CEMENT BLENDING

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1 INTRODUCTION

The process of uniformly mixing dry cement additives into the cement at the design concentration is termed cement blending. A cement blend is delivered to location where a cement mixer mixes it with water to produce a cement slurry.

The importance of proper cement blending is evident when one considers that for some cement systems as little as 18 lbm of an additive are blended with 18,000 lbm of cement. Nonuniform additive blending (e.g., small variations in additive concentrations) or incorrect additive concentration results in improper slurry performance in the wellbore and can have drastic consequences in the well.

The blending procedures presented in this manual section do not address special blending requirements dictated by certain cement additives (e.g., D124, D154). For these additives or when in doubt about the correct blending procedure for any additive, refer to the respective section in the *CEMENTING MATERIALS MANUAL*.

When practical and feasible, dry additives can be added directly to the mix water contained in a tank (see *SECTION 7.B.1—ADDITIVE MIXING*).

2 EQUIPMENT

The required equipment for cement blending are

- weigh batch blender (WBB)
- transfer holding tank or tanks (THT)
- pneumatic bulk storage tanks (BST)
- pneumatic loading bottle (PLB)
- additive weigh scales capable of calibration at ±0.5 lbm (AWS)
- sampling device or container (SD).

A typical configuration of this equipment is shown in Fig. 1. The numbers in this figure (e.g., #1, #2) identify the different possible cement transfers and are referenced in the blending procedures.

3 PROCEDURE

The size of each single batch to be blended ***must neither*** exceed 100% of the bulk volume of the smallest vessel in the blending system ***nor*** 75% (depending on the system being blended) of the total volume of the weigh batch blender.

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1 INTRODUCTION

SECTION 7.A.1—CEMENT BLENDING presents the equipment associated with cement and dry additive blending, including a brief description of a bulk plant. *SECTION 7.B.1—ADDITIVE MIXING* describes the liquid additive metering systems. In this manual section, the remaining equipment associated with a cement job is addressed.

The following discussion describes the different cementing equipment and presents their functional principles and operating limits. Detailed operating instructions can be found in the respective operator's manual. Mixing and pumping equipment are individually presented although they are often contained on the same unit.

2 BULK CEMENT DELIVERY

The equipment used to deliver the cementing materials to the wellsite varies according to the location.

2.1 Land Rigs

Trucks or semitrailer transports are generally used for delivering cement blends to land operations. Truck-mounted vertical tanks or semitrailer-mounted vertical or horizontal tanks are the most common.

In addition to delivering cement blends to the wellsite, these transports may be used as temporary wellsite storage. Instead of transferring the blends from the transports to the field bulk tanks before the cement job, the cement blends are directly transferred from the transports to the cement mixer during the job. For this reason, the transports have a cement delivery rate sufficient to meet most slurry mixing rates.

2.2 Offshore Rigs

Supply boats or cementing vessels deliver cementing materials to the offshore operations. They normally have built-in tanks, pneumatic unloading equipment, and a supply of hoses. Sometimes, mobile skid-mounted tanks (with a low center of gravity) and mobile unloading equipment are used.

The pneumatic equipment must be capable of blowing high-density materials such as barite up to the drilling rig tanks, a vertical distance of 130 to 200 feet. The most commonly used air compressors deliver 250 to 350 ft^3/min with a pressure rating of 30 to 45 psi.

3 WELLSITE STORAGE

On offshore rigs, the bulk storage tanks are a permanent part of the drilling rig equipment.

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1 INTRODUCTION

To avoid reader confusion in this discussion, the terms "base fluid" and "mix fluid" must be first defined. Base fluid is fresh or salt water containing no liquid additives. Mix fluid is the base fluid plus the required liquid additives at the design concentrations. For cement systems using only dry additives, the base fluid is the mix fluid.

Additive mixing is the process of adding the required cement additives (liquid or dry) to the base fluid at the correct concentration. Additive mixing of dry additives is performed by adding the correct concentration of each additive to a tank containing a volume of mix fluid. Additive mixing of liquid additives is achieved by metering the additives into the displacement tanks, which are used to gauge the mix fluid during the mixing operation, or by adding them in the same manner as dry additives.

