Product Evaluation, Application and Testing of Stage Cementing Collars

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Product Evaluation, Application and Testing of Stage Cementing Collars

1 Scope

Develop an API document on recommended testing, evaluation and performance requirements for stage cementing collars used in cementing applications. Use of stage cementing collars for non-cementing applications and annulus casing packers are outside the scope of this document.

2 References

This document contains no normative references. For a listing of other articles associated with this publication, see the Bibliography.

3 Terms, Definitions, and Abbreviations

3.1 Terms and Definitions

For the purposes of this document, the following terms and definitions apply.

3.1.1 annulus
The space between the borehole and tubulars or between tubulars, where fluid can flow. The annulus designation between the production tubing and production casing is the “A” annulus. Outer annuli between other strings are designated B, C, D, etc. as the pipe sizes increase in diameter.

3.1.2 baffle plate
A landing seat wholly contained within a tubular string and placed at a predetermined location for the purpose of landing a shutoff or bypass plug.

3.1.3 ball
A spherical device used to actuate downhole tools or release sub-surface darts.

3.1.4 well barrier
A component or practice that contributes to the total system reliability by preventing liquid or gas flow if properly installed (refer to API 65-2).

3.1.5 borehole
Wellbore sections which are not cased with pipe, commonly called open hole.

3.1.6 bypass plug
Device designed to allow fluid bypass after it has landed on the seat.
3.1.7 cancellation device
cancellation plug
A device dropped through the casing to fully cycle the stage collar from the run-in position to the closed position in a single operation.

3.1.8 cementing plug
plug
A device used to separate fluids and wipe the internal surface of the pipes as it is pumped from one location in the pipe to another, and/or to operate downhole tools.

3.1.9 incompatible fluids
Fluids that when mixed undergo undesirable chemical and/or physical reactions.

3.1.10 static gel strength
Shear strength (stress) measurement derived from force required to initiate flow of a fluid.

NOTE The static gel strength of the cement slurry results in the decay of hydrostatic pressure.

NOTE Critical static gel strength (CSGS) is its value to the point at which pressure is balanced (hydrostatic equals pore pressure) at a point adjacent to the potential flowing formation(s), refer to API 10B-6.

3.1.11 dart
A device dropped or pumped through the casing or work string to launch plugs, operate downhole equipment, and/or shutoff or divert flow.

NOTE Darts may be free-fall or wiper type.

3.1.12 dogleg severity
DLS
Change in inclination and/or azimuth of a wellbore as a function of measured depth.

NOTE Typically expressed in degrees per 30 m or 100 ft.

3.1.13 equivalent circulating density
ECD
The effective density of the circulating fluid in the wellbore resulting from the sum of the hydrostatic pressure imposed by the static fluid column and the friction pressure.

3.1.14 float equipment
Casing accessories that contain one or more check valves and become part of the lower section of a casing string for the purpose of preventing the flow of fluid from the annulus into the casing.
hydraulic stage collar
A non-workstring operated stage cementing collar that opens with a predetermined differential pressure between casing and annulus at the tool (collar).

integral packer cementing collar
A stage cementing collar that includes an integrated annular packing element that can be energized through inflation or compression.

NOTE 1  The operational sequence of setting the packer is typically integrated into the operation of the cementer and not operated independently.

NOTE 2  The packer element is usually used to support and/or protect the second stage cement column and isolate the annulus below the tool.

NOTE 3  Chemical swelling element is outside the scope of this document.

mechanical stage collar
A non-workstring operated stage cementing collar that opens with a predetermined differential pressure inside the casing above and below the tool (collar).

opening device
Used to open a non-workstring operated stage cementing collar.

shutoff plug
A device used to terminate flow when landed on a seat.

sour service
Exposure to oilfield environments that contain sufficient H₂S to cause cracking of materials by the environments.

NOTE  Refer to NACE¹ MR0175/ISO² 15156 which are addressing materials resistance to environmental cracking that can be caused by H₂S.

stage cementing collar
stage cementing tool
A device that can be selectively opened and closed to allow communication between the inside of the casing or liner to the annular space.

3.1.23
sub-surface launch plug set
sub-surface release plug set
An integrated set of plugs installed in the liner hanger or casing running tool.

NOTE The individual plugs found in the assembly are usually released by dropping balls or darts from the surface through a work string – either drill pipe or tubing.

3.1.24
well barrier system
Well barrier system is one or more well barriers that act in series to prevent flow.

NOTE Well barriers that do not act in series are not considered part of a single well barrier system, as they do not act together to increase total system reliability (refer to API 65-2).

3.1.25
workstring
Drill pipe, tubing or coiled tubing string used to convey a treatment or manipulation of downhole tools for well activities.

3.2 Abbreviations

DLS  dogleg severity
ECD  equivalent circulating density
ID   internal diameter
LCM  loss circulation material
OD   outside diameter
TOC  top of cement

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4 Purpose and Applications of Stage Cementing Collars

4.1 General

Stage cementing collars allow communication between the inside of the casing or liner to the annular space at a predetermined distance above the bottom of the casing or liner string.

Stage cementing collars may be used in primary cementing of casing and liners in vertical, deviated, and horizontal wells. They can also be used as a contingency in case cement is not placed in the desired portion of the well.

Applications of stage cementing collars include

a) cementing across a potential flow loss zone;
   1) two-stage cementing, and
   2) three or more -stage cementing.

b) discontinuous cement interval;

c) reducing post-cementing annular flow potential;

d) off-bottom cementing above open hole completions;

e) placing specialty fluids in the top section of the annular space;

f) contingency cementing.

4.2 Cementing Across a Potential Loss Zone

Cementing across a potential loss zone (a zone lacking the integrity to withstand the equivalent circulating density (ECD) required to achieve the desired top of cement (TOC) in a single stage). Figure 1 illustrates the main challenge in cementing across weak zones.

When displacing cement into the annular space, pressure across a weak zone will begin to increase as the cement is pumped past that zone. As the height of the cement column increases, ECD at the weak zone may prevent cement from reaching the desired depth.
4.3 Two-stage Cementing

4.3.1 Two-stage Cementing Principle

In this application, the cement job is performed in stages, so that the maximum ECD during each stage never exceeds formation fracture pressure. A typical two-stage cement job is illustrated in Figure 2:
A stage cementing collar and optional inflatable annulus casing packer are made up to the casing string and run to true depth. The setting depth of the stage collar is typically above the weak zone.

The first stage would be pumped conventionally through the float equipment using a single or double plug system. The plugs must be compatible with the stage collar to ensure they do not cause the stage collar to function when passing through the seats.

When the first stage plug lands on the float equipment or landing collar or baffle, the cement column in the annular space will not exceed the formation fracture pressure of the weak zone. At that point, the casing string is effectively closed at the float collar or landing collar or baffle.

After pumping the first stage cement, the following operations are performed:

a) Open the stage collar to allow communication between the casing and the annular space so that the excess cement from the first stage can be circulated out to prevent premature cementation of the outside of the stage collar.
b) Isolate the weak zone to prevent further transmission of pressure when pumping the second stage cement. This can be done by waiting on first stage cement to set, or by using an annular casing packer.

c) Pumping cement down the casing, through the stage collar ports, and into the annular space. Second stage is pumped using a single or double plug system. After second stage is completed the stage collar is then closed.

NOTE The above illustrations show the stage collar being operated (opened and closed) by applying pressure using darts and/or plugs. Other stage collar types are available and described in Section 5.

4.3.2 Two-stage Cementing Procedure

Sample Operational Procedure for two-stage cement job (manufacturer’s recommendations should be followed when applicable) should be as follows:

a) Load the plugs on the cement head or plug launcher, and ensuring the plugs are not damaged in the process and loaded in the proper sequence.

b) If opening the tool hydraulically, install landing profile.

c) Install tool on casing string, observing manufacturer’s recommendations related to tong area.

d) Monitor flow rates and displacement pressure at multiple times while pumping and record any pressure anomalies or deviations from pumping schedule.

e) Mix, pump, and displace first stage cementing fluids (including spacers and preflushes).

f) Open stage cementing collar.

g) Circulate through stage cementing collar as per program.

h) Mix, pump, and displace second cement stage.

i) Close stage cementing collar.

j) Determine flow-back volume.

k) Confirm stage cementing collar closure.

4.4 Three-stage Cementing, or More Stages

In three or more stage operations the process is the same as in two-stage operations. However, there are specific equipment considerations that must be considered for plug or hydraulic operated stage collars for these applications.
4.5 Discontinuous Cement Intervals

In this application cement is placed in two separate intervals with a non-cemented interval between. In case of a two-stage cementing operation, first stage TOC is deeper than the stage collar. Operations are similar to multi-stage cement jobs as in 4.3 and 4.4.

4.6 Reducing Post-cementing Annular Flow Potential

The hydrostatic pressure of a cement column decreases as cement gains gel strength, increasing the potential for annular flow. Hydrostatic pressure loss increases with cement column length. Therefore, reducing cement column length will mitigate this effect. Stage collars can be used for this purpose.

In other applications, stage collars may be used to increase the length of the second stage cement column by isolating the weak or loss circulation zones below the tool.

See API 65-2 for a discussion on factors that affect cement success.

4.7 Off-bottom Cementing above Open Hole Completions

In this application a stage collar is installed above an annular packer to place cement above the uncemented completion without pumping cement below the stage collar (Figure 3), leaving the annulus below the packer uncemented.

![Figure 3—Example of Off-bottom Cementing above an Uncemented Completion](image-url)
4.8 Placing Specialty Fluids in the Top Section of the Annular Space

Stage collars may be used to allow for the placement or recovery of fluids above the stage collar. The process allows the user to circulate these fluids from a known point in the well, above the TOC. This process may be performed to allow recovery of drilling fluids, placement of corrosion protection fluids, introduction of freeze suppression fluids, or any other material to address specific well conditions. In these cases, the stage collar is opened following the primary cement job. Once the tool is opened a fluid circulation is initiated to ensure that the annular fluid is conditioned and clean and no cement will remain above the tool. Depending on the application, the first stage of cement may be allowed to set prior to continuing displacement operations.

4.9 Contingency Cementing

Stage collars are sometimes installed as a contingency measure in case TOC objectives are not met. If primary cement job objectives are met, a second stage cement is not required, and the stage collar is then permanently closed using a cancellation device or other method. This operation will vary by tool design.

5 Operating Types of Stage Cementing Collars

Currently there are two operating types of stage cementing collars: workstring operated and non-workstring operated tools.

For both non-workstring and workstring operated tools, some applications may require special features or performance specifications.

5.1 Non-workstring Operated Tools

Non-workstring operated tools are also referred as stage collars or stage collars. These tools are operated using hydraulic pressure with or without an operating plug and do not require a workstring to function the tool. When using plugs, these are launched from the top of the host string (surface or sub-surface launched). Stage collars may require the plugs, landing seats and any remaining cement to be drilled out.

Other non-workstring operated stage cementing collars include those functioned electronically or other means. These are not covered in this document.

5.2 Workstring Operated Tools

Workstring operated tools are also referred to as port collars. These tools are functioned mechanically using an opening and closing device on a workstring.

5.3 Special Features or Performance Tools

5.3.1 Integral Packer Cementing Collar

Integration of inflatable or compression set packer elements with stage cementing collars can be beneficial. The setting of the packer elements is included in the operation of the stage cementing collar, thereby
eliminating concerns of controlling multiple pressure events. This tool also enables actuating the packer independently from landing the first stage plug.

Traditionally, the inflatable packers will be used for setting in cased and open hole applications, while the compression set packers are used in cased hole applications. Selection of the appropriate packer should be based on the well construction needs.

5.3.2 Sub-surface Plug Launch

Where the use of stage cementing collars is needed in sub-surface or subsea applications, sub-surface launch plug sets are required. The plug set will make up to the liner or casing running tool assembly. Drillpipe darts or balls, or both are sequentially dropped or pumped down the workstring to release the plugs.

5.3.3 Drilling with Casing Compatibility

The main differences in two-stage cementing in drilling with casing applications are the potential loads or conditions and both to which the stage collars may be subjected. These conditions include:

- compression,
- tension,
- torsion, and
- bending.

