PRIMARY AND REMEDIAL CEMENTING GUIDELINES

DRILLING AND COMPLETION COMMITTEE ALBERTA

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I. INTRODUCTION

This Guide is proposed in response to one of the recommendations set forth by the DACC Surface Casing Vent Flow Subcommittee where the problem of uncontrolled gas migration was studied and various recommendations were made to try and prevent this problem from occurring. The purpose of this Guide is to improve the probability of getting a good primary cement job and if this is not achieved, to explain the consequences and remedial courses of action.

A primary cement job has few, but none-the-less, critical purposes. The most important of which is to provide a continuous, impermeable hydraulic seal in the annulus, preventing uncontrolled reservoir fluid flow behind the casing. Without cement behind the pipe, oil or gas may flow to surface and cause a blowout - a very serious situation which can result in massive environmental damage. Other types of uncontrolled fluid flow can also occur. In some cases this flow may not even be visible at surface. Reservoir fluids may commingle or they could migrate upwards, over-pressurizing other permeable zones, or they may invade a fresh water zone and contaminate Alberta's usable ground water. Other possibilities include the flow of gas up the inside or outside of the surface casing, venting into the atmosphere and/or destroying the near well-bore ecology.

It is clear to see that a good primary cement job is important in order to prevent this uncontrolled flow. It should also be emphasized that hydraulic isolation is not only necessary across hydrocarbon bearing reservoirs, but also across aquifers, and shallow gas zones. Thus, it can be seen that competent cement jobs must be obtained in all casing strings, including the surface casing, as this often is the string that will protect usable ground water and prevent shallow gas migration.

The industry must be made aware that good primary cement jobs are necessary to prevent uncontrolled annular gas and fluid flows. The Guide offers practical tips and a systematic procedure to obtain an adequate cement job. It also includes a small glossary of definitions, and a section on tips for remedial repair and well abandonment. The Guide is intended to help the people that drill oil and gas wells every day. It is important to recognize that this is only a guide, and there may be techniques different than those described that can result in good cement jobs. This Guide is not intended to replace local practices that have proven successful.
II. MECHANISMS OF GAS MIGRATION

Hydraulic isolation in the annulus is required to prevent shallow gas migration. Gas can migrate to surface a number of ways, the most obvious results from no-or discontinuous cement behind the casing, and gas pressure sufficient to overcome the hydrostatic pressure of the fluid column in the annulus. As frequently occurs, cement may have been placed into the annulus, but it may not have effectively displaced the existing drilling mud. Mud channels may be present, allowing potential pathways for the gas to enter the annulus and flow to surface. Another method of gas flow to surface could occur if micro annuli were formed either between the formation and the cement, or more commonly, between the cement and the casing. Also, under certain conditions, ms can actually flow into cement that is in the liquid-to-solid transition phase and percolate a channel through the hydrating cement column. It can be seen that the problem of obtaining a gas tight seal in the annulus is a difficult one and it is recommended to use all the technology available when cementing across gas zones.
III. PRIMARY CEMENT JOB DESIGN

1. It is important to obtain data pertinent to the cement job. The information should include the following:
   - Operating Company Name
   - Well Name
   - Location (LSD)
   - Type of job (surface, long-string, liner, etc.)
   - Casing sizes, grades, weights, and threads
   - Casing depths, and deviation data
   - Hole size and caliper if possible
   - Bottom hole static and circulating temperatures
   - Type of mud
   - Mud density and rheology
   - Expected pore pressures and formation fracture gradients
   - Any special well problem (lost circulation, kicks, salt sections, etc.)
   - Cement slurry fill requirements, minimum compressive strength and permeability requirements
   - Specific operating company cementing procedures

2. Once data is obtained it is recommended to run computer simulations for critical cement jobs. Most cementing companies have primary cementing simulation software capabilities, and simulations should be done on all long-strings and liners. Simulations should also be run on surface and intermediate casing strings if the job is in a new area or there is a particular problem to overcome, such as lost circulation or gas migration. When attempting to battle a gas migration problem emphasis should be placed on slurry transition time, mud removal, and placement pressures

3. Determine the required amount of dry cement or blend, total mix water, pump rates, surface and bottom hole pressures during the job, mixing time, mud displacement volume cumulative displacement to bump the top plug, and other relevant information.
4. If a simulator is not available, the previous information should be calculated.