2 DRY ADDITIVE MIXING

A dry additive can be added to a mix fluid only if it will completely hydrate, remain uniformly dispersed (no separation), and not lump under normal mix-fluid agitation conditions. For dry additive addition, the use of a mixing hopper or the addition at the eye of the mixing vortex will promote good dispersion and no lumping.

The volume of mix fluid in the tank must equal the total mix-fluid requirements + the water losses due to the suction piping and hoses + a safety factor. The required amount of each dry additive is based on this volume.

Dry additive mixing is the most simplest method of mixing additives with the mix fluid. However, an additional clean tank with sufficient volume is required and sufficient space to accommodate this tank may be a problem (e.g., offshore). Also, the maximum slurry volume that can be mixed is limited by the volume of mix fluid prepared in the tank.

2.1 Example

Calculate the required amount of each additive for dry additive mixing based on the following information.

Information

Cement system:
500 sacks Class G + 0.8% BWOC D160
+ 0.2% BWOC D13
Mix-fluid requirements: 4.97 gal/sack

Volume of suction piping and hoses = 4 bbl (estimate)
Safety factor = 10 bbl

Calculations

Mix-fluid requirements = 500 sacks x 4.97 gal/sack
= 2485 gal = 59.2 bbl

Tank water volume = 59.2 bbl + 4 bbl + 10 bbl
= 73.2 bbl

The mix fluid in the tank must contain the correct concentration of additives such that when the cement is mixed with the mix fluid, the slurry has the correct additive concentration. In order to determine the required amount of additives, the amount of cement that the tank water volume would theoretically mix must first be calculated.

$$\textit{Theoretical cement amount} = \frac{73.2\ \textit{bbl} \times 42\ \textit{gal/sack}}{4.97\ \textit{gal/sack}}$$

$$= 619 \text{ sacks}$$

The amount of additives is calculated based on this theoretical amount of cement.

D160 amount = 619 sacks x 94 lbm/sack x 0.008 (0.8%)
= 466 lbm

D13 amount = 619 sacks x 94 lbm/sack x 0.002 (0.2%)
= 116 lbm

These D160 and D13 amounts are added to the 73.2-bbl volume of mix fluid in the tank to achieve the correct additive concentration after slurry mixing.

3 LIQUID ADDITIVE MIXING

Liquid additive mixing enables cement to be continuously mixed with mix fluid containing the correct concentration of additives without the use of additional tanks. It employs a semi-manual or automatic metering system which delivers the correct amount of additives to each displacement tank during the slurry-mixing operation.

All liquid additive metering systems consist of two principle components—a storage/transfer unit and a metering unit. The storage/transfer unit generally includes four storage tanks of various capacities (usually from 250 to 1000 gal), each equipped with its own pump and agitation system to avoid segregation of the additive components. The storage and transfer unit allows the independent metering of additives according to the requirements of a particular job.

Liquid addition to the base fluid can also be achieved using the dry additive mixing procedure. The required amounts of liquid additives are calculated in the same manner as the amounts of dry additives. However, a volume equal to the total volume of the liquid additives must be removed from the tank prior to adding the liquid additives.

3.1 Metering System with Metering Tanks

The metering system with tanks generally consists of a set of three (see Fig. 1) or four 25-gal tanks, with visible level scales.

To prepare a batch (10 or 20 bbl according to the displacement tank capacity), the proper amounts of the selected additives are introduced into the metering tanks. The additives are then released into one displacement tank, which is being filled with base fluid. Finally, the mixture is agitated to obtain a homogeneous solution. The same operation is repeated for the following batch in the other displacement tank and so on. The repetitions of this operation may be automatically or semi-automatically controlled.

3.2 Metering System without Metering Tanks

The liquid-additive-system metering rack (see Fig. 2) is used to provide accurate (±2%) delivery of up to four additives into the displacement tanks. The metering rack behaves like four "smart valves", between the additive pumps and the displacement tanks. The valves are controlled by a microcomputer using data from electromagnetic flowmeters.

