Evaluation and Testing of Mechanical Cement Wiper Plugs

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1 Scope

The purpose of this technical report is for recommended testing, evaluation, and performance requirements for mechanical cement wiper plugs.

2 Normative References

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

3 Terms and Definitions

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

3.1
baffle
A ring or plate made of drillable material that is mounted in the casing to provide a landing surface for a cement plug and may (or may not) also provide a sealing surface.

3.2
bump pressure
The amount of pressure applied to the casing when a cementing plug is landed (bumped) onto a baffle, float collar, or another plug.

3.3
cement (slurry)
A mixture of calcium silicates and water, possibly containing other materials, that sets to a hard, rocklike substance.

3.4
cementation/cementing
The application of pressure pumping cementing fluids (spacers and cement slurries) to various points in a wellbore.

3.5
displacement fluid
The fluid used to displace the cement slurry from the casing that is normally separated from the cement slurry by a top wiper plug and / or a spacer fluid.

3.6
drillable
Capable of being drilled up in a reasonable amount of time by a drill bit.

3.7
elastomer
An elastic, flexible rubberlike material, including natural or synthetic rubber compounds, polyurethanes, and thermoplastic elastomers.

3.8
float collar
A tool containing a one-way check valve to prevent return flow of the cementing fluids from the annulus into the casing.

NOTE It has threaded connections that attached near the bottom of a casing string and may also provide a landing and/or sealing surface for wiper plugs.

3.9
frangible
Capable of being broken; breakable.

3.10
insert (body, core, plug insert)
A structural member used to provide mechanical stiffness and strength to the cementing wiper plug.

NOTE Common materials used in the fabrication of insert or cores could include, but are not limited to wood, sand resin, aluminum, hard rubber or thermoplastic, thermoset plastic, or composite.

3.11
knit lines
Imperfections in a molded part caused by the incomplete joining of the uncured rubber during molding.

NOTE Line or lines created where the rubber flows converge can cause weakening or breaking of the component.

3.12
landing collar
A component installed near the bottom of the casing string on which a cement plug lands during the primary cementing operation.

NOTE The internal components of the landing collar are generally fabricated from plastics, cement, and other drillable materials and may or may not include a backpressure valve.

3.13
landing pressure rating
Differential pressure that can safely be applied from above to one or more cementing plugs that are resting on a landing surface (such as landing collar or float collar).

3.14
liner
A string of pipe used to case open hole below existing casing and extends into another string of casing, but not all the way to surface, usually overlapping the previous casing by a few hundred feet.

3.15
liner running tool
A tool used to run, set, and release from a liner.

3.16
multistage cementing collar (diversion valve tool, port collar, cementer)
A tool with threaded connections for use in a string of casing or tubing to allow pumping cementing fluids into the annulus at a point up-hole from the bottom, in addition to pumping fluid around the shoe (at different intervals and times; commonly called two stages).

NOTE The tool usually has ports that are opened for communication to the outside of the casing and closed at the end of the job.

3.17
plastic
Any of various organic compounds produced by polymerization, capable of being molded, extruded, and cast into various shapes and films.

NOTE Examples include phenolic, composite (composed of a plastic or glass material with reinforcing filler), and any thermoplastic or thermoset resin.

3.18
plug container/cement head
An accessory attached to the top of the casing, tubing, or drill pipe to facilitate launching wiper plugs when cementing the casing or liner that has passages for cement slurry and chambers for cementing plugs.

3.19
rupture disk
The part of a bottom cementing plug that blocks the flow path through the center of the plug but is later broken to allow flow through the plug.

NOTE Sometimes referred to as diaphragm.

3.20
spacer
A fluid designed to separate cement slurries from other fluids, minimizing contamination of the cement and removing drilling fluid from the annulus during cementation.

NOTE A spacer is considered to be a cementing fluid.

3.21
wiper plug
A device that is used to separate fluids and wipes the internal surface of the pipe as it is pumped from one location in the pipe to another.

3.22
wiping efficiency
Wiping efficiency is the measure of mechanical wiping of the tubular inside diameter (ID) performed by the cementing plug or similar device.

3.23
wiping section
The part of the cementing plug that is flexible and wipes the casing, tubing, liner, or drill pipe.

4 Purpose of Mechanical Cementing Wiper Plugs

4.1 General

Mechanical cementing wiper plugs are used in most application including casing, liners, drill pipe, and tubing for primary and remedial cementing operations where they serve multiple functions in well operations, such as the following:

— separation of fluids inside of pipe;

— wiping of materials from the inner surface of pipe;

— operation of a downhole tool;

— surface indication of a downhole event; and

— formation of a temporary pressure barrier.

4.2 Fluid Separation

The separation of fluids inside of casing, drill pipe, or tubing during cementing operations is necessary to prevent intermixing and contamination that can compromise the objectives of the job. Fluids for a cementing job are normally designed with an increasing density hierarchy. Spacer fluids are designed to be denser than the drilling mud, the lead cement slurry (when used) is designed to be denser than the spacer, and the tail slurry is designed to be denser than the lead slurry or spacer (when no lead slurry is used).

This density hierarchy has been shown to improve mud removal in the annulus where buoyancy effects aid a fluid of higher density in displacing a fluid of lesser density when the fluids are moving in an upward direction. When moving in a downward direction (either free-fall and/or pressure pumping), as is the case inside of the pipe, this density hierarchy will cause the higher density fluids to fall through the lower density fluids ahead of them, resulting in fluid contamination and poor mud removal. This phenomenon is especially severe in cases of large diameter pipe or when the density differential between fluids is very high. The use of cementing wiper plugs between fluid types is the only technique that will prevent this from occurring. In the case of multiple fluids, the use of multiple bottom plugs should be considered.

During displacement, the displacement fluid is usually lower density than the tail cement, so the density differential inside of the pipe is not an issue. However, the displacement fluid is usually a drilling or completion fluid that is not fully compatible with the tail cement so use of a top cementing plug to separate the fluids is required.

4.3 Wiping the Inner Surface of the Pipe

Regardless of bulk mud removal inside of pipe, fluids may leave a thin film at the inner wall of casing, tubing, or drill pipe that cannot be removed by subsequent fluids. Depending on the fluid and the operation, this film can lead to several problems.

Inside of casing, the bottom plug(s) will serve to wipe the film of mud from the inner wall of the pipe(s) and the top plug(s) will serve to wipe the cement film from the pipe(s) (see Table 1). Without a bottom plug, the mud film may remain until it is eventually wiped by the top plug. This can result in a large volume of mud accumulating in front of the top plug that would end up in the shoe track or even in the annulus after the plug is bumped (see Table 1). This could potentially cause a failure to obtain a successful leak-off test after drilling out the shoe. Without the use of a top plug, a film of cement may remain on the inner wall of the casing. A subsequent bit and scraper run may be required to remove this film before continuing drilling or completion operations.

Table 1—Calculated Accumulated Volume of Wiped Fill Ahead of Top Cementing Plugs per 1000 ft (300 m) of Pipe Wiped

Mud Sheath Thickness in. (mm)	**7 in. (177.8 mm) Casing** ft (m)	**9 5/8 in. (244.5 mm) Casing** ft (m)	**13 3/8 in. (339.7 mm) Casing** ft (m)
1/16 (1.6)	40 (12.2)	28 (8.5)	20 (6.1)
1/32 (0.8)	20 (6.1)	12 (3.7)	10 (3.1)
1/64 (0.4)	10 (3.0)	7 (2.1)	5 (1.5)

In casing strings that are made up of more than one pipe size, it is important to use wiper plugs that are designed to wipe all internal diameters in the string. Failure to use the appropriately sized plugs may lead to a residual mud or cement film on the inside of the pipe.

An additional problem is cement accumulation in internal upsets in drill pipe or tubing if proper wiping devices are not utilized. It is important to use drill pipe wiper darts that have fins designed to wipe both the pipe body and the internal upsets. The use of foam wiper balls (fabricated from an air or frothy foam material) may also be effective, either alone or in conjunction with wiper darts to remove fluid accumulations from the upsets.

4.4 Downhole Tool Operation

4.4.1 General

In addition to serving to separate fluids inside the pipe and to wipe the interior of the pipe, wiper plugs are used to operate certain downhole tools. The following are among the operations performed by cementing wiper plugs:

— release of liner wiper plugs;

— release of subsea plug;

— shifting of stage cementing tools; and

— temporary barrier to set external casing packers with pressure.

4.4.2 Liner Wiper Plug

Full ID liner wiper plugs cannot pass through the drill pipe, and are therefore hung beneath the drill pipe when the liner is run. A dart is pumped through the drill pipe, wipes the drill pipe, and latches into the liner wiper plug. Pressure is increased to shear the pins, and the dart and liner wiper plug travel together, wiping the inside of the liner. Liner wiper plugs are available in either two plug or single plug sets.

4.4.3 Subsea Released Plugs

When a subsea wellhead is used, the configuration is much like a liner, with the casing hung beneath drill pipe. Either single or double plug sets are available.

4.4.4 Operate Stage Cementing Tool

Stage cementing tools are devices that provide ports in the casing string so that separate operations can be performed below and above the tool. These tools consist of ports, or holes, in the body of the tool with a sleeve and seals that shift to alternately open and then close the ports. Special opening and closing plugs are used to shift the position of the sleeve.

4.5 Event Indication

4.5.1 General

When plugs pass or land on a profile inside of pipe, a positive pressure indication can be detectable at surface. This pressure indication can mark a specific event in the operation, including, but not limited to, the following:

— plug landing (bumping the plug);

— landing of drill pipe wiper darts for liners or subsea released plugs;

— multiple stage cementing tool operation; and

— depth indication.

When determining an event from recorded data, the data sampling interval shall be appropriate for the expected duration of the event.

4.5.2 Plug Landing

4.5.2.1 General

A surface pressure increase can indicate when a wiper plug has reached the landing collar or other profile located inside of the pipe.

4.5.2.2 End of Displacement

A pressure increase indicates a wiper plug has landed on the landing collar during primary cementing. This pressure increase, usually referred to as bumping the plug, indicates displacement has been completed. This pressure slope is different and should not be confused from the lift pressure slope from lighter fluids displacing heavier fluids.

4.5.2.3 Remedial Cementing

In squeeze and plug operations, cement is placed in the well through drill pipe or tubing. In many cases, small volumes of cement are used and it is critical to control the exact location to ensure that the cement slurry is placed where required. The use of wiper plugs in conjunction with landing seats located near the end of the work string can provide a positive pressure indication when the wiper plug lands on the seat, indicating the cement is at the end of the work string as an example.

4.5.2.4 Displacement Volume Determination

Bottom cementing plugs can be used for obtaining accurate casing capacity. Prior to beginning the cementing operation, a bottom plug may be launched and displaced with drilling fluid to the landing collar. By measuring the volume pumped when the surface pressure indication from landing the plug occurs, the effective displacement volume can be determined. The effective displacement volume takes the following factors into account:

— actual casing capacity;

— fluid compressibility; and

— efficiency of surface pumping equipment.

Because fluids may by-pass a cementing plug during travel down a casing, using the pumped volume to land the bottom plug as the effective displacement volume of the casing should take into account the risks associated with under/over displacing the cement slurry.

4.5.3 Landing of a Drill Pipe Wiper Dart

For liners and subsea released plug systems, a pressure indication can be seen when the dart lands and the pins holding the subsurface wiper plug are sheared. This pressure indication can be used to reset the displacement volume counter, with the calculated liner or casing volume used as the displacement volume to land the plug. This helps to ensure the plug is displaced as close to the landing collar as possible and that cement is placed where desired without over displacing.

Because fluids may by-pass a drill pipe wiper dart during travel down drill pipe, using the pumped volume to land the bottom plug as the effective displacement volume of the drill pipe should take into account the risks associated with under/over displacing the cement slurry.

4.5.4 Multiple-stage Cementing Tool Operation

Wiper plugs are sometimes used to operate stage tools. An increase and/or decrease in surface pressure that indicates when each operation of the tool is completed.

4.5.5 Depth Indication

Some cementing plug designs provide event indications identifying the location of the plug during displacement. Generally, the depth indication is provided when coupled with an integral casing sub with an internal profile that engages a mating profile on the cementing plug.

4.6 Temporary Pressure Barrier

4.6.1 General

Mechanical plugs may also be required to function as a temporary pressure barrier for the following:

— pressure testing casing; and

— prevent fluid flow back with latch-down plugs.

4.6.2 Pressure Testing Casing

In order to test the casing using mechanical plugs, the plugs shall be bumped and a positive pressure seal shall be present between the plug(s) and the landing collar.

NOTE The pressure barrier provided by the plug is only in one direction; the plug does not provide a barrier to flow in the upward direction (from the annulus into the casing).

4.6.3 Latch-down Plugs

In certain cementing operations, such as cementing small diameter casing or cementing via an inner-string on large diameter casings, a latch-down type mechanical wiper plug may be utilized. A latch-down plug is designed to mechanically lock into the landing collar when the plug has been bumped and is generally used as a top plug. Once locked in, the plug cannot move back up the casing. A latch-down plug may be used to provide a temporary pressure barrier for casing pressure testing and also to prevent fluid from flowing back into the casing due to the hydrostatic differential at the shoe at the end of the job. Latch-down plugs shall be bumped into place in order to function properly.