5. For intermediate casing strings (when necessary), long-strings, and liners, the cementing company should run API Laboratory tests, preferably with the actual materials (including mix water) that will be used on the job. Tests should be conducted to include slurry thickening time, rheology, and fluid loss, as a minimum.

6. Whenever possible design the cement job so the spacers, washes, and cement slurries are displaced in turbulent flow. When this is not possible use alternate displacement techniques such as effective laminar flow technology.

7. In all cases - including the surface casing - centralization is a critical requirement for achieving proper mud removal, and hence, hydraulic zonal isolation.

8. Cement plugs should be used with the purpose of separating each change in fluid: mud from wash, wash from spacer, spacer from cement, cement from mud.
IV. LABORATORY TESTING

1. Cement tests should be performed according to API specifications when possible unless practical engineering judgment dictates otherwise.

2. If the bottom hole circulating temperature has not been determined by circulating temperature probes or any other mechanical measuring device, it should be determined using computer simulators or from API circulating temperature schedules.

3. Design fluid loss target values using 7 MPa (1,000 psi) differential pressure. The following general guidelines can serve as a point for design:
   - in slim hole cementing - less than 50 ml/30 minutes API
   - for liner cementing - less than 100 ml/30 minutes API
   - across producing formations less than 250 ml/30 minutes API
   - squeeze cementing - between 50 and 100 ml/30 minutes API

   It should be stressed that fluid loss control is dependent primarily on the permeability or ability of the formation(s) to accept fluids under static conditions. That is, the more permeable the formation, the more fluid loss control will be required, the less permeable the formation, the less fluid loss control is required. As stated, the numbers listed above are general guidelines that can serve as a starting point for design.

   In very highly permeable or fractured zones, it may be necessary to use a low fluid loss system followed by a high fluid loss system to get an effective squeeze.

4. For static temperatures above 110 °C add at least 35 % silica to the cement to prevent a structural breakdown of the cement called strength retrogression.

   Note: In thermal or steam flood wells where high temperatures will be seen through the entire well-bore, silica may also be required in the surface casing cement.

5. Use high sulfate resistant cement (HSR) when sulfate content is prominent in formation water.

6. Free water and sedimentation of cement slurries should be minimized. In highly deviated wells, to prevent gas channeling and for complete zonal isolation, it is imperative to have no free water in the slurry.

7. Determine slurry thickening time at bottom hole circulating temperatures and pressures. Although the API considers 100 Bc (Bearden consistency units) to be the termination point of a thickening time test, 70 Bc is essentially the maximum pumpable viscosity (often called pumping time). The pumping time should be at least one hour longer than the expected job duration.
8. When attempting to stop or avoid gas migration, the most important slurry quality is a short solid-to-liquid transition time. This is the key to avoiding gas-cut or gas-channeled cement.

9. Use the same mix water, cement, and additives in testing that will be used on the location for the job. The water should be without contaminants.

10. Check the compatibility of the cement slurry and the drilling mud. Test also with any washes, and spacers that may be required.

11. When pumping cement bugh coiled tubing, the effects of imparting extra shearing energy into the slurry should obviously be well tested before pumping the job.
V. **Pre-Job Preparation**

1. Physically check that all required materials and equipment have been delivered to the location. Weigh scale tickets should be checked in addition to loading tickets for the cement blends and additional additives that may be required.

2. In all cases, when different blends and/or mix water are used, every blend and tank should be clearly identified. During colder seasons, the mix water will have to be heated to at least 20 °C. Very cold mix water will adversely effect the additives in the cement slurry; and thus, the slurry properties such as thickening time, transition time, rheology, and sedimentation.

3. The service company engineer and the drilling company representative should independently recalculate the slurry volumes and displacements required. Changes to the original job program should be mutually agreed to and verified. Additionally, the latest mud properties should be taken, mix water temperature and volume confirmed, and maximum pressures and rates decided.

4. Calculate the hydraulic lifting forces that the casing string will see just before the plug is bumped. This is the moment of maximum differential pressure.

5. The service company engineer and the drilling company representative should agree on the displacement volume, and what action to take if the final plug does not bump after the theoretical volume has been pumped.

6. Rig up cementing equipment on location and discuss post job wash-up procedures and disposal.

7. The drilling company representative should witness the installation of the float equipment and assure that casing centralizers are placed according to the centralizer program.

8. The drilling company representative should also witness the pre-loading of the top and bottom plugs into the cement head.

