the Upstream Petroleum Sector – is still a regulatory (and not a statutory) body but that has not affected implementation of the OISD standards. It also goes to prove the old adage that self-regulation is the best regulation. The quality and relevance of OISD standards had been further endorsed by their adoption in various statutory rules of the land.

Petroleum industry in India is significantly globalized at present in terms of technology content requiring its operation to keep pace with the relevant world scale standards & practices. This matches the OISD philosophy of continuous improvement keeping pace with the global developments in its target environment. To this end, OISD keeps track of changes through participation as member in large number of International and national level Knowledge Organizations – both in the field of standard development and implementation & monitoring in addition to updation of internal knowledge base through continuous research and application surveillance, thereby ensuring that this OISD Standard, along with all other extant ones, remains relevant, updated and effective on a real time basis in the applicable areas.

Together we strive to achieve NIL incidents in the entire Hydrocarbon Value Chain. This, besides other issues, calls for total engagement from all levels of the stake holder organizations, which we, at OISD, fervently look forward to.

Jai Hind!!!

Executive Director

Oil Industry Safety Directorate
FOREWORD

The Oil Industry in India is more than 100 years old. Because of various collaboration agreements, a variety of international codes, standards and practices have been in vogue. Standardization in design philosophies and operating and maintenance practices at a national level was hardly in existence. This coupled with feedback from serious problems that occurred in the recent past in India and abroad, emphasized the need for the industry to review the existing state-of-the-art in designing, operating and maintaining oil and gas installations.

With this in view, the Ministry of Petroleum and Natural Gas in 1986 constituted a Safety Council assisted by the Oil Industry Safety Directorate (OISD) staffed from within the industry, in formulating and implementing a series of self-regulatory measures aimed at removing obsolescence, standardizing and upgrading the existing standards to ensure safe operations. Accordingly, OISD constituted a number of functional committees of experts nominated from the industry to draw up the standards and guidelines on various subjects.

OISD-STD-175 on “Cementing Operations” was prepared in 1999. As many new techniques, processes and chemical brands have evolved in the field of cementation Second edition of standard was published in the year 2008. In view of the recent major disasters, it was decided to review the requirements of safe well abandonment permanent or temporary the clause 11 on well abandonment was further elaborated to put more clarity in well abonnement requirement and procedure particularly temporary well abandonment. Thus the document was taken for amendment revision in Jan 2015.

Suggestions are invited from the users after it is put into practice to improve the document further. Suggestions for amendments to this document should be addressed
To
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This document is intended to supplement rather than replace the prevailing statutory requirements.
Functional committee
(Second edition - 2008)

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1.0 INTRODUCTION

Cementing of an oil/gas well is a precise and highly complex job. It is one of the most critical phases of well completion. Cementing operations are undertaken to seal the annulus after a casing string has been run or to set a plug in an existing well.

The cement slurry must exhibit certain hydraulic properties for proper placement in the wellbore while the set cement sheath must possess certain mechanical properties for long term structural support and zonal isolation. The set cement acts as a barrier to the flow of fluids/gas from formation to other formation or to surface in a successfully drilled well.

Factors, which contribute to success or failure in primary and secondary cementing operations, are described. Cementation of deep-water, high angle and CBM wells has also been briefed.

2.0 SCOPE

This document provides recommended practices for cementation jobs in onshore and offshore wells.

3.0 DEFINITIONS

**casing stand off ratio**: smallest distance between the well bore and out diameter of casing expressed as percentage of annular clearance for perfectly centred casing.

**lost returns**: the reduced or total absence of fluid returning to the surface after being pumped down a well. Lost returns occur when the drill bit encounters natural fissures, fractures or caverns, and the fluid flows into the newly available space.

**permanent abandonment**: a well status where the well or part of the well, will be plugged and abandoned permanently with the intention of never being used or re-entered again.

**shall**: “shall” indicates a mandatory requirement

**Should**: “should” indicates a requirement, which is recommendatory in nature

**temporary abandonment**: A well status where the well is abandoned or/and the well control equipment is removed with the intention that the operation will be resumed within a specified time frame (from days up to several years)

4.0 CEMENTATION REQUIREMENTS

4.1 Casing cementation

1. A cementing plan shall be issued for each cementation job.

2. The properties of the set cement shall be capable to provide lasting structural support and zonal isolation.

3. Cement slurries used for isolating permeable and abnormally pressured gas bearing zones shall be designed gas tight for preventing annular gas migration problem.

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4. The cement placement technique used should impose minimum overbalance on weak formations. Risk of lost returns and well activity during cementing shall be assessed and mitigated.

5. Cement height in casing annulus:
   
   a. For surface casing, cement height shall be based on load conditions from wellhead equipment and operations. Top of cement (TOC) should be inside the conductor shoe or up to surface / seabed if no conductor is installed.
   
   b. For casing through hydrocarbon bearing formations, cement height shall be based on requirements for zonal isolation. Cement should cover potential cross-flow interval between different reservoir zones.
   
   c. For casing strings which will not be drilled out after cementation, the cement height shall be 200 m above the point of potential inflow/leakage point/permeable formation with hydrocarbons or up to previous casing shoe, whichever is less.
   
   d. For casing where the cement column in consecutive operations is pressure tested or the casing shoe is drilled out, cement height shall be sufficient above the casing shoe.

6. Temperature exposure, cyclic or developing over time, shall not lead to reduction in strength or isolation capability.

7. Cementation verification:
   
   a. The set cement shall be verified through formation strength test when the casing shoe is drilled out. Alternatively the verification may be done by exposing the cement column to differential pressure from fluid column above cement in annulus. In the latter case the acceptance criteria shall be defined.
   
   b. The verification for having obtained the minimum cement height shall be defined, which can be
      
      ▪ Verified by logs (cement bond, temperature, LWD sonic), or
      
      ▪ Estimated on the basis of records from the cementing operation (volumes pumped, returns obtained during cementing, etc.).
   
   c. The strength development of the cement slurry shall be verified in laboratory under representative temperature and pressure conditions.

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d. For casing through hydrocarbon bearing formations, the zonal isolation shall be verified by cement evaluation logs like CBL/VDL, USIT etc.

8. Monitoring

a. The annulus pressure above the cement shall be monitored and recorded regularly when access to this annulus exists.

b. Annular space between surface casing and conductor shall be regularly monitored visually for any activity.

4.2 Plug Cementation

1. A cementing plan shall be issued for each cement plug job.

2. The properties of the set cement plug shall be capable to provide lasting zonal isolation.

3. Cement slurries used in plugs to isolate permeable and abnormally pressured hydrocarbon bearing zones shall be designed to prevent gas migration.

4. Permanent cement plugs shall be designed to provide a lasting seal with the expected static and dynamic conditions and loads downhole.

5. The cement plug shall be designed for the highest differential pressure and highest downhole temperature expected, inclusive of installation and test loads.

6. Minimum batch volume of cement shall be defined for the plug to ensure that that homogenous slurry can be made, taking into account the contamination on surface and downhole.

7. The firm plug length shall be minimum 60 m. If a plug is set inside casing and with a mechanical plug as a foundation, the minimum length shall be 15 m.

8. The plug shall extend minimum 30 m (measured depth) above any source of inflow/leakage point. A plug in transition from open hole to casing should extend at least 30 m (measured depth) below casing shoe.

9. Plug verification:

a. The strength development of the cement slurry shall be verified through observation of representative surface samples from the mixing cured under representative temperature and pressure conditions.

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b. The plug installation shall be verified through documentation of job performance; records from cement operation (volumes pumped, returns obtained during cementing, etc.).

a) Position and strength of the plug shall be verified by:

i) Open hole: Tagging to confirm depth of firm plug.
ii) Cased hole: Tagging to confirm depth of firm plug and a pressure test, which shall be 1000 psi above estimated formation strength at a point below casing/ potential leak path. For surface casing plugs, test pressure will be 500 psi.

However the test pressure shall not exceed casing test pressure, less casing wear factor. Cased hole plugs should be tested either in the direction of flow or from above.

If a mechanical plug is used as a foundation for the cement plug and is tagged and pressure tested, the cement plug need not be verified.

10. For temporarily abandoned wells, the fluid level/ pressure above the shallowest set plug shall be monitored regularly when access to the bore exists.

11. For radioactive material left in the well, a cement plug of minimum length 50 m and at least specific gravity 2.35 shall be placed over the location where the source is stuck. Guidelines of Atomic Energy Regulatory Board, Govt of India shall be followed in this regard.

5.0 OIL WELL CEMENT

5.1 Oil well cement selection criteria

Oil Well Cement shall be as per API Specification – 10 A on “Specification for Cements and Materials for Well Cementing” or ISO 10426-1:2005 on “Petroleum and Natural Gas Industries-Cements and materials for well cementing - Part1: Specification”.

5.2 Marking and packing

Marking and packing shall be as per API- Specification - 10A on “Specification for Cements and Materials for Well Cementing” or ISO 10426-1:2005 on “Petroleum and Natural Gas Industries-Cements and materials for well cementing - Part1: Specification”.

5.3 Handling and storage of cement and additives

5.3.1 Handling

1. Care shall be taken during handling and transportation of cement/ additive bags so as not to allow ingress of moisture.

2. Use of iron hooks should be avoided as it will puncture the bags and expose the material to moisture.

3. Contamination of cement by other bulk materials should be avoided in offshore operations.

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4. Air used for bulk transferring of cement / additives should be dry.

5. For offshore use, cement additives should be sent to the installation in sealed containers. In case additives are sent on pallets, these should be properly covered to avoid ingress of moisture.

5.3.2 Storage

1. Cement chemicals should be kept separate from other chemicals to avoid any intermixing of bags.

2. Storage of cement / chemicals should be such that oldest stock will be issued first.

3. Cement chemical bags should be stored away from the wall on a platform with approximately 6 inches air space and tarpaulin should be spread on the base of stacking in order to form a moisture proof seal.

4. While storing cement for a long time in silo, either on site or in bulk handling plants, cement should be transferred from one silo to another, at least once in a month.

6.0 CEMENTING EQUIPMENT

6.1 Cementing unit

1. The cementing unit shall be designed so that it will mix, store and deliver as accurate volume and density as possible of cement slurry with the necessary properties to ensure fully satisfactory anchoring and isolation integrity. The pumps and associated lines shall have rating to handle 1.5 times the maximum anticipated pumping pressure.

2. Pressure release safety valve shall be placed in discharge line so as to avoid sudden rise in pressure in the unit.

3. Recirculating system should be part of the cementing unit or otherwise batch mixer should be used.

4. The unit should have a densometer to monitor slurry density.

5. In case of offshore rigs, the unit should have two centrifugal pumps for mixing water, one directly coupled with the main transmission and other with independent drive motor.

6. Apart from recirculating system, unit should also have a ground mixing system using rotary jet, hopper, goose-neck pipe, slurry tub etc.

7. The unit should have high pressure mixing system lines so that in case of failure of both the mixing units, high pressure mixing can be carried out by isolating one triplex pump from the other.

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8. If the cementing unit with associated systems is intended to function as backup for the drilling fluid system, it shall have capacity and working pressure to be able to control the well pressure at all times preferably with independent power.

6.2 Cement silos

1. The cement silos shall be designed so that remains of unmixed chemicals as well as ready-mixed cement can be suitably handled / disposed in accordance with environment regulations in force.

2. Regular health check of silos and associated piping / valves shall be ensured as per OEM / company policy.

3. The silos shall be equipped with suitable safety valves.

4. There shall be suitable provision to know quantity of cement in silo.

5. All the inlet, outlet and vent lines from the silos should always be kept clean to avoid any blocking / choking.

6. In line filters should be installed on the inlet and outlet ports of silos to avoid any cement stones entering into the system and choking lines. These filters should be periodically cleaned.

7. Compressed air used for transfer of cement from silos to surge tank should be free of moisture. Compressor should be equipped with suitable air dryer unit.

