Lost Circulation

Introduction

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Losses of whole mud to subsurface formations is called *lost circulation* or lost returns. Lost circulation has historically been one of the primary contributors to high mud costs. Other hole problems such as wellbore instability, stuck pipe and even blowouts have been the result of lost circulation. Besides the obvious benefits of maintaining circulation, preventing or curing mud losses is important to other drilling objectives such as obtaining good quality formation evaluation and achieving an effective primary cement bond on casing.

Lost circulation occurs in one of two basic ways:

1. **Invasion** or mud loss to formations that are cavernous, vugular, fractured or unconsolidated.
2. **Fracturing** which is mud loss due to hydraulic fracturing from excessive induced pressures (see Figure 1).

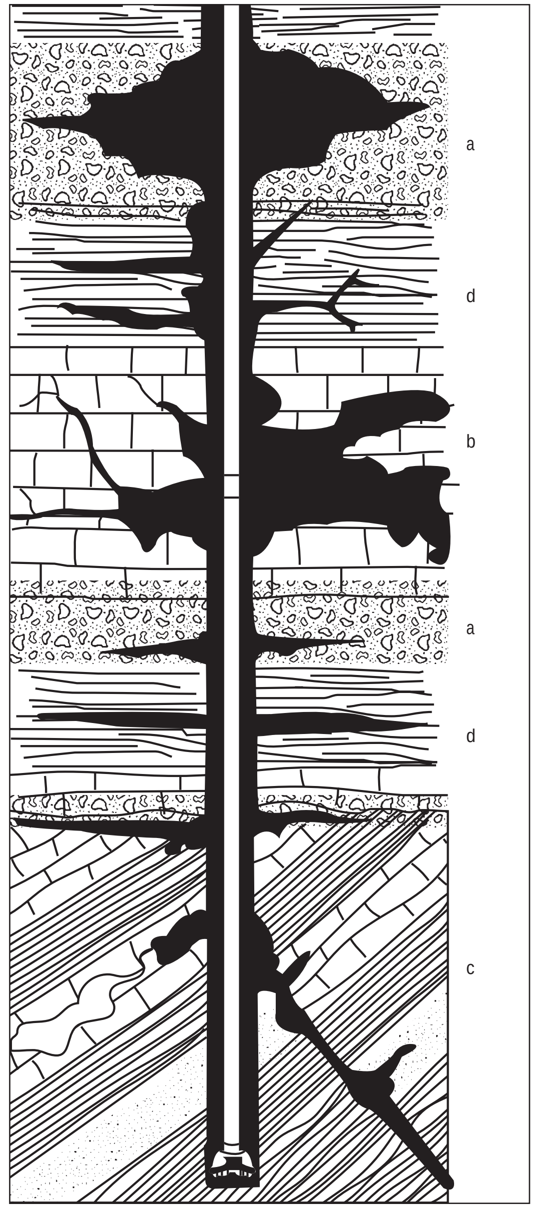


Figure 1: Lost-circulation sections:
a: High-permeability unconsolidated sands and gravel.
b: Cavernous or vugular zones in carbonates (limestone or dolomite).
c: Natural fractures, faults and transition zones in carbonates or hard shales.
d: Induced fractures from excessive pressure.

Causes of Lost Circulation

1. **Invasion.** In many cases, lost circulation cannot be prevented in formations that are cavernous, vugular, fractured or unconsolidated. Depleted low-pressure formations (usually sands) are similar relative to lost-circulation potential.
   a. Coarse, unconsolidated formations can have sufficiently high permeability for whole mud to invade the formation matrix, resulting in lost circulation. This high permeability is often present in shallow sands and gravel beds. Formations that were once reefs and oyster beds also have similar tendencies. One important reason for preventing mud loss in shallow intervals is that it may cause these unconsolidated formations to wash out, forming a large cavity that is less stable which could cave in more easily from overburden and rig weight.
   b. Another potential loss zone is in depleted formations (usually sands). Producing formations in the same field, or general vicinity, may cause subnormal (depleted) formation pressure due to the extraction of the formation fluids. In such a case, mud weights required to control other exposed formation pressures may be too high for the depleted formation, forcing mud to invade the low-pressure depleted formation (see Figure 2). If this situation exists, plans should be formulated to prevent lost circulation or stuck pipe from occurring in the depleted zone. Special bridging agents and sealing materials should be used to form a good seal and filter cake on the depleted zone.

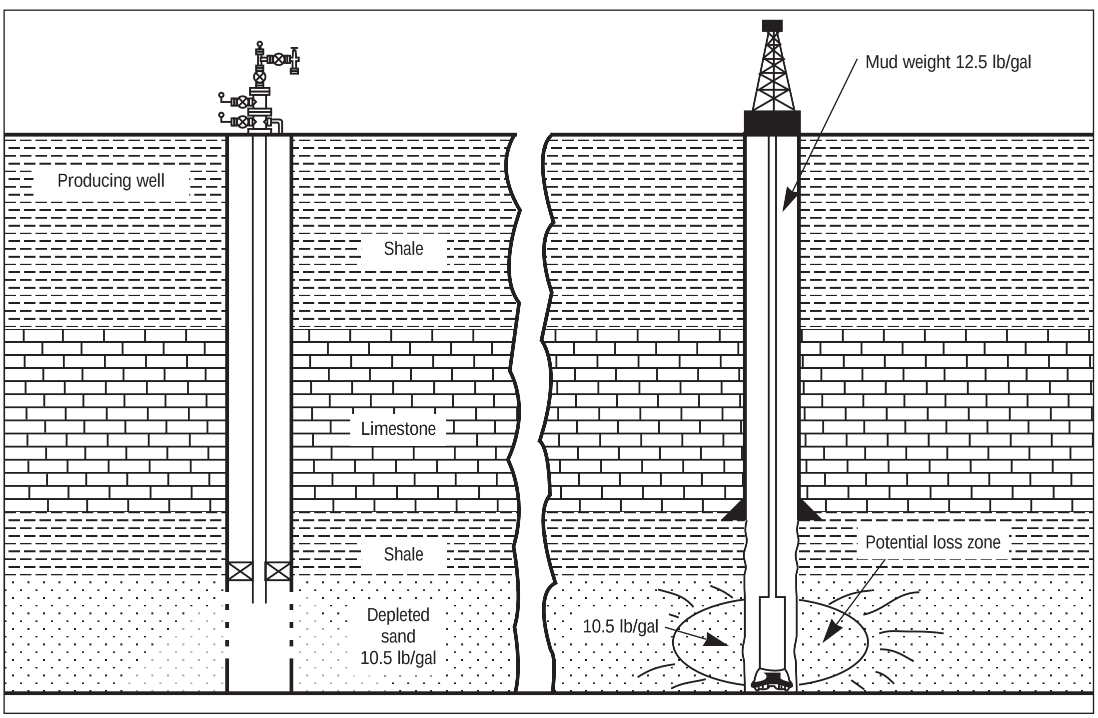


Figure 2: Depleted sand.

Cavernous or vugular zones are usually associated with low-pressure carbonate...

c. Cavernous or vugular zones are usually associated with low-pressure carbonate (limestone and dolomite) or volcanic formations. In limestone, vugs are created by the previous continuous flow of water that dissolved part of the rock matrix (leaching), creating a void space often later filled with oil. When these vugular formations are drilled, the drillstring may fall freely through the void zone and a rapid loss of mud is usually experienced. The volume and persistence of this kind of loss depends on the degree to which the vugs are interconnected. Similar vugs and caverns can develop during the cooling of volcanic magma or ash. Cavernous and vugular formations are often easily traceable from offset wells and predictable from mud logs and lithology.

Cavernous and vugular formations are often easily traceable... and predictable...

d. Mud loss also occurs to fissures or fractures in wells where no coarsely permeable or cavernous formations exist. These fissures or fractures may occur naturally, or may be initiated or extended by hydraulically imposed pressures. Natural fractures exist in many cases, which may be impermeable under balanced pressure conditions. Losses may also occur at unsealed fault boundaries.

2. **Fracturing.** Hydraulic fracturing is initiated and lost circulation occurs when some critical fracture pressure is reached or exceeded. Once a fracture is created or opened by an imposed pressure, it may be difficult to repair (heal) and it may never regain the original formation strength, as shown later in Figure 5. Lost circulation may persist even though the pressure is later reduced. This is one reason why it is better to pretreat for, and prevent, lost circulation than to permit it to occur. Lost circulation resulting from induced pressure is usually caused by one of two situations:

a. Setting intermediate casing in the wrong place. If casing is set above the transition zone crossing from normal to abnormal pressures, the pressures exerted by the heavier mud (required to balance the increasing pressures) will often induce fracturing at the weak casing seat. Losses due to fracturing are most commonly near the previous casing seat, not at bit depth, even if casing is properly set.

b. Excessive downhole pressures are the result of many conditions including:
   i. Mechanical forces.
      a) Improper hydraulics. Excessive pump rates and velocities causing high Equivalent Circulating Density (ECD) pressures.
      b) Drilling practices.
         1) Increasing pump rates too rapidly after connections and trips. This can be extremely important when dealing with oil-base fluids. Failure to bring the pumps up to speed slowly can put much higher circulating pressures on the formation due to the tendency of oil-base muds to thin at higher temperatures generated while circulating and to thicken at lower temperatures during trips. It is common for circulating pressures to decrease 100+ psi as the mud heats to circulating temperature.
         2) Raising or lowering the pipe too fast (surge/swab).
      c) Spudding bridges.
      d) Excessive Rate of Penetration (ROP) for a given flow rate will result in high cuttings concentration in the annular fluid causing a high ECD.
      e) Pipe whipping.

ii. Hole conditions.
  a) Sloughing shale or increased solids loading in the annulus and high equivalent circulating density.
  b) Accumulation of cuttings in a washed-out portion of the hole or in the mud.
  c) Cuttings beds or barite sag forming on the low side of a directional well, or possible slumping.
  d) Bridges.
  e) Kicks and well-control procedures.

iii. Mud properties.
  a) Excessive viscosities and gel strengths.
  b) Buildup of drilled solids.
  c) Thick filter cakes that reduce the hydraulic diameter of the wellbore.
  d) Excessive mud density or increasing mud density too fast.
  e) Unbalanced mud columns.
  f) Barite sag.