Torque and drag calculations should be performed to determine the maximum values of loading throughout the drilling and cementing process. These loads can then be assessed through Finite Element Analysis (FEA), or equivalent analysis, to determine probabilities of failure.

Other considerations include:

- fatigue life;
- circulation rates, times and fluids;
- fluid compositions, including loss circulation material (LCM); and
- retrieval of drilling assembly.

The following information should be provided to the manufacturer for a comprehensive analysis:

- well schematics;
- casing specifications;
- survey;
- fluid properties;
- expected weight on bit, rate of penetration, rotational speed, torque on bit;
- position of the stage collar in the string (distance from bit);
5.3.4 Contingency Cementing Operation

In these applications second stage cement may not be required. Most stage cementing collars will still require to be shifted to the permanent close position. A cancellation device and procedure should be supplied by the manufacturer.

5.3.5 Combined Loading

As stage cementing collars are made up into the casing string, they are subject to the same loads as the casing and some operators may require consideration of combined loads in the design of the product. These loads may include tension, compression, torque, bending, internal pressure, external pressure. In addition, these loads are applied in downhole conditions which may include temperatures and environments such as sour service which could affect the material properties of the tool (both metallic and non-metallic components).

5.3.6 Fluid Compatibility

During well construction and completion operations, many types of fluids are used. Fluids that will be in the well while running casing, circulating, cementing, and displacing the operating plugs should be reviewed for compatibility with plugs, seals and packers. Additionally, the compatibility of the well fluids with each other should be reviewed. Reactive interfaces of the different fluids can create operational difficulties during cementing and stage cementing operations.

NOTE API 10TR6 describes a standard test method for elastomer property and the effect of liquids.

5.3.7 Operating Pressures

Tool operating pressures should be confirmed to be compatible with the intended casing running and cementing operating procedure for each well. Consideration should be given to all other tools installed in the casing string, as well as casing specifications.

Depending on tool design, tool operating pressures should include:

- maximum internal pressure during running in hole;
- maximum external pressure during running in hole;
- hydraulic opening pressure;
- mechanical opening pressure;
- fluids displacement pressure;
- closing pressure;
— s Cancellation pressure;
— surge and swab pressure;
— casing pressure test;
— maximum internal pressure in closed position;
— maximum external pressure in closed position; and
— high pressure stimulation, when applicable.

In addition to nominal values for the above pressures, the user should understand and consider the manufacturer’s tolerances on nominal opening, closing, and cancellation pressures.

In some applications the standard operating pressures and specifications may not be suitable. Examples of these applications include:

— hydraulic fracturing;
— tool operating pressures higher than casing pressure ratings;
— limited pump capabilities;
— synchronization with other specialty downhole tools (casing floatation devices, toe sleeves, burst disk subs, etc.);
— high burst and collapse casing;
— high ECDs; and
— urge pressure.

For these applications, customer requirements must be clearly communicated to and confirmed by the manufacturer, including any field-service limitations or special requirements (i.e. ability to adjust pressures in the field).

5.3.8 High Pressure Stimulation

Before using cementing stage collars in a casing string that will be used for hydraulic fracturing a complete engineering assessment should be performed. This may include pressure, temperature, axial load, and erosion effects.

5.4 Purchasing Guidelines

When selecting or specifying stage cementing collars, it is important that the following information be considered as applicable:

a) casing specifications: size, weight, grade, connection,
b) workstring specifications,
c) minimum downhole restriction through which the stage collar must pass, including blow out preventer (BOP) and supplemental casing hangers,
d) maximum outside diameter (OD),
e) well profile, including maximum hole inclination at or above the tool and maximum anticipated dogleg severity (DLS),
f) tool setting depth,
g) tool length and weight,
h) maximum drillout inside diameter (ID),
i) seat(s) diameter,
j) operation type (refer to Section 5),
k) differential pressure ratings before and after tool functioning,
l) tension and compression ratings,
m) operating temperature range,
n) torque,
o) number and size of ports and total port flow-by area,
p) nominal operating pressures, forces and tolerances,
q) type of seal (elastomeric, metal-to-metal, other),
r) fluid compatibility,
s) drillout requirements,
t) operating plug requirements,
u) factory acceptance testing,
v) quality requirements, and
w) manufacturing and transportation times.

6 Manufacturing and Quality Considerations

6.1 Quality Management System Guidelines

Stage cementing collars should be developed and manufactured under a Quality Management System (QMS). Certification by an external body of the QMS to an established industry standard is recommended.

NOTE API Q1 provides sector-specific guidance on quality management systems.

The manufacturing facility’s QMS should include at minimum the following topics:

a) procurement and Supplier Qualification,
b) inspection and testing,
c) personnel qualification,
d) measurement and testing equipment calibration,
e) non-conformance control, and
f) documentation control.

6.2 Design Verification

Each new product model should go through a design verification analysis to confirm that the design meets the requirements specified in the technical specification. If the environment or application and both changes for a product model, the design verification process should be repeated to verify conformance to the new requirements. The design verification analysis should be reviewed and verified by a qualified individual(s) other than the individual(s) who did the original analysis.

Where verification and industry experience exist, design verification and validation documentation may be completed and approved by a qualified person to meet the functional and technical specifications and acceptance criteria. This should include a detailed field history of successful performance of the same design, and in an environment similar to that of the functional specifications. In this case, the validation methodology should be reviewed and approved by a qualified individual(s) other than the individual(s) who did the original analysis.

6.3 Design Validation Considerations

6.3.1 General

Testing should be considered as part of the manufacturer’s design validation process to confirm that the tool meets the design parameters, as applicable to each tool design.

a) Internal Pressure Test - Running-In-Hole Position

b) External Pressure Test – Running-In-Hole Position

c) Opening Test for Plug-operated tools

   NOTE The purpose of this test is to verify the free-fall or displacement-type opening device will seat within the stage collar at or above the maximum recommended inclination and that the tool can be opened for circulation within its rated opening pressure range without an excessive volume of fluid bypassing the opening device.

d) Opening Test for Workstring-operated tools

e) Opening Test for Hydraulic Tools

f) Differential Pressure Test on Opening Device

   NOTE The purpose of this test is to verify the stage collar can withstand the effects of increasing fluid displacement pressures on the opening device and its retaining mechanism while displacing fluid through the tool body ports into the annulus.
g) Closing Tests

h) Internal pressure test-closed position

i) External pressure test-closed position

j) Drillout Test

k) Test objectives and description

**NOTE** The first objective of this test is to verify overall integrity of stage cementing collar after the tool has been drilled out using the tool manufacturer’s recommendations. The second objective is to define recommended drillout parameters (weight on bit, torque, rotational speed, rate of penetration circulation rate, bit type, etc.).

**NOTE** The test setup should simulate as closely as possible actual downhole drilling conditions. Instrumentation should allow recording all relevant drillout parameters.

l) Test Considerations

**NOTE** The tests should be conducted on a full-size tool that has been fully functioned, including all operating plugs. Also, the addition of cement to stabilize the plugs inside the stage collar to simulate end-of-job conditions. Additional pressure tests after conclusion of the drillout test should be considered.

m) Closing Mechanism Test

**NOTE** The purpose of this test is to verify the stage collar closing sleeve or closing mechanism will remain closed and maintain pressure integrity when contacted by external loads.

n) Cancellation Device Test

**NOTE** The purpose of this test is to verify the tool can be functioned to the closed position using the cancellation device.

o) Tests of Operating Plugs and/or Mechanism and Associated Landing Seats

**NOTE** The purpose of tests are to confirm the plugs will successfully pass through the stage cementing collar, land on the designated seat, and seal or bypass fluid as designed. The following tests should be conducted using the stage collar and darts and/or plugs:

1) first stage cementing plug pump through test,

2) first stage cementing plug landing test,

3) second stage bottom plug bypass test,
4) second stage closing plug static and dynamic test,
5) first stage flexible plug bypass test,
6) additional tests for three stage cementing plugs,
7) compatibility of sub-surface launch plug sets with stage cementing collars, and
8) durability and function tests on the operating tool of workstring-operated tools.

6.4 Field Operations

Successful deployment of stage cementing collars is based on the user or operator or both having access to and knowledge of the following:

a) tool specifications,
b) pre-job inspection of plugs and tools,
c) installation and handling procedures, and
d) operating procedures and troubleshooting options.

6.5 Factors Affecting Stage Collar Life Span

The manufacturing and quality control processes of stage cementing collars should consider all factors that affect the tool’s life span. These should include:

a) shelf life:
   1) material selection;
      i. metal,
      ii. elastomers,
      iii. polymers, and
      iv. lubricants.
   2) manufacturer’s recommended storage conditions;
      i. temperature,
      ii. UV exposure,
      iii. environment,
         NOTE Environmental conditions that may impact shelf life include excessive moisture content, climate control, physical damage, overall cleanliness, storage position.
      iv. age, and
3) inventory control;
4) packaging;
   i. components,
      NOTE The history of individual components prior to tool assembly may have an impact on
      the tool’s shelf life. These include surface preparation, thread storage compounds, shelf life
      and storage of elastomers, and other.
   ii. assembled tool.
5) mobilization;

b) functional life:
   1) installation and running process;
   2) wellbore conditions;
      i. temperature, and
      ii. chemical environment.
      NOTE This can include corrosive fluids or gases, pH levels, and production composition.

c) drillout;
   NOTE Recommended manufacturers procedure.

d) post installation loading conditions.
   NOTE This can include stimulation treatments, production drawdown, pressure and temperature
   cycling, casing wear.

7 Relationship to Well Integrity

When a stage cementing collar is installed into a casing, or liner, it will become an element of the well
barrier system during drilling of subsequent hole section(s) below the installed casing or liner and will remain
as a component of the well barrier system until it is covered with a subsequently installed casing or liner.
During this time, the stage cementing collar could potentially be exposed to the maximum anticipated
pressure during a well control event, typically linked to the maximum allowable surface pressure (MASP)
load case for the hole section.

Stage cementing collars may also reside within the final well barrier system. When this occurs, the stage
cementing collar will become one of the mechanical well barrier elements making up the overall well barrier
system during production operations and should be confirmed to meet or exceed the projected well control
production load cases for the casing.
The stage cementing collar should be designed, constructed and selected to conform to the acceptance criteria of the well barrier system. The effect of environmental conditions in which the equipment will be run and operated should also be included in the design, construction and selection of the installed equipment.

8 Operations Job Planning Considerations

8.1 Simulations

8.1.1 First Stage Top of Cement (TOC)

Hydraulic simulators can be very useful in assisting the user to plan first stage TOC by calculating reasonable friction pressure for the wellbore fluids allowing the operator to pick the best density profile. The first stage TOC is nearly always planned to be at least 30 m (100 ft) above the stage collar and can be planned to surface. By using the simulator for TOC placement, one can determine:

a) best density for the cement and spacer,

b) desired lead and tail if necessary,

c) maximum length of lead and tail columns, and

d) maximum rate allowed to stay below a known breakdown pressure.

When simulations are being used to determine TOC, ensure that channeling and actual hole size are considered. Both conditions can change the actual TOC or ECD.

8.1.2 Fluid Compressibility

Independent of drilling fluid type (water-base, oil-base, synthetic), fluid compressibility should always be considered in the following decisions and calculations:

a) location of first stage plug landing collar;
   NOTE Sufficient fluid volume should be allowed below the stage collar to prevent hydraulic locking when opening the tool/Volume to land pump down plugs.

b) back flow volume after completing first stage;

c) volumetric calculation to open plug-operated stage collars;

d) volumetric calculation to open hydraulic stage collars;

e) volumetric calculation to close or cancel stage collars; and

f) back flow volume after closing the stage collar.

Observed volumes and pressures on the first stage provide for calibration of subsequent operations.
8.1.3 Torque and Drag

Torque and drag simulations should be performed to understand torque and axial load levels and variations at the tool throughout the casing running and cementing operations. Consideration should then be given to maximum tool specifications.

Additional considerations should be given to the likelihood, magnitude and location of casing buckling in selecting the position of the stage cementing collar in the casing string.