6.3 Mobile pneumatic bulk carrier

Regular health check of mobile pneumatic bulk carrier and associated piping / valves shall be ensured as per OEM/ company policy.

6.4 Loading pod

1. The loading pods shall be designed so that remains of unmixed chemicals as well as ready-mixed cement can be suitably handled / disposed in accordance with environment regulations in force.

2. Periodic health check of loading pod and associated piping / valves shall be ensured as per OEM/ company policy.

3. Loading pod shall be equipped with suitable ladder, otherwise a screw conveyor with a hopper placed at the ground be used for loading.

6.5 Cement surge tank

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1. The cement surge tanks shall be designed so that remains of unmixed chemicals as well as ready-mixed cement can be suitably handled / disposed in accordance with environment regulations in force.

2. Regular health check of surge tank and associated piping/ valves shall be ensured as per OEM / company policy.

3. The surge tank should be equipped for controlled discharge of cement to the mixing hopper.

4. It shall be equipped with safety valve and level indicator.

5. Surge tank should be kept empty after each cement job.

6. Provision should be made to back load excess cement from surge tank to silo.

7. Vent line of surge tank should be kept clean to avoid blocking/ choking.

6.6 Cementing head

1. The cementing head should be cleaned, serviced, greased before and after every cement job.

2. Cementing head should be equipped with positive lever type indicator for plug release. Plug release indicator and assembly should be serviced regularly to ensure its proper functioning at the time of job.

3. Health check up including pressure testing of cementing head shall be ensured as per OEM / company policy. HP valves on cementing manifold shall be tested periodically.

4. All 'O' rings should be checked for any cuts or damages.

6.7 Additive mixing tank / slug pit

1. A separate tank should be provided for mixing of cement additives with suction facility from bottom by centrifugal pump and with delivery line to cementing unit displacement tank.

2. Stirrers/jetting guns should be provided for proper mixing of chemicals in tank.

3. The tank should be provided with proper facility for cleaning.

6.8 High-pressure lines and manifolds

1. All high pressure lines and cementing manifold shall be of pressure rating minimum 1.5 times the maximum anticipated working pressure.

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2. Pipeline layout on offshore rig should have minimum bends to avoid excessive pressure loss.

3. For offshore rigs there should be two high-pressure lines from the cementing unit to derrick floor, with interconnections.

6.9 Batch mixer

Batch mixer shall be able to prepare homogeneous cement slurry of desired specific gravity to achieve design properties. The batch mixer may be skid type or movable type powered by diesel engine or electric motor. It shall be provided with proper facility for cleaning up after each job.

7.0 PRIMARY CEMENTING PRACTICES

Major areas requiring attention are:

1. Slurry design / job planning
2. Blending of cement with additives in bulk handling plant
3. Casing lowering
4. Pre-cement job arrangements
5. Job execution
   - Cement slurry mixing and pumping
   - Displacement
   - Waiting on cement
6. Post job analysis
7. Prevention of sustained casing head pressure

7.1 Cement slurry design / planning of cement job

1. The following information should be available for preparing slurry design and cementation plan:
   - Rig, Well No., field location
   - Type of job - casing or liner: conventional or sub-sea operation.
   - Casing sizes, grades, weights and threads.
   - Casing depths, deviation, hole size, caliper log and drilled depth.
   - Type of mud to be used, mud parameters and rheology.
   - Bottom Hole Circulating Temperature (BHCT) & Bottom Hole Static Temperature (BHST), expected pore pressures and fracture pressures.
   - Interested zone intervals with Oil Water Contact (OWC) and / or Gas Oil Contact (GOC).
   - Any special well problems (high pressure gas, Lost circulation etc).

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- Cement rise needed in the annulus
- Any other specific requirement like resistance to cyclic temperature/ pressure fluctuations, high cement strength etc.

2. At job planning stage, the availability of equipment and additives for the job execution should be assessed.

3. Calculate the cementing parameters which include quantity of cement, total mix water, pump rate, well head and bottom hole pressure during displacement, mixing time, mud displacement volume, surface pressure and other related information. This will assure that the well will remain under control during the cementing operation.

4. Design for maximum allowable down hole slurry density to prevent fracturing. Slurry density should be at least 1 lb/gal (preferably 2-3 lb/gal) heavier than the drilling mud.

5. Determine BHCT from logs and using API Temperature data. Temperature logged approximately 24 hours after the last circulation ceased can be used as BHST for API table use.

6. Fluid loss of cement slurry (as per test given in API Specification – 10 A) should have values as given below:
   a) For preventing gas channelling: less than 50 ml / 30 minutes.
   b) For Liner Cementing: less than 100 ml / 30 minutes.
   c) For casing cementing: approximately 250 ml / 30 minutes.

7. The design should provide displacement in turbulent flow to obtain minimum 10 minutes contact time at the top of pay zone. Preflush i.e. aqueous solution of dispersant and surfactants are not recommended in high pressure wells.

8. Weighted buffers should be used in high-pressure wells and preferably be designed for turbulent flow. The best results are obtained if not only the density but also the rheological properties of the spacer fall between those of mud and cement slurry. Design the spacer so that it is compatible with both the cement slurry and the drilling mud.

9. If turbulent flow is not possible, then design the job for mud displacement in effective laminar flow using rig pump rate as fast as possible within the limitations of fracture gradient.

10. 35% Silica flour by weight of cement may be used for BHST above 230° F (110°C) to prevent strength retrogression of set cement.

11. For normal slurries, control free water separation to 1.4% or less. To prevent gas channelling and in highly inclined wells, zero free water control should be primary objective.

12. Determine cement slurry thickening time at BHCT and bottom hole pressure. Minimum thickening time should be job time plus one-hour thickening time to a consistency of 50 Bc. Excessive slurry thickening time should be avoided.

13. In wells, where field slurries are to be batch mixed, while running the thickening time test in lab, before following API test schedules for increasing temperature and pressures, the slurry should be stirred in the consistometer at the surface temperature and atmospheric pressure for the estimated batch mixing and holding time at drill site prior to pumping slurry into the well.

14. Slurry consistency for normal turbulent flow should be 10 to 20 Bc. Since sometimes slurries can be mixed heavier in the field, so check consistency in the lab for 1 ppg heavier slurry also.

15. Use the same mixing water, cement and additives in laboratory testing that will be used at the well for the job. If additives are dry blended, a blended cement sample should be collected and tested in the cement test lab before the execution of the job.

16. In case of certain types of cement jobs, such as long cement column rise or long liners where the static temperature at the top of cement is lower than the BHCT, compressive strength test should be performed at the TOC temperature also to confirm the setting of the cement at the cement top.

17. Minimum compressive strength of set cement at BHST should be
   - 500 psi for drill out

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- 2000 psi for perforations

18. Cement additives such as fluid loss, dispersant, retarder, accelerator, light weight and heavy weight should be used in order to get the desired properties of cement slurry as per job requirement

19. Silica can be used as additive up to maximum BHST of 400° C. However in case of wells subjected to temperature cycling as in thermal wells, oil well cement with Silica cannot be used above 320° C as it disintegrates. Calcium- Aluminate cement can be used in such conditions.

20. For primary cementation of high-pressure gas wells, gas block additives should be added to cement slurry for effective blockage of gas leakage and the slurry should be tested for its gas tight property in the lab prior to use in the field.

21. During design of cement slurry, long term durability of the set cement subjected to stresses due to temperature and pressure cycling during the life of the well should be taken care of to prevent annular pressure build up problems.

22. Casing load is maximum when cement slurry is still inside the casing. While selecting casing, this aspect must be considered.

23. Large size surface casing with long column of cement rise will have a tendency to float. Arrangement for safe securing of casing should be made.

7.2 Blending of bulk cement with additives

1. Cement absorbs moisture from its surroundings, which adversely affects its properties. Therefore, cement should be purchased in staggered deliveries.

2. During blending of cement with dry additives, verify weight calculations, quantity and name of each additive going into the cement with the design composition. Count the additive sacks and cement sacks for each blend.

3. Visually inspect empty tanks prior to transferring blended materials to ensure that they are completely empty.

4. To ensure proper blending, transfer the blended material at least twice between silos before loading on mobile silos or bulk supply boats for drill site delivery.

5. Conduct fluid loss and thickening time test on samples taken from each container to verify blending.

6. Transfer dry blend to empty tank and back to original tank just prior to slurry mixing. If extra empty tank is not available on site, then fluff or percolate air through each tank from the bottom for 15-20 minutes to redistribute additives.

7. When different blends are used, each blend and corresponding tank should be clearly identified.

8. Collect and save sample of each composition for post job analysis, if failure occurs.

9. Check that all materials required for the job are loaded and identified on the transporting vehicles. Verify that correct chemicals are loaded with correct weight and volume.

7.3 Lowering of casing

Running in speed of casing should be controlled to prevent fracturing and mud loss. Casing lowering should be so regulated that the maximum annular velocity caused by the movement of the pipe does not exceed the annular velocity during normal circulation

2. Landing joint(s) should be spaced out so that the cementing head can be installed easily at the rig floor after casing is landed.

3. Casing centralisation is a critical parameter that must be part of the cementing programme. Placing of centralizers should be done with the help of cementing software in order to have casing stand off ratio minimum 67% for deviated wells and near to 100% for vertical wells.
Welding of stop ring on casing and use of welded steel bows should be avoided. API approved centralizers should be used.
4. Use scratcher against permeable formations and 60 m above and below the pay and water zones in case of casing reciprocation.
5. Use double float protection - a float shoe and a float collar. Check its functioning on surface before make up. Compatible float collar and float shoe should be used.
6. Put float collar and shoe 2-3 joints apart as depth increases. In case of differential float equipment, check the size of the ball for actuating them properly.
7. Last two casing joints should be lowered at a very slow speed.

7.4 Pre-cement job arrangements

7.4.1 Hook up

1. A detailed plan indicating the step by step job sequence duly approved by the drilling incharge should be prepared and circulated to all concerned prior to the cementation job.
2. After arrival at site, the cementing incharge should independently calculate the slurry volume and displacement volume required using actual parameters and also total water requirement including the water needed to flush cementing unit and high pressure lines.
3. Ensure that the supply rates of both mud and water required for the job are sufficient for uninterrupted operation.
4. The following parameters should be verified with the drilling incharge: mixing and displacement rates, pressure to apply when plug lands, and barrels (or cubic meters) of mud that will be pumped over the calculated displacement volume, if the plug fails to land, considering rig pump efficiency.
5. In case the displacement is to be performed by the rig pump, availability of both rig pumps should be ensured. Also the volumetric efficiency of mud pump, functioning of stroke counter and mud line flow meter should be checked.
6. Conduct a pre hook up meeting to review equipment placement, lay out of high pressure lines, material mixing and pumping sequence, pump rates, slurry densities, safety hazards during pumping operations and maximum allowable pressure.
7. Check air compressor operation, fluff the cement silos, prime the pumps & mixers and check for their operation.
8. Proper working of air dryer should be ensured, specially in offshore.
9. In case of floater rigs, a mandrel is used for carrying top and bottom plugs. Check its ball for correct size before installing. The mandrel should be serviced immediately after every use.
10. Check cementing head, plug release mechanism, plug dropping indicator and review the number and placement of rubber plugs in proper sequence.

7.4.2 Cementing equipment

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1. Check the cementing units, silos, surge tank, compressor and bunkers to avoid any breakdown during the operations.

2. Check the discharge of each cementing unit physically for their capacity in accordance with the liner size.

3. Check the tanks of cementing unit thoroughly.

4. Pressure test the cementing head and all connecting lines at 1.5 times the maximum pressure expected during the job.

7.4.3 Mud conditioning

Begin pipe movement and mud conditioning immediately after the casing is at bottom. The casing movement should continue throughout the circulation period. When reciprocating, the pipe is usually moved through a 6 m stroke, using a 2 minute interval for the cycle. For rotation, the pipe is rotated as slowly as possible, usually between 10 and 15 rpm.