Preventive Measures

Good planning and proper drilling practices are the keys to preventing lost circulation…

Good planning and proper drilling practices are the keys to preventing lost circulation by minimizing excessive pressures on the formation.

Several measures can be taken to prevent or minimize lost circulation:

1. Set the casing in the appropriate zone so the fracture gradient of the formation at the casing shoe will be sufficient to support the hydrostatic head of heavier muds required to balance pressures in the formations below.
2. Minimize downhole pressures.
   a. Pipe movement should not exceed critical speeds when tripping. When the drillstring is run in the hole, there is a surging pressure from the piston effect of the bit and collars increasing the pressure exerted on the bottom of the hole. Good drilling practices will keep these pressure surges within the fracture and formation pressure, as shown in Figure 3.

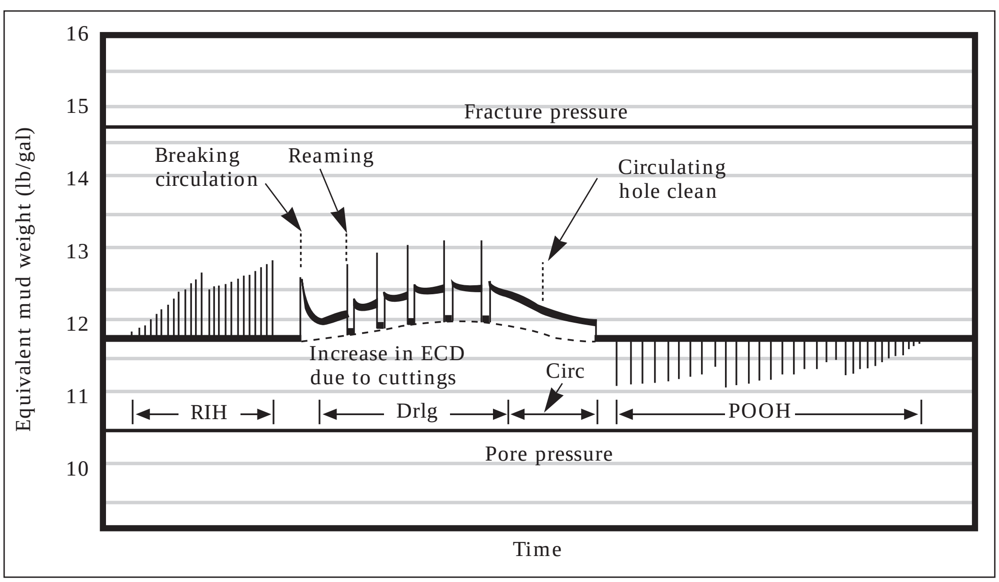


Figure 3: Bottom-hole pressure for normal drilling cycle (after Clark).

The longer the pipe, the greater the surge.

Many wells experience lost circulation while running pipe or casing into the hole. The length of pipe in the hole affects the magnitude of the surge. Tests show that the flow of mud along the pipe creates most of the pressure surge. The longer the pipe, the greater the surge. Therefore, the deeper the well, the slower the pipe should be run into the hole as the depth of the bit increases. Smaller annular clearances also increase surge pressures much in the same way annular pressure losses are increased as annular clearances decrease (see Figure 4).

b. Rapid movement of pipe while circulating also causes even greater pressure surges. Rapid "spudding" of the pipe or fast reaming while circulating can create large surges.

c. Very high ROP loads the annulus with cuttings, thus increases the ECD, making any further surging on connections more likely to cause fracturing as shown in Figure 5. It is important to control the ROP and circulate prior to making connections when the ECD is near the fracture pressure. Maintain the cuttings concentration in the annulus below 4% to minimize the effect of cuttings on ECD.

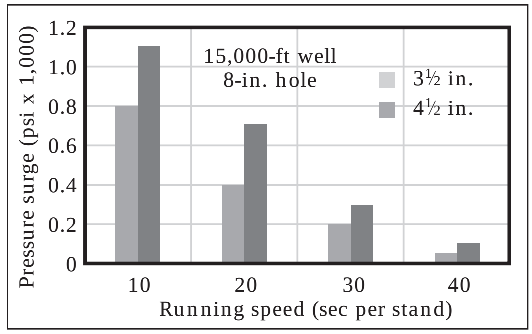


Figure 4: Effect of running speed and annular clearance on pressure surges.

Starting the pumps too rapidly will create a pressure that can cause lost circulation...

d. Rapid starting or stopping of the mud pumps can cause pressure surges. Starting the pumps too rapidly will create a pressure that can cause lost circulation, especially when breaking circulation on bottom after a trip. Part of the surge is caused by pressure required to break the gel structure of the mud. Rotating the pipe when starting circulation will aid breaking the gel strengths and greatly reduce the surge pressure. The other part of

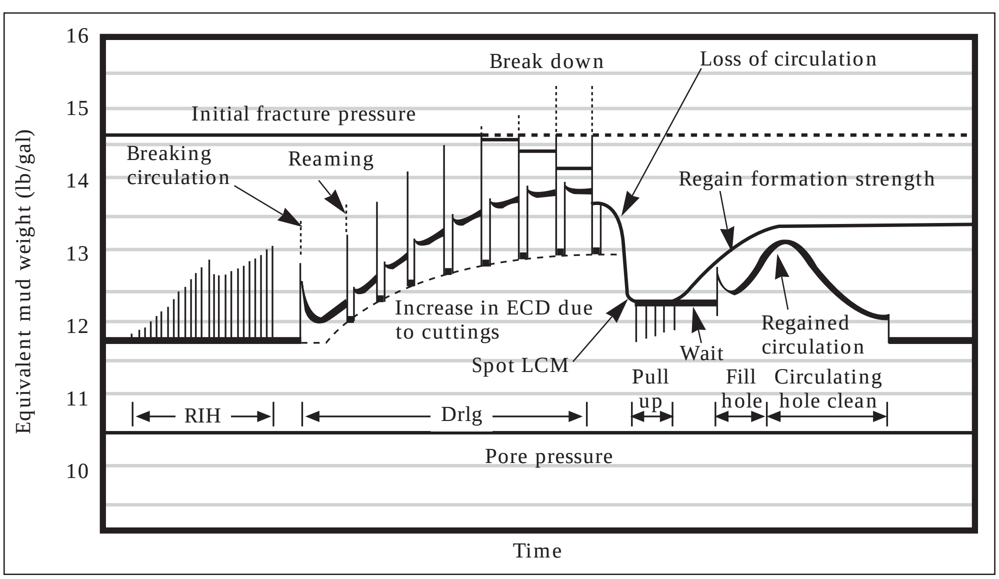


Figure 5: Drilling cycle causing fracturing and subsequent regain of some formation strength (after Clark).

the surge is the pressure required to accelerate the mud column to the normal circulating rate. Maintaining low gel structure and gradually increasing the pump rate will reduce this type of surge pressure. Breaking circulation at several intervals when tripping in hole is another way to minimize these pressures.

e. Use enough drill collars to keep the neutral point in the Bottom-Hole Assembly (BHA) to minimize drillstring whipping.

f. During the planning phase of the well, casings and drillstring design should be engineered for proper and safe operation, and also to optimize hydraulics for good hole cleaning and minimum ECD, especially in sensitive areas.

g. Wash and ream cautiously through bridges.

h. Avoid kicks if possible. Shut-in pressure at the surface is transmitted down the wellbore, often breaking the formation down at the weakest point. This not only results in loss of circulation, but losing control of the well. Proper research, well planning and execution will minimize the possibility and severity of a kick. Those responsible for the operation at the wellsite should always be aware of the maximum shut-in casing pressure and volume. The volume of the intruding fluid is directly related to the shut-in pressures and should be minimized. If a well has to be shut-in, proper kill procedures should be used to maintain the right constant bottom-hole pressure required to kill the well.

i. Control mud properties in the proper ranges.

   i. High viscosity and gel strengths increase surge pressures each time circulation is interrupted and restored (see Figure 6). They also increase the ECD while drilling. These values should be optimized to ensure good hole cleaning and solids suspension, and minimize ECD, surge and swab pressures.

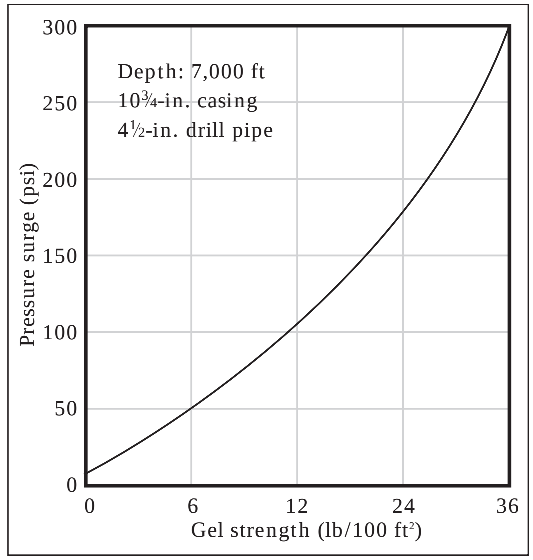


Figure 6: Effect of gel strength on pressure surge.