A liquid additive in an LAS* tank should not be sampled until it has been circulated for at least 30 minutes. The sample should be taken from the pump suction line or from the main fill hatch. For a liquid additive to be added to the base fluid before the job commences, its drum container must be thoroughly rolled to ensure it is well mixed prior to sampling with an open-ended tube.

A mix-fluid sample should be taken prior to job commencement.

4 SIZE OF SAMPLES

Table 1 presents the minimum required size of different types of samples.

TABLE 1
MINIMUM SAMPLE SIZE

Type of Sample	Minimum Sample Size
Base fluid	4 liter
Mix fluid	4 liter
Cement or cement blend	25 lbm
Liquid additive	1 liter
D66 or D30	10 lbm
D20	2 lbm
Other dry additives	1 lbm

The quantities of mix fluid, base fluid and additives should equal the estimated amounts required to perform testing on the total cement sample.

5 PACKAGING, LABELING AND SHIPMENT OF SAMPLES

The dry samples (e.g., cement, cement blend, dry additives) should be packaged in sealed metal or plastic containers lined with plastic bags that are sealed with a tie. For liquid additives, one-liter, plastic-sealed containers should be used. The base and mix fluids should be placed in four-liter, plastic-sealed containers.

All samples must be labeled with the following information:

- date
- additive type (Dowell code, blend composition, slurry density or volume of base or mix fluid required)
- Client
- rig name & number
- well name
- well number
- job type
- batch number
- silo number
- name of person (who took sample).

Each offshore rig must have three metal sample boxes marked for its use. This enables the rig and the Dowell laboratory to each hold one box while the third box is in transit. Each box is delivered to the rig containing

- three five-liter pails with sealing tops and plastic liners for dry bulk materials
- four one-liter containers for liquid additives
- one five-liter plastic container for the base or mix fluid
- labels to properly mark the containers.

When the sample box is forwarded to the laboratory, the SS/FE must provide the Client and the FSM/Cell Leader with the shipping information and the purpose of the samples. Offshore, this will be coordinated through the Client's rig superintendent. All information should be communicated in writing to the laboratory by using the appropriate analysis request form.

The samples delivered to the laboratory for testing are stored for a minimum of 30 days. For rig samples, the cement should be kept until the job has been proven successful.

SAMPLES AND SAMPLING

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1 INTRODUCTION

Laboratory testing of cement or cement blends is used to

- perform quality-control checks on newly delivered cement
- design cement systems
- ensure the properties of actual cement blends match the design objectives
- aid post-treatment investigations.

Meaningful laboratory testing of a material or blend is not possible unless it is performed using a representative sample of sufficient quantity.

Prior to any cement job, samples of

- dry cement or dry blend or both
- all additives whether dry or liquid
- base fluid to be used on the job (see Subsection 1 in *SECTION 7.B.1—ADDITIVE MIXING* for the definitions of base fluid and mix fluid)

are to be sent to your laboratory to test the slurry design chosen for the job.

2 BULK PLANT SAMPLING

Samples are taken at a bulk plant for

- quality-control testing of new cement
- slurry design testing
- quality-assurance testing of cement blends.

When receiving cement deliveries, a lateral sampling assembly (see Fig. 1) installed between the cement transport and the bulk storage tank can be used to obtain a representative neat cement sample. During the cement transfer, many small samples should be taken throughout the cement movement.

For slurry design testing, the cement sample can be taken by using a lateral sampling assembly or an automated diverted flow sampler (see Fig. 2). Cement is transferred from the bulk storage tank to a clean empty weigh batch blender or silo and then back to the storage tank, passing through the sampling device. Again, small cement samples should be taken throughout the cement movement.

Several sampling points should be used when taking a dry additive sample. For a liquid additive, its drum container must be thoroughly rolled to ensure it is well mixed prior to sampling with an open-ended tube.

Cement blends (cement and dry additives) must be collected during the middle of the last transfer (to the bulk transport vessel). One sample from each blend batch is required.

3 ON-SITE SAMPLING

A clean lateral sampling assembly (see Fig. 1) installed in the cement delivery line from the transport or field bin to the cement mixer can be used to obtain a representative cement or blend sample. During the cement job, many small samples should be taken. Cement samples should not be taken from the vent or discharge lines and surge cans.