8.1.4 Casing Wear

Stage cementing collars should be included in casing wear analysis because the tool geometry is different than casing. Wear may expose leak paths that are different in stage cementing collars than in casing. Also, the impact of wear on the maximum internal or external pressure capability of stage cementing collars may be different than on casing.

In a design phase, the well designer can evaluate hot spots using casing wear simulators and make a survey and tubular adjustments if necessary. The stage cementing collar installation point can be selected using the same well design process to avoid hot spots and consequent loss of wellbore integrity.

8.1.5 Hydraulic Pressures

The density of the fluid columns inside the casing and in the annular space dictate the differential pressure at the tool prior under static conditions. Differential pressure at the tool should be considered when applying tool operating pressures. Differential pressure can increase or decrease required surface pressure to operate the tool.

Equivalent circulating density (ECD) and surge pressure will impact differential pressure at the tool. When running hydraulic-opening tools, the opening pressure should be set accordingly.

Differential pressure should also be considered in setting the operating pressures of multiple tools in the casing string.

8.2 Cement Properties

Important cement properties are gel strength, thickening time and strength development.

When cement is brought above the stage collar, excessive gel strength will impact the ability to circulate following opening of the tool. There must be sufficient thickening time to allow for tool operation and circulation of the well after opening the stage collar.

Strength development in the first stage cement is important in determining how long to wait prior to beginning the second stage. Typical operations wait on cement to attain at least 700 kPa (100 lbf/in.²) strength above the upper most weak zone prior to beginning the second stage cement.

8.3 Tool inside Pass-through Geometries

The profile of the inside of the stage cementing collar, before and after drillout, should be known to allow subsequent tool running operations.
8.4 Tool installation

8.4.1 Pre-job Tool Quality Assurance (Pre-job inspection)

The tool and accessories should be verified prior to installation. Inspection should be according to the manufacturer's recommendation and at minimum should include the following:

a) Record manufacturer's tool identification information.

b) Confirm tool description matches casing program.

c) Visually inspect condition of the tool and confirm:
   1) no evidence of equipment damage;
   2) no signs of damage to the pin and box threads; and
   3) the inside of the tool is free from debris or foreign objects.

d) Confirm all accessories and required installation tools and materials arrived with the tool.

e) Confirm tool dimensions.

f) Verify all plug landing profiles or operating profiles are in good condition.

g) Verify compatibility and conditions of the running tool, plugs and associated equipment.

h) Visually inspect the inside of the cement head or plug launcher to confirm compatibility with the plugs.

8.4.2 Tool Make-up

When planning for a stage cementing job, the following make-up factors should be considered:

8.4.2.1 Location

Stage cementing collars can be made up to the casing in the field or offsite.

a) Additional considerations when made up in the field should include:
   1) placement of tongs and slips,
   2) handling and stabbing the tool in the casing string, and
   3) make-up torque accuracy.
b) Additional considerations when made up offsite should include:
   1) placement of tongs and slips,
   2) make-up torque accuracy,
   3) additional transportation and handling requirements, and
   4) offsite inspection.

8.4.2.2 Make-up procedures

Tool make-up procedures, including tools and materials, should be made available to field personnel prior to installation.

8.4.3 Tool centralization

When possible, stage cementing collars should be centralized using casing centralizers. Installing casing centralizers will help to:

a) reduce bending and bending stresses;

b) provide stand-off at the tool ports to;
   1) mitigate potential pack-offs while running in,
   2) aid in effective cement placement, and
   3) reduce risk of debris preventing the tool from closing.

Centralizers should be installed as close to the tool as possible.

Centralizer installation method, position, and minimum compressed diameter should be considered.

8.4.4 Tool Outside Diameter (OD)

The OD of stage cementing collars may be larger than casing or coupling OD. Prior to running the tool, field personnel must confirm that the maximum tool OD will pass through all restrictions between surface and setting depth, taking into consideration diametrical tolerances and jamming angle.

Additionally, the effect of tool OD on ECD and annular pack-off risk should be considered.

8.4.5 Casing Running Speeds

Casing running speeds impact surge and swab pressure in the casing and the annulus. Rapidly stopping casing movement may increase differential pressure at the tool due to fluid inertia inside the casing and inadvertently open the tool.
8.4.6 Tool Set Depth

Tool setting depths can be a function of the following parameters:

a) location of weak zone;

b) dogleg severity (DLS);

c) inclination;

d) tool type;

e) differential pressure;

f) future operation; and

g) fluid compressibility.

8.5 Stage Collar Selection

Stage collar selection considerations should include:

a) operating envelope,

b) operating type (workstring-operated, non-workstring, mechanical, hydraulic, etc.),

c) special installation requirements,

d) risk assessment,

e) future operations, and

f) operating plugs.

8.6 Operating Plugs Selection

8.6.1 General

Many plug sets exist to operate stage cementing collars. The appropriate plug set should be defined in the planning stage to ensure it is procured and sent to the field along with the tool.

8.6.2 Hydraulic Stage Collars

The minimum plug set for hydraulic stage collars consists of:

a) a landing seat,

b) a first stage top plug, and
8.6.3 Mechanical Stage Collars

The minimum plug set for mechanical stage collars consists of:

- a landing seat,
- a first stage top plug,
- a stage collar opening device (free-fall or pump down), and
- a second stage top plug (closing plug).

**NOTE** Using a pump-down opening device, a first stage bypass plug with a bypass baffle should be recommended. A closing plug should prevent open device to land and to open the stage collar.

8.6.4 Additional Optional Plug Sets

Additional plug sets options commonly used include:

- first stage bottom plug (bypass type),
- first stage bypass landing seat,
- cancellation device,
- second stage bottom plug,
- sub-surface release plug set and associated darts, and
- three-stage plugs: utilized when installing two stage collars in the same casing string.

The manufacturer should be contacted to ensure correct tool placement and plug launching sequence. Images for the above plug set options are shown in Annex A.

8.7 Cement Job Procedure

8.7.1 General

A multiple-stage cement job should be treated as a sequence of two or more cement jobs. The sequence of events and fluids pumped should be carefully coordinated between all involved parties including but not limited to the stage collar provider, cementing provider, drilling fluids provider, casing equipment provider, rig contractor and operator.

Prior to running the casing string, all fluids must be verified for chemical compatibility. Mechanical components should be verified for dimensional compatibility. Part numbers on manifests should be cross referenced with actual components and dimensions of critical components measured and confirmed.
The fluid volumes and rates for each stage and associated launching of darts and/or plugs to operate stage collars should be clearly defined with roles and responsibilities. Stage collar providers may have specific pressure and rate limitations at various stages during the job such as just before landing operating darts and/or plugs and during the operation of said tools. The predicted and actual pressure comparison for each stage should be done during the job and any anomalies identified and explained prior to proceeding to the next stage. Fluid compressibility, when applicable, should be considered when estimating static and circulating pressures, and calculating the differential pressure between the annulus and pipe ID at the depths of the stage collars.

The laboratory work for each cementing stage should consider the effects that prior operations will have had on wellbore temperature and pressure schedules, inclusive of but not limited to extended circulation times and rates before and between stages, extended static periods, and lost circulation when applicable. The static and circulating temperatures in the annulus at the depth a stage collar placed above a horizontal or extended reach section of wellbore as compared to a vertical wellbore of the same true vertical depth can be substantially different.

### 8.7.2 Fluid Management and Testing

Surface management of fluids includes but is not limited to pit management, solids control, and overall quality of fluids pumped is important for pressure model matching, ECD control, and tool operation. The presence of excessive drill solids and/or LCM, risks tool failure. Reducing the density of the displacement fluid may be considered to facilitate circulation after opening the tool. The surface arrangement of preflushes, spacers, cement slurry(ies), and displacement fluid must be verified prior to starting the job.

Lab testing schedules for each cement slurry stage should incorporate any shut-down periods in the placement schedule to ensure no interference with tool operation. Failure to include a shut-down to model the static period of cement slurry that may be either intentionally or inadvertently placed in the annulus around the stage collar may prevent the tool from opening or otherwise prevent circulation of the annulus after the tool is opened. Explanation of shut-down periods or hesitation schedules for lab testing may be found in API 10B-2. Alternatively, the static gel strength testing methodology of API 10B-6 may be considered.

Compatibility testing of fluids that may intermix should be conducted in accordance to API 10B-2 to ensure fluid interfaces remain pumpable in the annulus around and above the stage collar. Cement-contaminated fluid that may be circulated to surface after a tool is opened should be diverted from the working mud pits and disposed of.

### 8.7.3 Plug Launching Sequence and Procedure

#### 8.7.3.1 Stage Cementing Collars Mechanically or Hydraulically Opened—Planning Phase

Non-workstring operated stage cementing collars utilize specific darts and/or plugs for each tool operation: opening and closing or cancelling. When planning a multi-stage cement job, it is important to understand and communicate to field personnel the required plug launching sequence and procedure. This sequence and procedure for plug launching should include:

1. **Define the type of darts and/or plugs that will be used:** manufacturers offer multiple plug sets that may affect the launching sequence and preparation procedure. Some examples of darts and plugs are shown in Annex A.
b) For the specific plug set that will be used, define requirements and procedures (including installation tools or landing collar) for landing the first stage plug, such as installation of a receptacle (baffle) or landing collar in the casing string.

c) If planning on landing the first plug on float equipment, confirm the float equipment used will be compatible, and define any limitations such as flow rate, landing velocity, etc.

d) Determine if the first stage plug(s) will be launched from the cement head or manually inserted in the casing.

e) If pre-loading the cementing plugs in the cement head:
   1) review specifications of the cement head and crossover to the casing;
   2) confirm compatibility of retaining mechanism and plug(s) profiles; and
   3) determine where and when the cementing plug(s) will be pre-loaded.

f) Based on the pumping schedule, the following should be defined:
   1) when the first stage plug(s) will be launched,
   2) plug pumping and landing rates, and
   3) estimated displacement volumes to land the first stage plug(s).

4) If the stage collar is mechanically open, should be defined:
   i. when the stage collar opening device will be launched, and
   ii. estimated time for the opening device to land at the stage collar.

5) Surface pressure to seat the opening device, and to open and to close the stage collar.

8.7.3.2 Stage Collar Plugs Launching—Operating Sequences

The procedure described hereafter should be applicable to plug sets most commonly used. First stage cement is displaced with a flexible plug; stage cement collar should be hydraulically or mechanically open.

NOTE Other plug sets, such as using a first stage bottom plug or latch down plugs, may require different procedures.

a) Load the plug(s) onto the cement head, and
   1) confirm the plug release mechanism and launch indicator is in good condition;
   2) confirm there is no damage to the plugs during loading.
b) If opening the stage collar hydraulically:

1) Launch first stage flexible plug on top of first stage cement slurry (ies). NOTE Confirm the plug was launched (if applicable).

2) Pump the calculated amount of fluid to displace the first stage plug to the stage cementing collar.

3) Slow down pumping rate per manufacturers recommendations to pump the plug through the stage cementing collar.

4) Resume regular pumping rate after the plug passes the stage cementing collar.

5) Pump the calculated amount of fluid to land the first stage plugs(s) on the float equipment or landing collar (see Section 11 Table 1 if plug(s) does not land).

6) Slow down pumping rate per manufacturers recommendations to land the plug.

7) Record final circulating pressure.

8) Apply the recommended amount of pressure over circulating pressure to seat the plug.

9) Release pressure to confirm float equipment is closed, and record the amount of fluid bled back to the pumping unit.

10) Apply the recommended amount of pressure to open the stage collar.

c) If opening the stage cementing collar mechanically

1) Launch first stage flexible plug on top of first stage cement slurry(ies). Confirm the plug was launched (if applicable).

2) Pump the calculated amount of fluid to displace the first stage plug to the stage cementing collar.

3) Slow down pumping rate per manufacturers recommendations to pump the plug through the stage cementing collar.

4) Resume regular pumping rate after the plug passes the stage cementing collar.

5) Pump the calculated amount of fluid to land the first stage plugs(s) on the float equipment or landing collar (see Section 11 if plug(s) does not land).