Many times mud properties can not be kept at a level which will provide adequate hole cleaning due to other operational considerations. Higher flow rates and aggressive drill pipe rotation are the best methods to improve hole cleaning. High viscosity sweeps are recommended in such cases where good hole cleaning is questionable. These sweeps are usually made of mud from the active system that has been viscosified by additions of bentonite, polymers or Lost-Circulation Material (LCM). The use of LCM in these sweeps is preferable in many cases since they are screened out at the surface and have no permanent effect on the viscosity of the mud. Controlling the ROP may be necessary if efficient hole cleaning can not be achieved. Although this may lengthen the rotating hours, it will generally be less expensive than the costs incurred by losing returns.

ii. Control drill solids at the minimum practical level and add proper treatment to minimize filter-cake build-up. Anything that reduces the annular clearance causes a pressure increase. Balling of the bit, collars, stabilizers or tool joints decreases the annular clearance. In the case of extensive bit and/or stabilizer balling, a significant pressure will be exerted on the formation. An increase in drag or swabbing on connections are possible indicators of balling. Sometimes a ball can be pumped off a bit, but if that fails, the common practice of spudding the bit should be avoided. The combination of the reduced annular clearance and the pipe surge can cause the pressure to exceed the fracture pressure.

iii. High fluid-loss muds deposit a thick filter cake that can reduce the annular clearance. The smaller annular space increases the ECD. Therefore, fluid loss and filter-cake thickness should always be controlled in the proper range. Mud that develops a thin, strong filter cake is more effective in preventing lost circulation to small fractures or pores.

iv. Drill with minimum mud density. This not only enhances the ROP but also diminishes other mud-related effects.

v. A good selection of the proper size of bridging materials helps reduce and eliminate whole mud losses into porous formations. The choice of such bridging agents will depend on the formation characteristics. Generally, particles that are one-third to one-half the square root of the permeability in millidarcies (md) should be able to bridge such formations.

When Lost Circulation Occurs

The probable location of the loss zone may be determined from knowledge available at the rigsite.

Analysis of the problem

When lost circulation is first noted, the conditions at the time the loss occurred should be accurately recorded and studied. The time of the occurrence (while drilling, circulating or tripping), the type of the loss (seeping, partial or complete) and the severity of the loss with respect to the exposed formations should be considered. This information will help determine why the loss occurred, where in the hole the loss occurred and the best remedy for the situation. The probable location of the loss zone may be determined from knowledge available at the rigsite. For example:

1. Formation information.
   a. Carbonate formations contain cavernous and vugular zones. This type of loss would be indicated if the loss was swift, large and accompanied by a drop in the drillstring.
   b. Shale formations tend toward fracturing that may be a slower type of loss. This loss needs to be controlled quickly, as continued losses will enlarge the fracture and compromise formation integrity.
   c. A change in the drill rate may indicate a formation change with possible change in formation integrity.

2. Operational information.
   a. Some type of hydraulic-pressure-induced lost circulation would be indicated if the mud weight was being increased at the time of loss. This type of loss may seal itself (seepage) or require treatment (induced fracture) depending on the severity of the loss.
   b. Rapid movement of the drillstring will cause pressure surges that can induce fractures or reopen previously sealed loss zones. Unless a previously sealed loss zone has been pressure tested it should always be assumed this area remains a potential source of losses. The rate of pipe movement during trips and while reaming should be adjusted to compensate for this weakness.

A more informed decision can be made regarding the proper steps to eliminate the losses with the information gathered above.

Locating the zone

Restoring circulation as quickly as possible is very important...

Restoring circulation as quickly as possible is very important since lost circulation increases mud cost and can cause other wellbore problems that result in additional operational costs.

1. Locate the exact point of lost circulation. Contrary to the common belief, the majority of the losses do not occur at the bottom of the hole. It has been established that more than half of the losses occur just below the last casing shoe. Several methods are available for locating the point of lost circulation. These include:
   a. Spinner survey.
      The spinner survey is made by running a small spinner attachment into the well on a single conductor cable in such a manner that the vaned rotor will spin or turn if there is any horizontal motion of the mud. The RPMs of the rotor are recorded on film as a series of dashes or spaces. The RPM will be very slow until the point of loss is reached. There is a definite increase in the rotor's speed at the point of loss.
      There are two objections to this method:
      i. It requires deliberate loss of large volumes of mud.
      ii. It is not effective where sealing material is already present in the mud.
   b. Temperature survey.
      The temperature survey depends on a subsurface thermometer for measuring the difference in the mud temperature and the formation temperature. It is made by running a sensitive element in the hole that changes its resistance as the temperature changes. Two surveys are run. The first is run to establish the temperature gradient of the well after the mud has come to equilibrium with the formation. The second survey is run immediately after adding fresh cool mud to the well. A sharp temperature discrepancy will occur at the point of loss.
   c. Radioactive tracer survey.
      Radioactive surveys for locating the point of loss consist of making two gamma ray surveys. A base log is run before the introduction of radioactive material. A slug of mud containing radioactive material is then pumped down the hole and a new log is run. High concentrations of the radioactive material will be located at the point of loss. This method provides accurate data for locating the point of loss, but requires expensive equipment and additional deliberate loss of mud to obtain the desired information.

d. Hot wire survey.

The hot wire tool is essentially a calibrated resistance wire that is sensitive to temperature changes. It is run to a desired point in the hole and the resistance is noted. Mud is then pumped into the hole. If the tool is above the point of loss, mud will flow by it, changing the resistance. If the resistance does not change, the tool is below the point of loss. The tool can be used in any kind of mud, but a large amount of mud is required while making the survey.

e. Pressure tansducer survey.

This type of survey involves using a short cylinder open at the top and swaged at the bottom to restrict the flow of mud through the tube. A window with a neoprene diaphragm is fitted on one side of the tube. There is an electrode that moves back and forth between the two fixed electrodes on the diaphragm. As the pressure differential varies across the diaphragm, the potential varies in the electric circuit indicating the rate of flow of the mud and where the mud becomes static.

This method appears to have certain advantages:

- It is simple in construction and operation.
- It is not easily clogged by lost-circulation material.
- It is workable in almost any type of mud.
- It can be used to locate a hole inside of casing.

Two apparent disadvantages are:

- Considerable mud flow is required.
- The equipment may not be readily available.

Though it is good practice to locate the thief zone, there are several reasons why surveys are not run more often:

i. Considerable time is spent getting the necessary equipment to the rig, and a deliberate loss of mud is required for these surveys.
ii. The results of these surveys are sometimes difficult to interpret.
iii. Conditions are not always such that the tools may be run because of abnormal subsurface pressure.

2. Determine the severity of loss. This is best determined by the amount of loss and the static mud column height. If the static mud column height is not visible it can be determined by running a piece of wood (4 in. x 4 in. x 4 ft) on a wireline. Another option is the use of a sonic echo-measuring device.
   a. Loss zones can be classified as:
      i. Seeping losses (1 to 10 bbl/hr).
      ii. Partial losses (10 to 500 bbl/hr).
      iii. Complete loss (hole full to mud level at 200 to 500 ft).
      iv. Partial or complete loss to deep induced fractures.
      v. Severe complete loss (hole full to mud level at 500 to 1,000+ ft).
3. Determine the type of loss. This is best determined by the lithology. Lost circulation as it relates to lithology is discussed above in “Causes of Lost Circulation.” These classifications can be related to the four types of formations in which mud losses occur (see Figure 1).
   a. Shallow, unconsolidated formations where rock permeability can exceed 14 darcies (see “a” in Figure 1).
      Identifying features.
      i. Offset records that identify the zone and its characteristics.
      ii. Gradual lowering of mud level in pits.
      iii. Loss may become complete if drilling is continued.

b. Formations that have natural fractures such as limestone and some hard shale formations (see "c" in Figure 1).
   Identifying features.
   i. Offset records and geological markers.
   ii. May occur in any type of hard, brittle rock.
   iii. Loss is evidenced by gradual lowering of mud in pits.
   iv. Loss may become complete if drilling is continued and more fractures are exposed.

c. Fractures that are induced through mechanical or hydraulic forces exerted on the formation (see "d" in Figure 1).
   Identifying features.
   i. Offset records that include excessive annular hydraulics.
   ii. Could occur in any type rock, but would be expected in formations with characteristically weak planes, such as soft shales.
   iii. Loss is usually sudden and complete.
   iv. Loss may follow any increase in mud weight or sudden surge in pressure.
   v. Can be in competent or incompetent formations.

d. Cavernous zones normally confined to limestone (see "b" in Figure 1).
   Identifying features.
   i. Normally confined to limestone and dolomite.
   ii. Loss of returns is usually sudden and complete.
   iii. Bit may drop from a few inches to a few feet just preceding loss.
   iv. Excessive torque may be experienced before loss.

4. Classification of loss by determining the pressure within the zone.
   a. Position the bottom of the drill pipe at the top of the suspected loss zone.
   b. Attach a suitably sized length of wood, approximately 4-ft long, to the rig survey line and run it down through the drill pipe until the static fluid level is found. A sonic echo-measuring device can also be used to find the fluid level.
   c. The pressure within the loss zone is then calculated as follows:

$$Pz = (Dz - Df)(MWp)(0.052)$$

Where:

Pz	=	Pressure of the loss zone (psi)
Dz	=	True Vertical Depth (TVD) of the loss zone (ft)
Df	=	Fluid drop inside the drill pipe (ft)
MWp	=	Fluid density inside the drill pipe (lb/gal)

   d. The static mud density which the zone will support is calculated as follows:

$$MWz = Pz\ (0.052 \times Dz)$$

Where:

MWz	=	Mud weight that the zone will support (lb/gal)

Corrective Measures

...make an assessment of the severity of a loss zone and match the remedial material and technique to it in terms...

Correlation of technique to severity

The best approach to control lost circulation is to make an assessment of the severity of a loss zone and match the remedial material and technique to it in terms of both the size of the material and its function.