TABLE 1
WORKING AND SAFETY RELIEF-VALVE PRESSURES FOR PRESSURIZED BULK TANKS

Pressure Vessel Location	ASME Coded Tank Allowable Working Pressure (psi)	Safety Relief-Valve Pressure Setting (psi)
Inland barges	30	35
Offshore tanks	40	45
Land bulk storage tanks	30	35
Truck bulk tanks	30	35
Portable field bins	30	35

4 CEMENT MIXING

Cement mixing is the process where a flow of pressurized water (possibly containing additives) meets a flow of cement (possibly containing additives), and a cement slurry is formed.

The primary differences between the Dowell cement mixers are

- the physical mechanism by which cement mixing is achieved
- the events that the cement slurry experiences in the mixer prior to being pumped down the well.

Each cement slurry is to be mixed at a predetermined density. The slurry density during mixing is normally measured by a densitometer on the mixing unit. The pressurized mud balance is used to verify the measurement accuracy of the densitometer.

4.1 Cement Mixers

The mixing capabilities of a cement mixer are significantly affected by

- the delivery rate of the cement blend
- the delivery rate of the mix water
- the composition of the cement blend
- the composition of the mix fluid.

Therefore, the performance of cement mixers in practical terms is difficult to determine and, in most cases, not available.

The different Dowell cement mixers are

- Jet Mixer
- SLURRY CHIEF* Mixer
- TORNADO* Mixer
- VIP Mixer* Unit
- Batch Mixer.

4.1.1 Jet Mixer

The jet mixer consists of

- a hopper
- a mixing bowl
- a discharge gooseneck
- a slurry tub.

Figure 3 shows a configuration for sacked cement, and a system for pneumatically delivered cement is illustrated in Fig. 4.

The cement is delivered to the hopper. The water is injected into the bowl through the jets for mixing with the cement, and into the gooseneck for adjusting the slurry density. The jets are chosen according to the operating pressure, slurry mixing rate, and the type of dry materials.

The movement of cement down the hopper is assisted by the high-pressure flow of water through the jets. The resulting pressure drop pulls the dry cement into the stream of water. To reinforce this effect, the gooseneck can be given a venturi tube profile. Further along the gooseneck, turbulent flow mixes the cement particles with the water, and the result is a cement slurry.

The slurry density is adjusted by using the bypass system to change the water-to-cement ratio. As the bypass is opened, the suction effect decreases, and reduces the amount of cement drawn out of the hopper. At the same time, the water bypassing the jets enters the slurry. The combined effect is a decrease in the slurry density. Conversely, if the bypass is closed, the slurry density increases.

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* Mark of Schlumberger

On land rigs, the bulk tanks are brought to the rig site for the cement job. These tanks are similar to those used at central storage locations, but their dimensions allow transport on a truck or semitrailer. When empty, the tanks do not exceed the weight limits specified by various countries.

A large variety of storage tanks exists within two principal categories—atmospheric and pressurized. Both are equipped with a set of skids for proper installation on imperfectly leveled ground and easy winching onto trucks and trailers.

3.1 Atmospheric Bulk Tank

The atmospheric tank (see Fig. 1) is always operated in a vertical position. Air at low pressure (about 3 psi) is blown into a gutter fixed to the slant bottom of the tank. The roof of the gutter is made of a porous material that allows air to pass through it and aerate the cement blend. The cement blend glides along the slant bottom to the chute gate and into the hopper of the slurry mixing system.

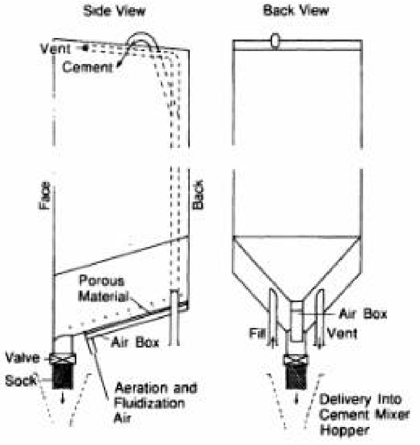

Fig. 1. Atmospheric transportable bulk tank (typical piping arrangement).