Adjust Plastic Viscosity (Pv) and Yield Point (Yp) of the mud to the lowest possible values. Condition the hole with good surface conditioned mud at maximum possible rate within the limitation of formation fracture gradient for 1.5 to 2 cycles (minimum). For critical jobs, such as production casing cementation, fresh mud having low rheology should be pumped ahead of cement slurry.

7.5 Job execution

7.5.1 Cement Slurry Mixing And Pumping

1. Pressurise bulk units to 15-25 psi just prior to starting mixing of slurry.

2. Start the pumping operation to establish circulation to ensure that the casing shoe is open and check the mud return.

3. Do not premix the cement additives in the water more than 5-6 hours before the cementing job. It is preferable to wait until the final circulation is started after casing lowering to the target depth. Verify metering device if liquid additives are pre mixed in water. Continue to agitate the chemical mixed water thoroughly until the job is complete.

4. The chemical water should be measured through displacement tank because it helps to calculate easily how much quantity of cement has been pumped in the event of unplanned shutdown.

5. Control slurry density with online densometer / pressurised mud cup balance. Check calibration of densometer as well as mud cup balance with fresh water to ensure the reliability of density readings.

6. Inspect top and bottom cement rubber plugs before loading. Turn bottom plug upside down and inspect hollow core and rubber diaphragm. Do not puncture diaphragm of bottom plug

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prior to loading. Bottom hollow plug is loaded first and then top solid plug is loaded. Ensure correct order of plug loading and locking of plug release shaft.

7. A bottom plug is not recommended with large amounts of lost circulation material in the slurry or with badly rusted or scaled casing, as such material may collect on the ruptured diaphragm and block the flow through the casing.

8. Use preflush or spacer equal to volume of 150-200 m annular height. Pump preflush or spacer ahead of bottom plug. Better prevention of contamination can be achieved by use of two bottom plugs, one ahead of preflush and one ahead of cement slurry.

9. To ensure good control of slurry density and other properties, batch mix cement slurries. Alternatively use continuous mixing devices like Precision Slurry Mixer (PSM) or Recirculating Cement Mixer (RCM).

10. Release top plug from cementing head without shutting down operations. Do not open cementing head to drop top plug as it will allow the well to suck in air and cause honey combing of cement around the shoe joints.

11. Do not try to get the last quantity of cement out of the cement bunker or surge tank. This will cause reduction in slurry density and will result in poor slurry at shoe joint and outside bottom joints.

12. If the density cannot be controlled within acceptable limits and slurry thickening time is too short to allow job completion, then it is advisable to call off the job and circulate the cement slurry out of the hole.

7.5.2 Displacement

1. Determine displacement rate on the basis of the type of casing string to be cemented. Turbulent flow displacement is usually accepted as being the most efficient technique for achieving good mud removal. However when turbulence all around the casing cannot be achieved mainly due to stand off, pump or fracture gradient limitations, then the maximum permissible / attainable discharge for high laminar flow is recommended during displacement.

2. Cement displacement rate should be as high as possible to attain annular velocity of at least 1.3 m/sec and preferably 1.8 m/sec to achieve good zonal isolation with reasonable degree of certainty.

3. Field validated computer programs should be used to calculate the highest possible displacement rate within the constraints imposed by formation strength and surface / downhole equipment limitation.

4. Casing pipe should be kept in motion to improve mud displacement. Reciprocation should be on a two minute cycle over 4 to 6 m length. Rotation at 3 to 10 rpm is satisfactory.

5. Displace top plug from cementing head with minimum down time.

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6. Continue pipe movement until the top cementing plug is bumped or casing tends to become stuck.

7. Calculate the anticipated mud return volume throughout the job.

8. Mud return is measured in trip tanks or by other means. High return rate is predicted during the free fall period due to U-tube effect.

9. To check the fluid return, observe pH change, funnel viscosity and density.

10. Monitor the displacement and bumping of plug. Check the flow back by releasing the pressure. Leave casing open during waiting on cement (WOC). A small amount of back flow is expected because of thermal expansion and cement reaction.

11. Even if the rig pump performs the displacement, then also cementing unit must remain completely lined up until plug bumps. The plug hitting must be observed carefully and pressure recorded in cementation job report.

12. In the event of failure of float valves, the casing should be kept closed at pressure equal to the differential pressure till the cement slurry thickens.

13. During cementation, ‘mud returns’ from the annulus should be continuously monitored.

14. Pressure tests the casing for leaks immediately after the top plug bumps in cases where the displacement fluid is water.

15. Maintain log of operations to include operation in progress, time, density measurement, mixing rate, volume of fluid pumped, pumping pressure, displacement rate etc.

16. All specific events occurring throughout the cement job must be recorded along with other relevant points for post job evaluation.

17. Carry out material balance calculations for mix water, cement and cement additives and compare with volume of each slurry pumped.

18. Prepare a summary of the completed job.

7.5.3 Waiting-On-Cement (W.O.C.)

1. Sufficient WOC time must be observed for the cement to develop adequate strength before operations are resumed. During the W.O.C time, the cement though rigid, has very little strength, and any damage sustained by the cement sheath during this period does not ‘re-heal’.

2. The required period of WOC time varies depending on the cement blend and downhole condition of temperature and pressure.

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3. Cement used for intermediate casing string should have compressive strength of at least 500 psi before drilling is resumed.

4. Completion interval cement should have compressive strength of at least 2000 psi before the well is perforated.

7.6 Post job analysis

Evaluation of cement job is very crucial to determine its success. A complete post job analysis comparing field job parameters with evaluation results is the best way to reasonably understand what happened downhole and accordingly necessary corrective measures for future operation should be applied.

1. Caliper, CBL-VDL, CET or USIT or equivalent logs can provide accurate and useful information regarding job success or failure. However, production results are the actual proof of the acceptable quality of cementation.

2. The cement bond log, normally, should not be run until 48 hours after the cementation in order to achieve the true cement bond reading. This again is highly dependent on the cement type and additives used in the slurry and bottom hole conditions.

3. Field results show that more than 90% of wells exhibit a micro-annulus on a primary cement job. CBL-VDL should be recorded under 700-1000 psi pressure to eliminate micro-annulus effect.

4. The bond index method is most commonly used for interpretation of amplitude curve in CBL-VDL towards achievement of zonal isolation. This method is essentially a graphical solution, which allows determination of amplitude value corresponding to a particular bond index.

One of the guidelines followed by international operators based on the bond index method is given below.

Satisfactory ‘length & bonding’ required for zonal isolation for different size casings:

- 5” Casing - 5 feet of 60% bond
- 51/2” Casing - 6 feet of 60% bond
- 7” Casing - 10 feet of 60% bond
- 75/8” Casing - 12 feet of 60% bond

(Source: SPE technical paper # 52810)

7.7 Prevention of sustained casing head pressure

The main objective of cement sheath in oil & gas well is to prevent any fluid communication during the life of the well so that the reservoir can be produced safely and economically. To achieve this objective, during cementation, the drilling fluid should be displaced evenly and the cement slurry should be placed homogeneously in the annulus. However sustained casing pressure observed on a number of wells in the old fields around the globe in the last few years has led to the conclusion.

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that even if the slurry was properly placed during the cementing job, and initially fulfils its isolation role, changes in downhole conditions can induce sufficient stresses to destroy the integrity of the cement sheath. The consequence will be loss of zonal isolation, leading to long-term gas migration problem. Therefore besides placement, the set cement should be able to withstand the stresses induced by the well events and maintain its integrity during the life of the well.

Studies indicate that in the long term, more important than compressive strength is the ductility / flexibility of the set cement to withstand downhole stresses imposed by pressure and temperature oscillations during drilling, workover and production operations. Cement systems that are stiffer or possess a high Young’s modulus are more susceptible to damage when subjected to changes in pressure and temperature. Therefore, for long term durability, the set cement should have high tensile strength to Young’s modulus ratio, low Young’s modulus value compared to that of rock and higher value of poison’s ratio. Also in a weak formation, chances of cement sheath failure are more, as it cannot mechanically support the cement deformation.

Examples where well integrity can be lost due to cement failure because of high stresses are

- Deep water wells
- HPHT wells
- Wells completed in weak unconsolidated formations
- Steam injection wells
- Producing wells converted to injectors

The following are the stresses induced by different type of events during the life of a well:

a) Large increase in wellbore pressure
   - Pressure integrity test
   - Increase of mud weight
   - Casing perforation
   - Stimulation
   - Gas production

b) Large increase in wellbore temperature
   - HT/HP wells
   - Deepwater wells
   - Thermal recovery wells
• Geothermal production

c) Formation loading
  • Creep
  • Faulting
  • Compaction

Traditionally, cement sheath design in the majority of wells was focused on short-term properties and concentrated only on compressive strength as a quality indicator. The effects of well events and their subsequent effect on the cement sheath during the well’s life have not normally been considered. In general, no attention has been paid to mechanical properties of set cement such as tensile strength, Young’s modulus etc. This approach could serve well if the sealant is not subjected to a large change in stress level. But in actual conditions, wells are exposed to many changing conditions that create mechanical stresses on the casing and the cement sheath behind it. These stresses can come from pressure changes; fluid weight changes during drilling and completion; pressure testing and pressure treating such as squeeze cementing or high-pressure stimulation treatments; changes in well pressures caused by reservoir pressure depletion. Temperature changes, especially in upper portions of a well producing high-temperature fluids, can also generate mechanical stresses.

Design procedures should be developed to estimate the risk of cement sheath damage over time as a function not only of the cement sheath properties, but also of those of the formation, casing and representative well events. Designing cement to maintain seal in the wellbore throughout the life of the well should be based on informations regarding the rock and casing properties, well geometry and future loading which is expected during the life of the well, as detailed below:
  - Physical and thermal properties of cement casing and formation
    • Young’s modulus
    • Poisson’s ratio
    • Tensile strength
    • Thermal expansion
    • Thermal conductivity
    - Formation in-situ stresses
    - Well design
    - Representative well events

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Softwares should be used to predict the stresses to be experienced by the cement sheath throughout the life of the well due to the changing conditions of the well. These softwares also assess the mechanical properties of the cement to determine if the cement will survive these stresses. Thus, the mechanical properties of the cement can be modified so that the cement will survive to provide isolation for the life of the well. This methodology allows custom fit cement designs for individual well bore stress environments.

8.0 PRACTICES FOR SPECIALISED CEMENTING

8.1 Multistage cementing

It comprises of conventional placement of cement slurry around the lower portion of the casing string followed by placement of cement slurry in successive upper stages through ports of stage collar. Mostly it is in two stages, although additional stages are possible.

1. Design cement slurries for the first stage and second stage at temperature and pressure at the casing depth and stage collar depth respectively.

2. Before the stage cementing collar is made up in the casing string, check the size of the trip plug/freefall plug/opening bomb, internal diameter of the opening sleeve and closing sleeve and the size of the seats provided in opening & closing sleeves.

3. Regardless of the type used, caution must be exercised in the initial handling of the stage collars, as the equipment is manufactured to close tolerances. Smooth sliding and sealing of the concentric sleeves is necessary for proper operation. Rough handling prior to or during installation can “eggs” or misalign the moving parts, causing failure during job execution.

4. Compatibility of float collar and the stage collar should be ensured. The first-stage wiper plug (if used) and the first-stage displacement plug must fit and seal against the float collar.

5. Run in the casing with the stage collar at the desired depth. Stage collar should be tightened by putting the tong at the designated place on the outer sleeve of the stage collar only. The stage collar should preferably be placed against the shale section.

6. Besides slurry displacement time and safety factor, the first stage slurry thickening time should include the travelling time of bomb, opening of ports and one cycle circulation through stage collar ports.

7. If there is requirement of positioning stage collar in high inclination section of the well, hydraulic stage collar should be used. Circulating pressures during first stage should be maintained well below recommended sleeve opening pressure.