1. Seeping losses can occur in any formation type when the bridging agents are not large enough to form a seal (see Figure 8a), or when there are no fine particles to complete the seal.
   a. The pull-up-and-wait technique should be the first technique used to attempt to regain full returns (see pull-up-and-wait technique).
   b. If the hole will not stand full while waiting, the technique of mixing an LCM slurry containing fine to medium bridging agents or utilizing a high-filter-loss slurry squeeze should be considered.
   c. Reduce mud weight if possible.
2. Partial losses occur in gravel, small natural fractures and barely opened induced fractures (see Figure 1). The same techniques used in seeping losses should be used in partial losses.
   a. The pull-up-and-wait technique should be the first technique used to attempt to regain full returns (see pull-up-and-wait technique).
   b. If the hole will not stand full while waiting, the technique of mixing an LCM slurry containing a blend of medium to large bridging agents or utilizing a high-filter loss slurry squeeze should be considered.
   c. Reduce mud weight if possible.
3. Complete losses occur to long, open sections of gravel, long intervals of small natural fractures, large natural fractures or open induced fractures (see Figure 1).
   a. The pull-up-and-wait technique should be the first technique used to attempt to regain full returns (see pull-up-and-wait technique).
   b. Use high-filter-loss slurry squeeze technique (see high-filter-loss squeeze technique).
   c. If returns are not regained with this technique, a hard plug such as a cement, cement-bentonite, cement-gilsonite or diesel-oil-bentonite-cement is recommended (see techniques for cement slurries).
   d. Reduce mud weight if possible.
4. Partial or complete loss to deep, induced fractures.
   a. The pull-up-and-wait technique (4 to 8 hr) should be the first technique used to attempt to regain full returns (see pull-up-and-wait technique).
   b. Apply soft plug squeeze (see techniques on soft plugs).
   c. If the hole will not stand full while waiting, the technique of mixing an LCM slurry containing a blend of large bridging agents or utilizing a high-filter-loss slurry squeeze should be considered.
   d. Reduce mud weight if possible.
5. Severe complete losses occur to large, open natural fractures, caverns and open induced fractures.
   a. Squeeze with either a high-filter-loss slurry squeeze or large amounts of diesel-oil-bentonite-cement slurries (see techniques for each).
   b. If the severe, complete losses continue to occur as more open, natural fractures or caverns are penetrated, the technique of drilling blind or with aerated mud and setting casing should be considered.
   c. Reduce mud weight if possible.

...lost-circulation techniques and materials must be functionally related to the losses they cure.

Fractured shales exposed to water-base muds will generally heal and circulation can be regained...

Causes for failure to regain circulation

Some of the most usual causes, directly or indirectly, for failure to control loss of circulation are:

1. The location of the loss zone is not established many times, resulting in attempts to place materials at the wrong spot. Loss zones are usually not on bottom but are near the last casing seat or lost-circulation point.
2. Lost-circulation materials are not systematically matched to the type and severity of the loss zone. There must be a mixture of particle sizes to initiate and propagate an effective seal.
3. There is sometimes a reluctance to proceed to the technique required to match the severity of the loss zone (i.e. drilling blind and setting pipe).
4. Adequate records are not kept that describe the losses and the materials and techniques used against them. Accurate accounts of experience in an area are valuable.
5. In cementing, the columns are not balanced and drilling mud breaks through the plug before it sets. In addition, when the pipe is withdrawn from the hole after placement, the mud level in the annulus goes down and mud from the formation can break through the freshly placed slurry. Balanced columns and plug-dropping techniques should be employed.
6. The formation strength is too weak to support the hydrostatic pressure of the fluid column needed to control the pressure in other exposed zones.

To be effective, the lost-circulation techniques and materials must be functionally related to the losses they cure. For example, where a reasonable amount (15 to 20 lb/bbl) of LCM has not worked in a high-filter-loss slurry, it is usually useless to use higher concentrations of the same or similar materials. The next step should be to increase the size of the bridging materials.

NOTE: It cannot be stressed too strongly that the lost-circulation technique must be matched to the severity of the loss zone.

Pull-up-and-wait technique

This technique should be used against seeping and partial losses, and losses to induced fractures.

Except for sudden, complete losses to limestones where large fractures, vugs or caverns occur, drilling and circulation should be stopped at the first indication of lost circulation.

The bit should be pulled to a point of safety and the hole permitted to remain static for a period of 4 to 8 hr. Carefully monitor the well for signs of intruding fluids and risk of a kick. After the waiting period, good drilling techniques must be followed in getting back to bottom to keep minimum pressures on the formations.

On the speculation that returns will not be obtained by waiting, a 100-bbl LCM slurry or a similar volume of high-filter-loss slurry can be mixed during the waiting period. If it is anticipated that the LCM pill will remain in storage for any length of time a biocide should be added to prevent bacterial degradation of any organic components.

Half of the losses in the Gulf Coast area were corrected by using this technique. Fractured shales exposed to water-base muds will generally heal and circulation can be regained, especially if pressures can be reduced with improved hydraulics and drilling practices. Oil-base fluids do not exhibit this self-healing behavior to the same extent.

This technique is particularly applicable to deep-induced fractures.

NOTE: The remaining techniques require the use of lost-circulation materials.

The size of the bridging material must be tailored to the severity of loss...

LOST-CIRCULATION MATERIALS (LCM)

Fibrous

- M-I-X II.™
- Cedar fiber (wood fiber).
- Sawdust (wood fiber).
- Drilling paper (paper).
- Magma Fiber® (mineral fiber).

Granular

- NUT PLUG® (nut shells - fine, medium and coarse).
- G-SEAL® (coarse graphite).
- Calcium carbonate (fine, medium and coarse).

Blends

- Kwikseal® (blend of fibrous, granular and flakes).
- M-I SEAL™ (blend of flake, granular and fibrous).

Flakes

- Flake (cellophane).
- Mica (fine and coarse).
- Pheno Seal.®

REINFORCING PLUGS

Water-base squeezes

- High-filter-loss squeeze (Salt gel — diatomaceous earth).
- Diesel-Oil/Bentonite (DOB) (soft plug).
- Bentonite — Bengum® (soft plug).
- Crosslinked polymer (soft plug).
- Diesel-oil/bentonite/cement (hard plug).
- Cement slurry (hard plug).

Oil-base squeezes

- Diatomaceous earth.
- Calcium carbonate — M-I-X.™
- Gunk squeeze for oil muds (VG-69® in water).

USE OF PLUGGING OR BRIDGING AGENTS

This technique should be used against seeping and partial losses and the less severe complete losses. A plug of bridging agents in the mud is mixed and applied as follows:

1. Establish the approximate point of the loss, type of formation taking the mud, height the mud stands in the hole and the rate of loss. The most probable point of the loss is just below the casing shoe if a fracture of the formation due to a pressure surge is suspected.
2. Use open-ended drill pipe for placement of the plug if practical. Otherwise use open watercourse bits or jet bits with the nozzles removed. If materials must be placed through a jet bit or MWD/LWD tools, medium-to-fine, sized bridging agents should be used to prevent plugging the bit. *NOTE: Use acid-soluble materials for losses to the reservoir.*
3. Mix a 100- to 250-bbl LCM slurry. Blends of coarse, medium and fine granular, fiber and flake bridging agents are commercially available and could be substituted for those added separately. Use mud from the circulating system or mix LCM in a freshly prepared, viscous, bentonite slurry.
   Add 15 lb/bbl of coarse NUT-PLUG.
   Add 5 lb/bbl coarse-to-medium fibers.
   Add 5 lb/bbl of medium-to-fine fibers.
   Add 5 lb/bbl of ½-in. cellophane flake.

NOTE: The size of the bridging material must be tailored to the severity of loss since the size of the openings taking the mud are seldom known. This logic is based on the knowledge that low rates of loss occur through small openings and higher rates of loss occur through larger openings. Figure 7 illustrates how materials that are too large will form a bridge at the face of the opening, while properly sized materials form a bridge in the opening where it is not as likely to be eroded away when circulation is resumed. Figure 8 illustrates how the use of materials that are too small go through the opening and do not form a bridge. When selecting the size of materials to use, the size of the nozzles in the bit and other possible restrictions (e.g. MWD tools, mud motors) should always be considered.

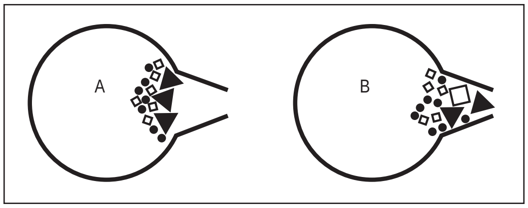


Figure 7a: Fracture seal at face of wellbore.
Figure 7b: Fracture seal within the formation.

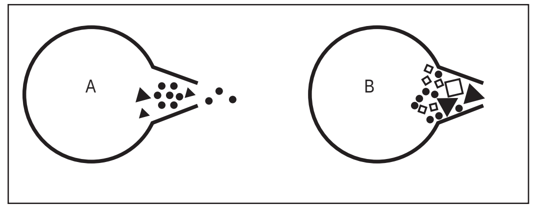


Figure 8a: Small lost-circulation materials failing to form a bridge. Figure 8b: Initial bridge being formed by large particle with final seal by smaller particles.

4. Pump the LCM slurry through the open-ended drill pipe opposite the loss zone. Pump at a slow rate until the materials have stopped the loss. Repeat once more if the hole does not fill and then proceed to a high-filter-loss slurry squeeze technique, if there still is no indication of success. If the hole fills, close the blowout preventers (rams) and squeeze the annulus with 50 psi for 30 min. Measure the pressure on the annulus using a 0- to 300-psi gauge. LCM slurries containing a blend of materials are most effective. Bridging agents must contain at least granular and fibrous agents to be effective. A useful LCM mixture is 3 to 6 parts granular, 2 parts fibrous and 1 part flake material.

The size of the granular and flake bridging agents should be matched to the severity of the loss. No advantage is gained if the concentration of lost-circulation materials in the total mud system or high-filter loss slurry exceeds 15 to 20 lb/bbl (see Figure 9). Pump

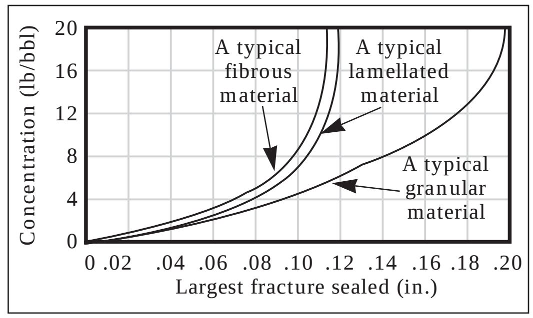


Figure 9: Effect of concentration and type of lost-circulation material on sealing fractures (after Howard and Scott).

trouble and poor mud properties may result from higher concentrations.