3.2 Pressurized Bulk Tank

Pressurized tanks can operate horizontally or vertically. Vertical tanks (see Fig. 2) are generally cylindroconical in shape, while horizontal tanks are more complex.

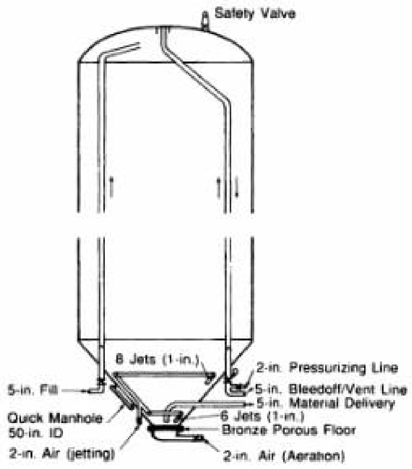

Fig. 2. Pressurized bulk tank (typical piping arrangement).

The cement blend is delivered from the tank to the mixer as described in the following steps.

1. The cement is aerated by blowing pressure-reduced air into the tank bottom through the cement.
2. The tank is pressured up to the tank allowable working pressure (see Table 1).
3. The tank discharge valve is opened enabling cement to flow out through the discharge line to a surge tank, which feeds the cement mixer.
4. Cement flow (and tank pressure) is maintained by injecting air into the tank.

CEMENTING EQUIPMENT

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1 INTRODUCTION

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The following discussion describes the different cementing equipment and presents their functional principles and operating limits. Detailed operating instructions can be found in the respective operator's manual. Mixing and pumping equipment are individually presented although they are often contained on the same unit.

2 BULK CEMENT DELIVERY

The equipment used to deliver the cementing materials to the wellsite varies according to the location.

2.1 Land Rigs

Trucks or semitrailer transports are generally used for delivering cement blends to land operations. Truck-mounted vertical tanks or semitrailer-mounted vertical or horizontal tanks are the most common.

In addition to delivering cement blends to the wellsite, these transports may be used as temporary wellsite storage. Instead of transferring the blends from the transports to the field bulk tanks before the cement job, the cement blends are directly transferred from the transports to the cement mixer during the job. For this reason, the transports have a cement delivery rate sufficient to meet most slurry mixing rates.

2.2 Offshore Rigs

Supply boats or cementing vessels deliver cementing materials to the offshore operations. They normally have built-in tanks, pneumatic unloading equipment, and a supply of hoses. Sometimes, mobile skid-mounted tanks (with a low center of gravity) and mobile unloading equipment are used.

The pneumatic equipment must be capable of blowing high-density materials such as barite up to the drilling rig tanks, a vertical distance of 130 to 200 feet. The most commonly used air compressors deliver 250 to 350 ft^3/min with a pressure rating of 30 to 45 psi.

3 WELLSITE STORAGE

On offshore rigs, the bulk storage tanks are a permanent part of the drilling rig equipment.

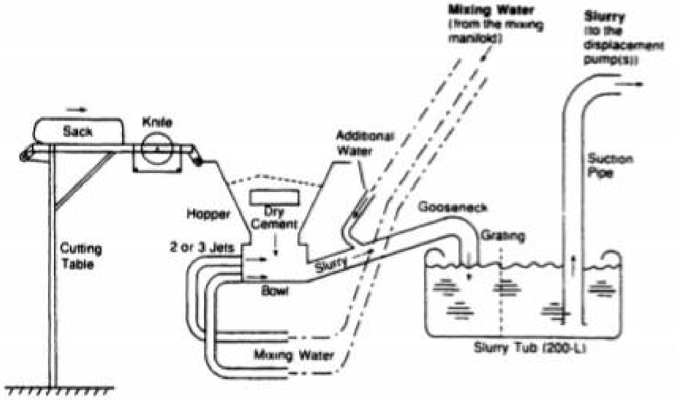

Fig. 3. Jet mixer (sacked cement).