8. One centraliser each may be placed just above and below the stage collar.

9. After completion of first stage cementation job, drop the opening plug or bomb and allow it to reach the stage collar. Opening plug velocity is approximately 1 m/sec in normal mud. Ensure the seating of free fall plug for opening of stage collar port. To open the ports, slowly
build-up pressure usually approximately 1200 to 1500 psi. A drop in pressure will indicate that fluid has escaped into the annulus after opening of ports.

10. Circulate the well through the stage collar ports for 2 cycles to flush out any extra / contaminated cement from the first stage and the well must be circulated until the mud is conditioned for the second stage.

11. In case of loss prone sections, pumping of cement slurry for second stage should be resumed after thickening time of first stage cement slurry to avoid loss/ activity.

12. Release closing / shut off plug in such a manner so as to have some cement slurry over it. This will ensure cement outside the stage collar and minimize the hazards of displacement fluid outside the stage collar. Further, cement above shut off plug will ease drilling of the plug.

13. For closing the cementing ports, recommended closing pressure in excess of second stage final pressure should be built up over the shut off plug in one continuous operation without slowing down or stopping the pumps. Confirm the closure by bleeding back.

8.2 Stab in cementing

Stab in cementing is done when large size of casing would require high displacement volume in conventional cementing or when combined strings do not allow the use of conventional plug. This cementing operation is carried out with drill pipe with a stabbing unit attached to its bottom end. The drill pipe with stab in unit (stinger) is stabbed into the stab-in cementing collar or shoe and then cementation is carried out.

1. Run in the casing in place with a stab-in float shoe/collar and set in the casing slips suspending the string off bottom.

2. With the casing set, fix the stinger equipped with a centraliser at the end of drill pipe string and run in the assembly until it is approx. 1 m above the float shoe/collar

3. When running in, the pipes should be filled with the same fluid as the one placed in the well.

4. Establish circulation and check the returns coming from the annulus between the drill pipe and the casing.

5. Stop circulation and lower the drill pipe to stab and seal the stinger in the stab-in float shoe/collar in the casing. The stringer should be engaged into the collar or shoe only once, as far as possible. Test the surface lines and hermeticity of the inner string.

6. Again establish circulation and observe for return from annulus between the conductor pipe and the casing.

7. Mix cement and pump through the drill-pipe and up the annulus until it reaches the surface. As soon as mud contamination is no longer evident in the cement returns, mixing can

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be stopped and the drill-pipe volume displaced. Continuously monitor the weight on string during displacement to ensure proper engagement of stringer at all the time.

8. If lost circulation is noticed before the cement reaches the surface, mixing should be stopped and the cement displaced, avoiding pumping of large quantities of cement into the fractured zone. Care must be taken to avoid collapse of the casing because of excessive differential pressure between the outer annulus and the drill-pipe/casing annular space.

8.3 Liner cementing

A liner is a standard casing string that does not extend all the way to the surface up to the well mouth, but it is hung from inside the previous casing, generally keeping an overlap of 50 to 100 m.

1. **Slurry Design:** While designing the cement slurry for liner cementation job, the following parameters should be considered:

   - **Thickening time:** Time taken for reversing out the excess slurry above the liner hanger top should be considered while designing slurry. However, the wells where high pressure gas is being isolated behind the liner, relatively short thickening and setting time are necessarily required to reduce chances of gas penetrating the unset cement.

   - **Slurry Density:** High-density low water ratio slurry should be used to prevent water separation and entry of fluid into the wellbore, but the combined density and displacement pressure must remain below the fracture pressure of the weakest zone.

   - **Fluid Loss Control:** Fluid loss of the slurry should remain less than 100 ml / 30 minutes so as to avoid building up of cement filter cake and to reduce chances of annulus bridging due to small annular channels.

1. A four-arm calliper should be run prior to the liner operation to ascertain the hole size for calculation of cement slurry volume which is very critical for liner cementation.

2. No lost circulation material (LCM) should be used in liner cementation to avoid plugging of float equipment or the narrow annulus. If loss control material is added in mud to combat loss, then after lowering of liner the well should be circulated with fresh mud free from LCM.

3. Centralising the liner in the hole is very critical, because annular clearance are so small that the liner must be kept clear of borehole wall for effective cement placement. This is particularly true in case of deviated wells. Bow spring centralizers should be used in the open hole if there is sufficient annular clearance. Rigid centralizers should be used in the casing/liner lap region, and also in the open hole in cases of very narrow annular clearance.

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Centralizers or positive stand off devices also reduce the likely hood of differential pressure sticking of the liner in the open hole.

4. In deviated wells rotating type liner is recommended to facilitate mud removal and placement of cement slurry at the lower side of the hole.

6. Use combination dart in case combination string is used for lowering liner to avoid bypassing of cement slurry.

7. In case of loss prone areas, preferably use liner hanger with integral packer or with top seal to avoid hanger top squeeze job.

8. The small clearance also makes it difficult to run liners. Swab/ surge pressure can be extremely severe and running speed should be slow to avoid pressure surges that could break down formations leading to lost circulation. It is therefore necessary to restrict running speed to one stand of drill pipe in two to three minutes.

9. Circulation should be carried out before setting the liner to clean the mud system of any cuttings or debris. Cuttings, if not removed can accumulate at the restricted area of liner hanger leading to bridging of annulus & rise in pressure during circulation & cementation. The circulating pressure should be monitored and restricted up to shear pin rating of hanger.

10. Where bottom plug is not used in liner cementation, a spacer fluid compatible with mud and cement should be pumped between mud and cement to provide a buffer to avoid contamination.

11. The amount of excess cement for liner cementing must be carefully calculated by taking into account the well conditions and displacement efficiency. Displacement efficiency is a key variable in determining cement slurry volumes as it is not uncommon to have 60% to 80% displacement efficiency in liner cementing. Excess volume increases the likelihood of good cement placement but it also increases the possibility of operating problems.

12. The volume of cement used on most deep liners is usually rather small. Since slurry design parameters are critical for liner cementation, batch mixing should be done to ensure uniformity.

13. Displacement rate should be slowed down when the pump down plug (dart) approaches the liner wiper plug in order to observe the first pressure surge (about 300psi) corresponding to the shearing of the pins.

14. Pull the setting tool free from the liner and reverse out any excess cement above the liner top. If no packer is incorporated into the liner hanger then reverse out keeping excess cement over the top of the liner so that 8 to 10 joints of the intermediate casing will contain cement to be drilled out after setting.

15. Reverse circulation places an extra pressure on the annulus and this additional pressure should be pre-calculated and controlled to avoid formation break down. A liner packer keeps reverse circulation pressure off the formation.

16. In long liners, there may be a considerable temperature differential between the bottom and top of the liner. The cement may take very long time to set at the top and as such drilling of cement should be done after the cement develops minimum compressive strength at the top of the liner also.

8.3.1 Testing of liner top

A leaking liner top can become a serious and expensive problem during future drilling operations or during the production life of the well. Therefore, top of the liner, after it has been cemented should be tested for successful completion. Two methods can be used to test the pressure integrity of a cemented liner top.

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a) Hydrostatic testing

Testing the liner top with applied pressure can be done with or without a packer. However, in either case, burst limitation of the intermediate casing must be considered. In case of a drilling liner, pressure applied to the liner top should be equal to or greater than the hydrostatic pressure at the liner top when the maximum anticipated mud weight will be used in subsequent drilling operations. To ensure the pressure integrity of liner top, fracture gradient of the formation at the shoe of the intermediate casing must also be considered. Also the test pressure should be more than the equivalent of hermetrical testing pressure of the casing.

b) Differential testing

For this test, a negative pressure equal to differential pressure that the well may encounter later in drilling or completion should be applied. For high-pressure gas wells, differential pressure test should be carried out in stages.

9.0 SECONDARY CEMENTING PRACTICES:

Secondary cementation jobs are mainly classified as

a) Plug Cementing
   b) Squeeze cementing

9.1 Plug cementing

Cement slurry of specified volume when placed and set across a selected interval in an open hole or a cased hole is called ‘Cement Plug’. The most commonly used technique for plug placement is known as ‘Balanced Plug Method’. Following the standard best practices as detailed below can prevent plug failures:

1. Select a gauge section of the hole. Consult caliper log for selecting a location to set the plug and determine the temperature of the formation where the plug is to be set.
2. Circulate enough to condition the well so as to ensure that the entire mud is uniform.
3. Check the mud system carefully for loss of returns, fluid gain or gas entry. Any movement of the plug after it is placed may cause the cement not to set.
4. A cement plug is best set against a competent hard rock. Shale should be avoided as they are often caved and out of gauge.
5. However, if ‘kicking off’ is the objective, the plug should not be set in an excessively hard formation. Ideally, the plug should extend from a soft shale down to a hard formation. Logs and drilling rate records should be consulted when selecting a location to set a plug for kick-off.

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6. **Slurry design**

- Viscous slurries with high gel strength and low density are needed for lost circulation plugs, to restrict flow into voids or fractures.

- High compressive strength is required in kick-off plug to have a sharp contrast between the plug and the formation hardness. Use densified cement slurry that will tolerate considerable mud contamination.

7. Carefully calculate cement, water and displacement volumes and always plan to use more than enough cement (1.5 to 2 times the calculated volume) to compensate for contamination effect so as to get the desired plug length.

8. Batch mix the cement slurry to ensure uniform slurry density.

9. Pump preflush that is compatible with drilling fluid. Preflush volume should be sufficient to cover an annular height of 150 to 250 m and the after flush volume should cover the same height in the string as that of the preflush.

10. For open hole cement plugs in gas wells, use a weighted spacer 1 to 2 ppg heavier than the mud. Using water as preflush can cause reduction of hydrostatic head, resulting in gas migration through the cement.

11. Whenever possible preflush / spacer should be pumped in turbulent flow conditions

12. Try to rotate or reciprocate the string slowly till the completion of displacement.

13. Under displace the plug by 200-300 litres to avoid any back flow.

14. Pull out the drill pipe/tubing slowly (10-15 m/minute) out of the cement to minimize contamination.

15. Reverse wash twice the string volume to wash excess slurry out of the hole.

16. Ample WOC time should be allowed (12 to 24 hours) for a plug job. A common practice is to allow for longer WOC time since accurate well temperature for a cement plug job is difficult to determine.

17. Always test the cement plug by tagging top of cement with bit and apply required weight.

18. While placing a cement plug for kick-off special measures as given below should be followed for success at first attempt:

   - Use either a mechanical or chemical method to provide some static barrier below the intended bottom of the plug.

   - When a high viscous pill is used for achieving a static barrier below the cement column, then the length of the pill should be equal to the cement plug length and funnel viscosity of

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the pill should exceed 150 seconds. Also, the pill density should be greater than the mud weight and 10 seconds gel strength of the pill should be above 50 lbs/100 sq.ft.

- Use a ‘Diverter tool’ for placement of cement to achieve uniform placement of cement slurry all around the well bore and to prevent contamination due to downward movement.

- Typically 2 7/8” tubing should be used as tail pipe in the string to minimize contamination during pulling out as it will create less disturbance of the cement plug when the pipe is being pulled. The length of tail pipe should be 1.5 - 2 times the plug length.

- Sufficient time as WOC may be provided for attaining required hardness/ strength for kick-off plug.

9.2 Squeeze cementing

Squeeze cementing is the process of forcing cement slurry, under pressure, through holes or splits in the casing / well-bore annular space and then allowing it to dehydrate by further application of pressure. Squeeze cementing is necessary for many applications but the most important use is to segregate hydrocarbon-producing zones from the formations producing other fluids. A key element of a squeeze cementing job is placement of cement at the desired point(s).

In squeeze job, regardless of the technique used, the cement slurry (a suspension of solids) is subjected to differential pressure against a permeable rock that acts as a filter. The resulting physical phenomena are filtration, filter-cake deposition and, in some cases, fracturing of the formation. The slurry, subjected to a differential pressure, loses part of its water to the porous medium, and a cake of partially dehydrated cement is formed.