6) Slow down pumping rate per manufacturers recommendations to land the plug. Record final circulating pressure.

7) Open the cement head and drop the opening device.
8) Allow enough time for the opening device to land at the stage collar per the estimated free-fall rate, accounting for mud weight and hole inclination.

9) Apply the recommended amount of pressure to open the stage collar.

d) After the stage collar has opened, if circulation is possible, circulate through the stage collar while waiting on cement (if applicable). Circulation time should be defined as per required wait on cement time below the stage collar.

e) Start pumping second stage cement fluids without exceeding maximum rate recommended by the manufacturer.

f) Launch second stage closing plug on top of second stage cement slurry.

NOTE Confirm the plug was launched, if possible

g) Pump the calculated amount of fluid to land the second stage closing plug on the stage cementing collar (see Section 11 if plug does not land)

h) Slow down pumping rate per manufacturers recommendations to land the closing plug

i) Apply the manufacturer’s recommended amount of pressure over final circulating pressure to close the stage collar.

NOTE Hold this pressure for the manufacturer’s recommended period.

j) Release pressure per manufacturer’s recommendations and,

k) Check for flow back to confirm the stage cementing collar is closed and locked.

If excessive flow back is observed, follow the manufacturers recommendations to reattempt to close the tool (see Section 11)

8.7.4 Casing Rotation

When planning to rotate the casing during cementing the following requirement and sequence should be applied:

8.7.4.1 Surface Equipment:

a) Review and confirm the compatibility of the cementing plugs with the rotating cement head or the casing swivel.

b) Define and review the plug lunching sequence.

8.7.4.2 Casing Centralizers

a) When possible, stage cementing collars should be centralized using casing centralizers (see section 8.4.3).
b) When rotating casing, ensure the centralizers will be free to rotate (not fixed to the casing).

8.7.4.3 Rotation Torque and Drag

a) Run torque and drag simulations to determine:

1) maximum torque the stage cementing collar(s) will be subjected to during the cement job,
2) maximum torque in the casing string, and
3) maximum torque requirements at surface.

b) Confirm all components in the casing string (pipe body, connections, casing equipment) can withstand the maximum expected torque.

c) Confirm availability of required surface torque.

d) Run hydraulic simulations to calculate the effect of pipe movement on ECDs.

8.7.5 Liner Hanger and Liner Plugs

8.7.5.1 Stage Cementing Operations Below a Liner Hanger

Stage cementing operations can be performed in conjunction with a liner hanger. However, it must be understood that devices used to function the stage cementing collar must be capable of being run in the liner below the liner hanger and remotely released to function the stage cementing collar.

Planned TOC and the liner hanger setting process must be known prior to establishing the detailed running procedure. The procedure should include operational steps for activating the liner hanger prior to pumping operations or a procedure for setting the liner hanger after pumping operations.

Attention to cement slurry thickening time specific to liner hanger setting procedures may be necessary, depending on the slurry design and liner hanger.

Attention should be given to the wiping diameter range and restrictions in the inside diameter of the work string and liner running tool to verify the wiper darts can pass through without issue.

Procedures are generally divided into two operations: two stage cementing using hydraulically opened stage collars below a liner hanger, and off-bottom cementing below a liner hanger.

8.7.5.2 Stage Cementing Operations Using a Hydraulically Opened Stage Tool Below a Liner Hanger

For a two-stage liner cementing operation, the basic operational procedure should be followed:

a) Tools are installed into and run with the liner and liner hanger to the desired setting depth. The hydraulic stage cementing sub-surface launch plug set is installed below the liner hanger.

b) While running in hole, circulation can be performed through the liner with attention to circulation pressures to prevent premature opening of the stage collar or activation of the liner hanger.
c) Once at target depth, a liner hanger activation device is dropped and is pumped down or allowed to free fall to the liner hanger running tool.

d) Once the activation device lands, surface pressure is applied to activate the liner hanger.

   NOTE Once the liner hanger is activated, additional surface pressure causes the activation device to pass through a seat. The activation device is then captured, allowing fluid bypass.

e) Mix and pump first stage cement slurry(ies) followed by the first stage shutoff plug releasing dart.

f) The first stage shutoff plug releasing dart is displaced behind the first stage cement slurry (ies); the first stage shutoff plug releasing dart engages the first stage shutoff plug.

g) Differential pressure is required at the first stage shutoff plug to release and displace it.

h) After the first stage shutoff plug is landed, surface pressure is released to check the float valves.

i) Surface pressure is applied to open the hydraulic stage collar.

j) Circulation through the stage collar is performed.

k) The second stage closing plug releasing dart is displaced behind the second stage cement slurry.

l) The second stage closing plug releasing dart engages the second stage closing plug.

   NOTE Differential pressure at the second stage closing plug causes it to be released and displaced through the liner to the stage collar.

m) Once the second stage closing plug landed on the stage cementing collar, surface pressure is applied to close the stage collar.

n) Surface pressure is released to confirm closure of the stage collar.

o) Liner hanger release operations are performed.

p) Circulation above the top of liner is performed to circulate any cement slurry pumped above the top of the liner out of the hole.

q) Perform end of cementing operations.

To apply this procedure, additional considerations should include the following:

— well inclination;
— preferred location for capturing the activation device;
— circulation operations (time, pressure, erosion of landing seats and limitations on the plugs);
— LCM content and limitations;
— other types of liner hangers and corresponding operating procedures; and
— potential failure or anomaly and both root causes described in section 11.

8.7.5.3 Off-bottom Stage Cementing Operations Using a Hydraulically Opened Stage Tool Below a Liner Hanger

For an off-bottom two stage liner cementing operation, the basic operational procedure should be followed:

a) Tools are installed into and run with the liner and liner hanger to the desired setting depth. The hydraulic stage cementing sub surface plug set is installed below the liner hanger.

b) While running in hole, circulation can be performed through the liner with attention to circulation pressures to prevent premature opening of the stage collar or activating the liner hanger.

c) Once at target depth, a liner hanger activation device is dropped and is pumped down or allowed to free fall to the liner hanger running tool.

d) Surface pressure is applied to activate the liner hanger.

e) Additional surface pressure causes the activation device to pass through a seat.

The activation device is then captured, allowing fluid to bypass it.

f) Surface pressure is applied to open the hydraulic stage cementing collar.

NOTE Some operations use the liner hanger setting activation device as the means of opening the hydraulic stage cementing collar in addition to setting the liner hanger.

g) Circulation through the stage collar is performed.

h) The second stage closing plug releasing dart is displaced behind the second stage cement slurry(ies).

i) The second stage closing plug releasing dart engages the second stage closing plug.

Differential pressure at the second stage closing plug causes it to be released and displaced through the liner to the stage collar.

j) Once the second stage closing plug landed on the stage collar, surface pressure is applied to close the stage collar.

k) Surface pressure is released to confirm closure of the stage tool.

l) Liner hanger release operations are performed.

m) Circulation above the top of liner is performed to circulate any cement pumped above the top of the liner out of the hole.

n) Perform end of cementing operations.
To apply this procedure, additional considerations should include the following:

- well inclination;
- preferred location for capturing the activation device;
- circulation operations (time, pressure, erosion of landing seats and limitations on the plugs);
- LCM content and limitations;
- use of an inflatable external casing packer and corresponding running and operating procedure;
- plug operated stage cementing collars requirements;
- other types of liner hangers and corresponding operating procedures; and
- potential failure or anomaly and both root causes described in section 11.

8.7.6 Workstring Operated Tools

Workstring operated tools are used to place multiple stages of cement within a wellbore. Unlike plug operated tools, a workstring operated tool utilizes drill pipe or tubing fitted with an operating device to manipulate an internal sleeve from the closed to open position and back to closed position at the end of the operation. Because the operating sleeves within workstring operated tools are designed to an inside diameter equal to or greater than the casing, they do not require drill out. Additionally, there are no restrictions on the number of tools that can be run in a given casing string.

In application, the first stage cement may be placed in the casing string conventionally with cementing plugs. Alternatively, the workstring, with the operating device installed, may be used to perform inner string cementing through the float collar or shoe at the bottom of the casing string.

After the first stage cement has been placed, manipulating the workstring to engage the internal sleeve of the workstring operated tool can begin. With either reciprocation or rotation the internal sleeve is shifted to allow communication from inside the casing to the outside. Circulation of excess first stage cement that had been circulated above the workstring operated tool can be initiated.

Once isolation has been established to support the second stage, cementing operations can continue. At the conclusion of each stage of cementing, the workstring is once again manipulated to engage the operating sleeve and close it from further communication between the ID and OD of the casing string.

A clear knowledge of the operating parameters of the workstring operated tool is important. There are two types of operating tools, reciprocating and rotational.

a) Reciprocating operational devices:

Reciprocating workstring tools operate by engaging shoulder profiles in the operating sleeve of the workstring operated tool. Usually, slacking off against this profile will open the tool. A closing subcomponent of the operating tool (designed in the reverse of the opening device) is required to engage the operating sleeve in order to close the tool with upward movement or tension. Hence, diligent hookload management is important to successfully open and close the workstring operated tool. Published compressive and tensile loads are normally provided for verification of each step during the operation.
b) Rotational operational devices:

Rotational workstring tools operate by engaging operating sleeve profiles of the workstring operated tool. Once engaged, rotation against this profile will rotate the operating sleeve to the open position. Further rotation or rotation in the opposite direction will then close the operating sleeve and prevent ID to OD communication through the workstring operated tool.

Applied torque to the workstring requires attention while opening or closing a workstring operated tool.

Additional accessory equipment that is available for inner string cementing through a workstring operated tool is available. Packer elements can be run above the bottom of the workstring to prevent cement from flowing up through the workstring annulus. Similarly, a port between packers can be used to selectively pump cement through the tool. This provides very accurate placement control of the second stage cement.

8.8 Compatibility with Other Casing Equipment (if present)

8.8.1 Shoe Track Accessories

Opening stage cementing collars hydraulically requires a proper seal formed between the first stage plug and the landing profile. When planning to land the first stage plug on the float collar, compatibility between the two should be confirmed to ensure seal integrity. For example, some float collar designs may prevent the installation of landing plates. Latch down plugs will require a compatible latching profile.

8.8.2 Landing Collars

Some plug sets or operations implement the use of landing collars to ensure compatibility between plugs and landing profiles. Some advantages of using landing collars or seats should include:

- improved seal reliability,
- increased shoe track length,
- seal contingency and
- facilitated use of first stage bottom plug.

Compatibility for seal integrity should also be confirmed. Additional considerations should be given when the plug(s) will need to pass through the landing collar. These considerations should include required dimensions and pumping rates to ensure no damage to the plugs.

8.8.3 Inflatable Casing Packers

When conducting multi-stage cement jobs using stage cementing collars and inflatable packers, the operating pressures of both tools must be carefully defined to ensure they operate in the desired sequence. Tolerances in the operating pressures of both tools should be considered. The compatibility of the plugs with the packers should also be confirmed.

When possible, it is advantageous to create an operating procedure defining the steps that will be followed to actuate both tools.
8.8.4 Other Stage Collars

Multi-stage cement jobs can be conducted in three stages by utilizing two stage cementing collars. The plugs, or darts and both to operate the lower tool will have to pass through the upper tool. Specifications and launch sequence of each set of plugs should be carefully documented and communicated to field personnel.

8.8.5 Other Pressure Activated Equipment

Other hydraulically operated tools installed in the casing string must be considered when defining the operating pressures required for stage cementing collars. These include casing floatation subs, toe initiator valves, landing collars and seats, auto-fill float equipment, etc.

8.8.6 Dimensional Clearances for Operating Plugs

The minimum diameter and geometry of all restrictions in ID in the string should be considered to ensure operating plugs will pass through without damage to the plugs or the equipment, including inadvertent activation of the tools.

8.9 Review Potential Failure Modes and Contingency Planning

When planning a multi-stage cementing job, all potential tool failures or anomalies or both, and corresponding root causes and remedies and preventive actions should be reviewed and understood, refer to Section 11.