5 Background Information

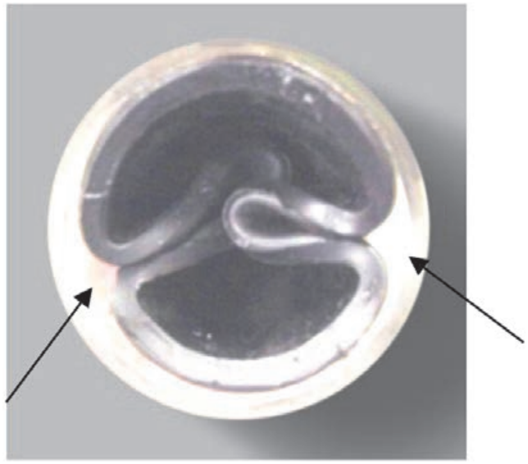
5.1 Short and Long Fin Plugs

5.1.1 Short fin cementing plugs are typically designed for use in single ID applications versus multiple ID applications (such as internal upset or tapered/combination strings) where the cementing wiper plug is used to wipe with uniform inside diameter from top to bottom. Short fins are generally considered to provide increased stiffness as compared to long fins of similar thickness.

5.1.2 Long fin cementing plugs are typically designed for use in applications where the cementing plug is used to wipe with varying inside diameters. ID variations can be caused by tapered casing strings, drill pipe tool joints, internal seats of stage cementing tools, and other restrictions. Long fins on cementing plugs are less stiff compared to short fins. Therefore, long fin cementing wiper plugs typically have an increased length than short fin cementing wiper plugs to maintain stability while inside the pipe. As the long fin cementing plugs are installed into or pumped through decreasing diameters or restrictions, the long fins will tend to wrinkle, thereby reducing wiping efficiency and allowing fluid bypassing. (See Figure 1.)

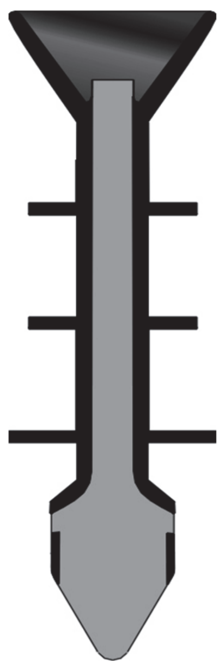
5.2 Combination or Multiple Diameter Fin Cementing Plugs

Combination cementing wiper plugs generally incorporate multiple fin diameters on a single assembly as shown in Figure 2 or Figure 3. These figures represent possible plug configurations that can be used in multi-diameter strings. Each fin diameter is designed to wipe a different range of pipe IDs. The larger, more flexible fins wipe the larger pipe.



NOTE This photo shows how wrinkling of long wiper fins can occur, potentially allowing bypassing and affecting displacement efficiency; two arrows point to sections where no wiper contact is made with the ID of the tube.

Figure 1—Photo of 5 in. (127.0 mm) Drill Pipe Dart Installed into 3 in. (76.2 mm) ID Tube



NOTE Typically used for wiping multiple diameters.

Figure 2—Typical Long Fin Cementing Plug

The smaller ID, stiffer plug will wipe the smaller diameter pipe with the larger more flexible fins buckling and bypassing fluids. Thus, when the combination cementing wiper plug assemblies are used, fluid separation and improved wiping efficiency of the different IDs is achieved.

5.3 Other Wiping Mechanisms

Several other mechanical devices are used in place of short and/or long fin cementing plugs. Such devices could include but are not limited to deformable balls, tear drop darts, or any combination of these into assemblies. These wiping devices have unique performance characteristics that enable fluid separation, wiping, and/or landing indication for specific wellbore applications.

NOTE Typically used for wiping tapered casing or tubing strings.

Figure 3—Example of Combination Cementing Wiper Plugs

5.4 Launching Methods and Apparatus

5.4.1 Cementing Heads or Plug Containers

A cementing operation is commonly performed using a cement head or plug container to attach surface circulating equipment to the pipe being cemented. One or more cementing plugs are preinstalled into the plug container prior to being attached to the pipe. Figure 4, Figure 5, and Figure 6 show typical types of plug containers used in cementing operations. When cementing operations are performed, valves and retention devices are manipulated to divert fluid flow and release the cementing plug, launching the cementing plug from the plug container and into the pipe being cemented. Plug containers may incorporate a visual means of indicating plug launch (tattletale devices). The use of multiple cementing plugs is desired to provide separation of multiple fluids. Special cementing heads or systems can be used to contain and launch more than the typical one or two cementing plugs during the execution of cementing operations. Heads are available for manual or remote control operation.

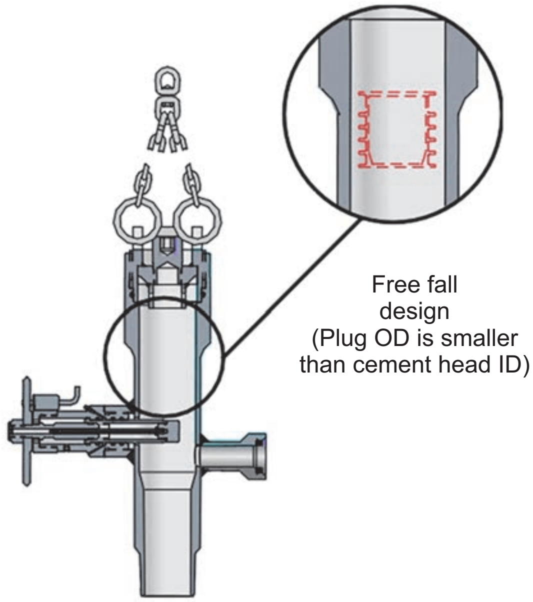
5.4.2 Top Drive Casing Cement Head

Cement plugs are loaded into a canister and protected from flow during circulation and cementing. Upon retracting the pin puller mandrel, the plug will free fall into the main section of the cement head and will be pumped into the casing. Figure 7 shows a flow-around top drive cement head.

Some models may have a ball dropper located below the bottom plug pin puller where a ball of a given size can be dropped into the casing to function a tool downhole.

5.4.3 Top Drive Cementing Head

A top drive cementing head is typically used for selectively launching darts used to release liner wiper plugs and subsurface released cementing plugs. Figure 8 shows a typical top drive cementing head with top and bottom dart releasers and a ball drop system.



NOTE Free fitting refers to the ID of the head being larger than the OD of the plug that may be used; this type of cementing head can be used to launch cementing plugs with or without the use of a manifold.

Figure 4—Typical Free Fitting Cementing Head

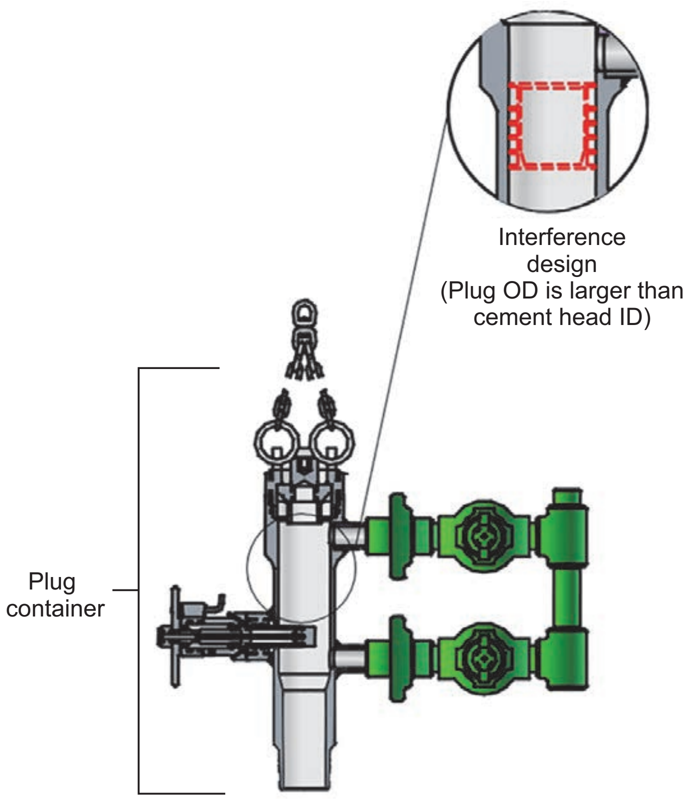


Figure 5—Typical Cementing Head with Manifold for Launching a Single Plug

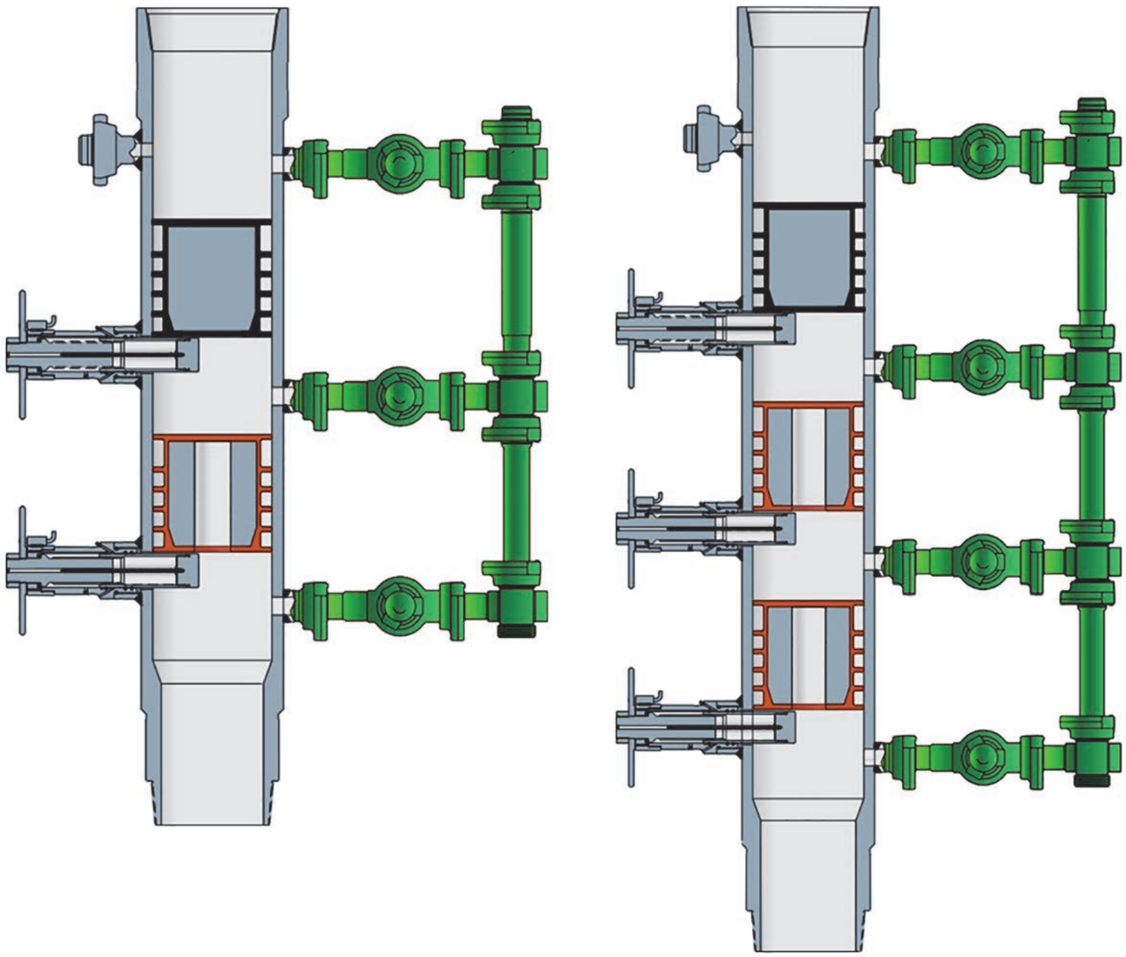


Figure 6—Double and Triple Cementing Heads Designed to Launch Two or Three Full Casing ID Cementing Plugs Without Reloading

The bottom sub of the top drive cementing head is normally made up to the top of the running string (normally drill pipe) from which the liner or casing is suspended. The top sub of the top drive cementing head is designed to connect directly to the top drive of the rig. One or more darts and/or balls (trip balls) are preinstalled in the cementing head before being made up to the running string and top drive. Fluids can be pumped into the cementing head through the top drive or through an optional side port on a swivel. The swivel side port allows cement to be pumped directly into the cementing head without contaminating the drilling mud or displacement fluids in the top drive system, and it allows the running string to be rotated while leaving the cementing lines connected. A ball is often released prior to cementing operations to activate liner hanger setting tools and/or float equipment.

A ball is also used in some liner or subsurface plug systems to release the lower plug. Flow is diverted around the darts before release so that they are not affected by circulation.

When cementing operations are performed, the dart releasers are manipulated to divert fluid flow and selectively release the bottom and top darts, which then release the bottom and top plugs in the liner or casing. Since the top drive cementing head is normally suspended by the top drive while cementing, it should be capable of withstanding the following:

a) full tensile load of the liner or casing and running string;

b) effects of pressure while circulating;

c) reciprocating pipe;

d) activating downhole equipment;

e) pumping cement;

f) launching plugs;

g) displacing cement; and

h) bumping the top plug.

The cementing head may include a dart release indicator or tattletale device, which gives a visual indication when a ball or dart is pumped past it. Top drive cementing heads are available for manual and remote control operation.