9. Complete the hookup of all equipment. As soon as the casing is landed, rig cement head to casing and begin circulation. Computer simulations can give effective circulation rates for mud conditioning. If simulators are not used, fluid calipers may be run to measure the volume of mud in movement. Good mud circulation should displace more than 85 % of the hole volume. In order to break down the yield pint of stationary mud, it is imperative that the casing be reciprocated and/or rotated during mud conditioning.
10. If the rig pumps are to displace, install a pressure transducer to record displacement pressures from the rig pumps.

11. Calibrate and record all electronic sensors. Compare density readings to pressurized mud balance measurements. Service company engineer and drilling company representative should agree in advance on the most accurate measuring equipment which will remain the reference for the job.

12. Conduct on location pre-job meeting with the cementing crew, drilling company representative, and rig personnel who would be involved with the job. The meeting must include safety procedures and contingency plans.
VI. JOB EXECUTION

1. Pressure test all high pressure lines and reconfirm the maximum allowable pressures during these pre-job pressure tests. Note: The cement head is usually the weakest link during a cementing operation and it should be noted that the cement head maximum working pressure is often below the casing burst pressure.

2. Start pumping operation by establishing circulation from the cement equipment. Observe mud tanks or pits for returns.

3. Pump any preflushes, washes, and spacers, launching plugs as necessary between fluids. Have all tanks physically checked to assure correct sequences and volumes are pumped. In order to improve mud removal efficiency, it is imperative that the casing be reciprocated and/or rotated during the cement job.

4. Begin mixing lead slurry. Measure and record the mix water either through gauged storage tanks, through mixing unit tanks or by metering methods. Check electronic density measurements against the pressurized mud balance measurements.

5. Collect samples of the dry blended cement and mix water as mixing progresses. Samples must be taken in clean, well marked containers, and stored securely at proper temperatures should they be required for post job evaluation.

6. Mix entire lead slurry and subsequent slurries as per design densities and rates. Observe well for returns during the entire cementing process. If possible record the volume and densities of the returns. Observe the difference between “full” returns and “partial” returns, which would indicate losses.

7. Take slurry samples during the job. Do not use the setting of the surface samples as a guide to cement working time or drill out times. These samples do not accurately reflect the downhole treatment of cement during or after placement.

8. Do not maintain the designed downhole rate at the expense of slurry density. If the slurry density cannot be controlled within the acceptable limits (within 25 kg/m³), the pump rate needs to be adjusted until the slurry density control is acceptable. With slower pump rates, the job becomes longer and a recalculation of job time versus available slurry thickening time needs to be made.

9. Above all, do not sacrifice the slurry density in the last two cubic meters of slurry mixed to save the expense of the dry cement. As the bulk equipment empties, cement delivery becomes erratic and density control
more difficult. When proper density cannot be maintained, stop mixing at a reduced slurry volume and dispose of the remaining cement.

10. Drop the top plug in accordance with the equipment operating procedure. When possible, launch the plug "on the fly" rather than shutting down pumping operations. Record the total amount of mix water used in the cementing operation. If not dropping the plug "on the fly" the cement head valves should be closed as soon as pumping is stopped. This will keep the air volume below the plug, caused by U-tubing, to a minimum. Also, if this is the last casing String to be cemented, all cement should be washed out of the surface treating lines so that cement is not placed on top of the plug.

11. If displacement is through the cement unit, gauge the displacement fluid through the displacement tanks -do not rely on flow meters recording drive shaft rotations, pump strokes or other indirect measure. When possible, use in-line flow metering equipment --that minimizes the effect of fluid aeration. For production casing strings displace, when possible, with fluid of the same or lesser density than the completion fluid. This is to avoid getting a micro-annulus as mentioned later.

12. If the rig pumps are displacing, flow rate and volume should be measured and recorded by the stroke rate of the mud pump and a physical backup of tank gauging to assure correct volumes are being pumped.

13. If the top plug does not land after the calculated displacement volume, then the previously agreed to contingency plan should be put into effect. The best practice is not to over displace. Even if some cement has to be drilled out from above the collar, the cement shoe and bottom of the casing will be firmly anchored in place. If the plug was "not there" (several explainable reasons exist for this phenomenon), and additional volumes of mud are pumped, the slurry will be over displaced resulting in a loss of good cement bond at the shoe (i.e. a "Wet Shoe").