Considerations for potential well control issues should also be addressed. These include unexpected losses or influxes.

9 Operational Considerations

9.1 On-site Job Review

Prior to the cementing job, the following information should be reviewed by parties involved in the operation:

a) applicable safety considerations;
b) required pre-job pressure tests;
c) review plug launching procedure and contingency plans;
d) pipe tally and planned installation depth of stage cementing collar and landing profile;
e) based on the pipe tally, mark the joint where tool should be installed;
f) pumping schedule:
   1) fluid volumes and densities,
   2) estimated final displacement and plug bump/landing pressures and rates (if applicable).
g. contingency plan;
   1) stage collar opening, and
   2) stage collar closing or cancellation

h. for non-workstring operated tools;
   1) plug identification and launching sequence,
   2) displacement rates when passing plugs through the tool and when landing, and
   3) free-fall time.

i) for workstring operated tools;
   1) limitations on allowable displacement rates,
   2) verify sufficient slack-off and pick-up weight available,
   3) verify sufficient torque capacity,
   4) aack-off equipment (at the surface and/or at the tool),
   5) appropriate running tool:
      i. critical dimensions,
      ii. surface and downhole spacing considerations,
      iii. depth confirmation method,
      iv. workstring centralization, if applicable, and
      v. downhole isolation packers.
   6) fluid flow path, and
   7) performance reporting.

NOTE In preparation for a post job review, refer to 8.7 and Section 10 and define a procedure to collect the relevant information.
9.2 Non-workstring Operated Cementing Stage Collars

9.2.1 First Stage Considerations

9.2.1.1 Use of Top Plug Only

For non-workstring operated stage collars, the act of pumping the first stage of cement and any operating plugs through the stage tool needs to consider that some stage collars may have limits on the plug displacement rates and velocities through the stage tool and these rates and velocities may vary depending on the type or size and both of plugs being pumped. Similarly, the pump rate and velocity when landing the first stage top plug may depend on the plug design and the landing collar or baffle used to catch the plugs. At this point in the job, the cement is usually not in free-fall (i.e. it must be pumped into place) but if free-fall is experienced, this should be accounted for in determining the landing velocity or rate. Similarly, the pump rate and velocity used to land a displacement-type opening device to open the stage tool should be provided by the stage tool manufacturer.

Careful attention must be paid to the volume of each fluid pumped. The method of determining the volume pumped (displacement tanks, stroke counters) should be agreed to by all parties prior to the job. Consideration should also be given to actual tubular and annular capacity, and fluid compressibility.

9.2.1.2 Use of First Stage Top Bypass Plug with Pump-down Opening Device

The volume to be pumped is especially important for jobs using displacement-type opening plugs. In this case, the first stage top bypass plug and the pump-down opening plug are in the casing string at the same time.

If the volume between the two is larger than intended, due to differences in pumped volumes or casing capacity, the first stage top bypass plug may land prior to the pump down opening plug landing on the stage cementing collar, resulting in over-displacement of the cement.

If the volume between the two is smaller than intended, the pump down opening plug will land early and excess cement will remain above the shoe track.

9.2.1.3 Use of Top and Bottom Plugs

When separation of displaced fluids is desirable, the use of first and second stage bottom plugs may be considered.

When using a first stage bottom plug, the ability to pass through the landing seat of the first stage top plug should be confirmed. The ability of the fluid to bypass the bottom plug should also be confirmed. Introducing additional plugs requires further preparation to assure the proper sequence of release. It will also require estimating the pump down volume (time) to land the additional plugs. The bypass pressures should also be defined.

To land the bottom plugs, additional baffle plates or landing collars may be required.

Using a second stage bottom plug should require adjusting the closing pressure or the bypass pressure. Also, the compatibility of the bottom plug, closing seat, and closing plug must be confirmed.

When bypassing the bottom plug, the flow by area may be reduced and pumping pressure may increase.
Consult with the manufacturer for recommended procedures.

The larger number of plugs poses additional operational concerns and requirements. These should include proper identification, loading and launching procedures to ensure the correct sequence is followed.

Drillout operations may also be impacted by a larger number of plugs.

### 9.2.2 Second Stage Considerations

For non-workstring operated stage collars, the volume pumped and setting time of the first stage cement should be considered in the pre-job planning to allow for operating the stage tool. If the volume of first stage cement slurry(ies) puts the TOC above the stage tool, then the static setting time should be sufficient to allow operation of the stage tool before the cement slurry sets. The volume of first stage cement slurry in the annulus above the stage tool should be circulated out with displacement fluid before it sets to eliminate bridging of the annulus, preventing the second stage cement job.

The act of pumping the second stage of cement and any closing plugs used to close the stage tool needs to consider that some stage collars may have limits on the plug landing rates or velocities for landing in the stage tool and these rates and velocities may vary depending on the type or size and both of plugs being pumped. At this point in the job, the second stage cement slurry is usually not in free-fall (i.e. it should be pumped into place). If free-fall is experienced, this should be accounted for to determine the landing velocity or rate. Similarly, the pump rate and velocity used to land the closing plug to close the stage tool should be provided by the stage tool manufacturer.

### 9.2.3 Three-stage Considerations

Multi-stage cementing can also be performed in three stages by installing a second additional stage cementing collar in the casing string. The complexity of this operation is significantly higher as it requires additional synchronization of operating pressures and plug launch sequence.

The main operational considerations when conducting a three-stage cement job should consider the following.

a) types of tools that will be used (hydraulic, mechanical);

b) operating pressures of both cementing collars AND all other tools in the casing string;

c) pressure tolerance stack-up analysis;

d) position of each tool in the casing string;

e) type, compatibility, and identification of the plugs;

f) plug launch sequence; and

g) operational verification and contingency procedures.
9.2.4 Hydraulic Stage Tool Opening Considerations

9.2.4.1 Well inclinations

For non-workstring operated tools (mechanical or hydraulic), the hydrostatic pressures at the tool should be calculated based on true vertical depths for each tool in the string.

9.2.4.2 Opening Device Free-fall Rate

When using free-fall opening devices, consideration should be given to the amount of time that it may take the device to arrive to the tool (settling time). This time can vary significantly from application to application and will depend on the following variables: well trajectory, casing diameters, fluid properties, plug specifications (density, geometry) and stage tool depth.

Settling time in comparable offset wells may also be considered. When settling times are excessively long, consideration should be given to pump down opening device.

9.2.4.3 Fluid Compressibility and Potential Hydraulic Locking

When using a free-fall opening device, the first stage of cement is typically pumped until the first stage top plug lands on a baffle or landing collar. This landing then closes off the bottom of the casing. When the opening device lands in the stage tool, the fluid between the stage tool and landing or baffle collar shall be compressed for the free-fall opening device to travel down and open the stage tool. While this travel is small, limited compressible volume between the free-fall opening device and the first stage plug can result in hydraulic lock. Subsequent cycling of higher pressures will usually open the stage tool. Alternatively, the stage tool can be opened with drill pipe weight; see 11.2 Table 5 Failure to Open.

9.2.4.4 Loss Circulation Material (LCM)

LCM present in either the drilling fluid system or cement slurries may tend to accumulate on the low side of the casing during circulation or static periods. These accumulations vary in thickness, strength, and adhesion to the casing. LCM may interfere with the operation of the sleeves.

Displacement-type plugs will vary in their effectiveness to wipe away this material and in some cases may have wiper fins worn away on one side by the abrasion resulting in lack of landing pressure signals. Fluid displacement rates may mitigate this issue.

9.2.5 Tool Closing Considerations

9.2.5.1 Standard Operation

Closing the non-workstring operated stage cementing collar is typically achieved by pumping a closing plug down to the stage tool following the second or later stage of cement. This plug typically has a nose designed to engage the closing sleeve in the stage tool. The landing rate or velocity of the plug should be recommended by the manufacturer. The pressure required to close the stage tool will depend on the final pump pressure required to place the second stage of cement plus the actual closing pressure of the tool according to the manufacturer’s recommendations. After landing the closing plug and achieving the required closing pressure, pressure is then released, and a backflow check taken. If backflow persists, see 11.2 Table 10.
9.2.5.2 Tool Cancellation

If a stage tool is included in the string but is not used, its function should be cancelled (permanently closing the tool) to prevent accidental opening during drillout. This operation may be performed by dropping a free-fall cancellation device and applying pressure after it has landed on the stage tool.

Alternatively, the tool can be shifted using workstring weight applied directly on the tool or on a closing plug modified to allow fluid bypass. The manufacturer should be consulted in these operations.

9.2.6 Drillout

Drillout of non-workstring operated tools should follow manufacturer’s recommendations. Refer to Section 11 for contingencies.

9.2.7 Additional Liner and Sub-surface Operated Stage Collars Considerations

9.2.7.1 Sub-surface Release Plug Compatibility

Some non-workstring operated stage collars can be used in a sub-surface application where operating plugs are attached to the liner or subsea running tool. These operating plugs are typically released by drill pipe darts that are pumped from the surface down to the running tool. As before, the release sequence, volumes pumped, and pressures applied are important.

Sub-surface applications require using additional darts or balls and both. These increase the complexity of the system and require additional checks for compatibility between plugs, drillpipe and liner and casing strings, and plug launching equipment. Also, additional contingency procedures should be reviewed; refer to 8.6.3 for additional information.

9.2.7.2 Liner Considerations

For multiple stage cementing below a liner hanger, consideration should be given to when and how the liner hanger is set. This may include drill pipe rotation, set-down weight, the application of pressure to the drill pipe, dropping a ball, etc. The liner hanger setting procedure should be assessed for compatibility with the methods used to launch the cementing plugs.

In some liner applications (off bottom cementing), stage cementing collars are used to selectively place a single stage cement job above the stage cementing collar. In these cases, a different plug set and procedure may be required.

9.2.7.3 Restrictions in the Drillpipe and Liner Strings

Darts or balls or both for non-workstring operated tools shall be carefully selected for the running string used in order to pass through restrictions

9.2.7.4 Operational Procedure

Operational procedures of the stage cementing collar, sub-surface launch plug sets, and liner setting tool should be considered as a system and checked for compatibility.
9.2.7.5 Fluid Compressibility

Larger non-aqueous fluid volumes in subsea applications increase the impact of fluid compressibility on displacement and flow back volumes.

9.2.7.6 Subsea Annular Clearances

Annular clearances in deepwater applications may be significantly smaller than in conventional wells, particularly when running through the wellhead or supplemental casing hangers. The maximum OD of the tool should be confirmed.

9.2.8 Other Considerations

9.2.8.1 Existing Rig Systems

Non-workstring operated tools generally require cementing plugs to operate. Therefore, consideration of how these plugs are safely inserted into the casing during operations is suggested. The following rig systems should be evaluated:

a) rotary and kelly bushing (if required);

b) hoisting equipment (bail lengths);

c) top-drives and connections to cementing string; and

d) compensators for floaters.

9.2.8.2 Fluid Management

The flows of fluid into and out of the well need to be evaluated for compatibility with existing fluid management systems. Returning gas or cement-contaminated fluid, mixing and pumping spacers, adding LCM, and mixing/pumping cement stage slurries should be addressed. Communications between rig floor and cement pumping equipment are particularly critical during plug launching operations.

9.2.8.3 Cementing Plug Insertion (Launching)

Plug containers are commonly used to insert plugs into the flow stream. The method of plug release can be manual or remote. If operated manually, the method of safely delivering a person to the plug container for operation needs to be planned. If operated remotely, verify operation of the launch system prior to the job.

In all cases, confirm sequence of dart, ball, or both, launch and verification of release.

9.2.8.4 Annular Clearances and Equivalent Circulating Density (ECD) Concerns

The annular clearances around casing and liner can be affected by stage cementing. This includes both the OD of the stage cementing collar as well as the flow path around a liner hanger (when it is set or unset) if used. The pressure drop from both restrictions can increase the ECD at the shoe and modeling is suggested to evaluate the effects and prevent future problems.
9.3 Additional Workstring Operated Stage Cementing Collar Considerations

9.3.1 Workstring Depth and Location Control

The following practices should be recommended for operating a shifting stage cementing sleeve with a latching shifting tool:

In order to correctly function a shifting stage tool, it is imperative the casing and work string tallies are correct and matched-up correctly. The casing tally should be inspected for any errors and confirm the point from where the tally was measured. If the rig floor (Kelly bushing) height has changed between when the casing was run in the hole and when the shifting tool is picked up, the height difference should be factored into the work string tally. All joints of the workstring (drill pipe, tubing, etc) should be correctly measured and make-up lengths accounted for.