However, if bridging agents are to be applied in a slug of mud, then concentrations up to 30 lb/bbl can be more effective (see Tables 1 and 2). It is important to increase the size and amount of the granular agent if conventionally-sized materials are not effective. The effectiveness of granular, fibrous and flake bridging agents in plugging a simulated fracture is shown in Figure 9.

	Static Slot		Marble Bed		BB-Shot Bed	
Concentration (lb/bbl)	Largest Slot Sealed (in.)	Volume Thru at 1,000 psi (ml)	Volume Thru at 1,000 psi (ml)	Seal	Volume Thru at 1,000 psi (ml)	Seal
10	0.10	500	All	No	1,700	Yes
20	0.13	250	1,900	Yes	2,050	Yes
30	0.16	400	1,700	Yes	800	Yes
40	0.20	300	1,700	Yes	1,800	Yes

Table 1: Performance of various concentrations of mixed sealing materials (after Lummus).

	Test	30 lb/bbl Coarse-Grind Material	30 lb/bbl Medium-Grind Material
1	Pumping test through 9⁄32-in. standard jet bit nozzles	Plugged immediately	Flowed through at 200 psi
2	Static slot: Largest slot sealed (in.)	0.16	0.08
	Total vol through (ml)	400	100
3	Dynamic slot: Largest slot sealed (in.)	0.13	0.06
	Total vol through (ml)	600	0.50
4	Static marble bed: Vol through at 100 psi (ml)	500	400
	Vol through at 1,000 psi (ml)	1,700	1,200
5	BB-shot bed: Vol through at 100 psi (ml)	400	300
	Vol through at 1,000 psi (ml)	800	800

Table 2: Comparison of coarse and medium grinds of mixed sealing material in mud (after Lummus).

For a bridging agent to function, some of it must be of sufficient size to bridge the opening to be plugged.

Mud losses ranging in severity from seeps to complete losses into 1⁄8- to 1⁄4-in. natural and induced fractures can be stopped by using bridging agents. For a bridging agent to function, some of it must be of sufficient size to bridge the opening to be plugged (see Figure 10). Accordingly, fine granular material, fine fiber and cellophane flake should be used against seeping losses.

There is considerable evidence that a sufficient quantity of properly-sized granular material can prevent the propagation of induced fractures in permeable formations. This occurs when the granular material can pack into the fracture tip openings and prevent fluid and pressure from being transmitted. In the stimulation industry this is called fracture-tip "screen out." Fluids treated with 15 to 30 lb/bbl of material having a particle size similar to medium and coarse NUT PLUG, G-SEAL and extra-coarse calcium carbonate have the potential to limit hydraulic fracturing in weak sandstones.

Coarse granular material, coarse fiber, medium fiber, fine fiber and coarse flake should be used against complete losses.

NOTE: As the severity of the loss zone increases, only the size of the bridging agent should be increased — not the concentration. Concentrations above 20 to 30 lb/bbl do not improve effectiveness (See Figure 9).

Material	Type	Description	Concentration (lb/bbl)	Largest Fracture Sealed (in.)
				0 .04 .08 .12 .16 .20
Nut shell	Granular	50% – 3⁄16+ 10 mesh 50% – 10+ 100 mesh	20	
Plastic	Granular	50% – 3⁄16+ 10 mesh 50% – 10+ 100 mesh	20	
Limestone	Granular	50% – 3⁄16+ 10 mesh 50% – 10+ 100 mesh	40	
Sulphur	Granular	50% – 3⁄16+ 10 mesh 50% – 10+ 100 mesh	120	
Nut shell	Granular	50% – 10+ 16 mesh 50% – 30+ 100 mesh	20	
Expanded perlite	Granular	50% – 3⁄16+ 10 mesh 50% – 10+ 100 mesh	60	
Cellophane	Lamellated	3⁄4-in. flakes	8	
Sawdust	Fibrous	1⁄4-in. particles	10	
Prairie hay	Fibrous	1⁄2-in. fibers	10	
Bark	Fibrous	3⁄8-in. fibers	10	
Cotton seed hulls	Granular	Fine	10	
Prairie hay	Fibrous	3⁄8-in. particles	12	
Cellophane	Lamellated	1⁄2-in. flakes	8	
Shredded wood	Fibrous	1⁄4-in. fibers	8	
Sawdust	Fibrous	1⁄16-in. particles	20	

Figure 10: Summary of lost-circulation material tests (after Howard and Scott).

It is through filtration that the lost-circulation materials and mud solids are left as a firm plug in the opening taking mud.

HIGH-FILTER-LOSS-SLURRY SQUEEZE

Almost any mud can be used as a carrying fluid for spotting lost-circulation materials, but fluids that have extremely high-filtration rates are best. It is through filtration that the lost-circulation materials and mud solids are left as a firm plug in the opening taking mud. The principle of this technique is illustrated in Figure 11. Once the initial bridge forms, filtration allows filtrate to be lost from the slurry depositing a firm filter cake within the fracture itself. This very much resembles a wedge being driven into the fracture. This wedge is not only difficult to move, but serves to stop fracturing the wellbore.

This technique should be used against seeping and partial losses, and the less severe complete losses. The preparation of high-filter-loss slurries and their application to loss zones varying in severity from seeping to partial to complete are described later.

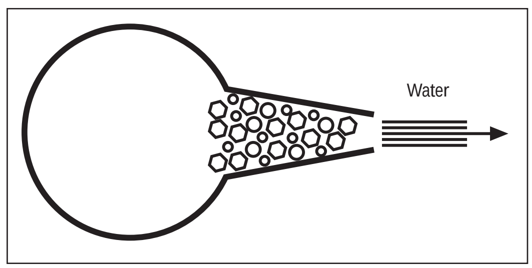


Figure 11: High-fluid-loss-squeeze technique for lost circulation showing water being lost through filtration depositing solids within fracture.

There are slight differences in application to these zones, but the main distinction is increasing the size of the bridging agent as the loss zone becomes more severe.

If hydraulic fracturing of the formation is suspected, the most probable point of loss is just below the casing shoe.

First, the severity of the loss should be established from the fluid level and the rate of loss. Then, the approximate point of the loss should be established and the type of formation taking mud defined. If hydraulic fracturing of the formation is suspected, the most probable point of loss is just below the casing shoe.

FOR SEEPING LOSS

1. Mix 100 bbl of slurry:
   a. Add 10 to 20 lb/bbl of attapulgite or sepiolite clay to 80 bbl of water (attapulgite and sepiolite clays behave similarly in saltwater). If these clays are not available, use 5 to 20 lb/bbl bentonite and pretreat the water with ¼ lb/bbl of soda ash and ¼ lb/bbl of caustic soda to remove calcium and magnesium ions. Allow clay to yield. If bentonite is used, add ½ lb/bbl of lime to flocculate the bentonite and increase the fluid loss.

or:

   b. Add 50 lb/bbl of diatomaceous earth materials (Diaceel® D, Diaseal® M or a suitable substitute such as LO-WATE™). Diaseal M is a mixture of diatomaceous earth, lime and paper. If this mixture is used, attapulgite is not required.

Add different LCM sizes and shapes to obtain a 10- to 20-lb/bbl total concentration of LCM.

2. Set the bit at the top of, or opposite, the loss zone. Displace the LCM slurry to the end of the drill pipe.
3. Close the rams. Gently squeeze (50 psi maximum) material into the loss zone at a rate of 1 bbl/min. Hold the squeeze pressure 4 to 8 hr or until it dissipates. Measure the squeeze pressure on the annulus using a 0- to 300-psi gauge.

To avoid fracturing other zones, safe squeeze pressures in excess of mud hydrostatic pressure should be used.

To avoid fracturing other zones, safe squeeze pressures in excess of mud hydrostatic pressure should be used. For example:

Depth (ft)	Squeeze Pressure (psi)
0 - 1,000	0 - 200
1,000 - 5,000	100 - 500
5,000 and deeper	500

NOTE: Surface pressure plus mud-column pressure should never exceed overburden pressure (1 psi/ft).

FOR PARTIAL LOSS

1. Mix 100 bbl of slurry:
   Add 10 to 20 lb/bbl of attapulgite or sepiolite clay to 80 bbl of water. If these clays are not available and bentonite is used as the viscosifier, add ½ lb/bbl of lime to flocculate the clays and increase the fluid loss.

or:

   Add 50 lb/bbl of diatomaceous earth materials (as before) or a suitable substitute (LO-WATE). Use barite only if the mud weight is 12 lb/gal or higher or if it is the only inert powdered material available.

Add a combination of different LCM sizes and shapes to obtain a 15-lb/bbl total concentration of LCM.

2. Set the drill pipe with the open end at the top of or opposite the loss zone.
3. Displace 25 bbl of slurry into the zone at a rate of 2 to 4 bbl/min.
4. Shut down for 20 to 30 min.
5. Displace another 25 bbl of slurry at the same rate.
6. Continue this procedure, alternately waiting and displacing until the hole fills. Sometimes two 100-bbl batches will be required. The drill pipe should be reciprocated during these operations to prevent it from sticking.

Various hard cement plugs are often effective against complete losses and severe complete losses.

7. When the hole fills, close the rams and squeeze the annulus with 50 to 100 psi by displacing the slurry very slowly (1 bbl/min) down the drill pipe. Attach a 0- to 300-psi gauge to the annulus so that low pressure values can be easily read. Maintain the squeeze for 30 to 60 min.
8. Pull out of the hole, pick up the bit and continue drilling.