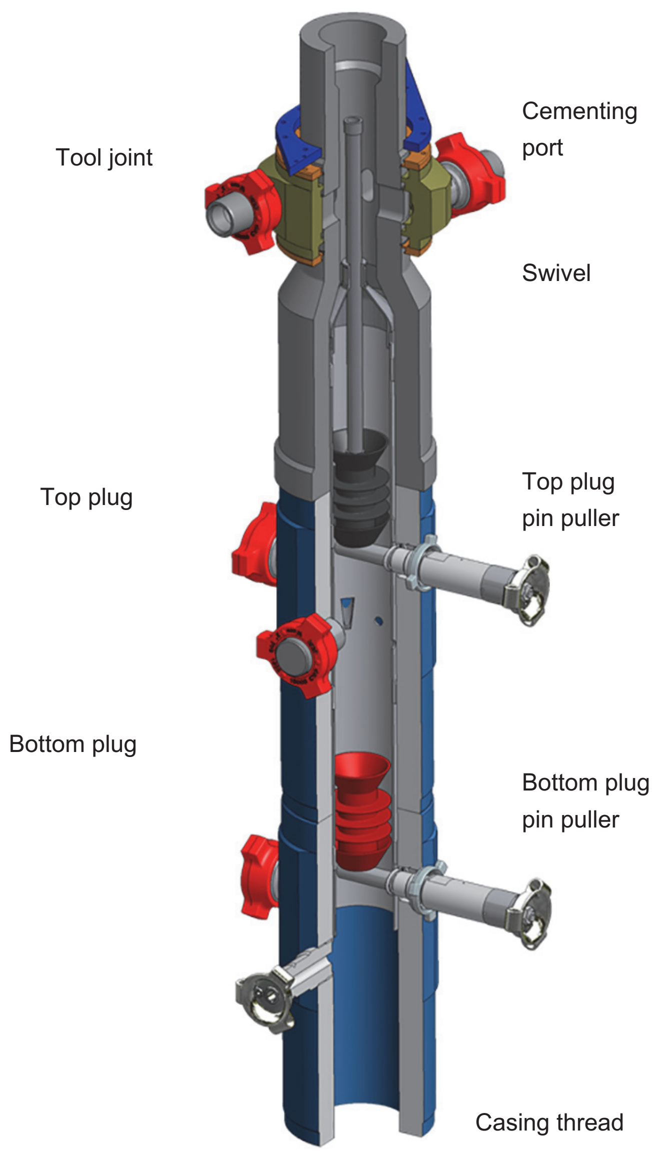


Figure 7—Top Drive Cement Head for Launching Short Fin Cementing Plugs

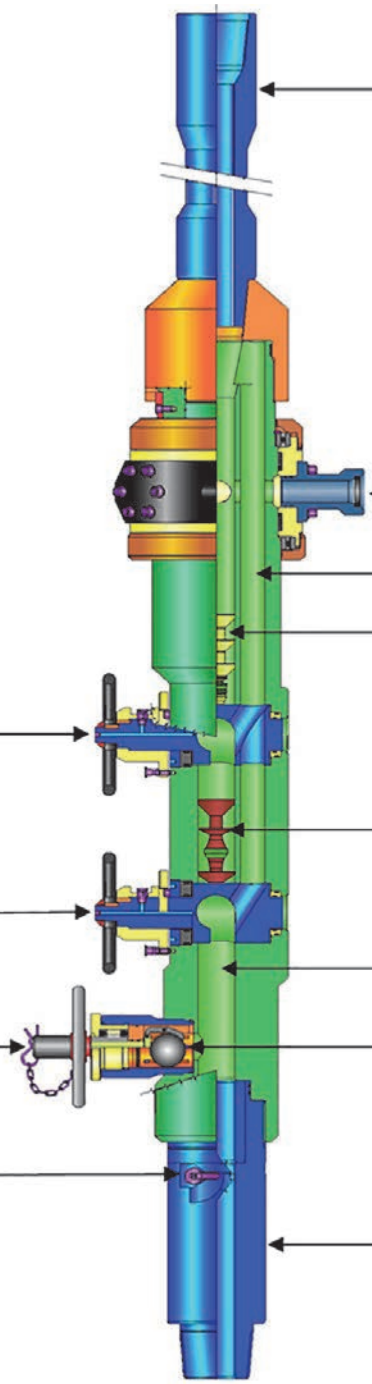


Figure 8—Top Drive Cementing Head with Integral Swivel and Internal Bypass for Launching Drill Pipe Wiper Darts and Balls

5.4.4 Swages

Some cementing operations are performed using a circulating swage (Figure 9) attached to the pipe being cemented. In such a case, the circulating swage is removed and the cementing plug is inserted into the pipe at the stage of the operation where the plug is required. The swage is reattached and the operation is continued. In some cementing applications, a casing fill-up tool may be used in lieu of a swage. In such case, the fill-up tool is removed to drop the plug as described for the swage.

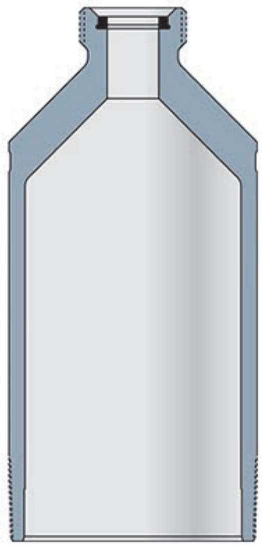


Figure 9—Example of a Circulating Swage

5.5 Landing Seats for Mechanical Cementing Plug

Displacing cementing wiper plugs from the surface equipment ahead of and/or behind the cementing fluids/slurry and come to rest on a landing seat. The landing seat could be a float collar, float shoe, baffle collar or plate, landing collar, or other device that stops the movement of cementing wiper plugs. The configuration of the seat shall be compatible with the profile used on the cementing plug to accomplish a temporary hydraulic seal. Figure 10 shows a landing collar without a check valve (baffle collar).

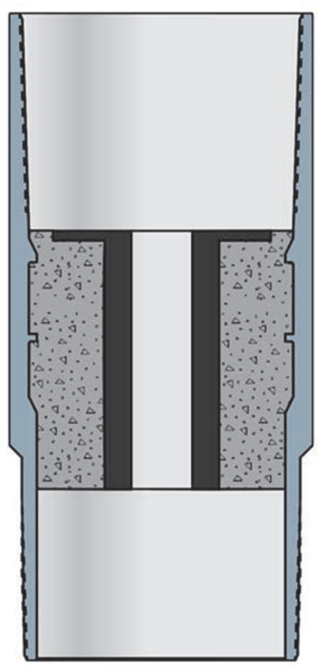


Figure 10—Example of a Plug Landing Seat, Baffle Collar

6 Possible Failure Modes of Cementing Wiper Plugs

6.1 General

Some common failure modes include the following:

— debris inside the pipe;

— poor wiping efficiency;

— fluid bypassing;

— failure to launch;

— improper installation order;

— construction defects;

— plug damage;

— improper installation order of cementing plugs in cementing head;

— hostile storage environment;

— misapplication of cementing plugs;

— plug deformation; and

— crossovers or transitions.

6.2 Debris in or Condition of Pipe

6.2.1 Solids may accumulate inside pipes by different mechanisms and may erode the fins to the point that they may lose their effectiveness to wipe the casing or drill pipe.

6.2.2 Solids or debris, such as scale or rust, can accumulate ahead of plugs which may prevent them from reaching and/or establishing a temporary seal on the landing collar. This debris could also plug or bridge the float valve, causing premature end of the job. The pipe should be checked and removed as needed for scale, rust, and other debris prior to the job.

6.2.3 Lost circulation materials (LCMs) are designed to bridge or plug flow paths where fluid movement is occurring. LCMs may be used in drilling fluids and cementing fluids, however, their use should be carefully considered prior to the cementing job. These materials can interfere with the proper function of cementing plugs and floating equipment.

6.2.4 As cementing bottom plugs mechanically wipe the mud sheath containing LCMs from the casing ID, this material accumulates ahead of the bottom plug and may cause problems when it nears the float equipment. A float valve may not allow the accumulated LCMs to pass through. If LCMs are present behind the bottom plug, bridging could prevent the bottom plug from rupturing and allowing the cement to flow through it. These conditions can result in a premature end to cementing operations leaving cement in the pipe or insufficient cement fill in the annulus. Some valve types are more tolerant to higher concentrations and/or larger particle size of solids or LCMs in the fluids being used.

6.2.5 Dilution of drilling fluid with a thin fluid (low viscosity such as a fresh water spacer) can result in separation of solids and settling on and subsequently plugging of floating equipment or bottom cementing plugs. This is known as

“Solid Segregation Due to Dilution” and these conditions can result in a premature end to cementing operations leaving unplanned cement in the pipe or insufficient cement fill in the annulus.

6.2.6 In highly deviated wells, solids settling in pipes may cause severe damage to the plug fins and prevent them from reaching the landing seat. Such solids may be barite, calcium carbonate, drill solids, or residual cement. An example of severe damage that solids settling can do to cementing plugs in a deviated wellbore is shown in Figure 11.

6.2.7 Debris ahead of a bottom cement plug in a horizontal section can require additional force to maintain movement of the plug within the casing. This force generates a differential pressure across the bottom plug and its diaphragm. As the amount of debris ahead of the plug increases, differential pressure across the plug also increases. Should the differential pressure required to move the plug exceed the diaphragm rupture pressure, premature rupture of the diaphragm in the bottom plug can occur leading to fluid bypassing. This is known as “Premature Rupture of Bottom Plug Diaphragm Due to Debris (or Solids) Ahead of Bottom Plug”. See 6.9 for information related to higher pressure rupture diaphragms for bottom cementing plugs.

6.3 Poor Wiping Efficiency

Poor wiping efficiency is the failure of the cementing plug to wipe the inside of the pipe. Poor wiping efficiency may be caused by fin erosion, chemical attack of the fin material, incorrect plug size, and insufficient fin stiffness.

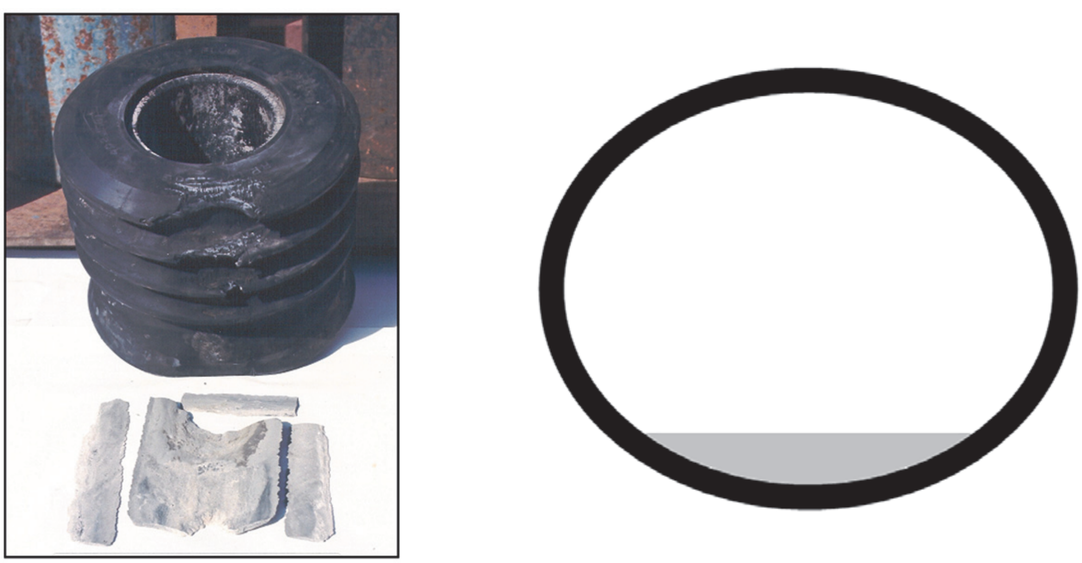
6.4 Fluid Bypassing

The plug getting caught/trapped or slowed down in cement heads, casing collars, tapered casing crossovers, or liner tools, for example, may cause fluid bypassing. One example is shown in Figure 11.

6.5 Failure to Launch

6.5.1 Failure to Launch from the Cementing Head at the Proper Time

Premature or late launch of cementing plugs from the cementing head results in the cementing plug failing to separate the fluids as desired, landing at the wrong time, or failing to land.



NOTE Graphic on right represents low side solids shown in the photo to the left.

Figure 11—Photo from Large-scale Experiment Showing Damage to Wiper Plug Caused by Solids on Low Side of Casing

6.5.2 Failure of Cementing Plugs to Launch

Causes of this type of failure may include the following:

a) improper loading or handling, worn-out, leaky equipment, incompatible cementing plug/cementing head, and failure of indicator mechanism; and

b) damage to the plug retention device caused by pressure differential that results from insufficient bypass channel in the cementing head.

6.5.3 Failure of the Plugs to Leave Tools

This is particularly serious since there is no definitive way to verify that the plug has launched. These realizations of these failures are upon retrieval of the liner setting tool and visual observations of the liner wiper plugs still intact to the mandrel.

6.6 Improper Installation Order of Cementing Plugs in Cementing Head

The plugs shall be loaded in a manner that ensures the top plug launches last.

6.7 Construction Defects

Potential construction defects could include, but not limited to, the following:

— debonding of fins from plug core or insert;

— voids in the insert or fin;

— improper insert placement within fin section (e.g. not centered);

— improper curing of construction materials; and

— knit lines or imperfections in a molded part caused by the incomplete joining of the uncured rubber during molding.

An example of knit lines can be seen in Figure 12 and there are two primary reasons for this occurrence:

1) the failure of the rubber flow to sufficiently fuse due to the drop in temperature after flowing over long distances; and

2) the presence of residual air at the rubber flow convergence point at the cavity obstruction, prohibiting the proper fusion of the flows.