All linear dimensions of the stage tool should be recorded as well, including distance from the top of the tool to the ports and to the shifting profile. Similar linear dimensions should be recorded on the latching shifting tool, most importantly the distance from the top of the bottom hole assembly (BHA) to the shifting dogs. Using the casing tally and the stage tool dimensions, the exact length from the rig floor to the shifting profile can be calculated. Comparing this to the shifting tool dimensions and workstring tally, the exact number of workstring joints required to latch into the stage tool can be calculated. Various lengths of workstring pup joints should be on hand so the top of the workstring can be conveniently spotted above the rig floor, giving enough space to perform all operations (shift the stage tool, set the workstring slips, make-up pump to workstring, etc.).

Once the shifting tool space out has be calculated, the shifting tool is run to depth at a speed according to the manufacturer’s recommendations. The running speed should slow down as the shifting tool approaches the calculated latch-in depth. The latching shifting tool will latch into the profile as per the manufacturer’s operating instructions, and all cementing operations can be performed as necessary.

9.3.2 Reciprocating Operational Devices

The first stage can be cemented via inner string or conventionally. If the first stage is cemented conventionally, the operating tool may be located relatively close to the end of the workstring. If done by inner string, the stab-in adapter for the floating equipment will need to be carefully spaced out with the operational tools for the stage cementing collar.

The operating tool will be used to open or close the stage cementing collar by slacking off weight or applying tension, depending on its design. With the stage cementing collar closed, the inner string is run to the float collar or shoe where the first stage is completed. Other designs may require a different operating procedure. Refer to the manufacturer’s documentation.

Once the first stage is displaced the operating tools are repositioned to open the stage cementing collar. Excess cement above the stage cementing collar is then circulated out of the well.

Once isolation has been established to support the second stage, cementing can continue. After completing the second stage cementing job, the operating tools can close the stage cementing collar.

In some operations, integral packers (cups) are installed as part of the operating tool assembly instead of a surface seal. The packers (cups) straddle the stage cementing collar ports for second stage cementing. Consult the manufacturer for the proper spacing of the assembly.
9.3.3 Rotating Operational Devices

The first stage can be cemented via inner string or conventionally. If the first stage is cemented conventionally, the operating tool may be located relatively close to the end of the workstring. If done by inner string, the stab-in adapter for the floating equipment will need to be carefully spaced out with the operational tools for the stage cementing collar.

The operating tool will be used to open or close the stage cementing collar by rotating clockwise or counter clockwise, depending on the design. With the stage cementing collar closed, the inner string is run to the float collar or shoe where the first stage is completed. Other designs may require a different operating procedure. Refer to the manufacturer’s documentation.

Once the first stage is displaced the operating tools are repositioned to open the stage cementing collar. Excess cement above the stage cementing collar is then circulated out of the well.

Once isolation has been established to support the second stage, cementing can continue. After completing the second stage cementing job, the operating tools can close the stage cementing collar.

In some operations, integral packers (cups) are installed as part of the operating tool assembly instead of a surface seal. The packers (cups) straddle the stage cementing collar ports for second stage cementing. Consult the manufacturer for the proper spacing of the assembly.

9.3.4 Workstring Tool Centralization

When running workstring operating devices centralization of the operating components is important. Centralization enables the circumferential engagement of the operating sleeve for reciprocation or rotation. Centralization of the workstring is also important as casing deviation from vertical grows. Awareness of the running force of these centralizers is important.

10 Post-job Review for Multi-stage Cementing Operations

Many of the items reviewed for multi-stage cementing jobs are common to all cementing operations (pressures, rates and volumes, densities) and should be evaluated for each of the cementing stages as well as additional information on the tools used.

Post job review of multi-stage cementing operations include evaluation of the mechanics of the job (casing running and tool performance), review of pressures during the job (displacement, cement pressure lift, tool shifting, plug landing etc.), volumes of fluids pumped and associated rates and a review of returns during various portions of the job.

The following list is an example of post-job information needed to evaluate a multi-stage cement job:

a) Record any difficulties running casing in hole. Include requirements to pump casing down, rotate the casing, high drag, etc.

b) Were there any difficulties loading the plugs into the cement head?

c) Were there any difficulties launching the plugs from the cement head?
1) For sub-surface release plugs, did the plugs release at the planned pressures and volumes?

d) Were first stage pumping operations (rates, volumes, pressures, densities, times, returns) executed as planned?

e) Did the first stage plug bump?
   1) If yes, was the volume as predicted?
   2) If no, what remedial action was taken?

f) How long was the first stage circulated prior to cementing? What was the volume and rate(s)?

g) What was the final first stage final circulating pressure prior to the end of cementing?

h) What was the final first stage bump pressure?

i) Did the float equipment hold at the conclusion of the first stage?

j) What was the pressure applied and flow back volume when checking the floats?

k) If an opening device was used, did it land as predicted? Record time or volume required to land.

l) Did the tool(s) open at the expected pressure? Record the opening pressure.
   1) If not, what was the opening pressure?

m) If the tool did not open, what was the pressure applied and flow back volume?

n) What was the initial circulating pressure after the tool was opened?

o) What volume of first stage cement slurry returns was observed (if any) after the tool was opened and circulated? Record the volume of circulation and when cement returns were observed.

p) Were second stage pumping operations (rates, volumes, pressures, densities, times, returns) executed as planned?

q) Did the second stage plug bump?
   1) If yes, was the volume as predicted?
   2) If no, what remedial action was taken?

q) What was the final second stage circulating pressure?

r) What was the final second stage bump pressure?

s) Did the stage tool hold at the conclusion of the second stage?

t) What was the flow back volume?
u) What volume of second stage cement slurry returns was observed (if any)?

v) Did the tool(s) close at the expected pressure?
   1) If not, what was the closing pressure?

w) During drillout:
   1) Were the plugs tagged at the anticipated depths?
      i) If not, at what depth were the plugs tagged?
   2) Were drillout operations performed as planned?
   3) Were there any difficulties during drillout?

x) Did the casing test successfully after drillout?

y) Were cementing objectives met?

11 Prevention and Investigation of Potential Tool Failures

11.1 Prevention and Investigation

The following section and Tables 1 through 13, provide a list of potential failure modes. Probable root causes, remedies and preventive actions are presented. Proper selection and use of equipment for the job to be performed is not covered but is critical.

Prior to specifying, procuring, and running stage cementing collars, the user should become familiarized with these issues.

This list should be referenced when conducting failure mode and effect analysis (FMEA), for design or investigation purposes.

11.2 Non-workstring Operated Tools

Failures for non-working operated tools with their preventive and potential remedial actions should be summarized as:

a) Opening device is not landing or it takes an excessive volume to time to land, see Table 1.

b) During opening operation a leak is detected, see Table 2.

c) High pressure is recorded during tool opening, see Table 3.

d) A premature opening or a low pressure is recorded during opening, see Table 4.

e) Tool failed to open see Table 5.
f) Closing device is not landing or it takes an excessive volume to land, see Table 6.

g) Closing device or dart or both are leaking, see Table 7.

h) High pressure is recorded during tool closing, see Table 8.

i) Tool failed to close, see Table 9.

j) After tool closing, a casing to annulus or annulus to casing pressure build-up is observed, see Table 10.

k) Difficulties to drillout closing device or first stage plug or both, see Table 11.

l) After drillout, leaking casing to annulus or annulus to casing is observed, see Table 12.

m) Fluids bypassing plugs is encountered, see Table 13.
Table 1—Opening Device Not Landing, or Taking Excessive Volume or Time to Land

<table>
<thead>
<tr>
<th>Potential Root Cause</th>
<th>Potential Remedy / Preventive Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incorrect displacement calculations</td>
<td>Confirm pump volumetric efficiency and actual casing ID/capacity and recalculate required displacement volume</td>
</tr>
<tr>
<td>Fluid compressibility</td>
<td>Calculate the effect of compressibility on displacement volumes</td>
</tr>
<tr>
<td>Plug launching issues</td>
<td>Confirm compatibility of the plug with the cement head to avoid the plug getting stuck or delayed launch</td>
</tr>
<tr>
<td></td>
<td>Confirm operating sequence of cement plug retaining devices and valves to ensure the plugs launch at the correct time, and to avoid risk of simultaneously releasing multiple plugs</td>
</tr>
<tr>
<td>Incorrect settling velocity estimations</td>
<td>The effect of wall shear stress on the settling velocity of a free-fall opening device can be significant and difficult to calculate. An empirical approach based on data from offset wells may be required.</td>
</tr>
<tr>
<td>Well inclination</td>
<td>Confirm maximum inclination recommended by the manufacturer for free-fall opening device. Consider pump down opening device or hydraulic tool.</td>
</tr>
<tr>
<td>Casing interference</td>
<td>Confirm what the smallest restriction is in the casing string and ensure the opening device can pass through it. Ensure diametrical tolerances are considered.</td>
</tr>
</tbody>
</table>

Table 2—Leaking during Opening Operations

<table>
<thead>
<tr>
<th>Potential Root Cause</th>
<th>Potential Remedy / Preventive Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incorrect installation of baffle plate</td>
<td>Review baffle plate installation procedure and location. Review compatibility of baffle plate with the landing collar. Review condition of the baffle plate.</td>
</tr>
<tr>
<td>Opening device incompatibility</td>
<td>Confirm opening device is compatible with the landing seat. Prior to launching the opening device, confirm the correct specifications (type and dimensions).</td>
</tr>
<tr>
<td>Damaged opening device</td>
<td>Confirm the correct procedure is followed when loading the opening device in the cement head. Check compatibility of the opening device with crossovers or ID transitions. Review storage conditions and shelf life and inspect the opening device on location prior to launching them.</td>
</tr>
<tr>
<td>Debris at the seat</td>
<td>Build and release pressure quickly to flush out accumulated debris.</td>
</tr>
<tr>
<td>Damaged seats</td>
<td>Confirm there is no evident damage on the opening seat that could prevent sealing.</td>
</tr>
<tr>
<td>Potential Root Cause</td>
<td>Potential Remedy / Preventive Actions</td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Incorrect installation procedure</td>
<td>Review tool installation procedure to ensure tongs are correctly placed and do not damage the tool.</td>
</tr>
<tr>
<td>Incorrect operating procedures</td>
<td>Review the opening pressure and pressurization rates in the operating manual.</td>
</tr>
<tr>
<td>Hydraulic opening tools</td>
<td>Confirm hydrostatic head pressure of annular column and casing column and corresponding differential pressure at the tool. With this information, confirm expected surface pressure.</td>
</tr>
<tr>
<td>High differential pressure</td>
<td></td>
</tr>
<tr>
<td>Incorrect pressure setting</td>
<td>Confirm the correct number of shear screws was used for the actual differential pressure expected at the tool.</td>
</tr>
<tr>
<td>Incorrect tool setting</td>
<td>Review operating manual and confirm the correct procedure is being followed when adjusting opening pressure in the field.</td>
</tr>
<tr>
<td>Debris or LCM</td>
<td>Confirm solid particle type, size distribution and concentration. Discuss with manufacturer and adjust accordingly. Confirm mud stability and potential for other sources of debris, such as scale, etc.</td>
</tr>
<tr>
<td>Hydraulic locking (Mechanical opening tools)</td>
<td>Determine fluid compressibility below the tool and increase distance between the tool and the float or landing collar (baffle plate).</td>
</tr>
<tr>
<td>Temperature effects</td>
<td>Confirm temperature rating of the tool and expected downhole temperature.</td>
</tr>
<tr>
<td>Running in hole conditions</td>
<td>Confirm maximum DLS recommendations with manufacturer and adjust tool setting depth accordingly. Install casing centralizers as close to the tool as possible. Confirm axial load (static and dynamic) limitations with the manufacturer and adjust tool setting depth or operating procedure accordingly. Consider potential effects of well conditions such as losses on axial load imparted on the tool and revise accordingly. If the casing will be rotated, discuss fatigue and torque limitations with the manufacturer.</td>
</tr>
</tbody>
</table>
Table 4—Premature Opening or Low Opening Pressure