As the filter cake builds, the pump in pressure increases until a squeeze pressure less than fracturing pressure is attained. A good guide for a squeeze pressure is 500-1000 psi above the pump in pressure with no flow back in 3 to 5 minutes.

While carrying out squeeze jobs at shallow depth, application of pressure may result in upward force greater than the weight of string. Pressure limitation/ securing of drill pipe / tubing string should be considered before taking up such jobs.

In case of cement squeeze job through cement retainer, the integrity of string and seal should be ascertained by pressure testing it in hermetic position. If anticipated maximum squeeze pressure exceeds collapse pressure of the casing, pressure should be applied through string annulus to neutralise pressure acting on casing from outside.

9.2.1 Injectivity test

Prior to placement of cement slurry, conduct injectivity test against the interval to be squeezed to determine if and at what rate below the fracture gradient, fluid can be placed against the formation. When the fracture gradient is to be exceeded to obtain sufficient rate for cement placement, it should be done without giving excessive pressure above fracture gradient.

A minimum of ten barrels volumes should be used when obtaining an injection rate. Deep perforations require more volume than shallow ones because of the additional hole volumes.

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Consider spotting a clear fluid such as water across the perforations when obtaining an injection rate. The injection test is performed for several reasons:

- To ensure that the perforations are open and ready to accept fluids.
- To obtain an estimate of the proper cement slurry injection rate.
- To estimate the pressure at which the squeeze job will be performed, and
- To estimate the amount of slurry to be used.

If suitable injection rate can not be established at the desired injection pressure, it may be necessary to clean up the perforations, channels etc. Acids are commonly used for the purpose. While taking injectivity test, raise the pressure very slowly up to the point of injection without fracturing the exposed formation.

9.2.2 Design of cement slurry for squeeze job

The properties of cement slurry should be tailored according to the characteristics of the formation to be squeezed, and the technique to be used. Squeeze slurry should be designed to have the following general attributes:

- Low viscosity: to allow the slurry to penetrate the small voids
- Low gel strength: a gelling system restricts slurry movement
- Proper thickening time: to safely meet the anticipated job time
- No free water
- Appropriate fluid loss control

The following factors should be considered in designing the cement slurry for any squeeze operation:

a) Fluid Loss Control:

Fluid loss and filter cake growth rate vary directly i.e. higher the fluid loss, faster will be the filter cake build up. As such, while designing the slurry, fluid loss should be tailored to the formation type and the permeability so as to achieve a uniform cake build up against the squeeze interval.

The generally accepted API fluid loss rates are listed below:-

- Extremely low permeability formation - 200 ml / 30 minute
- Low permeability formation -100 to 200ml / 30 minute
- High permeability formation -35 to 100 ml / 30 minute

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b) Thickening Time:

The temperatures encountered in squeezing can be higher than those of primary jobs, because fluid circulation before the job is usually less. For this reason, special API testing schedules for squeeze cement slurry design should be followed to prevent premature setting. The additional feature of this API schedule is that it simulates the actual temperature the slurry is subjected to, when held near bottom for extended periods.

Thickening time must be sufficient to assure slurry placement and reversing out of the excess slurry. For running squeeze method, requirement of thickening time should be less. Whereas for a hesitation squeeze method, higher pumping time must be designed so that cement slurry remains in fluid stage till squeeze pressure is achieved.

c) Compressive Strength:

High compressive strength though desirable is not a primary concern for squeeze slurry design, as a partially dehydrated cement cake of any normal cement slurry will develop sufficient compressive strength.

9.2.3 Slurry Volume

An optimum amount of cement is required to seal the void. The volume of slurry needed is generally inversely proportional to the injection pressure and directly proportional to the injection rate. The appropriate volume of cement slurry depends upon the length of the interval to be cemented and the placement technique to be used. A low-pressure squeeze requires only enough slurry to build a certain filter cake in each perforation tunnel. In many cases less than a barrel is sufficient. However, for job convenience and because of problems in placing the cement into the correct place to provide a seal, a 5-15bbl batch should be prepared. A high-pressure squeeze, in which the formation is fractured, requires more volume of slurry.

9.2.4 Squeeze Pressure

Squeeze pressure is the pressure at the injection point. In most cases, if the cement can be placed at the proper point, a successful squeeze can be obtained with 500 to 1000 psi standing pressure above the injection pressure. The pressure should be held for 10 to 15 minutes with no flow back. A safety factor of about 300 psi below formation fracturing pressure is reasonable for low pressure squeeze.

a) Low-pressure squeeze

The aim of this operation is to fill the perforation cavities and interconnected voids with dehydrated cement. The bottom hole treating pressure should be maintained below the formation fracturing pressure. The volume of cement is usually small, as no slurry is actually pumped into the formation. In low-pressure squeezes, it is essential that perforations and channels be clear of mud or other solids. If the well has been producing, such openings may already be free of obstructions. However, for newly completed wells, it may be necessary to clean the perforations before performing the squeeze job. A low-pressure squeeze should be run whenever possible as this technique has the highest success rate.

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b) High-pressure squeeze

In some cases, low-pressure squeeze of the perforations will not accomplish the objective of the job. The channels behind the casing might not be directly connected to the perforations. Small cracks or micro annuli that allow flow of gas may not allow the passage of cement slurry. In such cases, these channels must be enlarged to accept a viscous solids-carrying fluid. In addition, many low-pressure operations cannot be performed if it is impossible to remove plugging fluids, or debris, from ahead of the cement slurry or inside the perforations. Placement of the cement slurry behind the casing is accomplished by breaking down the formation at or close to the perforations. Fluids ahead of the slurry are displaced in the fractures, allowing the slurry to fill the desired spaces. Further application of pressure dehydrates the slurry against the formation walls, leaving all channels (from fractures to perforations) filled with cement cake. However, during a high-pressure squeeze, the location and orientation of the created fracture cannot be controlled. A properly performed high pressure squeeze should have the cement as close to the wellbore as possible.

After a squeeze is obtained, the pressure should be bled off and the volume of returned fluid measured. The squeeze should then be re-pressured and the volume measured again. If the volumes are equal, this indicates that the squeeze has held and the volume of fluid pumped has compensated for tubular expansion.

9.2.5 Slurry preparation

In most squeeze jobs, the amount of slurry involved is quite small, but the requirements of its quality are quite high, therefore special care must be taken while preparing it. Use of a recirculating mixer or batch mixer is strongly recommended to ensure that the properties of the slurry pumped in the well are as close as possible to the slurry designed in the laboratory.

9.2.6 Evaluation of squeeze job

Pressure testing is the most common means of evaluating the success of the squeeze operation. Both a positive and negative test should be carried out. A squeeze job may appear successful when pressure is applied to the wellbore but may fail to hold back the pressure from the zone into the casing.

a) Positive pressure test

After the WOC, test the cement by applying required surface pressure for checking integrity of the perforations squeezed. The pressure applied at the face of the perforation is predetermined at the job design stage. It may be the reservoir pressure or pressure equal to future working pressure in the well during fracturing or acidizing treatments but should not exceed the formation fracturing pressure.

b) Negative pressure test

A negative test or differential pressure testing of the well-bore may be done either by swabbing / compressor application to lower the fluid level or by displacing work over fluid with some lighter fluid. Negative pressure test should be conducted using pressure not greater than the expected maximum drawdown in the well when it is put on production.

When the objective of the squeeze is to repair a primary cement job, the normal cement log (CBL/VDL) should be run to evaluate the effectiveness of the repair by comparing pre and post squeeze logs.

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9.2.7 Squeeze cementing procedure

a) Low pressure / High pressure squeeze cementing

1. Consult a CBL / VDL log prior to squeeze job.
2. Decide the point of perforation and perforate against a permeable formation at least 6 to 8 shots per foot for achieving better intake.
3. Carry out injectivity test in water. If injectivity is found to be poor, acid job and back surging should be done to improve injectivity.
4. Follow all the recommended practices as given for a normal cement plug job so as to spot the slurry against the perforated interval.
5. Then pull out drill string sufficiently above the cement top.
6. Close BOP and apply pressure through drill string to squeeze cement.
7. In case of low-pressure squeeze, maintain the bottom hole treating pressure below the formation fracturing pressure to fill the perforation cavities and interconnected voids with dehydrated cement.
8. For high-pressure squeeze, placement of the cement slurry behind the casing is accomplished by breaking down the formation at or close to the perforations by application of the bottom hole injection pressure exceeding the formation fracturing pressure.
9. Squeeze calculated volume of slurry and close the well under pressure for a period equal to slurry thickening time.

b) Block / circulation squeeze cementing

1. For block squeeze, perforate 2 sets of perforation i.e. above and below the cement retainer.
2. Establish circulation through cement retainer behind casing with water or clean fluid to ensure good clean up of the channels.
3. Maintain the downhole treating pressure below the formation fracture pressure when carrying out injectivity test or establishing circulation behind casing.
4. Calculate slurry volume keeping in consideration the annular volume and the volume below cement retainer which is to be filled with slurry.
5. Use spacers ahead and behind cement slurry for a minimum length of 50 to 75 m to avoid contamination.

6. During displacement, monitor free falling /U tubing of cement slurry by controlling through choke. Displace cement up to the tip of cement retainer so as to keep the cement inside the string and engage tubing string to retainer, and squeeze to circulate out cement between the two perforations.

7. Disengage the string from retainer and pull out the string above the top of upper perforations. Reverse wash and squeeze cement in the upper perforation (optional) and keep the well under final squeeze pressure.

c) Water /Gas shut off squeeze cementing

1. For elimination of water intrusion or reduction of gas oil ratio, this squeeze cementing is carried out to seal all the perforations and then re-perforate a selected interval.

2. All procedures of low pressure squeeze cementing should be followed for placement of cement slurry against the perforated interval.

3. In case of good injectivity, squeeze calculated volume of slurry into the perforations leaving a cement plug inside the casing. Squeezing should be done by hesitation method, so that final squeeze pressure is achieved.

4. In case of no injectivity, squeeze cement slurry at the maximum permissible squeezing pressure and close the well under squeeze pressure for a period equal to slurry thickening time.

10.0 CEMENTATION OF SPECIFIC WELLS

10.1 Cementing deep water wells

Cementation of surface and conductor casing are critical in deepwater wells due to the following main reasons:

a) Where conductor pipes are cemented at less than 600 m; the formations below mud-line are relatively young geologically and are not consolidated. These shallow formations have the potential for abnormally pressured saltwater sands, also known as shallow water flow zones. These over-pressed zones are prone to uncontrolled flows of massive amounts of salt water, especially after cementing operations. Uncontrolled flows from such sands have led to total loss of the well in several cases. Weak formations and pressured sands present very narrow margins between pore pressure and the fracture gradient, which can cause a loss of cement returns and hence require lightweight cement slurries.

b) The low temperatures that occur at deep-water depths slow the cement hydration process and pose serious challenges for optimum strength development of cement slurry within a reasonable
short period of time. This is particularly important from the point of view of WOC period because of the high day rates for deepwater rigs.

Thus special attention to cement system design is required for cementing of conductor and surface casing in deep water areas. API Recommended Practice on Testing of Deepwater Well Cement Formulations, API RP 108-3 or ISO 10426-3: 2003 Petroleum and natural gas industries-Cements and materials for well cementing- Part 3: Testing of deepwater well cement formulations should be referred to.

A number of ‘best practices’ have been developed from lessons learnt while cementing in the deepwater, shallow water flow environment such as API Recommended Practice 65, First Edition, September 2002 on Cementing Shallow Water Flow Zones in Deep Water Wells. The application of these practices will aid in successfully cementing the casing in deep-water conditions.

10.2 Cementing high angle / horizontal wells

Effective well completion is the key to obtaining the potential benefits of high angle / horizontal wells. Successful primary cementing is one of the vital components for effective completion in such wells. Though the horizontal sections of the horizontal wells are mostly completed without cementation yet the achievement of good quality cementation in the previous intermediate casing, which is frequently highly deviated, is very critical for zonal isolation. Cement slurry properties thus have significant role in achieving zonal isolation for high angle well bore cementation and therefore need proper attention in the design stage.