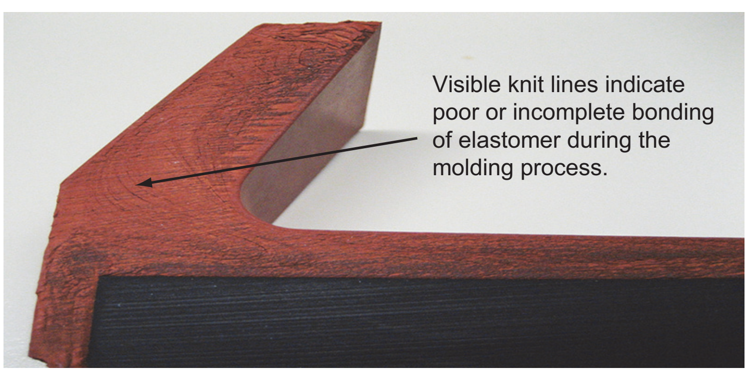


Figure 12—Plus Cross Section Showing Knit Lines

6.8 Plug Damage

6.8.1 Most causes for plug damage results from improper applications. Using a cementing plug in casing with an ID that is outside of the recommended wiping range can cause damage to the plug. Using a plug too large for a casing ID could cause excessive wear of the wiper fins or cause the fins to be torn from the plug body. A plug too small for the casing could tilt during displacement, resulting in uneven wear of the wiper fins and bypassing fluid.

6.8.2 Plug damage that occurs during casing testing can be caused by several failure modes. Some typical failure modes are identified in the following.

a) Figure 13 and Figure 14 show bond loss between elastomer and insert.

b) Figure 15 and Figure 16 shows insert failures during pressure test.

6.8.3 Certain additives in drilling fluids [particularly in nonaqueous fluids (NAFs)] can have a detrimental effect on the rubber materials used to make cementing plugs. These effects include softening of the fins and/or actual deterioration of the rubber. This negative effect can be particularly severe in long, high temperature applications. It is possible, if the chemical attack is severe enough, for fins to break off from the plug.

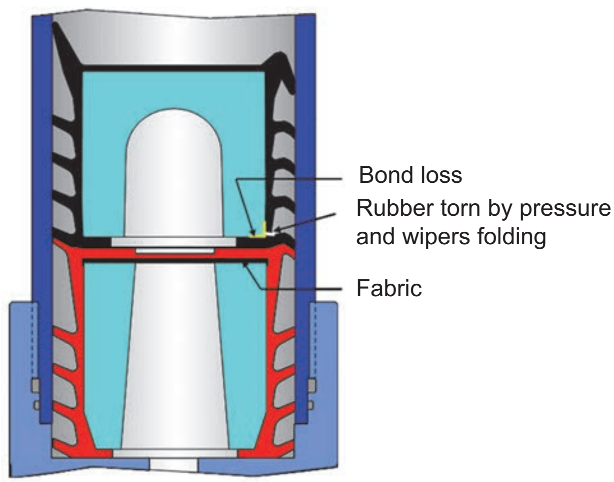


Figure 13—Loss of Bond Between Elastomer Fins and Plug Insert

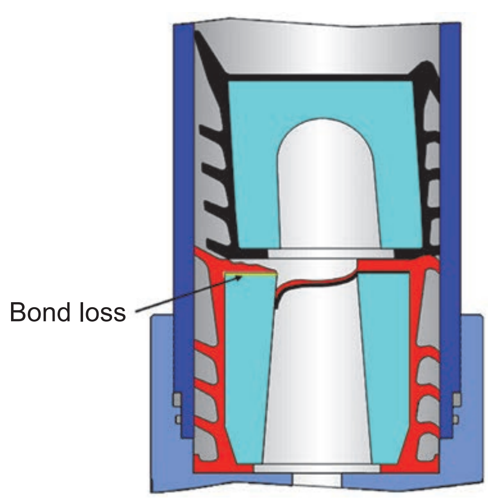


Figure 14—Loss of Bond Between Elastomer and Insert at Interface near Diaphragm

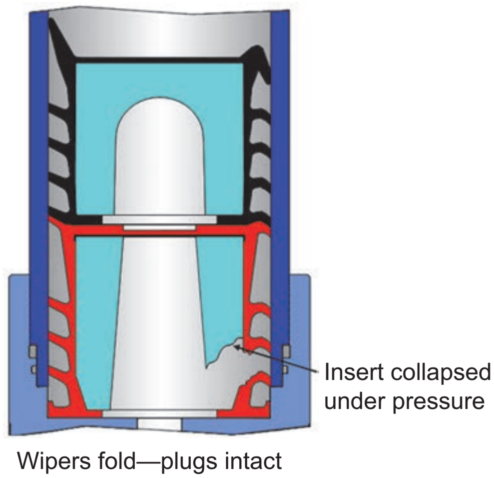


Figure 15—Failure of Plug Insert During Pressure Testing

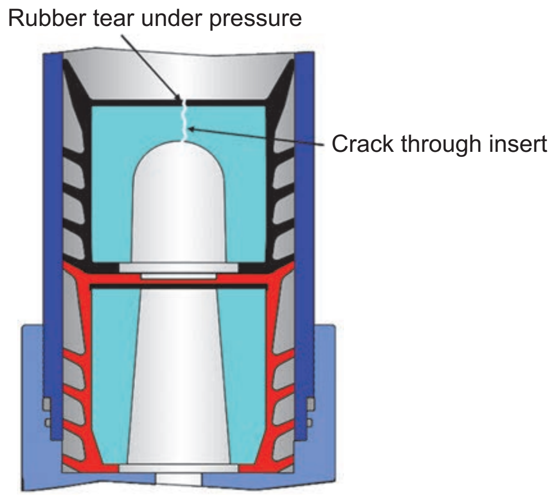


Figure 16—Failure of Plug Insert During Plug Bump Pressure Testing

6.8.4 Bottom plugs allow fluid to flow through them after landing on the landing collar, by rupturing a diaphragm (or disk) under differential pressure. Damage or modifications to the diaphragm (or disk) can cause premature rupture of the diaphragm before reaching the landing seat.

NOTE Damage could be caused by knife, hammer, or operator error.

6.9 Incorrect Diaphragm Pressure Selection

Selecting a bottom plug with a rupture pressure that is too low may result in the bottom plug not reaching the landing seat. Casing/tubing weight that is heavier than the weight range for which the bottom plug is designed or other ID restrictions in the string (such as landing nipples) may require the use of a higher pressure rupture diaphragm to ensure the successful displacement of the bottom cementing plug. For combination casing/tubing strings that incorporate crossovers and/or smaller casing/tubing sizes, a higher pressure rupture diaphragm may be required.

6.10 Hostile Storage Environment

6.10.1 General

Elastomeric cementing plug components in assemblies and sub-assemblies should be protected from the following types of adverse conditions:

a) atmosphere;

b) contaminants such as, but not limited to, oils and solvents;

c) UV light;

d) ozone produced by electrical arcing devices; and

e) radiation from electromagnetic source.

6.10.2 Guidelines

Individual requirements may vary between suppliers. The following are general guidelines for packaging, handling and storage, and shelf life.

a) *Packaging*—Appropriate packaging will minimize the damage to the plug caused by adverse conditions listed in 6.10.1.

b) *Handling and Storage*—The following should be considered when determining storage location for cementing plugs:

   1) storage temperatures above 120 °F (50 °C) may shorten the shelf life;

   2) storage temperature does not have a lower limit (plugs should be allowed to warm to 32 °F (0 °C) prior to use);

   3) cementing plugs should not come into contact with contaminants (such as oils or solvents) during storage;

   4) cementing plugs should be protected from direct sunlight or other UV light sources;

   5) cementing plugs should not be stored in areas where ozone is produced by electrical devices;

   6) cementing plugs should not be stored in areas where electromagnetic radiation is prevalent;

   7) cementing plugs should be stored in unstressed conditions (avoid distortion of package by stack weight or other confinement to smaller storage space);

   8) cementing plug warehouse stock should be reviewed annually and those items past their discard date should not be used;

   9) cementing plugs should not be stored in opened packages;

   10) once a bag is opened the article should be used for its intended purpose or resealed inside of its original or other suitable bag;

   11) if the original bag is no longer usable, then the article can be sealed in a new opaque bag and relabeled with the exact information as was on the original bag; and

   12) care should be taken to assure that all information is transferred to the new label.

c) *Shelf Life*—Even under optimal packaging and storage conditions, elastomeric materials have a finite shelf life. Usage of elastomeric assemblies outside shelf life may adversely affect performance. The manufacturer should specify appropriate shelf life for cementing plugs supplied.

6.11 Misapplication of Cementing Plugs

6.11.1 Plugs for Mixed Casing Sizes

A common failure of mechanical cementing plugs is caused by using them in mixed casing sizes. For mixed casing sizes, cementing plugs shall be specially built to effectively wipe the casing, maintain the fluid separation, and be successfully displaced to the required location. Due to the possible unavailability of these cementing plugs at the required time, operators may be forced to use less than desirable plugs, resulting in damage to the wipers or damage to the cementing plugs prior to reaching the landing collar.

6.11.2 Damage to Fins

Cement plug wiper fins are designed to flex inward towards the ID of the casing in order to maintain contact to the casing ID as the casing weights change. In the presence of multi-diameter casing sizes or weights, the larger fins designed to maintain contact to the larger casing ID shall be forced into the ID of the smaller casing. As a result, the larger wipers may be compressed or deformed more than their design limit. This may result in tears at the wiper root (where the fin joins the core cover at the body), sheared off wipers, and other damage, all of which can lead to inadequate performance.

6.11.3 Damage to Bottom Plug Diaphragm or Rupture Disk

Bottom plugs are designed with a frangible membrane (rubber diaphragm, fabric diaphragm, rupture disk, or other device) in order to allow fluid to be pumped through it after the plug has landed on the landing seat. When plugs are used in pipe smaller than their design range, additional force (pressure) is required to push the plug through the casing. This additional pressure can damage the diaphragm or disk and, in some cases, prematurely rupture the membrane, causing the bottom plug to stop moving through the pipe.

6.11.4 Passing Through Small Diameter Tools

Certain tool applications require plugs to pass through small diameters to perform certain functions prior to landing on seats. The wipers on these plugs shall be sized correctly in order to pass through the small diameters (restrictions) and not be damaged or to trip the tool. The plug material shall be selected with consideration of the restriction in which it shall pass. A cross section that is too large or an elastomer that is too hard can have adverse results including failure of tools to operate or premature operation of tools.

6.11.5 Mismatched Sealing Profile with Landing Seat

The plug nose profile shall be compatible with the landing seat profile. In the case of primary cementing plugs, profiles shall be matched between the float collar and the bottom plug (if used), between the bottom plug and the top plug (if two plugs are used) and between the float collar and the top plug (if single plug is used). When nonrotating cementing plugs are used, the nonrotating profile on the cementing plugs shall match the nonrotating profile of the float collar. Also, if stage cementing tools are used, then the profile of the opening plug and the seat profile shall be matched and the profile between the closing plug nose and the closing seat shall also be matched.

For certain equipment such as liner hangers, subsea cementing plugs, and subsea stage tools, darts are used to operate the tool located in the casing. The sealing profiles for the darts shall match the sealing profiles for the devices they are to operate. Failure to match these profiles can result in equipment malfunctions, potentially resulting in failure.

6.11.6 Cementing Head Geometry Incompatibility

6.11.6.1 General

Cementing plugs are designed to fit into cementing heads either using a small interference fit or with a small clearance between the wipers and the cementing head. The change in diameter between the head and the casing shall not cause damage to the plug.

6.11.6.2 Cementing Head ID is Too Large for the Cementing Plugs

Cementing plugs installed into cementing heads with ID significantly larger than the intended plug can cause the cementing plug to tilt within the cementing head. This can prevent the cementing plugs from launching as desired.

6.11.6.3 Cementing Head ID is Too Small for the Cementing Plugs

Installing a cementing plug into a cementing head smaller than the wiper will affect the seal between the cementing head and the cementing plug (see Figure 5). A pressure differential across the cementing plug while retained in the cementing head can rupture the bottom plug diaphragm or damage the retaining device.

6.11.6.4 Cementing Head Adapter ID is Too Small for Cementing Plugs

After launching the cementing plugs from the cementing head, the cementing plugs shall enter the casing through an adapter. Should the ID of this adapter be too small for the cementing plugs, pressure required to push the bottom cementing plug into the adapter may be greater than the pressure limits of the diaphragm. The result could be premature rupture of the bottom plug diaphragm, rendering the bottom plug ineffective.

6.11.7 Postmanufacturing Modification to Cementing Plugs

Modifications to plugs are sometimes performed to alter the form, fit, or function of the plug. Such modifications could alter the performance of the plug and should only be made with the approval of the manufacturer. Some common modifications that could be made to cementing plugs include, but not limited to, the following.

a) *Reduction of the OD (Shape) of the Plug*—When a plug is required to wipe diameters beyond its standard range, some modification may be required. One such modification can be to reduce the OD of the fins and/or plug body. This may be accomplished by machining in a lathe or grinding. The material should be properly removed to avoid tearing the compound or creating excessive heat.

b) *Modification of the Bottom Plug Diaphragm*—Modification to some bottom plug diaphragms can be made for the purpose of changing the rupture pressure of said assembly. The diaphragm can be cut or damaged accidentally when modification to the plug is made. Therefore, any modification to the bottom plug diaphragm should be made with the approval of the manufacturer. The altered plug should be inspected thoroughly after modifications are performed.

c) *Chemical Compatibility*—Materials used for the construction of cementing plug wipers can be affected by the surrounding fluid environment. Caution should be taken to ensure the wiper material is compatible with the fluid it will contact. Certain elastomers used in the construction of cementing plugs can exhibit swelling up to 100 % of its original size when exposed to incompatible fluids. Also, physical strength of the elastomer can be significantly reduced by exposure to certain fluids. For example, the synthetic based elastomers exhibits little degradation in water-base mud, but can be severely affected in diesel oil base mud. Nitrile has good chemical compatibility in diesel oil base mud, but swells severely in high ester base mud.

d) *Pressure and/or Temperature Limitations*—Cementing plugs and landing collar together have specified pressure and temperature limitations. Exceeding this pressure/temperature limit may cause the cementing plugs or landing collar to fail.

e) *Drill Bit Compatibility*—The construction of cementing plugs, as described in Section 7 pumped out ports, range from cores made of aluminum, plastic, sand/resin, and wood. Most of these plugs are drilled up in order to continue drilling deeper. The selection of cementing plugs with the core type compatible with the type of drill bit to be used to drill ahead should be considered. Damage to drill bits can occur if a plug with an incompatible core type is used. For example, the use of PDC bits on cementing plugs with cast aluminum or cast iron cores can damage the PDC buttons and decrease the rate of penetration. This can result in poor drilling performance and require an unscheduled bit change.