<table>
<thead>
<tr>
<th>Potential Root Cause</th>
<th>Potential Remedy / Preventive Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low differential pressure</td>
<td>Confirm hydrostatic head of annular column and casing column and corresponding differential pressure at the tool. With this information, confirm expected surface pressure. Consider partial or complete losses resulting in lower annular pressure at the tool.</td>
</tr>
<tr>
<td>Incorrect pressure setting</td>
<td>Confirm the correct number of shear screws was used for the actual differential pressure expected at the tool.</td>
</tr>
<tr>
<td>Incorrect tool setting</td>
<td>Confirm number correct number of shear screws.</td>
</tr>
<tr>
<td>Incorrect installation</td>
<td>Confirm installation procedure.</td>
</tr>
<tr>
<td>Damage during first stage displacement</td>
<td>Confirm the manufacturer's recommendations for pump rate (velocity) when passing the first stage plug through the stage cementing collar. Consider cement free-fall (U-tube) rate.</td>
</tr>
<tr>
<td>High displacement rate and velocity at plug landing</td>
<td>Confirm the manufacturer's recommendations for pump rate / velocity when landing the first stage plug. Consider cement free-fall (U-tube) rate.</td>
</tr>
<tr>
<td>Pressure cycles</td>
<td>Discuss with the manufacture the potential impact of pressure cycles prior to opening the tool. Consider pressure surges while running in or circulating.</td>
</tr>
</tbody>
</table>
Table 5—Failure to Open

<table>
<thead>
<tr>
<th>Potential Root Cause</th>
<th>Potential Remedy / Preventive Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical tool: Opening device not landed</td>
<td>Refer to above sections on Settling Velocity, Well Inclination and Casing Interference to confirm the opening device is landed on the tool prior to applying opening pressure. Confirm plug has landed based on fluid compressibility calculations and actual pressure applied and volume bled back to tanks. If launching the opening device from a cement head, confirm the opening device leaves the cement head as expected.</td>
</tr>
<tr>
<td>Insufficient applied pressure</td>
<td>Confirm hydrostatic head of annular column and casing column and corresponding differential pressure at the tool. With this information, confirm required surface pressure. Consider applying additional pressure above the pressure specified to open the tool, within system integrity limitations.</td>
</tr>
<tr>
<td>Annular bridge</td>
<td>Review free-falling rate and cement thickening time and adjust accordingly. Consider other potential causes such as incompatible fluids, unstable wellbore, etc.</td>
</tr>
<tr>
<td>Pressure bleed off</td>
<td>Bleed off pressure quickly, re-apply pressure at a higher rate and attempt opening the tool again.</td>
</tr>
<tr>
<td>Lack of pressure increase</td>
<td></td>
</tr>
<tr>
<td>Hydraulic locking</td>
<td>When opening the tool mechanically, ensure sufficient distance is left between the float/landing collar and the stage cementing collar to prevent hydraulic locking.</td>
</tr>
<tr>
<td>Incorrect installation procedure</td>
<td>Review tool installation procedure to ensure tongs are correctly placed and do not damage the tool.</td>
</tr>
<tr>
<td>Debris or LCM</td>
<td>Confirm solid particle type, size distribution and concentration. Discuss with manufacturer and adjust accordingly. Confirm mud stability and potential for other sources of debris, such as scale, etc.</td>
</tr>
<tr>
<td>Running in hole conditions</td>
<td>Confirm maximum DLS recommendations with manufacturer and adjust tool setting depth accordingly. Install casing centralizers as close to the tool as possible. Confirm axial load (static and dynamic) limitations with the manufacturer and adjust tool setting depth or operating procedure accordingly. Consider potential effects of well conditions such as losses on axial load imparted on the tool and revise accordingly. If the casing will be rotated, discuss fatigue and torque limitations with the manufacturer.</td>
</tr>
<tr>
<td>Potential Root Cause</td>
<td>Potential Remedy / Preventive Actions</td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Incorrect displacement calculations</td>
<td>Confirm pump volumetric efficiency and actual casing ID/capacity and recalculate required displacement volume.</td>
</tr>
<tr>
<td>Plug damage</td>
<td>Confirm correct procedure to load plugs into the cement head.</td>
</tr>
<tr>
<td></td>
<td>Confirm compatibility of the plugs with crossovers or changes in IDs, including torque rings.</td>
</tr>
<tr>
<td></td>
<td>Confirm suitability of plug materials.</td>
</tr>
<tr>
<td></td>
<td>Review manufacturer's recommendations on pumping rates / plug velocity.</td>
</tr>
<tr>
<td></td>
<td>Review storage conditions and shelf life and inspect the plugs on location prior to launching them.</td>
</tr>
<tr>
<td>Plug launching issues</td>
<td>Confirm compatibility of the plug with the cement head and/or casing crossover to avoid the plug getting stuck or delayed launch.</td>
</tr>
<tr>
<td></td>
<td>Confirm operating sequence of cement head plug pins and valves to ensure the plug launches at the correct time.</td>
</tr>
<tr>
<td></td>
<td>Confirm the plug leaves the cement head as expected.</td>
</tr>
<tr>
<td>Fluid compressibility</td>
<td>Calculate the effect of compressibility on displacement volumes.</td>
</tr>
<tr>
<td>Casing interference</td>
<td>Consider potential casing collapse or parting.</td>
</tr>
<tr>
<td></td>
<td>Confirm what the smallest restriction is in the casing string and ensure the closing plug can pass through it. Ensure diametrical tolerances are considered.</td>
</tr>
<tr>
<td></td>
<td>Consider potential interference from torque rings, if applicable.</td>
</tr>
</tbody>
</table>
Table 7—Closing Device or Dart or Both Leaking

<table>
<thead>
<tr>
<th>Potential Root Cause</th>
<th>Potential Remedy / Preventive Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plug incompatibility</td>
<td>Confirm closing dart and/or plug is compatible with the stage cementing collar.</td>
</tr>
<tr>
<td>Wrong dart or plug or both</td>
<td>Prior to launching the dart and/or plug, confirm the correct specifications (type and dimensions).</td>
</tr>
<tr>
<td>Damaged dart or plug or both</td>
<td>Confirm the correct procedure is followed when loading dart and/or plug in the cement head.</td>
</tr>
<tr>
<td></td>
<td>Check compatibility of the plug with crossovers or ID transitions.</td>
</tr>
<tr>
<td></td>
<td>Inspect dart and/or plug before launching it.</td>
</tr>
<tr>
<td></td>
<td>Review manufacturer’s recommendations on dart and/or plug landing rate / velocity and pressure.</td>
</tr>
<tr>
<td></td>
<td>Review storage conditions and shelf life and inspect the dart and/or plug on location prior to launching them.</td>
</tr>
<tr>
<td>Debris at the seat</td>
<td>Build and release pressure quickly to flush out accumulated debris.</td>
</tr>
<tr>
<td>Damaged seats</td>
<td>Confirm there is no evident damage on the closing seat that could prevent sealing.</td>
</tr>
<tr>
<td></td>
<td>Review manufacturer’s recommendations on dart and/or plug landing rate / velocity and pressure.</td>
</tr>
</tbody>
</table>

NOTE When the tool cannot be closed with pressure, wait on cement and apply weight (or weight and pressure) with workstring on the closing dart and/or plug to close the tool mechanically.
Table 8—High Closing Pressure

<table>
<thead>
<tr>
<th>Potential Root Cause</th>
<th>Potential Remedy / Preventive Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incorrect installation procedure</td>
<td>Review tool installation procedure to ensure tongs are correctly placed and do not damage the tool.</td>
</tr>
<tr>
<td>Incorrect operating procedures</td>
<td>Review closing pressure and rates in the operating manual.</td>
</tr>
<tr>
<td>High differential pressure</td>
<td>Confirm hydrostatic head pressure of annular column and casing column and corresponding differential pressure at the tool. With this information, confirm required surface pressure.</td>
</tr>
<tr>
<td>Incorrect pressure setting</td>
<td>Confirm the correct number of shear screws was used for the actual differential pressure expected at the tool.</td>
</tr>
<tr>
<td>Incorrect tool setting</td>
<td>Review operating manual and confirm the correct procedure is being followed when adjusting closing pressure in the field.</td>
</tr>
<tr>
<td>Debris or LCM</td>
<td>Confirm solid particle type, size distribution and concentration. Discuss with manufacturer and adjust accordingly. Confirm mud stability and potential for other sources of debris, such as scale, etc.</td>
</tr>
<tr>
<td>Hydraulic locking</td>
<td>Determine fluid compressibility below the tool and increase distance between the tool and the float or landing collar (baffle plate). Confirm that the correct closing and opening devices were used.</td>
</tr>
<tr>
<td>Temperature effects</td>
<td>Confirm temperature rating of the tool and expected downhole temperature.</td>
</tr>
<tr>
<td>Running in hole conditions</td>
<td>Confirm maximum DLS recommendations with manufacturer and adjust tool setting depth accordingly. Install casing centralizers as close to the tool as possible. Confirm axial load (static and dynamic) limitations with the manufacturer and adjust tool setting depth or operating procedure accordingly. Consider potential effects of well conditions such as losses on axial load imparted on the tool and revise accordingly. If the casing will be rotated, discuss fatigue and torque limitations with the manufacturer.</td>
</tr>
</tbody>
</table>
### Table 9—Failure to Close

<table>
<thead>
<tr>
<th>Potential Root Cause</th>
<th>Potential Remedy / Preventive Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insufficient applied pressure</td>
<td>Confirm hydrostatic head of annular column and casing column and corresponding differential pressure at the tool. With this information, confirm expected surface pressure and re-apply pressure. Review manufacturer's recommendations/warnings on over-pressuring.</td>
</tr>
<tr>
<td>Debris interfering with the sleeves</td>
<td>If WOC between stages, ensure to keep adequate circulation through the tool to help prevent any solids settling in the tool sleeves which may prevent full tool closure. Bleed off pressure quickly, re-bump the plug and attempt closing the tool again.</td>
</tr>
<tr>
<td>Inadequate landing rate and velocity</td>
<td>Low or high plug landing velocity may interfere with tool operation. Review manufacturer's recommendation on landing rates.</td>
</tr>
<tr>
<td>Temperature effects</td>
<td>Confirm temperature rating of the tool and expected downhole temperature.</td>
</tr>
<tr>
<td>Running in hole conditions</td>
<td>Confirm maximum DLS while running in and at setting depth and discuss with the manufacturer. Confirm maximum axial load on the tool while running in and discuss with the manufacturer. If the casing will be rotated, discuss fatigue and torque limitations with the manufacturer.</td>
</tr>
</tbody>
</table>

NOTE When the tool cannot be closed with pressure, wait on cement and apply weight (or weight and pressure) with workstring on the closing plug to close the tool mechanically.