10.2.1 Cement slurry design

For designing cement slurry for horizontal/ highly deviated wells, proper estimation of BHCT is important. As the change in true vertical depth is significantly less with increasing measured depth in highly deviated wells, the conventional API table cannot be used for estimating the BHCT from BHST. Temperature simulating software programs should be used to predict, with a degree of accuracy, the accurate BHCT for use in slurry design of high angle wells. By using cement job simulator, as a design tool in the pre slurry design stage, the effective slurry density for safe placement during the job can also be predicted.

The two most important key factors to be considered for deviated/horizontal well bore cementing are slurry stability and fluid loss.

a) Slurry stability

Good displacement practices minimize the occurrence of inter zonal communication channels that are created when cement by passes the mud during primary cementing. However, communication channels can also be created after the cement has been displaced but while it is still in fluid state. These channels arise from cement slurries that are unstable and cause sedimentation and production of large quantities of free fluid when static. Though an unstable slurry may also cause zonal isolation problem in vertical wells but it will be particularly harmful in a deviated or horizontal well where free fluid can collect along the high side of the annulus and sedimentation can result in a highly porous, low strength & low density channel, which in turn may contribute to zonal communication and gas migration. Therefore stable...
slurry should be designed to minimize the risk of annular communication and gas migration. Slurry stability is dependent on two properties i.e. free water and sedimentation. API Recommended Practice 10B-2 on “Recommended Practice for Testing Well Cements” specifies requirements and gives recommendations for the testing of cement slurries and related materials under simulated well conditions. Equivalent ISO standard is ISO 10426-2.

Free water should be maintained at zero. Measurement of free water percentage at ambient conditions has been found to be inadequate for horizontal/high angle well conditions. More realistic procedure for free fluid determination at simulated bottom hole conditions and well-bore deviation as given in API RP 10B-2 should be followed.

b) Fluid loss

Fluid loss control is particularly important in high angle / horizontal wells, because slurry exposure to long permeable sections are more extensive than in vertical wells. Loss of mix water from the slurry, during displacement, will reduce the slurry’s thickening time and increase its viscosity. As the slurry loses water it forms a filter cake, against the permeable formation wall. If uncontrolled, it changes the flow regime of the slurry from the calculated one to some unpredictable value and may result in excessive ECD. Low fluid loss rates are necessary to preserve the carefully designed rheological properties of the slurry. To reduce the amount of fluid loss from the slurry to the permeable reservoir section, API fluid loss of less than 50ml/ 30 minute tested with a differential pressure of 1000 psi and at bottom hole temperature should be maintained as recommended in API RP10B-2.

10.3 Cementing Coal Bed Methane (CBM) wells

The critical difference between gas bearing coal seams and conventional oil and gas sandstone reservoirs is the cleat system of the coal. Cleats are a network of natural fractures within the coal, which facilitates gas production in CBM wells. The cleats not only act as the drainage path for the gas during exploitation but also are conduits for undesired cement slurry filtrate loss / whole cement loss during cementation operations. Loss of cement filtrate and especially whole cement into the cleat system causes productivity damage. Since most CBM wells produce gas at rates far below conventional gas wells; this loss of gas production can seriously affect the economics of the venture. Over and above this factor, the requirement of long cement column rise because of completion of multiple coal seams in the same well and the need for very good zonal isolation for multiple hydro-fracturing treatments, to increase the permeability of coal seam, makes the cementation even more critical.

Cementing casing in wellbores that have penetrated coal-beds therefore requires special considerations because of the above circumstances. The cement slurry should be designed to accommodate the following conditions:

⇒ Low bottomhole pressure, low breakdown pressure
⇒ Requirement of long cement column
⇒ Hole enlargement in the vicinity of the coal
⇒ Natural fractures in the coal

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⇒ Potential for low pressure gas leakage
⇒ Potential for cement channelling
⇒ Pressure near casing burst pressure during hydro-fracturing job
⇒ Multiple zones for completion and stimulation

Most coal well completions are simply a production string set through a shallow surface casing. A few of the deeper completions utilize a drilling liner to depth just above the major coal, then a short liner through the coal formation. In both circumstances, the surface casings are generally 60-90 m of 9-5/8” casing set in a 12-1/4” hole.

In consideration of higher compressive strength requirement for hydro-fracturing job, the use of normal weight cement slurry in CBM wells is ruled out as in that case the ECD during the cementation job will be more than the fracture opening pressure of the coal seams resulting in losses during cementation. Moreover, as the cleat network in the coal seams provides the permeability for fluid flow in coal, use of normal weight slurry may damage the formation due to cement invasion inside the cleats.

In consideration of all the above factors, the cementation in CBM wells should be carried out either in stages by use of stage collars or by using lightweight slurries.

The production from a CBM well mainly depends on a properly executed hydro fracturing operation to increase the permeability by interconnecting the cleats in the coal seams. The success of a fracture job highly depends on the degree of isolation achieved in the annulus by cementation. Considering this importance of cementation jobs in a CBM well, the use of a cement job simulator as design tool is recommended. The simulator can generate critical information that provides the most efficient design of surface flow rates, thereby allowing maximum mud removal. By using the simulator prior to actually conducting the job, possible problems such as lost circulation or fluid invasion should be identified and the placement schedule should be modified accordingly.

10.3.1 Slurry Design

The above listed cementing conditions are generally satisfied by one of the four slurry designs that have the necessary properties to combat typical problems in CBM wells i.e.
- Pozzolol mix cement blend with small additions of bentonite;
- Silicate based cement;
- Foam cement systems; and
- High performance lightweight slurries developed based on particle packing technology.

The tight economic constraint of coal well completions is also accommodated when using these slurry designs.

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A 50/50 blend of pozzolon mix cement with 4% bentonite is generally used at a slurry weight of 12.7 to 12.8 ppg in the lead cement and the same slurry mixed at 13.5ppg, or occasionally neat cement mixed at 15.6ppg is used as tail slurry. Low fluid loss additive that do not delay thickening time and do not cause increased slurry viscosity should be used in areas where the leak-off is high, and lost circulation materials such as gilsonite are often included to help prevent cement contamination of the fractured coal.

In areas with zones that will not support cement weight of 12 to 14 ppg, silicate based cement system should be used. These slurries exhibit excellent fluid loss characteristics, low slurry viscosity, essentially no free water, and high early compressive strengths. The normal slurry weights of silicate-based cement are from 11 to 13 ppg.

The third option for CBM wells is foam cement. Foam cement should be used when the well bore integrity requires slurry weight under 11 ppg. Nitrogen foam cement has a density approaching that of water while still providing adequate compressive strength. Ductile foam cement is also resistant to fracturing when perforating. A great number of shallow, low-pressure wells are cemented with the foam cement system. Foam cement usually is formulated with basic cement, foaming agents, stabilizing agents, and nitrogen. This slurry would be most economical except that many of the coal wells are located in areas that do not have nearby nitrogen facilities, so the cost goes up. Relative cost and probability of success when using foam cements is usually compared to the alternative of using a stage collar with other cement formulations.

The fourth option that is very appropriate for application in CBM wells is the recently developed high performance lightweight slurries based on particle packing technology. The density range of these slurries is from 12 to 9.5 ppg. These slurries in spite of their low weight, develop high compressive strength and fulfill the cementing requirement of CBM wells i.e. lightweight to prevent losses and cleat damage during cementing as well as adequate set cement strength for hydro-fracturing.

Regardless of the slurry chosen to cement CBM wells, a flush should be used for conditioning the hole to enhance the quality of bond of the cement and to limit the penetration of cement into the fractures of the coal. Flushes are especially suited for removing coal fines and uncirculated drilling debris from the annulus to reduce bridging of these materials in the annulus ahead of cement.

### 11.0 WELL ABANDONMENT

Well abandonment shall prevent pressure build-up, or cross flow, in the well and its surroundings by isolating all permeable hydrocarbon zones and water zones of different pressure regimes from each other. Abandonment shall also prevent contamination of freshwater aquifers, block leakage of any wellbore fluids to the surface, and minimize the consequential effects of well operations on the environment. The abandonment procedure given in this section applies to a well that
1. Is completed as a non-productive well;
2. ceases to produce oil or natural gas;
3. is no longer operated for the purpose for which the well is drilled.
Cement top, cement bond behind the intermediate and production casings shall be reviewed prior to planning well abandonment.

Cement behind casing above porous interval having hydrocarbon bearing or high pressure water bearing, shall have good cement bonding (both formation to cement and cement to casing) at least 100 meters above and below the interval.

In case of multi porous zones, each zone shall have good cement of 5 to 10 meters above and below the zone for zone isolation and in addition to this at least 100 meters of cement above the top of uppermost zone and below the lower most zone.

> If there are porous intervals not covered by the primary cementation of intermediate casings, remedial cementing must be conducted to isolate these intervals.

It shall be ensured from cementing operation records (volume of cement slurry pumped, returns during cementing, cement plug top tagged inside casing) that surface casing is cemented up to surface and fresh water zones behind it are isolated.

Well shall be stabilized before abandonment process.

The requirement of cement bond repair may not be applicable in cases where gas or hydrocarbon presence and migration through annulus cement & subsequent pressure build up in annulus were not observed.

For placement of plug, the requirements given in section 4.2 shall be fulfilled.

11.1 Permanent Abandonment
The process of abandonment essentially consists of down hole abandon plug(s), and surface abandon plug.

11.1.1 Downhole abandon plug

11.1.1.1 Open hole downhole abandonment

1. In uncased portion of well, cement plug shall be set to extend from a minimum of 30 m below the bottom to 30 m above the top of any oil, gas, or freshwater zones.

2. In addition, minimum 30 meters of cement shall be set above and below the previous casing shoe. This cement plug will also be considered as back up to the plug placed against the hydrocarbon bearing zone. The bottom of this back up plug shall be positioned such that the formation fracture strength at the base of the plug is in excess of the expected potential internal pressure. (Expected potential internal pressure refers to the pressure developed by the formation fluid at the base of the plug due to failure or leakage of the plug below it).

3. For longer drilled intervals and multi porous zones in the open hole, where with one cement plug to cover all porous zones is difficult, two or more cement plugs shall be placed.

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The lowermost cement plug shall extend 30 meters below the bottom most porous zone and the uppermost plug shall extend 30 meters above the uppermost porous zone.

4. The plug(s) in the open hole shall be tagged after WOC by applying weight of at least 8 MT on the plug. It should also be pressure tested by applying pump pressure of 500 psi or 80% of LOT value of previous casing shoe, whichever is less.

5. In case there is no oil, gas, or freshwater zone, the open hole shall be isolated by placing one cement plug of minimum 60 meters (30 m below and 30 m inside deepest casing shoe).

6. Casing patch, casing failure point, cement squeezed intervals shall be covered by cement plugs, 30 meters above and below the extremities.

7. For expected or known lost circulation conditions, a mechanical barrier device like bridge plug/retainer should be set 15 to 30 m above the casing shoe with minimum of 15 m of cement on top of the device. Alternatively lightweight slurry designed for adequate compressive strength may be used.

8. Low plug(s) shall be build up and high plug(s) shall be drilled out until good hard cement plug is still within the deep-set target.

11.1.1.2 Cased hole downhole abandonment

1. Cement plug shall be set at least 30 m above to 30 m below the perforated interval, or down to a casing plug, whichever is less. When abandoning multiple permeable zones, due consideration shall be given to the number of permeable zones and whether isolation of all the zones is required or not. If multiple zones are not required to be isolated from one another isolation of all zones from the rest of the well can be achieved by squeezing & plugging the shallowest zone.

2. To ensure good quality cement plug, it would be preferable to provide a platform (bridge plug or cementing retainer) for placement of the cement plug. This will be compulsory for known loss circulation situations.