6.12 Plug Deformation

Cementing plugs and darts are sometimes loaded into cementing heads or casing for significant lengths of time prior to being launched. If the fins are compressed for a significant time to a smaller diameter than the ID of the pipe or casing through which they will be run, the wiper fins may take a permanent set and lose wiping efficiency. To determine if a dart or plug is affected by this situation, a test can be performed by preloading it into a test fixture with a profile matching the cementing head or casing for the period of time in question.

6.13 Crossover or Transitions

ID transitions, such as those found in tool joints, check or kelly valves, safety joints, slip joints, and other devices, can create an ID detrimental to the continuous movement of mechanical cementing plugs. High-angle transitions (angles greater than 45 degrees from the centerline) have been found to potentially stop the movement of mechanical cementing plugs. Increased pressures have been noted with high-angle transitions over low-angle transitions for similar ID geometry. Efforts should be taken to minimize the transition angles from a larger ID to a smaller ID.

7 Mechanical Cementing Plug Construction

7.1 Surface-launch Plugs

7.1.1 General

Surface-launch plugs wipe a continuous string of casing, or tubing that extends all the way from the surface or rig floor to the desired depth near the casing point. These plugs are either launched from a plug container/cement head or manually inserted into the casing.

7.1.2 Bottom Plug

Three key components generally constitute a bottom plug (sometimes called a separation or spacer plug): wiping section, core, and rupture disk. The outer wiping section is flexible and made from an elastomer or other flexible material, and usually constructed with multiple ridges or fins. The outer wiping section is mounted on a core or insert made from a soft metal or plastic (shall be drillable). The core has a flow path through the center. It has a rupture disk mounted so as to block an internal flow path through the plug. The rupture disk is made from an elastomer, plastic, glass, or other breakable (frangible) material. (See Figure 17.)

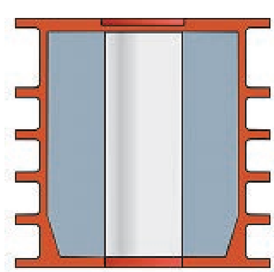


Figure 17—Short Fin Bottom Plug with Hollow Core and Frangible/Rupturable Member to Allow Flow Through the Core

7.1.3 Top Plug

A top plug has a construction similar to a bottom plug, except there is no flow path through the plug. There are only two main components, the wiping section and the core, which may be made from the same types of materials as the bottom plug components. (See Figure 18.)

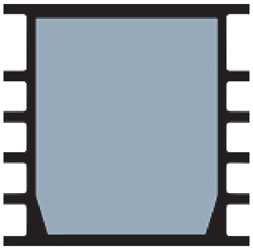


Figure 18—Short Fin Top Cementing Plug with Solid Core

7.1.4 Multistage Cementing Collar Plugs

7.1.4.1 General

Surface-launched plugs may be required to operate multistage cementing collars (also called port collars) for cementing a casing string in two or more separate “stages” (different depth intervals and timeframes). The first-stage cement is pumped all the way down to the bottom of the casing and up into the annulus. A subsequent upper stage of cement is pumped through ports of the stage collar, which provide a flow path from inside to outside the casing. The ports are opened and then closed by the use of wiper plugs or other devices or means. (See Figure 19.)

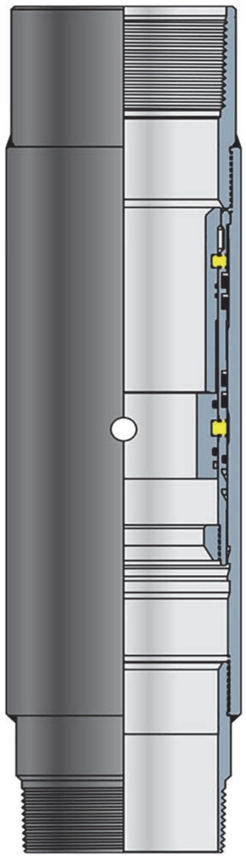


Figure 19—Typical Stage Cementer

7.1.4.2 First-stage Plugs

This plug is usually a flexible plug, with broad (long, thin) wipers or fins and a smaller "insert/core" section so that it will pass through restrictions that may be present in the stage collar without activating the stage collar. The construction of this plug sometimes allows it to also be used as a first-stage bottom plug when used with proper mating equipment.

A first-stage plug may be pumped to separate the first-stage cement and the displacement fluid. The plug may or may not seal on the top of a float collar or baffle, depending on its construction.

7.1.4.3 Opening/Activating Plugs

This plug is usually a flexible plug with a profile at the top or bottom in order to seal and shift a sleeve, or open ports to the outside of the casing. Alternatively, the stage collar may be opened by a gravity tool.

7.1.4.4 Closing Plugs

This plug can be a flexible type plug or one similar to a top cementing plug with a profile at the top or bottom that will seal and shift a sleeve or close the ports to the outside of the casing.

7.2 Liner (Wiper) Plug Systems

When a liner is run on drill pipe, in most cases it is not possible or practical to launch plugs from surface capable of wiping both the drill pipe and liner. In that case, a single liner wiper plug or top and bottom liner wiper plugs are attached to the bottom of the liner running tool. These plugs will wipe the liner section only and perform the same functions as a regular top and bottom plug. These liner wiper plugs shall be released from their tool, normally by a drill pipe wiper plug or balls.

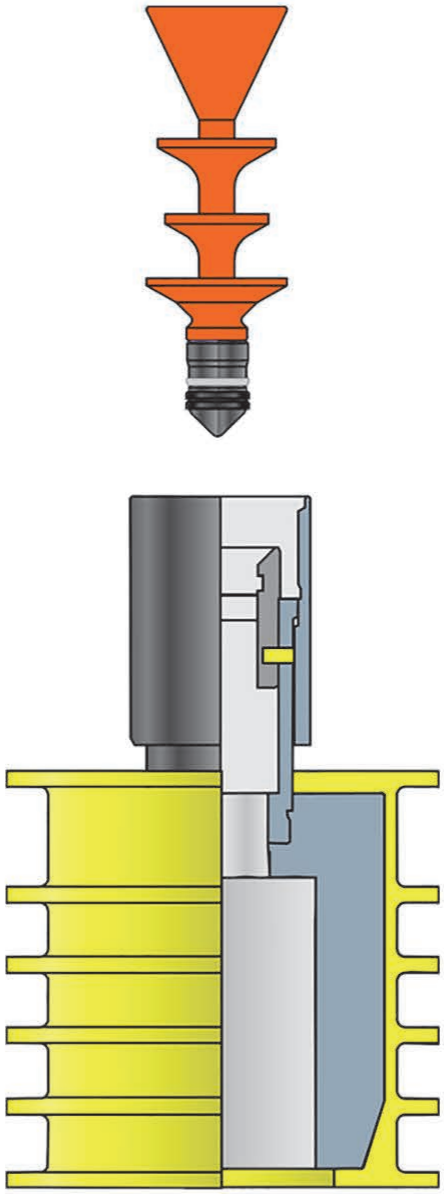
Liner (wiper) plug systems have the following three main components and a depiction can be seen in Figure 20.

a) *Launching Mechanism*—Constructed from steel or drillable materials and attached to the liner running tool. A mechanism releases (launches) the liner wiper plug at a selected pressure. If two liner wiper plugs are typically used (top and bottom), then two releasing devices are necessary, usually constructed to work independently so that both plugs cannot be launched at the same time.

b) *Liner Wiper Plug*—Attached to or held in the launching mechanism, it has a wiping section and core that may have a flow path through the center of the plug (or there is a bypass around the plug). It is constructed from drillable materials similar to surface-launch plugs. The core is constructed from a stronger material (aluminum or high-strength composites) than surface-launch plugs in order to withstand higher forces/pressures associated with disconnecting from the launch mechanism. There may be two liner wiper plugs, constructed to perform similar to a top and bottom plug.

c) *Drill Pipe (Pump-down) Plug*—A flexible plug, capable of wiping differing IDs of the drill pipe and running tools with a latch or locking mechanism to attach itself into the liner wiper plug or activate the release mechanism. Drill pipe plugs may also be run by themselves to wipe drill pipe and displace cement from the drill pipe as in "open-hole balanced cement plugs" or other remedial pumping operation.

   The drill pipe plug is launched from the plug container (on a container, plug launcher, head) at surface, displacing the cement and wiping the drill pipe. Pressure applied to the drill pipe plug after it reaches the liner wiper plug releases the liner wiper plug. The drill pipe wiper may be retained in a cage or may latch in the liner wiper and both plugs travel together to wipe the liner (casing). In either case, they then seat on a baffle or float collar in the same manner as surface-launched plugs.



NOTE One or more bottom plugs can be incorporated into this style of plug assembly.

Figure 20—Typical Liner or Subsea Release Top Plug Assembly

If two liner wiper plugs are used (top and bottom), then two drill pipe plugs are required, one to launch each liner wiper plug. Alternatively, a ball may be required to launch the bottom liner wiper plug and then a drill pipe plug required to launch the top liner wiper plug. If a releasing ball is used to launch one of the plugs, the ball provides no fluid separation or wiping efficiency.

7.3 Subsea-released (Launched) Plugs

These plugs are similar to liner plugs (Figure 20) used in cases where a casing string is hung and cemented at a given depth below the sea floor. The casing string is run into the well on drill pipe with a running tool that has the subsea plugs attached below (inside the casing).

8 Evaluation of Mechanical Cementing Plugs

8.1 General

This section is not intended to specify desired results, but only the procedure for testing plugs with suggested information may be recorded for evaluation. Appropriate safety measures should be followed when using these procedures:

— for all pressure testing described in this section, the pressure recording equipment should be adequate to record pressure changes experienced during testing; and

— for all temperature testing described in this section, the temperature recording equipment should be adequate to record temperature changes experienced during testing.

8.2 Standard Test Method for Elastomer Property—Effect of Liquids

The test procedure below outlines the process for fluid compatibility testing of elastomer compounds used in mechanical cementing plugs.

a) Cut test samples from ASTM D471 test slabs (see Figure 21).

NOTE 1 Sample size is dependent upon autoclave capacity.

NOTE 2 Samples may be obtained from molded plug assemblies or other suitable material source for which testing is required.

b) Notch test samples for identification (see Figure 22).

c) Measure hardness and volume prior to testing then record data (see Sample Test Form).

NOTE Hardness, mass, and volume can be determined prior to and after testing. Hardness can be determined according to ASTM D2240.

Figure 21—ASTM Test Slabs

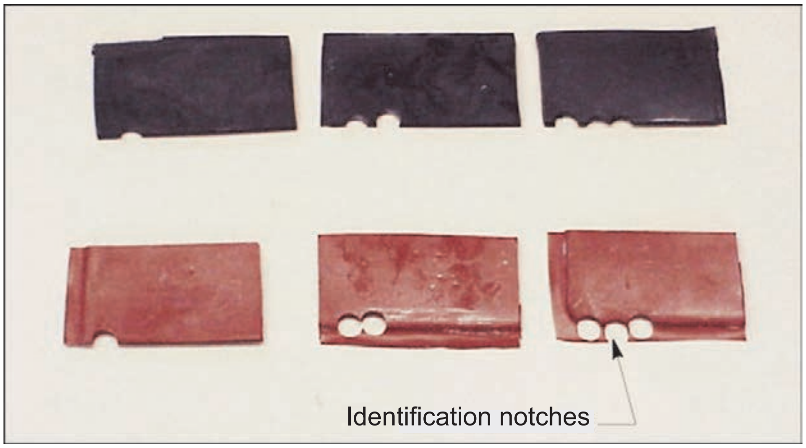


Figure 22—Samples Notched for Identification

d) Using available test apparatus, immerse in test fluid and soak for 22 hours ±0.5 hour at 176 °F ±10 °F (80 °C ±5 °C) and 2500 psi ±50 psi (17,200 kPa ± 300 kPa).

NOTE 1 Other temperature or pressure or time combinations can be used based on specific applications or requirements; if application dictates, any time required to ramp up of temperature and/or pressure should be recorded and should be in addition to the 22-hour soak time stated above.

NOTE 2 Cure temperature of the elastomer should be considered; as the test temperature approaches the cure temperature, additional curing will occur, which could affect the physical properties of the elastomer.

e) Measure hardness, mass, and volume after testing, then record data (see Sample Test Form).

f) Acceptable change in hardness, mass, and volume can be determined based on potential applications.

8.3 Bottom Plug Rupture (Flow Through) Static Pressure Test Procedure

8.3.1 Test Description and Apparatus for Static Testing

The purpose of the bottom plug diaphragm rupture pressure test is to determine the pressure at which the diaphragm of a bottom plug on a landing seat will rupture and allow the fluid to flow through the bottom plug. The test fluid may be water, synthetic oil, a user specified mud system, or base fluid. The test fixture is heated to the test temperature with a variety of heat transfer fluids. Plugs can be loaded into the casing size for which they are designed, or a high pressure test chamber (with ID simulating the casing into which the cementing plugs will be run) that is made up to the landing seat on which the plugs will be landed. (See Figure 23.)