### Table 10—Pressure Leak (Casing to Annulus or Annulus to Casing) or, Casing Pressure Build-up after Closing

<table>
<thead>
<tr>
<th>Potential Root Cause</th>
<th>Potential Remedy / Preventive Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tool not locked</td>
<td>Review section on failure to close above.</td>
</tr>
<tr>
<td>Leak in casing string</td>
<td>Identify leak location to determine potential root cause and remedy.</td>
</tr>
<tr>
<td>Damaged seals</td>
<td>Confirm maximum temperature rating and tool burst and collapse ratings have not been exceeded. Review section on Running in hole conditions above. Review manufacturer's recommendations on pressure bleed off.</td>
</tr>
</tbody>
</table>
### Table 11—Drillout Issues

<table>
<thead>
<tr>
<th>Potential Root Cause</th>
<th>Potential Remedy / Preventive Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incorrect drillout parameters and procedure</td>
<td>Review manufacturer's recommendations on drill out weight on bit, rotational speed and circulation rate. Confirm adequate hole cleaning practices are followed.</td>
</tr>
<tr>
<td>Bottom hole assembly (BHA) issues</td>
<td>Discuss with the stage cementing collar manufacturer the bottomhole assembly that will be used for drillout.</td>
</tr>
<tr>
<td>Drilling bit</td>
<td>Confirm the recommended drilling bit size and type used.</td>
</tr>
<tr>
<td>Cement practices</td>
<td>Consider spotting cement above the closing dart and/or plug.</td>
</tr>
</tbody>
</table>

### Table 12—Leaking after Drillout (Casing to Annulus or Annulus to Casing)

<table>
<thead>
<tr>
<th>Potential Root Cause</th>
<th>Potential Remedy / Preventive Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Damaged seals</td>
<td>Confirm maximum temperature rating and tool burst and collapse ratings have not been exceeded. Review section on Running in hole conditions above. Confirm fluid compatibility with seal material.</td>
</tr>
<tr>
<td>Leak in casing string</td>
<td>Identify leak location to determine potential root cause and remedy.</td>
</tr>
<tr>
<td>Incorrect drillout parameters and procedure</td>
<td>Review manufacturer's recommendations on drill out weight on bit, rotational speed and circulation rate. Confirm adequate hole cleaning practices are followed.</td>
</tr>
<tr>
<td>Bottom hole assembly (BHA) issues</td>
<td>Discuss with the stage cementing collar manufacturer the bottomhole assembly that will be used for drillout.</td>
</tr>
</tbody>
</table>
Table 13—Fluid Bypassing Plugs

<table>
<thead>
<tr>
<th>Potential Root Cause</th>
<th>Potential Remedy / Preventive Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plug wear</td>
<td>Consider materials with higher wear resistance, such as urethane or hydrogenated nitrile butadiene rubber (HNBR).</td>
</tr>
<tr>
<td>Incorrect plug</td>
<td>Review and confirm plug specifications.</td>
</tr>
<tr>
<td>Drilling mud compatibility</td>
<td>Check compatibility of plug material with non-aqueous fluids.</td>
</tr>
<tr>
<td>Displacement rate and velocity</td>
<td>Confirm recommended flow rate and plug velocity range.</td>
</tr>
<tr>
<td>Damaged plug</td>
<td>Confirm the correct procedure is followed when loading plugs in the cement head.</td>
</tr>
<tr>
<td></td>
<td>Check compatibility of the plug with crossovers or ID transitions.</td>
</tr>
<tr>
<td></td>
<td>Review manufacturer's recommendations on plug landing rate / velocity and pressure.</td>
</tr>
<tr>
<td></td>
<td>Review storage conditions and shelf life and inspect the plugs on location prior to use.</td>
</tr>
<tr>
<td>Plug launching issues</td>
<td>Confirm compatibility of the plug with the cement head to avoid the plug getting stuck or delayed during launch.</td>
</tr>
<tr>
<td></td>
<td>Confirm operating sequence of cement head plug pins and valves to ensure the plug launches at the correct time.</td>
</tr>
</tbody>
</table>

11.3 Additional Considerations for Workstring Operated Tools

The additional considerations below should be taken related to failures for working operated tools and their preventive and potential remedial actions:

a) high opening force required to open the tool, see Table 14;

b) failure to open the tool, see Table 15;

c) high force required to close the tool, see Table 16;

d) tool failure during closing, see Table 17;

e) after tool closing, an observed casing to annulus or annulus to casing pressure build-up, see Table 16.
Table 14—High Opening Force

<table>
<thead>
<tr>
<th>Potential Root Cause</th>
<th>Potential Remedy / Preventive Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incorrect installation procedure</td>
<td>Review the operating manual and installation procedure to ensure tongs are correctly placed and do not damage the tool.</td>
</tr>
<tr>
<td>Incorrect operating procedures</td>
<td>Review the opening force in the operating manual.</td>
</tr>
<tr>
<td>Insufficient applied force or torque and both at the tool</td>
<td>Conduct pre-job torque and drag simulations to ensure enough force and/or torque are applied at the tool. Review and revise BHA and workstring design accordingly.</td>
</tr>
<tr>
<td>Temperature effects</td>
<td>Confirm temperature rating of the tool and expected downhole temperature.</td>
</tr>
<tr>
<td>Running in hole conditions</td>
<td>Confirm maximum DLS recommendations with manufacturer and adjust tool setting depth accordingly. Install casing centralizers as close to the tool as possible. Confirm axial load (static and dynamic) limitations with the manufacturer and adjust tool setting depth or operating procedure accordingly. Consider potential effects of well conditions such as losses on axial load imparted on the tool and revise accordingly. If the casing will be rotated, discuss fatigue and torque limitations with the manufacturer.</td>
</tr>
<tr>
<td>Potential Root Cause</td>
<td>Potential Remedy / Preventive Actions</td>
</tr>
<tr>
<td>---------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Opening tool does not engage opening sleeve</td>
<td>Examine surface finish and profile of opening tool interface before running in the well.</td>
</tr>
<tr>
<td></td>
<td>Ensure proper centralization of operating tool.</td>
</tr>
<tr>
<td>Insufficient applied force or torque and both at the tool</td>
<td>Conduct pre-job torque and drag simulations to ensure enough force and/or torque are applied at the tool.</td>
</tr>
<tr>
<td></td>
<td>Review and revise BHA and workstring design accordingly.</td>
</tr>
<tr>
<td>Incorrect installation procedure</td>
<td>Review tool installation procedure to ensure tongs are correctly placed and do not damage the tool.</td>
</tr>
<tr>
<td>Debris or LCM located at the shifting shoulder in the stage collar</td>
<td>Raise the end of the operating string and flush the ID of the stage cementing collar to clear out solids or debris.</td>
</tr>
<tr>
<td>Running in hole conditions</td>
<td>Confirm maximum DLS recommendations with manufacturer and adjust tool setting depth accordingly.</td>
</tr>
<tr>
<td></td>
<td>Install casing centralizers as close to the tool as possible.</td>
</tr>
<tr>
<td></td>
<td>Confirm axial load (static and dynamic) limitations with the manufacturer and adjust tool setting depth or operating procedure accordingly.</td>
</tr>
<tr>
<td></td>
<td>Consider potential effects of well conditions such as losses on axial load imparted on the tool and revise accordingly.</td>
</tr>
<tr>
<td></td>
<td>If the casing will be rotated, discuss fatigue and torque limitations with the manufacturer.</td>
</tr>
</tbody>
</table>
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### Table 16—High Closing Force

<table>
<thead>
<tr>
<th>Potential Root Cause</th>
<th>Potential Remedy / Preventive Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incorrect installation procedure</td>
<td>Review tool installation procedure to ensure tongs are correctly placed and do not damage the tool.</td>
</tr>
<tr>
<td>Incorrect operating procedures</td>
<td>Review closing force in the operating manual.</td>
</tr>
<tr>
<td>Debris or LCM</td>
<td>Confirm solid particle type, size distribution and concentration. Discuss with manufacturer and adjust accordingly. Confirm mud stability and potential for other sources of debris, such as scale, etc.</td>
</tr>
<tr>
<td>Temperature effects</td>
<td>Confirm temperature rating of the tool and expected downhole temperature.</td>
</tr>
<tr>
<td>Running in hole conditions</td>
<td>Confirm maximum DLS recommendations with manufacturer and adjust tool setting depth accordingly. Install casing centralizers as close to the tool as possible. Confirm axial load (static and dynamic) limitations with the manufacturer and adjust tool setting depth or operating procedure accordingly. Consider potential effects of well conditions such as losses on axial load imparted on the tool and revise accordingly. If the casing will be rotated, discuss fatigue and torque limitations with the manufacturer.</td>
</tr>
</tbody>
</table>

### Table 17—Failure to Close

<table>
<thead>
<tr>
<th>Potential Root Cause</th>
<th>Potential Remedy / Preventive Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insufficient applied force or torque and both at the tool</td>
<td>Conduct pre-job torque and drag simulations to ensure enough force and/or torque are applied at the tool. Review and revise BHA and workstring design accordingly.</td>
</tr>
<tr>
<td>Debris interfering with the sleeves</td>
<td>If waiting on cement between stages, ensure to keep adequate circulation through the tool to help prevent any solids settling in the tool sleeves which may prevent full tool closure.</td>
</tr>
<tr>
<td>Temperature effects</td>
<td>Confirm temperature rating of the tool and expected downhole temperature.</td>
</tr>
<tr>
<td>Running in hole conditions</td>
<td>Confirm maximum DLS while running it and at setting depth and discuss with the manufacturer. Confirm maximum axial load on the tool while running it and discuss with the manufacturer. If the casing will be rotated, discuss fatigue and torque limitations with the manufacturer.</td>
</tr>
</tbody>
</table>
Table 18—Pressure Leak (Casing to Annulus or Annulus to Casing) or, Casing Pressure Build-up after Closing

<table>
<thead>
<tr>
<th>Potential Root Cause</th>
<th>Potential Remedy / Preventive Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tool not closed</td>
<td>Review operating procedures used during closure</td>
</tr>
<tr>
<td></td>
<td>Cycle the Stage Cementing Collar to the open position and reclose while following manufacturer recommendations.</td>
</tr>
<tr>
<td>Leak in casing string</td>
<td>Identify leak location to determine potential root cause and remedy.</td>
</tr>
<tr>
<td>Damaged seals</td>
<td>Confirm maximum temperature rating and tool burst and collapse ratings have not been exceeded.</td>
</tr>
<tr>
<td></td>
<td>Review section on Running in hole conditions above.</td>
</tr>
<tr>
<td></td>
<td>Review manufacturer's recommendations on pressure bleed off.</td>
</tr>
</tbody>
</table>
Annex A

Stage ToolPlug Set Options

A.1 Examples of Plug Sets

Examples images of plug sets used with mechanically or hydraulically –operated cementing stage collars are provided hereafter.

A.1.1 Landing Seats:

According the type or first stage closing device (top plug), landing seats, either a landing collar or a baffle plate are required (Figure A.1 items a) and b)). A latch down seat will be required with a latch down closing plug (Figure A.1 c). If a bypass plug (first stage bottom plug or top plug with an hydraulically operated stage collar) is used, in that case a bypass seat will be required (Figure A.1 d).

![Figure A.1—Examples of Landing Seats](image)

A.1.2 First Stage Top Plug

Figure A.2 a) is an example of a standard first stage closing (top) plug. An example of lach-down closing plug is provided, see item b). Figure A.2 items c) and d) are examples of bypass plugs which should be used with a pump-down (displacement type) stage collar opening device (9.2.1.2). They are required to land on a bypass seat.
A.1.3 Free Fall or Pump Down Opening Devices

Figure A.3 is showing examples of free fall opening devices (items a) to c)) and pump-down displacement type (Figure A.3 item d).

A.1.4 Second-stage Closing Devices (Top Plug)

Three examples of second-stage (or upper tool) closing device are given Figure A.4. These plugs are not only acting as closing device but as stage cement slurry top plug.
A.1.5 Stage Cementing Bottom plug

Optionnal bottom plugs are available for stage cementing. Figure A.5 a) is an example of bottom plug for a second stage or the upper stage (3 or more-stage). Figure A.5 b) is an example of first stage cement plug, in that case a bypass plug, landing on a bypass, seat is required.

A.1.6 Cancellation Device

An example of cancellation plug is provided Figure A.6

A.1.7 Sub-surface Release Plugs

Example of sub-surface release plugs for stage cementing (first stage top plug and second stage top plug) is provided Figure A.7 a). Darts to release these pluds are provided figure A.7 b).
Figure A.6—Example of Cancellation Plug

Figure A.7—Example of Stage Cementing Sub-surface Release Plugs and Darts

a) Sub-surface Release Plugs       b) Darts
Bibliography


[2] API Recommended Practice 10B-2, Recommended Practice for Testing Well Cements

[3] API Recommended Practice 10B-6, Recommended Practice on Determining the Static Gel Strength of Cement Formulations