For complete loss

The procedure for complete loss is the same as the procedure for "partial loss" except for the composition of the bridging agents. The composition of these materials should be as follows:

1. Add 10 to 15 lb/bbl of attapulgite or sepiolite clay to 80 bbl of water. If these clays are not available, treat the water as before. Add ½ lb/bbl of lime.

or:

Add 50 lb/bbl of diatomaceous earth materials (as before). Use barite only if the mud weight is 12 lb/gal or higher or if it is the only inert powdered material available.

Add a combination of different LCM sizes and shapes to obtain a 20- to 30-lb/bbl total concentration of LCM.

For displacement, see Steps 2 through 8 in "For partial loss."

2. When severe, complete loss returns occur in formations with large, naturally occurring fractures, vugs, channels or caverns; at least one conventional lost-circulation pill such as those previously discussed should be spotted. If this procedure fails to improve the lost-circulation problem, cavern treatments with bulk fillers such as rags, mud sacks, hay, paper, wood, etc. should be considered prior to pumping cement plugs.

Hard plugs

Various hard cement plugs are often effective against complete losses and severe complete losses.

The composition and technique of application of the cement slurry being used to combat lost circulation must be functionally adequate if the job is to succeed.

1. **Cement slurry composition.** Cement, or cement plus bentonite, is an important lost-circulation remedy because these slurries will often seal vugular loss zones.

   Three Portland cement slurries are recommended: neat, bentonite and gilsonite. These have been chosen because a wide variety of properties can be obtained and they are usually available.

   Neat-Portland cement. Mix to 15.6 lb/gal using 46% water and cement. This slurry is a dense fluid and develops high-compressive strength when it sets.

   Bentonite or gel cement. Bentonite cement formed by adding cement to water containing prehydrated bentonite gives optimum properties. The slurry formed has lower density and higher gel strength. It also has a higher set strength than a slurry formed by adding water to a dry mixture of bentonite and cement.

   In mixing the slurry, treat the freshwater to be used with ¼ lb/bbl of soda ash and ¼ lb/bbl of caustic to remove calcium and magnesium ions. Add 10 lb/bbl of bentonite and allow this to yield. Use this bentonite slurry to mix a 14.5 to 15.0 lb/gal bentonite-cement slurry. Use 100 sacks of cement or more for large hole sizes.

Gilsonite-Portland cement. Gilsonite can be added to cement slurries that are being used to regain returns. It decreases the density of the slurry and acts as a bridging agent, both of which help to keep the slurry in the vicinity of the wellbore. It should be run exactly like bentonite-cement slurries and should be squeezed if the hole fills during its application. Between 25 to 100 lb of gilsonite per sack of cement are recommended.

These three cements are recommended because they provide slurries with a range of properties from thin, heavy slurries that set hard, to lighter, thick slurries having bridging properties. They are also available everywhere. However, they are not intended to be used to the exclusion of all other cement formulations.

1. **Techniques for applying cement.** Cement slurries should be used to combat losses to natural fractures ⅓ in. to 1 ft in diameter, and to broken limestones or boulders.

NOTE: Cementing loss zones fails many times because mud has broken through the unset slurry. "Balancing columns" will usually prevent this, particularly if column weights are carefully calculated.

BALANCED-COLUMN METHOD

1. If possible, drill without returns through the entire lost-circulation zone.
2. Pull out of the hole. Measure the static mud level using a piece of wood (4 in. x 4 in. x 4 ft) on a wireline or a sonic echo fluid level meter.
3. Choose a cement slurry. According to the severity of the loss zone, mix and run 100 to 300 sacks.
4. Locate the loss zone, using an appropriate technique described previously.
5. Run the drill pipe and cementing sub past the loss zone to make sure it is exposed. Clean the hole past the zone if required. Pull up the cementing sub at a point 50 ft above the top of the loss zone.
6. Calculate the slurry volume of cement needed to be spotted. Mix and pump the cement until the desired volume is pumped. Displace the drill pipe at ±10 bbl/min. Leave enough cement inside the drillstring to balance the plug in the annulus. This will eliminate the U-tube effect and minimize cement contamination.
7. Slowly pull out of the hole. As the pipe is withdrawn, the mud level in the annulus will fall and cause an imbalance of pressure from the formation to the hole. This may cause mud or formation fluids to break through the cement slurry. To prevent this, very carefully add mud to the annulus through the fill-up line.

   Adding too much mud to the annulus will force mud from the annulus into the formation through the cement slurry before it has a chance to set. The amount of mud pumped must match the volume displacement (not capacity) of the pipe. If it is done carelessly, it can do more harm than good. Pump the required amount of mud every 10 stands. Wait on cement at least 8 hr.
8. Measure fluid level. If it is lower or higher than the original static level, do not attempt to adjust. If it is higher and another plug is run, adjust by adding proportionately less mud as the pipe is withdrawn.

DIESEL-OIL/BENTONITE/CEMENT SLURRY SQUEEZE

Use this technique against complete losses and severe complete losses. These steps should be used in applying this technique:

1. If possible, drill without returns through the entire lost-circulation zone.
2. Pull out of the hole. Measure static mud level as previously mentioned.
3. Locate the loss zone as in Step 4, balanced-column method.
4. After locating the loss interval, set the bottom of the mixing sub 50 ft above it. Set a maximum squeeze pressure.
5. Pump in a 10-bbl cushion of water-free diesel oil ahead of the slurry.
6. Mix 100 sacks of regular cement and 100 sacks of bentonite with 50 bbl of diesel oil. For volumes other than 50 bbl, mix two, 96-lb sacks of cement and two, 100-lb sacks of bentonite with each barrel of diesel oil. For large fractures or long sections of honeycombed vugs, 300 sacks of each material should be used.

   For large batches, use a cementer and mix the dry materials with the diesel oil continuously. For small batches use a suitable tank. This mixture will yield 1.39 bbl of slurry for each barrel of diesel oil. This slurry will weigh 11.5 lb/gal.
7. Displace the slurry down the drill pipe and follow it with 5 bbl of diesel oil.
8. Start pumping drilling mud into the annulus when the 10-bbl cushion of diesel oil reaches the mixing sub. Close the rams. Control the pumping rates so the ratio of the slurry volume to the mud volume is 2:1. Pump rates of 4 bbl/min down the drill pipe and 2 bbl/min down the annulus will usually be satisfactory with 4½-in. drill pipe in 7⅞-in. and larger holes.
9. Displace one-half of the slurry into the formation at this fast pumping rate. The drill pipe may occasionally be reciprocated slowly to indicate whether the slurry might be moving up the annulus. If the weight indicator shows any increased drag, break the connections and raise the pipe until it is free. Make connections and continue displacement. There is no need for concern over short shutdown periods since the slurry has no pumping time limitation inside the pipe.
10. Displace the next quarter of volume of slurry and mud at one-half the rate used in Step 9.
11. Displace the remaining quarter volume of slurry at one-half of the rates used in Step 10. If the hole fills, as shown by pressure on the annulus, attempt (by a hesitation squeeze) to obtain a pressure buildup using rates of 1 bbl/min into drill pipe and 0.5 bbl/min into annulus.

    NOTE: One barrel of slurry should be left in the drill pipe at the completion of the squeeze, if pressure has developed. Balance columns if no pressure develops. Do not attempt to reverse circulate because mud will contact the slurry and gel up inside the drill pipe.
12. After the squeeze job, pull out of the hole and wait a minimum of 8 hr for the cement to set before drilling out. If the first attempt is unsuccessful, repeat the procedure after waiting on the cement for 8 hr.

Avoid contamination of the slurry with mud or water in the suction lines and pumps.

PRECAUTIONS

Avoid contamination of the slurry with mud or water in the suction lines and pumps. The following steps will minimize the possibility of contamination.

1. Field test for diesel-oil suitability.
   a. Fill a sand content tube to the 20% line with the diesel oil.
   b. Add water to the "mud to here" line.
   c. Shake vigorously for 10 sec and allow to stand for 10 min.
   d. If the oil and water separate into two distinct layers, the diesel oil is suitable for use. However, if the fluid separates into three layers with the oil on top, the water on bottom and a white emulsion between, the diesel oil is not suitable and should not be used.
2. Drain all water and mud out of all pumps, lines and tanks prior to mixing.
3. Use diesel oil to thoroughly flush the pumps, lines and mixing facilities prior to mixing.

SOFT PLUGS

Downhole-mixed soft plugs (diesel-oil/bentonite, Bengum). Use this technique against induced fractures and to hold cement slurries at or near the wellbore until they set.

The success of downhole-mixed soft plugs depends on having the right amount of components meet and mix near the loss zone.

The success of downhole-mixed soft plugs depends on having the right amount of components meet and mix near the loss zone. Close attention should be paid to this.

For example, in using diesel-oil/bentonite, mud can be pumped into the annulus to establish the optimum constant mudflow rate before the diesel-oil/bentonite slurry leaves the drill pipe.

How to mix and apply diesel-oil/bentonite:

1. If possible, drill without returns through the entire lost-circulation zone.
2. Pull out of the hole. Measure the static mud level as previously described.
3. Locate the loss zone as previously described.
4. After locating the loss interval, run the placement sub past the loss zone to make sure it is exposed. Place the bottom of the mixing sub 50 ft above it. Set a maximum squeeze pressure.
5. Pump in a 10-bbl cushion of water-free diesel oil ahead of the slurry.
6. Mix 200, 100-lb sacks of bentonite with 50 bbl of diesel oil. For volumes of other sizes, mix 4 sacks of bentonite with each barrel of diesel oil. Mixing can be done continuously using a cementing truck. This mixture will yield 1.39 bbl of slurry for each barrel of diesel oil. For severe loss zones, 600 sacks of bentonite in 150 bbl of diesel oil mixed continuously should be used.
7. Displace the slurry down the drill pipe and follow with 5 bbl of diesel oil. When the front of the 10-bbl diesel oil cushion reaches the end of the drill pipe, begin pumping drilling mud into the annulus at a rate of 4 bbl/min with a second pump. Close the rams.
8. Control the pumping rates so that the ratio of slurry volume to mud volume is 1:1. Pump rates of 4 bbl/min down the drill pipe and 4 bbl/min down the annulus will usually be satisfactory with 4½-in. drill pipe in 7⅞-in. and larger holes.
9. Displace one-half of the slurry into the formation at this fast pumping rate or until pressure begins to build up on the annulus. When pressure is obtained, slow the pump rate on both the drill pipe and annulus to get the slurry into the loss zone without exceeding the maximum pressure set (100 to 500 psi). Attach

a 0- to 300-psi gauge to the annulus so that low-pressure values can be easily read.