8.3.2 Static Test Procedure

The steps for the test procedure are as follows:

a) assemble landing seat onto the chamber body such that the landing seat shall allow unrestricted flow;

b) install the bottom plug into the test chamber (while installing the bottom plug, the space between the wiper fins may be filled with test fluid);

c) install test assembly into pressure/temperature test cell and allow test assembly to reach test temperature;

d) apply pressure until fluid flow through the plug occurs;

Sample Test Form
Elastomer/Drilling Fluid Compatibility
Test Form

Test temperature: ____________________ Ramp time:______________________________________

Test pressure: ______________________ Ramp time:______________________________________

Soak time @ test conditions:____

Test fluid:____

Compound Sample No.	Sample Identification	Durometer Before Test	Durometer After Test	Volume (cc) Before Test	Volume (cc) After Test	% Change in Volume	Mass Before Test	Mass After Test	% Change in Mass
	1 Notch								
	2 Notches								
	3 Notches								
	1 Notch								
	2 Notches								
	3 Notches								

Comments: ____

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Tests performed by: ____ Date:_________________

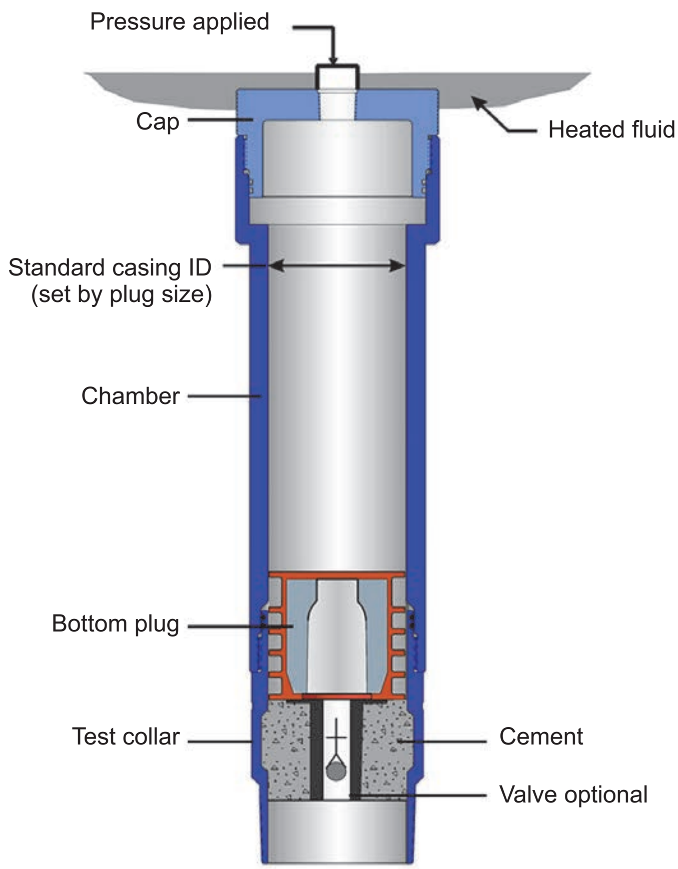


Figure 23—Typical Test Setup for Bottom Plug Rupture or Flow Through Testing

e) remove test assembly from pressure/temperature test cell;

f) inspect the inside of the test chamber to visually verify that the bottom plug is in contact with the landing seat and to ensure that the bottom plug rupture mechanism has actuated;

g) if no further testing is needed (such as plug landing pressure testing), remove the landing seat and bottom plug from the test chamber; and

h) inspect bottom plug and document test results (condition of plugs and rupture device, test fluid, test chamber ID, plug landing seat description, maximum pressure recorded, and rupture pressure).

8.3.3 Test Results

The test results that should be recorded are as follows:

a) describe and document (photo) test parts before and after testing;

b) note rupture pressure;

c) note test temperature; and

d) note rupture pattern and document with photos.

8.4 Bottom Plug Rupture (Flow Through) Dynamic Pressure Test Procedure

8.4.1 Test Description and Apparatus for Dynamic Testing

The purpose of the bottom plug diaphragm rupture dynamic pressure test is to determine the rupture pressure and rupture pattern of the diaphragm under dynamic conditions. The test fluid may be water, synthetic oil, a user specified mud system, or base fluid. Plugs should be loaded into the apparatus with ID simulating the casing into which the cementing plugs will be run and the landing seat on which the plugs will land. (See Figure 24.)

This test procedure can be used for ambient or elevated temperature testing.

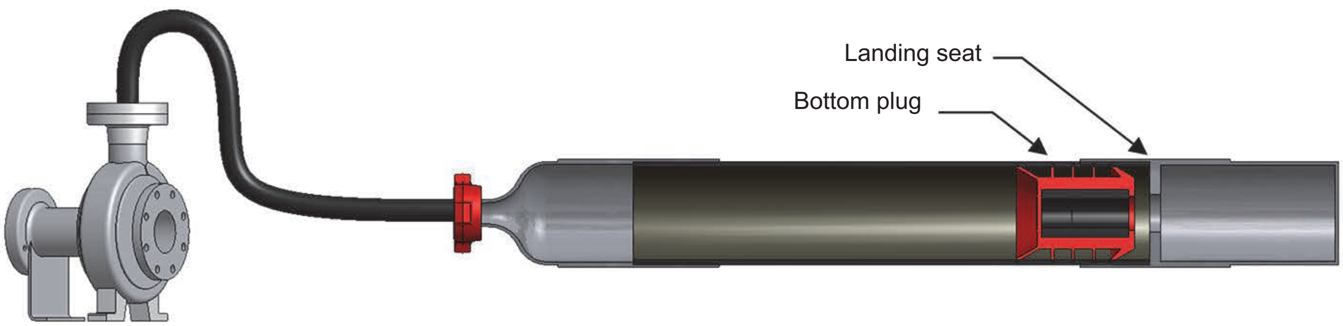


Figure 24—Generic Bottom Plug Rupture Test Setup for Dynamic Testing

8.4.2 Dynamic Test Procedure

The steps for the test procedure are as follows:

a) assemble landing seat onto the test apparatus such that the landing seat shall allow unrestricted flow;

b) install the bottom plug into the test apparatus (while installing the bottom plug, the space between the wiper fins may be filled with test fluid);

c) pump plug to landing seat at desired flow rate while recording rate and pressure to pump and to initiate flow through the bottom plug;

d) disassemble test apparatus;

e) inspect the inside of the test apparatus to visually verify that the bottom plug is bumped onto the landing seat and to ensure that the bottom plug rupture mechanism has actuated;

f) if no further testing is needed (such as top plug landing pressure testing), remove the landing seat and bottom plug from the test apparatus; and

g) inspect bottom plug and document test results (condition of plugs and rupture device, test fluid, test chamber ID, plug landing seat description, maximum pressure recorded, and rupture pressure).

8.4.3 Test Results

The test results that should be reported are as follows:

a) document test setup, fluid used, and condition of plugs prior to and after testing;

b) note pump flow rate;

c) note displacement pressure;

d) note rupture pressure;

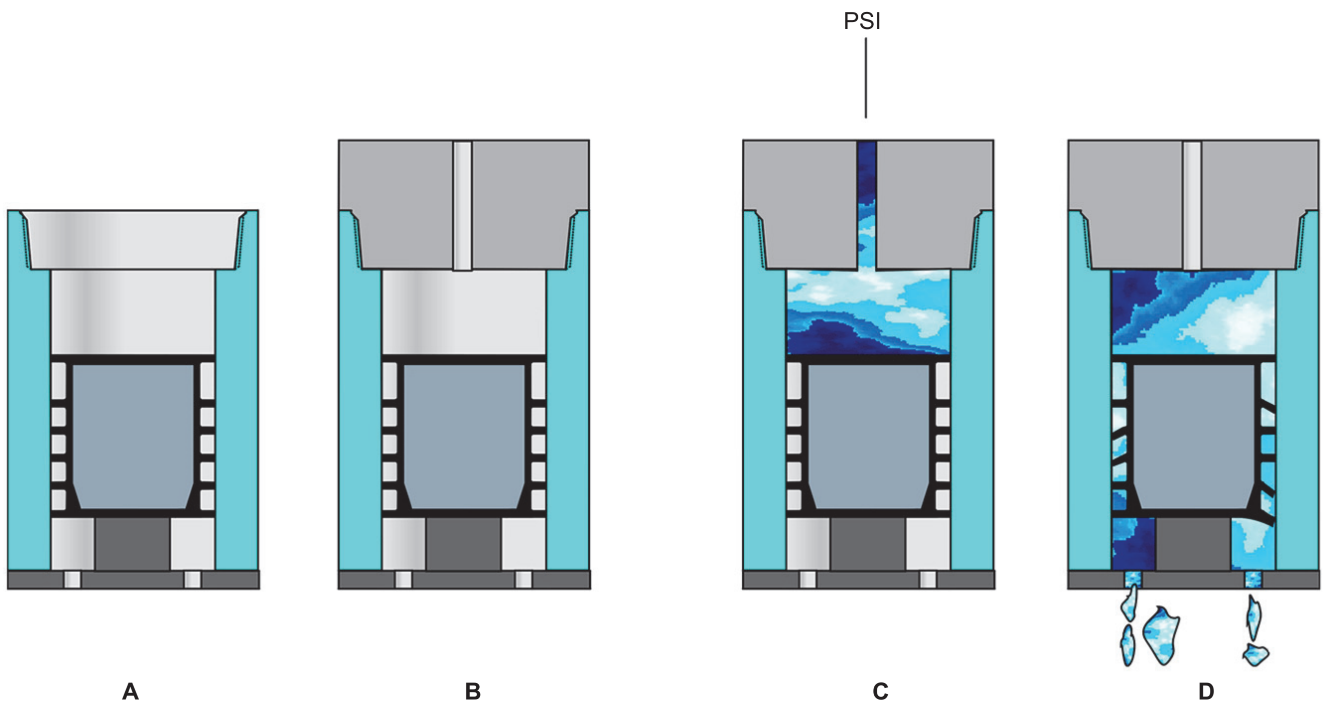
e) note flow through pump pressure; and

f) note rupture pattern and document with photos.

8.5 Plug Fin Bypass Pressure Test Procedure

8.5.1 Test Description and Apparatus

The purpose of the plug fin bypass pressure test is to determine the pressure at which the wiper fins invert within a given ID if stopped by an obstruction. The test fluid may be water, synthetic oil, a user specified mud system, or base fluid. Plugs can be loaded into the casing size for which they are designed, or a high pressure test chamber (with ID simulating the casing into which the cementing plugs will be run) that is made up to the landing seat on which the plugs will be landed. The test chamber shall incorporate a fluid bypass feature so the lowermost wiper is free to invert when sufficient pressure is applied. (See Figure 25.)



Key

A Cement plug installed into the test chamber. Plug rests above the lower end of test chamber that incorporates a fluid bypass feature so the lowermost wiper is free to invert when sufficient pressure is applied.

B Cap installed onto test chamber.

C Pressure applied through cap above cement plug.

D Wipers invert and fluid bypass is allowed.

Figure 25—Test Apparatus That Could Be Used to Determine Pressure Required to Bypass Wiper Fins on Cement Plug

8.5.2 Test Procedure

The steps for the test procedure are as follows:

a) assemble landing seat onto the chamber body such that the landing seat shall allow flow around the fins;

b) install the plug into the test chamber (while installing the plug, the space between the wiper fins may be filled with test fluid);

c) if applicable, increase temperature as required;

d) apply pressure until fluid bypass occurs; and

e) remove plug from test chamber.

8.5.3 Test Results

The test results that should be reported are as follows:

a) document condition of plugs (photo) prior to and after testing;

b) record bypass pressure; and

c) record test temperature parameters.

8.6 Plug Pressure Integrity Testing

8.6.1 Test Description and Apparatus

The purpose of the plug pressure integrity test is to simulate landing the top plug (with/without a bottom plug) on a landing seat and apply pressure from above the plug(s) to verify the plug(s) has been fully displaced. This should ensure a pressure seal has been established between the plug and the landing seat. The test fluid may be water, synthetic oil, a user specified mud system, or base fluid. If base oils are used, flammability should be considered. Plugs can be loaded into the casing size for which they are designed, or a high pressure test chamber (with ID simulating the casing into which the cementing plugs will be run) that is made up to the landing seat on which the plugs will be landed. (See Figure 26.)