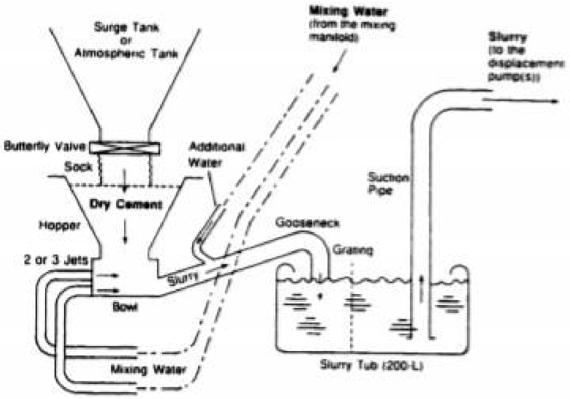

Fig. 4. Jet mixer (bulk cement).

The jet mixer can be operated at low (175 to 200 psi) or high (900 to 1200 psi) water pressure. For low water pressure, the mix-water pump is a centrifugal pump. For high water pressure, it is a reciprocating pump, usually identical to the displacement pump.

Double-pump cementers can mix at either low or high pressure. The low-pressure method is preferred because less horsepower is required and, because both high-pressure pumps are available to displace the slurry, higher mixing and displacement rates can be achieved. The high-pressure method is mainly limited to emergency use (when the centrifugal mix-water pump fails).

The disadvantage of the jet mixer is that no density adjustments can be made to the slurry after it exits the gooseneck.

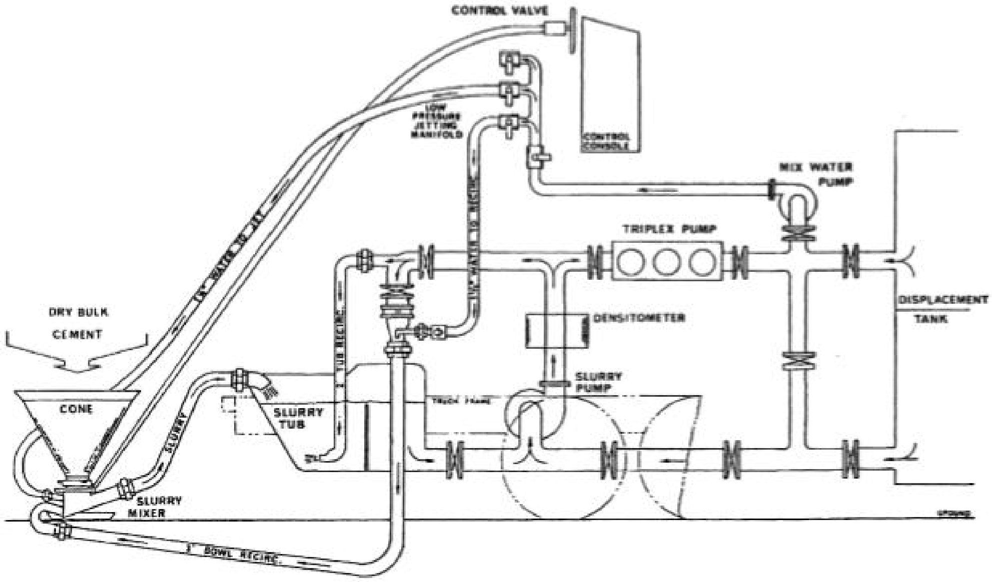

Fig. 5. Truck-mounted SLURRY CHIEF Mixer.

4.1.2 SLURRY CHIEF Mixer

The SLURRY CHIEF mixer (see Fig. 5) differs from the jet mixer in several ways:

- A remote controlled sliding gate (knife gate) is present between the hopper and the mixing bowl.
- The slurry density is adjusted by operating the knife gate.
- The slurry is removed from the slurry tub by a centrifugal pump (slurry pump). The slurry pump force feeds the reciprocating pump (triplex pump) and recirculates some slurry through the slurry mixer.

Recirculation through the slurry mixer and the slurry tub improves the homogeneity and rheology of the slurry. It also enables slurry-density adjustments to be made.