3. Bridge plug / cementing retainer without cement plug on the top of it shall not be accepted as a barrier.

4. The second 30 meter cement plug, back up to the first plug shall be placed if permeable zone is hydrocarbon bearing or over pressured water bearing. The backup plug shall be positioned such that the formation fracture strength at the base of the plug is in excess of the expected potential internal pressure.

5. When there is completion packer(s) in the hole that will not be retrieved, the perforated interval below the packers should be isolated by squeezing cement through the packer or spotting cement across the perforations. Cement should then be spotted above the packer.

6. The liner laps, if any, shall be isolated by setting a cement plug across the top of the liner, which shall extend at least 30 m into the liner.

7. In offshore exploratory locations, an intermediate cement plug of minimum 60 m length shall be placed in production casing at 1000-1500 m depth.

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7. The integrity of the cement plug(s) shall be tested by applying minimum weight of 8 tons and applying pump pressure of 1000 psi. It should be ensured that pressure does not drop more than 10% in 15 minute and then remains constant.
8. If casing(s) are cut and retrieved thereby leaving a stub inside the next larger string, abandonment cement plug(s) shall be set so as to extend a minimum of 30 m inside deepest stub and 30 m above largest stub covering all the annuli.
9. Low plug(s) shall be build up and high plug(s) shall be drilled out until good hard cement plug is still within the deep-set target.

While placing abandon plug in open hole or cased hole stated above it shall be ensured that the wellbore including the space between the cement plugs is filled with drilling fluid of sufficient specific gravity and other properties so as to enable it to withstand any subsequent pressure which may develop in the wellbore.

11.1.2 Surface abandon plug

11.1.2.1 Onshore wells

1. Before placing surface plug, all annuli shall be checked for any activity by opening wellhead valve.
2. Surface cement plug of at least 60 m length shall be placed in such a manner that the top of the plug is within 60 m below the mean ground level in the smallest string of casing.
3. All the casing annulus should be pressure tested to verify isolation and annulus integrity above TOC. (The test pressure should not exceed LOT value at shoe of outer casing of the annulus).
4. Capping and marking of the abandoned well shall be done to the satisfaction of the local authorities.

11.1.2.2 Offshore wells

11.1.2.2.1 Platform wells

1. Before placing surface plug, all annuli shall be checked for any activity by opening wellhead valve. All the casing annulus should be pressure tested to verify isolation and annulus integrity above TOC. (The test pressure should not exceed LOT value at shoe of outer casing of the annulus). In case of pressure in the annulus, it shall be brought to zero by bulldozing, bleeding & lubrication etc.
2. Surface cement plug of at least 60 m length shall be placed in such a manner that the top of the plug is within 100 m below the mud line level in the smallest string of casing. The well shall be capped.

[The above procedure is applicable when the platform is not to be decommissioned and removed for site restoration. In case of platform decommissioning and removal permanent well abandonment shall follow procedure given in the following section – 11.1.2.2.2].

11.1.2.2.2 Exploratory wells with jack up rig

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Procedure to be followed for a typical case of an exploratory well drilled from a jack up having 20” x 13-3/8” x 9-5/8” casings and 30” conductor is given here.

1. Place a cement plug of 60 meters (or bridge plug with minimum of 15 meters of cement above it) at maximum possible depth.

2. Check 20” x 13.3/8” annulus and 13.3/8” x 9.5/8” annulus for any activity. Fill both annuli with mud.

3. Perforate 9.5/8” & 13.3/8” casings simultaneously 25 m above 20” shoe with high density perforation gun. Open 20” x 13-3/8” annulus and 13-3/8” x 9-5/8” annulus valve one by one and try to establish circulation individually. Limiting pressure should be LOT value of corresponding shoe or 70% of collapse/burst pressure rating of casings. Place cement slurry of calculated volume. Close BOP. Open outer annulus first and raise 50 m cement slurry into annulus. Raise cement slurry in inner annulus by same height following above procedure. Close both the annuli and squeeze cement slurry up to LOT value or 1000 psi, whichever is less.

4. Cut and retrieve 9.5/8”, 13.3/8” and 20” casing or open and retrieve casings from MLS if used.

5. Place a balanced plug of at least 30 m below the 9.5/8” casing cut point up to 4 to 5 m below the mud line to cover all casing stubs as per 11.1.2.5.

6. The plug placed as per point 5 should be tagged after W.O.C by applying a wt of at least 8 tons and applying pump pressure of 1000 psi. It should be ensured that pressure does not drop more than 10% in 15 minute and then remains constant.

7. Cut and retrieve 30” conductor at least 5 m below seabed.

8. All casing and protective structures shall be removed to the satisfaction of the governing authority for the clearance of location.

In line with the above, surface abandon plug procedure shall be formulated well wise.

11.1.2.2.3 Sub-sea wells

Surface abandon plug of minimum 60 m length shall be placed in such a manner that top of the cement plug is at about 200 – 250 meters below wellhead.

Besides the surface abandon plug, there shall be the requirement of a permanent well barrier, at an appropriate depth, that must include all annuli, extending to the full cross section of the well and seal both vertically and horizontally (often referred to as rock to rock / restoring the cap rock).

11.2 Temporary abandonment

The temporary abandonment must be carried out such that the well can be re-entered safely and then secured using pressure control equipment without compromising the barriers in place.

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1. Two cement plugs (minimum 30 meters length each) shall be placed if a permeable zone is hydrocarbon bearing or over pressured water bearing. The second plug is back up to the first plug.
2. These two cement plugs shall be placed as close to the potential source of inflow as possible, covering all possible leak paths.
3. Both cement plugs shall be lapped by annular cement of at least length equal to that of the plugs.
4. Cement plug shall be set on a bridge plug or cementing retainer as a suitable base compulsorily where is possibility of cement plug slippage down hole due to cement slurry density or losses, well activity or high gas content in formation fluid. It would be preferable in normal situations.
5. Cement plug(s) shall be tagged after WOC by applying weight of at least 8 MT and pressure tested at 1000 psi or up to LOT value at shoe, whichever is less.
6. A cementsed shoe track shall not be accepted as a plug unless it is specifically designed and proved by adequate pressure testing at least 2.0 ppg above the expected LOT. (For situations where the rig has to be skidded between the slots during batch drilling, the weight and pressure tested shoe track with mechanical top plug can be treated as a plug for temporary abandonment)

7. A permanent bridge plug or cementing retainer (not activated) with minimum 15 meters cement plug on it will be accepted as an alternate to the first cement plug. Bridge plug / cementing retainer alone shall not be accepted as a barrier.
8. The production liner lap shall be isolated by setting a cement plug across the lap of the production liner which shall extend at least 30 meters into the liner.
9. For subsea wells, integrity shall be monitored during the abandonment / shut-in period six monthly.
10. Cement plug of at least 60 meter in length shall be set in the casing with top of the plug no more than 300 meter below the mud line.
11. For offshore wells drilled by jack up rigs without platform, dual seal type T/A caps should be installed on MLS (Mud Line Suspension System). The dual seal type T/A caps are installed through BOP. A single temporary abandonment cap shall cover both production bore as well as annulus, locking the hangers in place.

12.0 CEMENTING EQUIPMENT PRACTICES

Oil well cementation is an important and critical operation, which is accomplished at site in a relatively short period of time. Established safety procedures should be followed to avoid any untoward accident during cementation. To achieve this, pre-job safety meeting should be carried out with the rig crew. Following are some distinctive features of cementing operations.

1. Simultaneous running of various equipment requiring co-ordination
2. Several liquid chemicals and additives used in cementation.
3. High pressure fluids and air involved in cementation.
4. Simultaneous presence of crew of different disciplines.
5. Special attention during cementation in the night time.

The cementing incharge should ensure that all cementing service personnel and rig crew follow the practices outlined below:

12.1 Pre-departure checks of mobile cementing equipment

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1. Oil level, HSD level, radiator water level, steering hydraulic oil level, battery connections, tyre pressure etc. should be checked.
2. After initial warm up of engine, check engine oil pressure, water temperature, air pressure, brake application, auto electrical light indications etc.
3. Fire extinguisher, spark arrestor in engine's exhaust pipes and a first-aid kit should be available in all cementing vehicles.
4. Accessories like high pressure lines, valves, swivels, jet mixers, rubber hoses etc. should be clamped and fastened to avoid any loss and third party injury while plying the cementing vehicle on road.
5. While lifting the cabin of cementing vehicle for chassis & engine check up/repair, no person should be allowed to stand underneath till the cabin is locked and properly clamped in position.

12.2 Movement & placement of cement vehicle, hooking up of cementing lines and pre-job planning

1. Onshore cementing operator should be well conversant with traffic signals and road safety rules to avoid any road accident.

2. Before moving the cementing units/mobile silos to new well sites, route survey for road condition, sharp bends on road, bridge capacity for type & weight of vehicle, bridge clearance at top and safe clearance from live electrical wires on top should be carried out.

3. While carrying out any maintenance work beneath chassis, the electrical cut out switch at battery should be put in off position and starter key should be kept in safe custody.

4. While reversing a cementing vehicle, the driver should be certain that the sides and backing area are clear. The vehicle should not be reversed without a guide.

5. Use of prescribed personal protective safety kits like overhaul, hardhats, safety glasses, hard-toed shoes, hand gloves, facemask etc. should be ensured. Jewellery item like rings, bracelets and neck chains should be removed while at site.

6. A pre-job meeting should be held to ensure proper job layout and placement of cementing equipment.

7. Mobile cementing equipment positioning should be such that quick removal from the site is possible in case of an emergency. All vehicles should be placed with cabin facing away from the well and wooden wedge support should be placed behind wheels to minimise vibrations.

8. Place cementing pump/bunkers/mobile silos at least 1.5 - 2 m apart from each other and at least 25 m distance from the well head.

9. Park all vehicles, which are not required for the job in safe areas away from the wellhead so as not to block the well site exits.

10. Wherever radioactive densometer is used, safe operating procedures and danger sign of exposure to radiation must be prominently displayed. The sensor must be locked.

11. In hooking-up of high pressure lines from cementing units, avoid crossing of two discharge lines. Lines should not be run under cementing trucks. Ensure proper anchoring of high-pressure lines to prevent accident in case of line failure.

12. Use sufficient number of chicksans to provide flexibility to discharge lines for reducing vibrations during cementing operations.

13. Do not suspend discharge lines from cementing head without safety chains.

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14. Use high pressure fittings and steel pipes which have been inspected and are in good condition.
15. Cementing heads, manifolds, valves and plugs should be inspected, cleaned and lubricated prior to hooking up. Always clean threads before making up cementing lines.
16. The cementing incharge must inspect the hook up thoroughly prior to testing lines.
17. Care should be taken to avoid damage to the threaded pin end and stopper of cementing head during handling and tightening to the casing. Cementing head must be secured to the links by safety chains. Thread protectors must be used on all exposed male threads of circulating subs or cementing head to avoid thread damage.
18. Only steel lines should be used for releasing pressure and checking back flow from the well.
19. In electrical rigs, all cementing equipment should be earthed to the derrick structure to avoid electrical shock. Electrical powered cementing skid unit should also be earthed properly.
20. NDT testing of cementing head, safety valves and high-pressure lines of cementing units should be done at an interval of 3 years.
21. High pressure lines shall be tested with water at 1.5 times the maximum pressure expected in pumping operations.
   a) Before testing, all persons shall be vacated from the vicinity of high-pressure lines. No one shall be permitted to step across, stand on or straddle or hammer on any pressurised line.
   b) Do not allow any one to take up line leakage repair operation until –
   i) The well site personnel are notified by the cementing incharge about the repair plan,
   ii) Pressure has been released from the line,
   iii) The release valve is left open during repairs and
   iv) The flow has stopped from the bleed-off line.
22. During pre-job safety meeting, cementing incharge should outline the job procedure, define pressure limits, discuss safety measures and give brief on emergency procedure and any unsafe conditions to all personnel participating in the job.
   He should describe the sequence, volumes and pumping rates. Also duties of persons during cementing job including equipment operation, mixing of chemicals, operation of valves, bulk delivery, cementing head and maintenance should be fixed.
   He should also review communication system, which plays an important role in executing cementing job.
23. Entire cementing operation should be controlled by cementing incharge to avoid any confusion in executing sequence of operations during cementation.
24. In many offshore rigs, the cementing unit is placed in relatively congested closed space. The cementing incharge should ensure that all exhaust fans are working and that all personnel present in the cementing room are wearing facemasks.