8.6.2 Test Procedure

The steps for the test procedure are as follows:

a) assemble landing seat onto the chamber body such that the landing seat shall allow unrestricted flow;

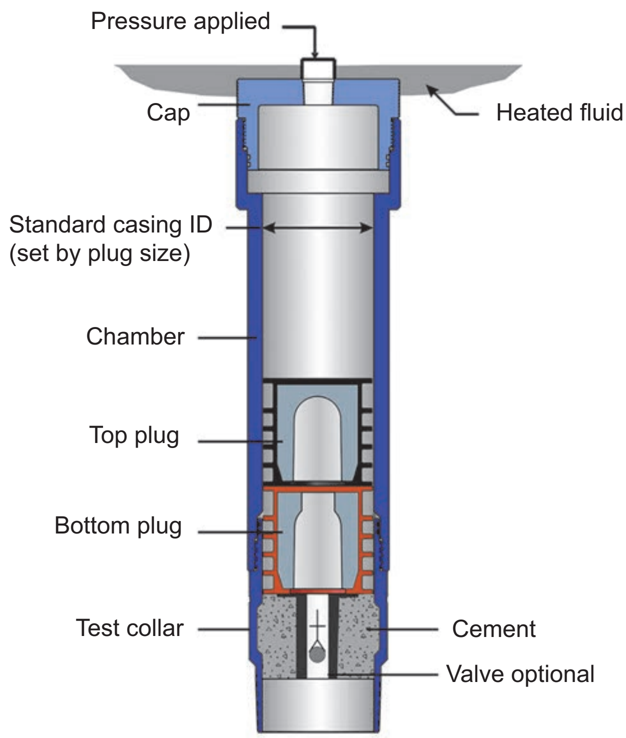
b) install the plug(s) into the test chamber (while installing the plug(s), the space between the wiper fins may be filled with test fluid);

c) install test assembly into pressure/temperature test cell;

d) soak for specified test time and temperature;

e) increase pressure in 1000 psi (7000 kPa) (differential pressure) increments, holding for 5 minutes per increment;

f) hold final pressure at test temperature for 15 minutes;



NOTE Though not shown, heat transfer fluid encapsulates the fixture.

Figure 26—Typical Test Setup for Bottom Plug Flow Through and Plug Bump Pressure Testing

g) remove test assembly from pressure/temperature test cell; and

h) remove the plugs from the chamber in such a way that they are not damaged during removal.

8.6.3 Test Results

The test results that should be reported are as follows:

a) record heat soak parameters;

b) record pressure test parameters; and

c) document condition of plugs prior to and after pressure/temperature testing.

8.7 Latch In and Out Test Procedure

8.7.1 General

Cementing plugs that are designed to latch into a receptacle and then hold backpressure are evaluated using this procedure. This type of cementing plug may be tested using the same procedure as conventional top and bottom plugs as described in 8.6 for the plug landing test. After initially bumping the plugs to the manufacturer's minimum recommended bump pressure to latch the plug, rated pressure should be applied from below to verify backpressure capabilities. Alternatively, a test performed using a load frame is an option; however, this test will not evaluate a temporary hydraulic seal. (See Figure 27 through Figure 31.)

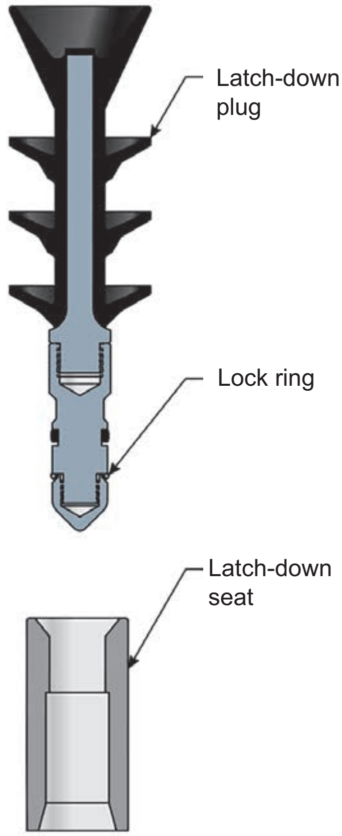


Figure 27—Sample Latch-down Seat and Latch-down Plug Prior to Latching Together

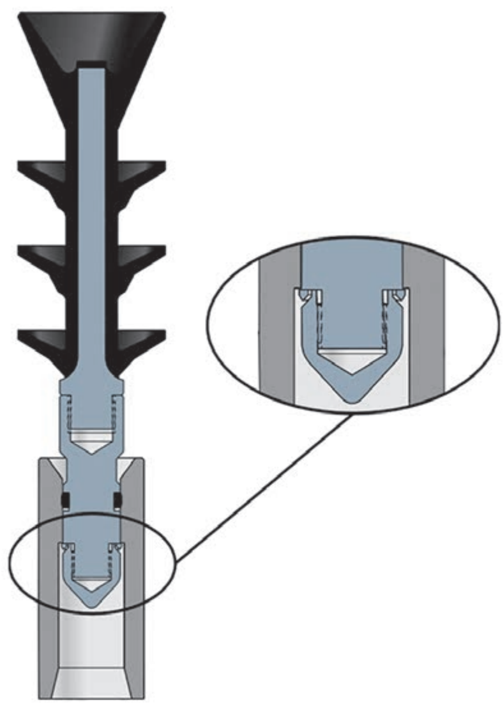


Figure 28—Latch-down Seat and Latch-down Plug After Seating

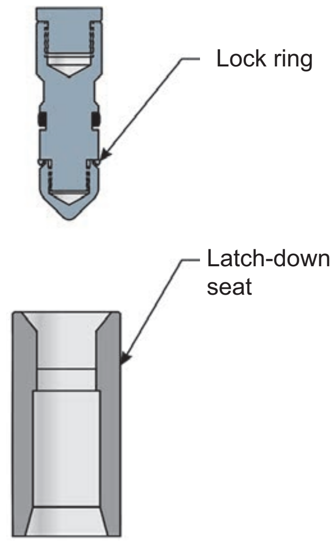


Figure 29—Latch-down Seat and Latch-down Plug Nose

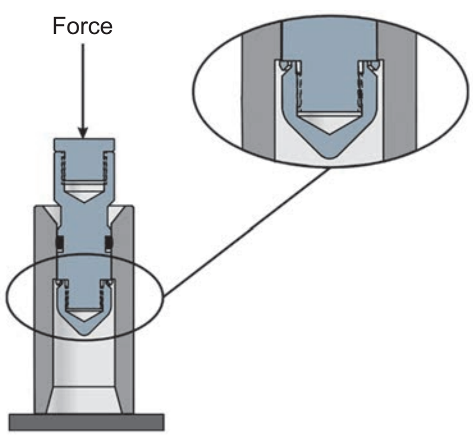


Figure 30—Latch-down Plug Nose Being Forced Into Latch-down Seat with a Mechanical Load Frame

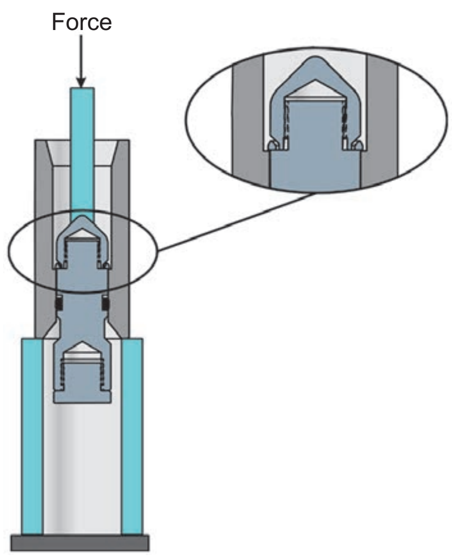


Figure 31—Latch-down Plug Nose Being Forced Out of the Latch-down Seat with a Mechanical Load Frame

8.7.2 Test Procedure Using Hydraulic Pressure from Above and/or Below

The steps for the test procedure are as follows:

a) temperature may be applied when using this procedure;

b) using a mechanical load frame or hydraulics, install the latch-down plug nose into the latch-down seat (nose can be installed with hydraulic pressure if suitable test setup is available);

c) install test assembly into pressure/temperature test cell;

d) soak for specified test time and temperature if applicable;

e) increase pressure in 1000 psi (7000 kPa) (differential pressure) increments (from above or below), holding for 5 minutes per increment;

f) hold final pressure at test temperature for 15 minutes;

g) repeat steps above to apply pressure in opposite direction;

h) remove test assembly from pressure/temperature test cell;

i) remove the latch-down plug from the chamber in such a way that they are not damaged during removal; and

j) disassemble and inspect.

8.7.3 Test Results for Using Hydraulic Pressure from Above and/or Below

The test results that should be reported are as follows:

a) record pressure/force required to insert latch-down nose into seat;

b) record pressure cycles from above and below as applicable;

c) record temperature cycle as applicable; and

d) document condition of the latch-down nose and seat prior to and after pressure/temperature testing.

8.7.4 Test Procedure Using a Mechanical Load Frame

The steps for the test procedure are as follows:

a) using a mechanical load frame, press the latch-down plug nose into the latch-down seat and record the force required to fully seat the nose;

b) using a mechanical load frame, press the latch-down plug nose out of the latch-down seat and record the force required to push the nose from the seat; and

c) disassemble and inspect.

8.7.5 Test Results for Using a Mechanical Load Frame

The test results that should be reported are as follows:

a) record force required to insert latch-down nose into seat;

b) record force required to unseat latch-down nose;

c) document condition of plugs prior to and after testing; and

d) based on nose piston area, calculate equivalent pressure based on measured force applied.

8.8 Plug Fin Wear Test Procedure

8.8.1 General

This section provides a method that may be used to evaluate the wear of a mechanical plug fins as the plug travels through a length of tubular. Two methods are proposed:

1) the method in 8.8.2.2 may be used to evaluate the wear of plug fins in a full scale flow test apparatus; and

2) the method in 8.8.2.3 may be used to evaluate the plug fins by examining fin pieces of a drilled up plug.

8.8.2 Fin Wear Evaluation Using a Flow Loop

8.8.2.1 General

This section describes a method to evaluate plug wear by cycling a plug through a length of casing and measuring the effects on the plug. The primary method of evaluating the desired plug and casing combination will be to measure the mass of the plug after passing through the desired length of casing. Plug condition shall also be noted and pictures before and after testing recorded to further document the observations.

8.8.2.2 Apparatus

The apparatus may be set up as in Figure 32 casing flow loop. The apparatus will consist of at least one joint of the casing size that the plug wear will be evaluated in. More than one joint may be assembled. Pump(s) and piping are required to circulate fluid through the casing and a tank is required to collect the flow out of the casing. The test fluid may be water, synthetic oil, a user specified mud system, or base fluid.

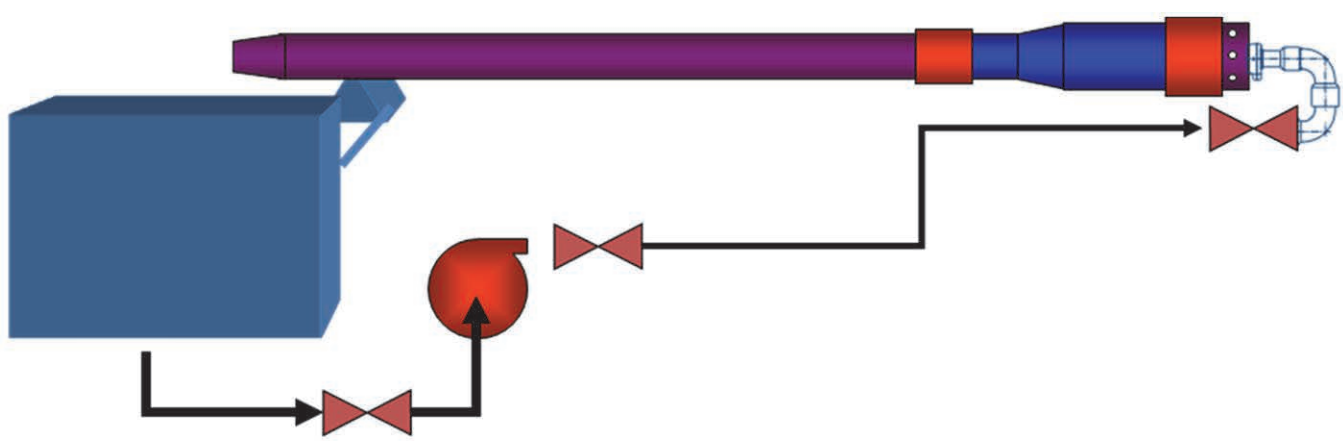


Figure 32—Casing Flow Loop Apparatus

8.8.2.3 Test Procedure

The steps for the test procedure are as follows:

a) perform initial plug measurements and photograph the plug from the side and both ends;

b) install plug in the "upper" end of the casing;

c) pump plug through casing;

d) remove the plug from the catcher and reinstall in "upper" end of the casing;

e) orient the plug the same way for each cycle;

f) repeat cycles until the plug has traveled the desired total distance through the casing; and

g) perform periodic measurements throughout the test.

8.8.2.4 Plug Measurements

The plug measurements that should be taken are as follows:

a) plug mass (kilograms or pounds); and

b) fin edge thickness—caliper.

8.8.2.5 Test Results

The test results that should be reported are as follows:

a) document casing size, weight, measured ID, and grade that the plug has been evaluated in;

b) document the number of joints assembled for the test and the length of the test apparatus;

c) document casing coupling type;

d) initially and periodically document the following:

   1) number of cycles,

   2) calculated length,

   3) plug mass,

   4) fin edge thickness, and

   5) minimum three pictures (top, bottom, and side view).

8.8.3 Wear Evaluation Method Using Plug Cuttings

8.8.3.1 General

This section describes a method to evaluate plug wear by evaluating the plug cuttings after a cementing wiper plug has been pumped through casing. This method can be used on cuttings retrieved from a plug that has been drilled out after being run through casing or a plug that is pumped through test casing. Worn plug fins that include a portion attached to the plug core are identified and sectioned along a plane through the longitudinal axis. By matching the profile of the fin at its base or edge where it joins the plug body with a full scale drawing or a section of a new fin, the area of the worn fin profile outside of the nominal casing diameter can be measured and compared to the area of a matching new or unused plug fin. Measurements may be made with a caliper, a comparator, or an electronic measuring device.

8.8.3.2 Plug Cuttings Measurements

A method of taking plug cutting measurements is illustrated below.

a) Identify a plug fin section that is identifiable with respect to its location on the cementing plug. (See Figure 33.)

b) Draw a cutting line and part a cross section of the fin at a location with minimal damage using an appropriate cutting device, such as a band saw or knife. Clean up rough edges with sharp blade or belt grinder. (See Figure 34.)