The drill pipe may occasionally be reciprocated slowly to obtain an indication as to whether the slurry might be moving up the annulus. If the weight indicator shows any increased drag, break the connections and raise the pipe until it is free. Make connections and continue displacement. There is no need for concern over the short shutdown periods since the slurry has no pumping time limitation inside the pipe.

10. Displace the next quarter of slurry volume and mud at one-half the rate used in Step 9.
11. Displace all except 1 bbl of the remaining quarter volume of slurry at a rate of one-half the rate used in Step 10. Attempt, by a hesitation squeeze, to get a pressure buildup.

    NOTE: One barrel of slurry should be left in the drill pipe at the completion of the squeeze. Do not attempt to reverse circulate because mud will contact the slurry and gel up inside the drill pipe.
12. In instances where the hole cannot be filled, a packer should be set in the bottom of the casing. Mud and slurries should be displaced down the drill pipe in alternate batches of 20 bbl of slurry to 5 bbl of mud using a spacer of 1 or 2 bbl of oil between slurries.
13. After the squeeze job, pull out of the hole for the bit, drill out the plug and then drill ahead. Repeat the procedure if no squeeze pressure develops.

PRECAUTIONS: Observe the same precautions mentioned previously for the diesel-oil/bentonite/cement slurry squeeze.

These pills may also be used to prevent water flow and consolidate loose gravels.

How to mix and apply a Bengum squeeze

Halliburton Bengum No. 1 is a natural guar gum plus a preservative and a completing agent. Bengum mix is a 10 wt % Bengum No. 1 and 90 wt % bentonite premixed together.

Bengum slurry is prepared by adding 100 lb of Bengum-bentonite mix to 13 to 15 gal of diesel oil. It sets harder than diesel-oil/bentonite because of the organics it contains, particularly when mixed in saline waters and muds. Its set strength falls between that of diesel-oil/bentonite and diesel-oil/bentonite/cement but is more nearly like diesel-oil/bentonite. It should be used:

- Where more strength than that given by diesel-oil/bentonite is required.
- Where saline mixing waters are significantly lowering the strength of diesel-oil/bentonite. For application, follow the instructions for diesel-oil/bentonite above. The recommended ratio of mud to Bengum varies from 4:1 to 1:1 according to the strength required.

Crosslinked-polymer squeezes

Several companies offer crosslinked-polymer-squeeze pills in addition to the gunk and high-fluid-loss squeezes designed for lost-circulation applications. M-I's Form-A-Set™ is a crosslinked polymer and LCM slurry.

These pills are usually a blend of polymers and lost-circulation materials that crosslink with temperature and time to form a rubbery, spongy ductile consistency that effectively stops loss of fluid by sealing fractures and vugular formations. These pills may also be used to prevent water flow and consolidate loose gravels.

Depending on the manufacturer, the product may be a one-sack additive containing polymers and lost-circulation materials or be individually packaged. Most offer a retarder and accelerator for specific cases if needed. In most situations, the retarder will be required to delay premature crosslinking until the slurry can be placed opposite the loss zone.

The pills may be weighted with M-I BAR® or FER-OX,® if needed for well control. Depending on the manufacturer and the specific product, the materials may generally be mixed in salt water up to saturation but cannot be used with calcium-based brines. Salt usually acts as a retarder for the crosslinking mechanism. They may be used with non-aqueous (oil-base) systems by incorporating spacers while the slurries are mixed in water. The manufacturers' recommendations should be closely followed due to the differences in the crosslinking mechanisms and product limitations.

After mixing according to the individual manufacturers' recommendations, the pill is spotted similarly to other lost-circulation pills. Pump the slurry to the drill pipe and displace the slurry from the bit, pull up and squeeze the pill.

Pilot testing is highly recommended to determine the correct concentration of retarder or accelerator to be used. Typically, the pills will reach consistency at 115°F (46°C) in approximately 60 min with no retarder or accelerator used. The crosslinking is faster at higher temperatures. Therefore, in most situations a retarder will be needed. Again, consult the manufacturers' recommendations to avoid premature setup of the pill.

DRILLING BLIND/AERATED MUD

Drill blind or with aerated mud and set pipe. Use this technique against severe complete losses. In the case of very severe loss zones such as big caverns (with or without water movement) or long (500 to 1,000 ft) zones of honeycombed vugs or fractures, drilling blind or with aerated mud through all the loss zones and then setting pipe is often the only technique that can succeed.

Techniques for Treating Lost Circulation in Oil-Base Muds

Water-base fluids typically have a higher "spurt" fluid loss causing an almost instantaneous filter cake...

Although there should be no difference between water- and oil-base muds in the pressure needed to initiate a hydraulic fracturing of the formation, there is a significant difference once the fractures are formed. Water-base fluids typically have a higher "spurt" fluid loss causing an almost instantaneous filter cake to form that aids in formation sealing in permeable formations.

Oil-base fluids do not display the same characteristics. Once a fracture is initiated by an oil-base fluid, the pressure necessary to propagate the fracture is much smaller by comparison. This is compounded by lack of a significant pressure drop across the filter cake of most oil-base fluids. This allows changes in wellbore pressures to be transmitted to the formation more readily and further propagate the fracture. Studies have shown that the pressure required to re-open a fracture is also lower when using an oil-base fluid. A further complication is introduced if the lost-circulation material being used acts to prop open the fracture.

As mentioned earlier, properties unique to oil-base muds need to be considered when preventing lost circulation. The major properties and their effects are:

- Flow property differences caused by temperature. After a bit trip, it may be necessary to operate at a reduced flow rate until a full hole cycle is complete.

...these materials increase the equivalent circulating density.

This allows the mud to heat to normal circulating temperature and viscosity, preventing unnecessarily high equivalent circulating densities. Pump pressure differences in excess of 100 psi in heavier fluids are not uncommon as the fluid heats up.

- Due to greater fluid expansion in comparison to water-base fluids, the measured mud weight will often increase as the fluid cools on surface as during a trip. Again, these differences are magnified at higher mud weights. For this reason, the temperature at which mud is weighed should always be recorded. The temptation to reduce the mud weight in the pits during a trip should be resisted unless the weights were taken at the same temperature.

INCORPORATING LOST-CIRCULATION MATERIAL INTO THE SYSTEM

Incorporating large concentrations of lost-circulation materials into the whole system is not recommended since these materials increase the equivalent circulating density. This often compounds the lost-circulation problem instead of solving it. However, there are some cases in which seepage losses can be temporarily stopped or minimized by carrying small concentrations of lost-circulation materials in the system. Recommended materials and concentrations are as follows:

Use 2 to 6 lb/bbl of M-I-X II and/or 2 to 5 lb/bbl of LO-WATE (calcium carbonate). Small concentrations of fine NUT PLUG (1 to 10 lb/bbl) may also be used. Other lost-circulation materials tend to cause water-wetting and loss of electrical stability. If circumstances require the use of these other materials, the system should be monitored for their effects and treated accordingly. Pretreating with a wetting agent (VERSAWET®) may minimize these effects in some cases.

Oil-base-mud squeezes. These have proven to be the most effective method of sealing a loss zone. These squeezes should be of a volume sufficient to at least fill the hole 50 ft above and below the loss zone. The following squeezes have been most effective in sealing loss zones when oil-base muds are used.

DIATOMACEOUS-EARTH (DIASEAL M)/DIESEL-OIL SQUEEZE

1. The chart below should be used for mixing a diatomaceous earth (Diaseal M) slurry. After the slurry is mixed, 5 lb/bbl each of fine mica, medium NUT PLUG, M-I-X and calcium carbonate (LO-WATE) should be added. These concentrations may be modified depending on drillstring geometry.
2. Set the bit at the top of, or opposite, the loss zone. Displace the slurry to the end of the drill pipe.

Density (lb/gal)	Diaseal M		M-I BAR		Diesel Oil		VERSAWET	
	lb	sacks	lb	sacks	gal	bbl	gal	lb
8	44.0	0.880	20	0.20	38.92	0.926	0.140	1.00
9	41.2	0.824	73	0.73	37.58	0.895	0.210	1.50
10	38.5	0.770	128	1.28	36.18	0.861	0.250	1.75
11	35.7	0.714	181	1.81	34.85	0.829	0.250	1.75
12	32.9	0.658	237	2.37	33.43	0.796	0.250	1.75
13	30.0	0.600	291	2.91	32.06	0.763	0.250	1.75
14	27.2	0.544	346	3.46	30.67	0.730	0.250	1.75
15	24.5	0.490	400	4.00	29.30	0.698	0.285	2.00
16	21.8	0.436	454	4.54	27.93	0.665	0.285	2.00
17	18.9	0.378	509	5.09	26.55	0.632	0.357	2.50
18	17.0	0.340	563	5.63	25.13	0.598	0.428	3.00

Formulations for preparing one barrel of weighted Diaseal M slurry in diesel oil.

3. Close the rams. Gently squeeze (50 psi maximum) material into the loss zone at a rate of 1 bbl/min. Hold the squeeze pressure 4 to 8 hr or until it dissipates. Measure the squeeze pressure on the annulus using a 0- to 300-psi gauge.