### 12.3 Pumping job

1. Safety announcement over public address system shall be made before pressurising the cementing lines.
2. All valves in discharge lines shall be checked to see that they are open before starting pumping.
3. No pumping shall take place while any personnel is working on, above or below rig floor level.
4. Flammable or combustible fluids shall not be placed in open displacement tanks on cementing equipment.

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5. Pumping of acid with cementing unit should be avoided. In case it cannot be avoided, it should be ensured that all the valves, caps, lines etc. are fitted correctly and only required persons are present in the vicinity. After the job, the cementing unit and the lines should be washed thoroughly so as to remove the acid totally.

6. When pumping into any system, be sure to have an accurate pressure gauge. Start slowly with little throttle to confirm that system is open. Be alert for any closed valves.

7. A pressure-chart to continuously record pumping pressure should be available for all cementing jobs. Pressure chart should be supplemented with pumping sequence volume, time and rate.

8. The pumping pressure should not connections used such as unions, chicksans, valves, crossovers etc.

9. When transferring or venting material through an open ended hose, its end should be secured properly to prevent its whipping around.

10. Loaded cement bunker or mobile cement silo should be parked on jacks at drill site.

11. During slurry mixing and chemical additions, adequate precautions should be taken to avoid chemical / additive contact with skin, eyes and clothing. Appropriate personal protective equipment like safety goggles, respirators, dust or vapour masks, face shield, rubber gloves, shoes and hearing protection should be worn. Fumes of defoamer should not be inhaled. Material safety data sheets of cement and its additives should be available at site.

12. Review method and hazards thereof in handling, transferring and chemical mixing as well as proper mixing sequence.

1. Proper illumination with adequate flame proof lighting arrangements should be provided in the operational area especially at slurry mixing point and additive mixing system to ensure safe and effective job execution.

12.4 Rigging down

1. After cement job is over, all pumps, lines and hoses should be flushed before rigging down. Valves and caps on all piping of each unit should be opened / removed to allow complete drainage of any fluid in the piping. Piping choked with cement slurry will damage cementing equipment and may lead to major breakdown.

2. Before dismantling the line, pressure must be released to zero. Tightening or loosening of connections under pressure shall not be done.

3. The air pressure in pneumatic bulk silo / mobile cement silo should be relieved before the vehicles are moved off location.

4. Chicksans, high-pressure lines, valves, swivels, hoses with end connections should be safely shifted from rig floor to ground.

12.5 Bulk cement handling plant

1. All cement silos and other pressurised vessels shall be emptied and pressure tested as per prevalent standards. Safety valves and pressure gauges attached to each vessel should be checked for proper functioning.

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2. Proper functioning of air dryer should be ensured to get rid of moisture in the air line of silos to prevent cement lump in the system and provide consistent dry cement supply for slurry mixing.

3. The discharge of air, dust and cement from vent line shall be in accordance with environment standards in force.

4. Personnel engaged in bulk handling plant operation must use all personal protective safety equipment including helmet, goggles, dust mask, ear protection etc.

### 13. EQUIPMENT CHECKLIST

<table>
<thead>
<tr>
<th>Activity/Check</th>
<th>Yes/ O.K</th>
<th>No/ Not O.K.</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Well-site identification /location?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Route survey (Road condition, bends, high tension wires, bridge load limit etc.) done</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Site ready for placement of the cementing unit &amp; bunkers / silos?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Securing of all hoses, steel pipes, chicksons, swivel, hopper etc. with chains/clamps on the mobile unit done</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Engine</td>
<td>Lube oil level &amp; condition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>Transmission oil level</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>Radiator water level</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>Radiator cap</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>Oil pressure gauges</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>Temperature gauge</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>Emergency shut down system</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>Any leakages from diesel/oil lines</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>Air filters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>Oil filters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>Condition of spark arrestors on engines</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6 | Chassis  
---|---
- | Brakes  
- | Air pressure for brakes  
- | Parking brakes  
- | Condition of hoses and clamps  
- | Tyre pressure  
- | Condition of tyre treads  
- | Availability & condition of jacks  
- | Shroud/guard on rotating parts  

7 | Light and Power of cementing unit  
---|---
- | Head lights  
- | Dippers  
- | Parking light  
- | Turning indicator light  
- | Reverse lights/horn  
- | Brake light  
- | Condition of battery  
- | Availability of battery cables for jump starting  
- | Battery cut-out switch  

8 | Cabin  
---|---
- | First aid box  
- | Fire extinguisher  

13.2 High pressure cementing pumps

<table>
<thead>
<tr>
<th>Activity/Check</th>
<th>Yes/ O.K</th>
<th>No/ Not O.K.</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Condition of plunger packing / liner-piston</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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2. Discharge through return line at low and high discharge rate (to check valves & seats) – smooth or intermittent

3. Minimum two no of calibrated main discharge pressure gauges

4. Lube oil level and condition

5. Lube oil pump pressure

6. Condition of heat exchangers for
   - any leakage (if any, plug leaking tube or replace heat exchanger)
   - cooling efficiency (clean tubes if cooling not sufficient)

7. Barrel counter (Flow meter) working

8. All high pressure valves of discharge and return manifold pressure tested and holding

9. High pressure mixing manifold available for any eventuality

10. Safety valve on discharge line fitted and its relief pressure set at maximum 10% above max. working pressure

11. Visual inspection of suction header and lines for any debris or cement sheath (clear same, if any)

12. Densometer (if installed) calibrated with water

### 13.3 Mixing system

<table>
<thead>
<tr>
<th>Activity/Check</th>
<th>Yes/ O.K</th>
<th>No/ Not O.K.</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Mixing pump discharge pressure (as per OEM) If low, check</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- starved of suction (suction line partially clogged)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- condition of gland packing/seals</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- adjust Impeller clearance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- rpm of the pump</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(If all above are O.K., dismantle pump and replace worn casing and/or impeller)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2. Recirculating pump discharge pressure (as per OEM)
   If low, check
   - starving of suction (suction line partially clogged)
   - condition of gland packing/seals
   - adjust Impeller clearance
   - rpm of the pump

   (If all above are O.K., dismantle pump and replace worn casing and/or impeller)

3. Check mixing jet and bowl for
   - correct slit/holes size for the slurry weight and mixing rate
   - cleanliness of bowl for proper suction
   - condition of O- ring on hopper to prevent suction of air
   - worn jet
   - vacuum killing cup working in case of RCM
   - knife gate movement and sealing of bowl when completely closed in case of PSM

4. Supply rate of mix fluid to the displacement tanks is sufficiently higher than mixing rate

5. Displacement tanks and mixing tub or batch mixer are properly cleaned

6. Isolation valves of displacement tanks working

13.4 Discharge lines

<table>
<thead>
<tr>
<th>Activity/Check</th>
<th>Yes/ O.K</th>
<th>No/ Not O.K.</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. All Discharge lines are pressure tested at 1.5 times maximum anticipated pressure during the job for 5 minutes</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Announcement over paging system and/or barricades put around pressurised lines for personnel to stay away from lines while pressurised</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. All lines including release line are secured with clamps and safety chains</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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4  CWP (Cold Working Pressure) rating of steel pipes connected is higher than maximum anticipated line pressure

5  In H₂S areas, pipes and fittings for sour gas service used

6  All hammer unions are compatible and are of same pressure rating

7.  Check for tightness of all hammer unions at zero pressure.

13.5  Bulk handling system

<table>
<thead>
<tr>
<th>Activity/Check</th>
<th>Yes/ O.K</th>
<th>No/ Not O.K.</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  Supply of air for bulk transfer is dry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2  Drained moisture from receiving tank</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3  Regulated pressure air supply to the Silos</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4  Mechanical integrity of silos/surge tank checked by closing all valves and charging to working pressure (30-40Psi)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5  Relief valve on silos and surge tank working with relief pressure set within 10% of max. operating pressure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6  Provision of proper dust collector in the vent of surge tank to maintain out coming air quality in accordance with applicable environment standards in force</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

13.6  Cementing Heads

<table>
<thead>
<tr>
<th>Activity/Check</th>
<th>Yes/ O.K</th>
<th>No/ Not O.K.</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>a.  Surface cementing Head</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1  Head is designed to handle maximum pressure anticipated during the operation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2  Condition of cap seal and x-over seal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3  Plug holding shaft</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- retracting and protruding (check number of turns and position of shaft each time)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- free movement of shaft</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- leakage from shaft seal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- locking device in place</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4  Free movement of plug release indicator &amp; its lubrication</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5  One high pressure valve provided for connecting line to the head for single plug container and two high pressure valves for double plug container</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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6 Swage (circulating head) with threads compatible with those of casing available

b. Cementing Head for sub sea operations:
1 Inspect swivel of the connector to mandrel
2 Condition of O-rings/seals of mandrel piston.
3 Check threads of the connector to the top plug
4 Check threads of plug connector and its shear groove. Note plug launch pressure
5 Ball seal ring on bottom plug for free rotation
6 Ball size and type for particular size of plug
7 Note ball extrusion pressure
8 Rabbiting (gauging) of all drill pipes above mandrel for the particular ball size done

13.7 General safety

<table>
<thead>
<tr>
<th>Activity/Check</th>
<th>Yes/ O.K</th>
<th>No/ Not O.K.</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 MSDS (Material Safety Data Sheet) for different additives used in cementing available</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Eyewash available in working condition near mixing hoppers.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Availability and use of prescribed personal protective safety kits like overhaul, hardhats, safety glasses, hard-toed shoes, hand gloves, respiratory nose masks etc</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

14. References:


- ISO/DIS 10426-3 Petroleum and natural gas industries-Cements and materials for well cementing-Part 3: Recommended practice for testing of deep water well cements.


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• Smith, D.K.: Cementing, Monograph Series, SPE, Dallas – 1991

• API world wide cementing practices, 1995 edition

• “Cement sheath evaluation”, API technical report 10TR1, First edition, June 1996.


• McPherson,S.A., “Cementation of Horizontal Wellbores”, SPE 62893


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• Smith, R.C.: Successful primary cementing can be a reality,” JPT 9Nov, 1984) 1851-1858.


• Erik B. Nelson, Improved cement slurry designed for thermal EOR wells, Oil and Gas Jr. Dec 1, 1986.


Abbreviations used:

1. API - American Petroleum Institute
2. Bc - Bearden consistency
3. BOP - blow out preventer
4. BHCT - bottom hole circulating temperature
5. BHST - bottom hole static temperature
6. BPM - barrels per minute
7. CBL/VDL - Cement Bond Log/Variable Density Log
8. CBM - coal bed methane
9. CET - Cement Evaluation Tool of Halliburton
10. ECD - equivalent circulation density
11. HP - high pressure
12. HPHT - high pressure, high temperature
13. HSD - high speed diesel
14. LOT - leak off test
15. LWD - Logging While Drilling
16. m - metre
17. ml - millilitre
18. MLS - mud line suspension
19. m/sec - metre per second
20. NDT - non destructive testing
21. NRV - non return valve
22. OEM - original equipment manufacturer
23. psi - pounds per square inch
24. Pv - plastic viscosity
25. PPG - pounds per gallon

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26. rpm – revolutions per minute
27. SPE – Society of Petroleum Engineers
28. SPM – strokes per minute
29. TOC – top of cement
30. USIT – Ultrasonic Imaging Tool of Schlumberger
31. W/Pr – working pressure
32. WOC- waiting on cement
33. Yp – yield point