14. Waiting on Cement (WOC) means just that. There are usually a few options at this point such as hanging off the casing, or to maintain tension during the cement hydration. Regardless of the procedure, do not disturb the setting cement column. Physically jarring or moving the casing can result in irreversible destruction of the early crystalline structure that is forming. Also, do not keep pressure on the casing while the cement is setting. This pressure causes ballooning, increasing the casing diameter. Later pressure release and casing relaxation to its original diameter will result in a micro annulus between the casing and cement. This implies that it is essential to use float equipment.
VII. CEMENT PLUGS

The following is a general guideline which can improve the success of plugging open sections with cement. Most cement plug failures occur because of cement plug contamination. The failure of a cement plug to achieve isolation may result from poor placement procedure, lack of centralization, inadequate mud conditioning, washed out sections of open hole, lack of pipe movement, excessive thickening times, incompatibility of mud and cement, gravity and displacement effects, and generally low prioritization of mud removal.

1. Use a caliper log to determine the actual open bole dimensions where the plug is to be set to ensure a properly designed plug.

2. Condition and clean hole as for primary cementing.

3. Use preflushes and spacers to aid in mud displacement and to prevent contamination.

4. Pull pipe from plug as slow as practically possible.

5. Rotate drill pipe during cement plug displacement.

6. Smaller sized tubing as a tail pipe and diverter pipes should be used.

7. Plug length should be no longer than 150 meters. They need only be long enough to prevent inter-zonal formation fluid contamination.

8. Consider cement blends that work most effectively under the temperature conditions at plug depth. Minimize cement slurry thickening and transition times.

9. Evaluate cement plug job results.

Further information and minimum requirements of Open Hole Abandonment can be obtained from AEUB G20, Drilling and Completions Operations Guide.
VIII. Remedial Cementing

Remedial cementing is defined as the process of placing plugging material into a void space, which exists in a well-bore annulus. This void space is usually allowing producing fluids to enter it. Often, the void space takes the form of a channel thus allowing produced fluid to flow. This flow is uncontrolled-and may allow fluid flow to surface, or it may result in an uncontrolled subterranean flow. Remedial repair is the process of stopping this uncontrolled flow.

When attempting to shut off a shallow gas migration leak, a technique that has found considerable success in various areas of Alberta is to damage the gas zone prior to plugging the channel. Since cement slurry cannot be injected into the matrix of most reservoirs, the use of solids free plugging materials should be considered. Matrix penetration of the plugging material is the key to success--not fracturing. On longer perforated intervals, effective diversion of the plugging material becomes an issue.

1. Identify the problem and design an appropriate treatment. Obtain an accurate well diagram. Review logs when available. Original hole caliper log may provide useful insight. Obtain BHST. This is an important parameter as the setting time of the cement and most plugging material is temperature dependent. Pay particular attention to tubular and wellhead pressure ratings. Use appropriate safety margins for older wells.

2. Conduct API lab tests on the slurry. The lower the viscosity of the slurry and API fluid loss, the greater the chances of success (in most cases). Obtain thickening time, theology, and API fluid loss from the lab. On critical jobs test with the actual products and mix water that will be used on the job. Modify API test schedule with actual temperatures and pressures to be encountered.

3. Plan the job with the cementing company. Review material requirements and assure that adequate cement and additives will be available on location. The norm is to double or triple required volumes as it may take several attempts to obtain a successful squeeze. Unless process control cement mixing equipment is available, batch mixing of the slurry should be considered. Assure an accurate weigh scale and liquid measuring device are available on site to measure the exact additive amounts as detailed in the laboratory.

4. Retain samples of cement and mix water before mixing. Ensure to use clean (even filtered) mix water. Measure the temperature of the mix water and have provision to heat the mix water if required. Retain samples of the final mixture. Density of the cement slurry is critical and should be within 25 kg/m$^3$ of the lab tested slurry.

5. Isolate the zone to be squeezed. If perforations already exist, wash them with a selective tool to assure they are all open. Alternatively, use the back surging technique. Old oil wells may require solvent to remove asphaltines or waxes which may be blocking perforations. All perforations
must be open. If shooting new perforations, a channel finder type gun should be considered. Because of its high shot density and multi-phasing, it has a high probability of hitting a channel.

6. Ensure well-bore fluids are clean and any fluid used for establishing a feed rate be solids free. Consider having 15 % HCL acid or Mud Acid (12 % HCL + 3 % HF) available if a good feed rate cannot be obtained. Avoid fracturing as this will simply open up a new path for uncontrolled flow.