To avoid fracturing other zones, safe squeeze pressures in excess of mud hydrostatic pressure should be used. For example:

Depth (ft)	Squeeze Pressure (psi)
0 - 1,000	0 - 200
1,000 - 5,000	100 - 500
5,000 and deeper	500

NOTE: Surface pressure plus mud-column pressure should never exceed overburden pressure (1 psi/ft).

Calcium-carbonate/ M-I-X II squeeze

1. Mud from the active system can be used as the base for this slurry. To the base mud, add 5 to 25 lb/bbl fine mica, 5 to 25 lb/bbl medium Nut Plug, 10 lb/bbl calcium carbonate (Lo-Wate) and 10 lb/bbl M-I-X II. The quantity of material mixed in the pill will depend on several conditions.
   a. The current mud weight. As fluid density increases, the quantity of lost-circulation material that can be added and maintain a pumpable fluid decreases.
   b. Restrictions in the drillstring. The size of the bit nozzles, internal restrictions from MWD, motors and other tools affect permissible lost-circulation material concentrations.
   c. Always check if the pumps or pumping units are equipped with suction screens. If so, the screens may need to be removed prior to pumping the pill.
2. Set the bit at the top of, or opposite, the loss zone. Displace the slurry to the end of the drill pipe.
3. Close the rams. Gently squeeze (50 psi maximum) material into the loss zone at a rate of 1 bbl/min. Hold the squeeze pressure 4 to 8 hr or until it dissipates. Measure the squeeze pressure on the annulus using a 0- to 300-psi gauge.

To avoid fracturing other zones, safe squeeze pressures in excess of mud hydrostatic pressure should be used. For example:

Depth (ft)	Squeeze Pressure (psi)
0 - 1,000	0 - 200
1,000 - 5,000	100 - 500
5,000 and deeper	500

NOTE: Surface pressure plus mud-column pressure should never exceed overburden pressure (1 psi/ft).

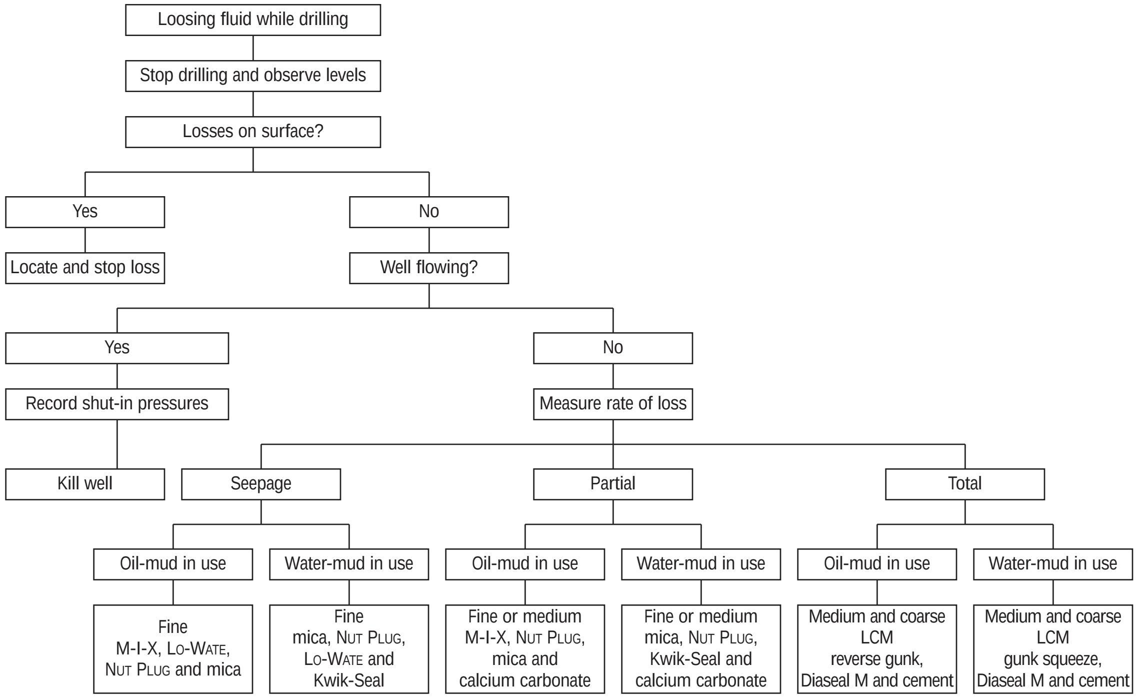
Gunk squeeze for oil muds

1. If possible, drill without returns through the entire lost-circulation zone.
2. Pull out of the hole. Measure the static mud level as previously described.
3. Locate the loss zone, using an appropriate technique as previously described.
4. After locating the loss interval, set the bottom of the mixing sub 50 ft above it. Set a maximum squeeze pressure.
5. Pump in a 10-bbl cushion of water ahead of the slurry.
6. Mix ½ lb/bbl of XCD® polymer and 250 lb/bbl of VG-69 in water to the desired volume of slurry.
7. Displace the slurry down the drill pipe and follow it with 10 bbl of water.
8. Start pumping oil-base mud into the annulus when the 10-bbl cushion of water reaches the mixing sub. Close the rams. Control the pumping rates so the ratio of slurry volume to the oil mud volume is 2:1. Pump rates of 4 bbl/min down the drill pipe and 2 bbl/min down the annulus will usually be satisfactory with 4½-in. drill pipe in 7⅞-in. and larger holes.
9. Displace one-half of the slurry into the formation at this fast pumping rate. The drill pipe may occasionally be reciprocated slowly to indicate whether the slurry might be moving up the annulus. If the weight indicator shows any increased drag, break the connections and raise the pipe until it is free. Make connections and continue displacement. There is no need for concern over short shutdown periods since the slurry has no pumping time limitation inside the pipe.
10. Displace the next quarter of volume of slurry and mud at one-half the rate used in Step 9.
11. Displace the remaining quarter volume of slurry at one-half of the rates used in Step 10. If the hole fills, as shown by pressure on the annulus, attempt (by a hesitation squeeze) to obtain a pressure buildup using rates of 1 bbl/min into drill pipe and 0.5 bbl/min into annulus.
    NOTE: One barrel of slurry should be left in the drill pipe at the completion of the squeeze. Do not attempt to reverse circulate because mud will contact the slurry and gel up inside the drill pipe.
12. In instances where the hole cannot be filled, a packer should be set in the bottom of the casing. Oil-base mud and slurries should be displaced down the drill pipe in alternate batches of 20 bbl of slurry to 5 bbl of oil-base mud using a spacer of 1 or 2 bbl of oil between slurries.
13. After the squeeze job, pull out of the hole and wait on the slurry to set a minimum of 8 hr before drilling out. If the first attempt is unsuccessful, repeat the procedure after waiting on the slurry for 8 hr.

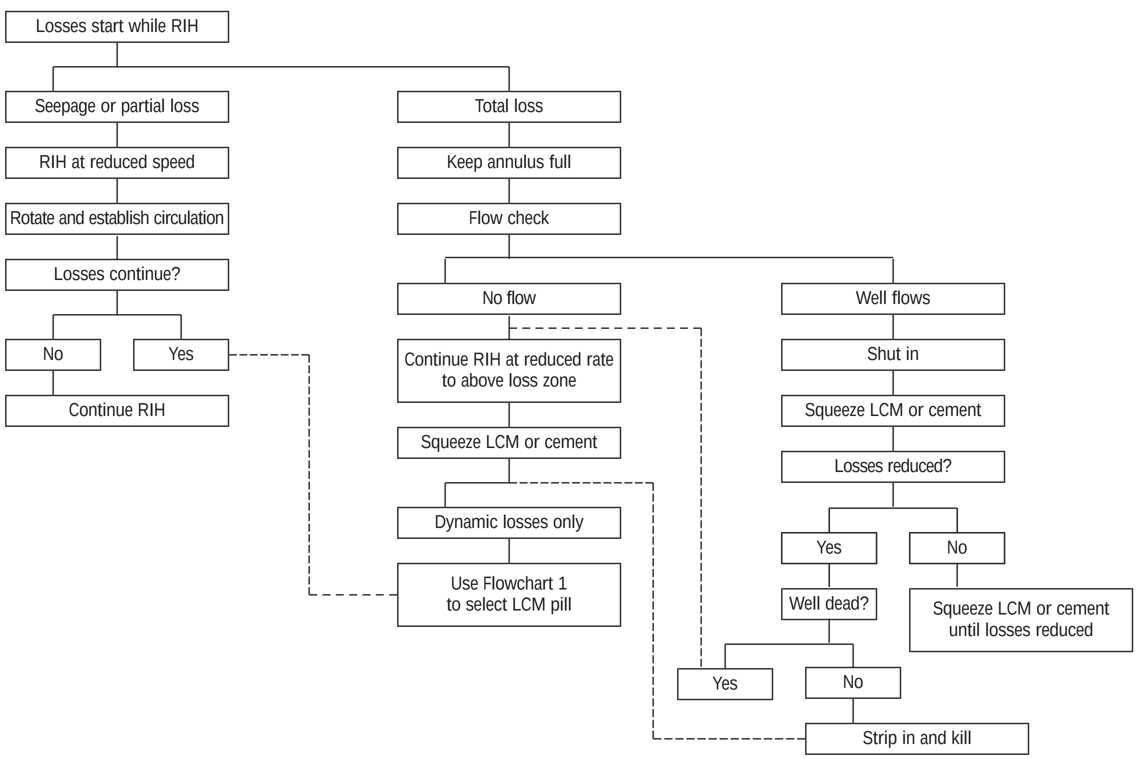
Precautions

Avoid contamination of the slurry with oil-base mud or water in the suction lines and pumps. The following steps will minimize the possibility of contamination.

1. Drain all oil mud out of all pumps, lines and tanks prior to mixing.
2. Use water to thoroughly flush the pumps, lines and mixing facilities prior to mixing.



Flowchart 1: Loosing fluid while drilling.



Flowchart 2: Losses start while RIH.