Figure 33—Recovered Plug Fin Section

Figure 34—Using an Appropriate Cutting Tool, Cut Line Down on Fin Section

c) Draw a second line parallel the first to part the cross section at 0.25 in. to 0.38 in. (6.5 mm to 10 mm) thickness. (See Figure 35.)

d) Print out a full scale drawing of the plug with a vertical line representing the casing nominal internal diameter as referenced from the plug body OD centered within the casing. Verify the printed drawing is to scale and matches fin dimensions from actual plugs. (See Figure 36.)

e) Place thin fin section over scaled drawing. Trace edges of worn fin and calculate the area of the fin segment outside of the line drawn to represent the nominal casing ID. The area of the fins outside of the nominal casing ID before and after use can be determined by using measurement tools such as optical comparators or fin thickness measurements at 0.1 in. (2.5 mm) increments from the nominal casing ID line outward to obtain dimensional data for importing into a CAD program. (See Figure 37.)

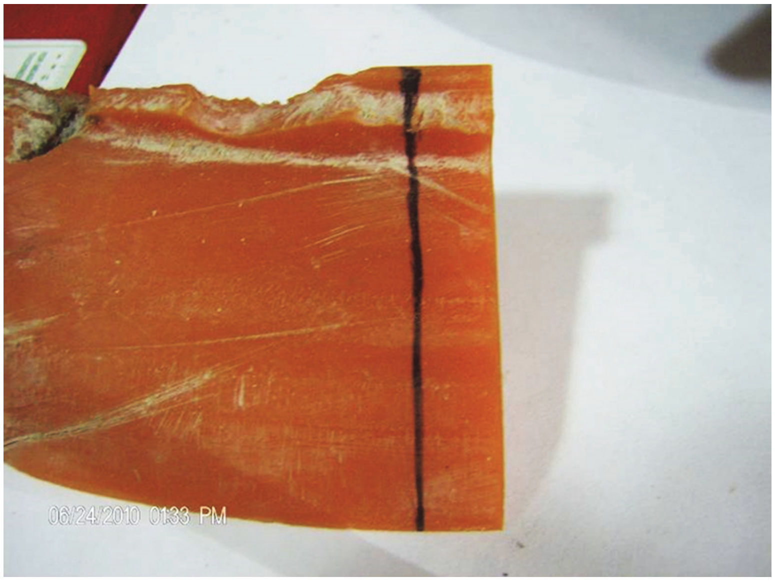


Figure 35—Second Cut Parallel to Marked Line on Plug Fin

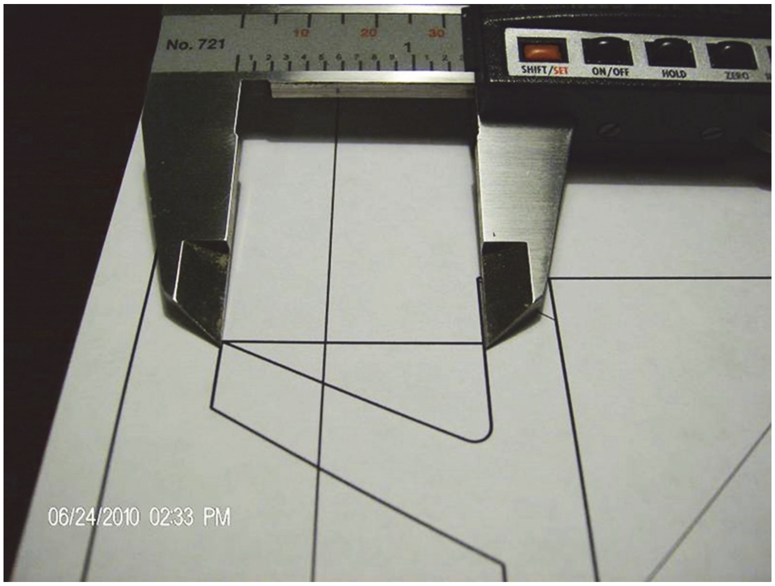


Figure 36—Full Scale Schematic of the Cross Section of the Plug Fin

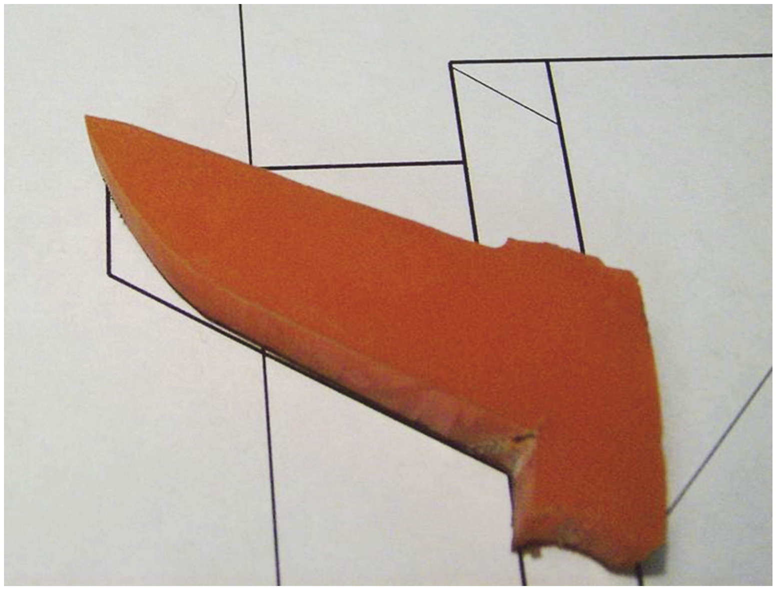


Figure 37—Place Cut Plug Fin Section Placed over Scaled Schematic

f) Trace edges of the worn fin and calculate the area of the fin segment outside of the line representing the nominal casing ID. The area of the fin outside of the nominal casing ID can be determined by using measurement tools such as optical comparators or fin thickness measurements at 0.1 in. (2.5 mm) increments from the nominal casing ID line to obtain dimensional data for importing into a computer aided drafting or mathematical program. Also, rubber swell as a result of contact with NAFs could also be determined using this measurement method.

g) Data can be recorded are the following:

1) divide the difference in fin area between the new and used plug outside of the nominal casing ID by the corresponding area of a new plug fin to obtain the ratio of fin wear;

2) multiply this ratio by 100 % to obtain the percentage of wear for this fin; and

3) distance that the plug was pumped and the environment in which it was pumped (casing size, weight per foot, nominal ID, threads, length, fluid properties, and temperature range if available).

8.8.4 Wear/Erosion Test Procedure

The relative wear resistance of cementing plug wiper materials can be determined by abrasion resistance tests as outlined in ASTM D2228 and/or ASTM D5963.

In an ASTM D2228 test, a circular test specimen of the cementing plug wiper material is abraded by a rotating knife blade under a standard load, number of revolutions, and speed. An index number for the material tested is obtained by dividing the standard volume loss of 5 reference compounds, tested in the same series, by the volume loss of the tested material and multiplying the quotient by 100. A higher index number indicates better abrasion resistance.

In an ASTM D5963 test, a 0.63 in. (16 mm) diameter cylindrical test specimen of the cementing plug wiper material is abraded by holding it against the surface of an abrasive sheet mounted to a revolving drum under specified conditions of contact pressure, sliding distance, and travel speed of the test piece, rotational speed of the drum, and degree of abrasiveness of the abrasive sheet. Results are normally expressed as volume loss in cubic millimeters (cubic inches). A smaller number indicates better abrasion resistance.

Two documents that may be reviewed are ISO 4649:2010 and ISO 23794:2010.

8.9 Wiping Efficiency

No current industry practice is available for evaluating the mechanical wiping efficiency of cementing plugs.

8.10 Cementing Plug Drillability Test Procedure

8.10.1 Test Description

Drill-out tests are normally conducted to evaluate the drillability of cementing plug systems with particular types of drill bits and procedures. Full scale drill-out testing can be used to determine the comparative time required to drill through plug systems with various types of drill bits and procedures.

The drill-out test can be used to determine drill-out performance based on time to drill through or damage caused to the drill bit depending on the intent of the test sponsor. The following procedures may be used to provide a basis for standard test setup and procedures. The objective of the test should be specified when determining the test parameters.

The tests can also provide information about the size of cuttings from the plugs. Drill-out testing can be performed on a well that has been cemented after the cementing plugs have been bumped, on a test rig, or a drilling simulator.

As a minimum, comparative testing should incorporate the following parameters for consistency of results:

a) size of plugs and bit,

b) type of plugs and bit,

c) fluid type,

d) weight on bit (WOB),

e) revolutions per minute (RPM),

f) bottom hole assembly (BHA),

g) circulation rate,

h) bit hydraulics,

i) surface solids control efficiency,

j) test assembly preparation, and

k) total flow area (TFA) of bit being used.

8.10.2 Test Procedure

The steps for the test procedure are as follows:

a) assemble test setup and fixture or target to be drilled;

b) run in with the drill bit to be tested until contacting the plug system; and

c) drill through the plug system following cementing plug manufacturer and/or drill bit manufacturer recommendations.

8.10.3 Test Results

Document test parameters used during drill-out test. At a minimum, the following should be documented:

a) slurry used (if applicable) to secure plugs in place and cure time;

b) pre-drill-out and post-drill-out bit inspection using IADC [1] inspection criteria;

c) size and shape of the cuttings from the plug system using pictures with a scale shown; and

d) plug system description, drill bit description, plug system drill-out time, drilling parameters (weight on bit, distance drilled, ROP, RPM, and pump rate), drilling fluid properties (type, density, plastic viscosity), and condition of the drill bit after drill-out.

8.11 Bonding of Individual Plug Components (Wiper Section to Insert)

This test method, found in ASTM D903, details the standard procedures for the determination of the comparative peel or stripping strength characteristics of adhesive bonds when tested on standard-sized specimens and under defined conditions of pretreatment, temperature, and testing machine speed.

Unique testing procedures may be provided by manufactures of cementing plugs as part of their acceptance and quality processes.

8.12 Restriction Testing

8.12.1 General

Two common evaluation techniques used to determine whether cementing plugs can be used through nonstandard pipe IDs are geometric evaluation and physical testing.

8.12.2 Geometric Evaluation

Geometric evaluation is the practice of using computer drawn three-dimensional solid models of the restriction and the plug to determine compatibility. Since most elastomer materials used in the fabrication of cementing plugs are incompressible, a determination of available space versus actual plug volume can enable the manufacturer or user to make knowledgeable decisions as to compatibility of the plug and restriction being evaluated.

8.12.3 Physical Testing

8.12.3.1 General

Physical testing is the practice of pumping plugs through the particular restriction that will be encountered by the plug when used. Though effective at determining compatibility, physical testing can be costly if multiple tests shall be performed.

8.12.3.2 Test Parameters

Test parameters should include, but not limited to, the following:

a) ID of the restriction;

b) entrance/exit geometry of the restriction;

[1] International Association of Drilling Contractors, 10370 Richmond Avenue, Houston, Texas, USA, www.iadc.org

c) length of the restriction through which the plug shall pass;

d) test fluid that will be used (restriction testing using a mechanical load frame is not considered to accurately reflect the results obtained with fluid testing); and

e) flow rate or velocity of the plug entering restriction.

8.12.3.3 Test Results

The test results that should be reported are as follows:

a) note pressures applied to the plug throughout testing;

b) note flow rate throughout testing; and

c) note damage to the plug.

8.13 Wiper Deformation Caused by Preinstallation Inside a Restricted ID

8.13.1 General

Cementing plugs and darts are sometimes loaded into cementing heads or casing for significant lengths of time prior to being launched. If the fins are compressed to a smaller diameter than the ID of the pipe or casing through which they will be run for a significant time, there is a concern that the wiper fins will be deformed and lose wiping efficiency. Testing can be performed to determine if a plug or dart is affected by preinstallation into a cementing head or restricted ID.

8.13.2 Test Procedure

The steps for the test procedure are as follows:

a) take appropriate measurements on the plug or dart prior to testing;

b) preload the plug or dart into a test fixture with a geometry matching the cementing head or casing;

c) store loaded test fixture for desired test period;

d) remove the plug or dart from the test fixture; and

e) measure the maximum and minimum outside diameters of each fin at appropriate time intervals (suggested time intervals are five, fifteen and thirty minutes after removal).

8.13.3 Test Results

The test results that should be reported are as follows:

a) note the restriction ID;

b) the ambient temperature range should be monitored during the test period; and

c) note dimensional measurements taken at multiple time intervals.

Bibliography

[1] ASTM D471 [2], *Standard Test Method for Rubber Property—Effect of Liquids*

[2] ASTM D903, *Standard Test Method for Peel or Stripping Strength of Adhesive Bonds*

[3] ASTM D2240, *Standard Test Method for Rubber Property—Durometer Hardness*

[4] ASTM D2228, *Standard Test Method for Rubber Property—Relative Abrasion Resistance by Pico Abrader Method*

[5] ASTM D5963, *Standard Test Method for Rubber Property—Abrasion Resistance (Rotary Drum Abrader)*

[6] ISO 23794:2010 [3], *Rubber, vulcanized or thermoplastic—Abrasion testing—Guidance*

[7] ISO 4649:2010, *Rubber, vulcanized or thermoplastic—Determination of abrasion resistance using a rotating cylindrical drum device*

2 ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.

3 International Organization for Standardization, 1, ch. de la Voie-Creuse, Case postale 56, CH-1211, Geneva 20, Switzerland, www.iso.org.

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