7. Attempt to establish circulation back to surface. Try to remove the old mud out of the channel. Attempt to swab back the channel if positive pressure does not work. Do not attempt a squeeze if rates are less than 0.1 m³/min. A fine particle cement and/or low viscosity solids free plugging material should be used.

8. A retrievable packer or retainer should be used over the Bradenhead technique. This way, contamination with by an old well-bore is less likely. Coiled tubing is also proving to be a viable method of conveying plugging material to where it is needed.

9. When the plugging material is correctly in place, stage squeeze until no more pressure leak-off is observed. A further pressure test of 3.5 MPa over the final injection pressure indicates the end of the process. The surface treating line pressure test must have been successful in order to ensure that slow leak-off rates are not slow leaks in treating lines.

10. Bleed-off the pressure and check returns. Tools should be retrieved and the well should be undisturbed during the WOC time.
IX. GAS MIGRATION AND SURFACE CASING VENT FLOW SPECIFICS

The gas migration and surface casing vents flow problems in Alberta have just started coming to light. With increasing environmental concerns, the governing requirements are constantly under review and are guaranteed to get more stringent with time. As a result of the DACC establishing a subcommittee to define a guideline for reporting, monitoring, and repairing leaking wells, certain terms and definitions have been developed:

**Surface Casing Vent Problem:** A well with a surface casing vent problem is any well licensed by the AEUB which has a measurable flow which may contaminate usable ground waters, or create an environmental hazard or safety concern at surface.

**Vent Flow:** A vent flow is any measurable flow of gas, water or hydrocarbon liquids and/or with an attainable pressure build-up.

**Migration Problem:** Is any well licensed by the AEUB which has a detectable amount of gas or fluid migration at surface, outside the outer most casing, which may contaminate usable ground waters, or create an environmental hazard or safety concern.

**Usable Groundwater:** Is defined by Alberta Environment as any groundwater with a total dissolved solids content of less than 4,000 mg/L

Once a vent flow problem has been identified, it must be categorized to determine the extent and timing of remedial action to be taken:

**Serious Vent Flow**

- Is any vent flow where any usable water-zones are not covered by cemented surface casing and/or cemented production casing.

- Is any vent flow with a stabilized gas flow equal to or greater than 300 m$^3$/day, and/or equal to a surface shut-in pressure:
  - greater than one-half the formation leak-off pressure at the surface casing shoe; or
  - greater than 11 kPa/m times the surface casing setting depth$^1$

- Is any vent flow with H$_2$S present which constitutes danger to public safety or poses an environmental hazard.

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$^1$...The criterion of 11 kPa/m, or half the known formation leak-off pressure, was chosen to avoid exceeding the fracture gradient. The surface shut-in pressure may vary with formation leak-off pressure, density of fluid in annulus, depth to fluid, lost circulation zones, or other well conditions that would limit the allowable shut-in pressure.
• Is any hydrocarbon liquid (oil) vent flow.
• Is any non-usable water vent flow.
• Is any usable water vent flow where the surface shut-in pressure is:
  o greater than one-half the formation leak-off pressure at the surface casing shoe; or
  o greater than 11 kPa/m times the surface casing setting depth
• Is any vent flow due to wellhead seal failures or casing failure.
• Is any vent flow that constitutes a fire, public safety or an environmental hazard.

Non-Serious Vent Flows: Is any vent flow that has not been classified as a serious vent flow.

Serious Migration: Is any gas or fluid migration to surface that constitutes a fire hazard, public safety hazard, or off-lease environmental damage.

Non-Serious Migration: Is any gas or fluid migration to surface that has not been classified as serious migration.

Repair Requirements Schedule:

Serious Vent Flows or Migration
• shall be repaired by September 1996 and within 1 year of discovery thereafter unless the AEUB grants an extension; and
• the operator shall determine appropriate remedial measures and a schedule of repair subject to the approval of the AEUB.
• Operators with numerous existing vent blows that are categorized as serious solely based on the criteria outlined in “Serious Vent Blows” shall submit a repair schedule for AEUB approval.

Non-serious Vent Flows or Migration
• after initial detection and notification to the AEUB, the flow shall be monitored on an annual basis, and results kept on file by the Licensee. These results shall be made available to the AEUB upon request; and
• non-serious vent flows shall be repaired at abandonment.

Note: The requirements as outlined above are current as of March, 1995, and are subject to change after the printing date of this pamphlet. The requirements may be modified by the AEUB having regard for the area, public safety, or level of environmental hazard.
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