By replacing the hopper with an adapter containing an air-actuated valve, the cement blend can be directly transferred from the pressurized bulk tank or truck transport to the mixing bowl.

4.1.3 TORNADO Mixer

A TORNADO mixer (see Fig. 6) consists of

- a downspout
- a mixing volute
- a mixing tub
- a metering valve
- a mixing/pressurizing centrifugal pump.

It functions by relying on the water and cement to be forced into the mixer.

The cement is forced into the downspout and the water enters the annulus around the outside of the downspout. The cement and water initially mix as they enter the mixing volute. The cement and water are thoroughly mixed by the swirling (tornado) action in the mixing volute. The swirling action is a result of the slurry or water from the tub being recirculated by the mixing/pressurizing pump through the volute.

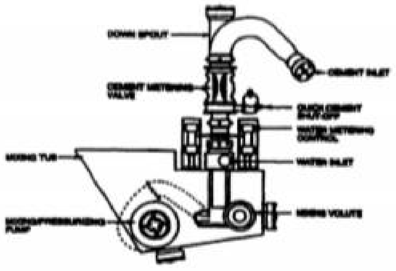

Fig. 6. TORNADO Mixer.

The dry cement is forced into the mixer by discharging it directly from a pressurized bulk tank or truck transport into the mixer. The mixer relies on a steady delivery of bulk material, which generally requires the pressurized tank or bulk transport to be within 20 ft of the mixer. These bulk delivery limitations prevent the TORNADO mixer from being used with atmospheric bulk tanks or in areas where the pressurized tank is well over 20 ft away from the mixer (e.g., offshore rigs).

Density control is obtained by

1. setting a constant water rate in the mixing system
2. ensuring steady delivery of the cement blend from the pressurized bulk tank
3. metering the amount of cement allowed into the system with a metering valve.

4.1.4 VIP Mixer Unit

Figure 7 is a sketch of the mixing components of the VIP Mixer unit. It illustrates the flow paths of water, cement, aeration air and slurry during the mixing process.

The slinger rotates inside a circular chamber called the mixer body. The rotation creates a very high shear zone: 150 hp are absorbed inside a half-barrel volume. This shear is comparable to that achieved during prejob laboratory testing (using the API mixing procedure).

The shape and size of the shear area, called the eye, are defined by well-controlled pressure balances within the mixer. Therefore, the liquid volume in the mixer body is constant.

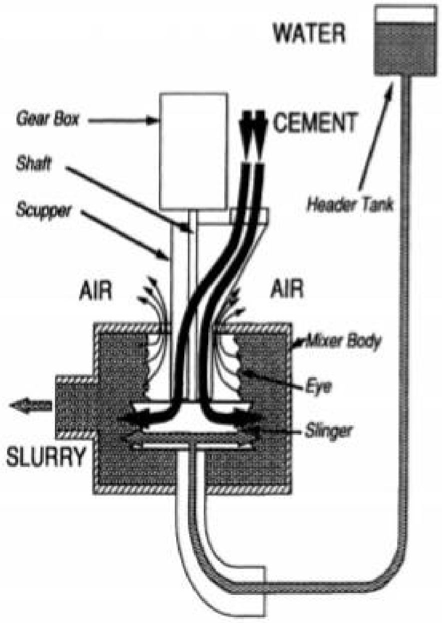

Fig. 7. Mixing components of the VIP Mixer unit.

Dry cement is added via the slinger into the eye, and the aeration air is rejected at the top of the eye. As a result of the constant volume, the water rate is self-regulated to the difference between the slurry rate and the cement rate. When dry cement is added to the eye, the water flow rate automatically drops to maintain a constant slurry rate. Thus, the slurry density is controlled by a single parameter — cement flow.

The small mixer volume enables very fast changes in the slurry density at start up and when changing cement systems.

The mixing capabilities of the mixer are illustrated in Fig. 8. Its capability limits are

- 12 bbl/min maximum slurry rate
- 2 bbl/min minimum slurry rate
- 21.5 lbm/gal maximum slurry density
- 40 ft^3/min maximum dry cement rate
- 60 psi maximum discharge pressure.

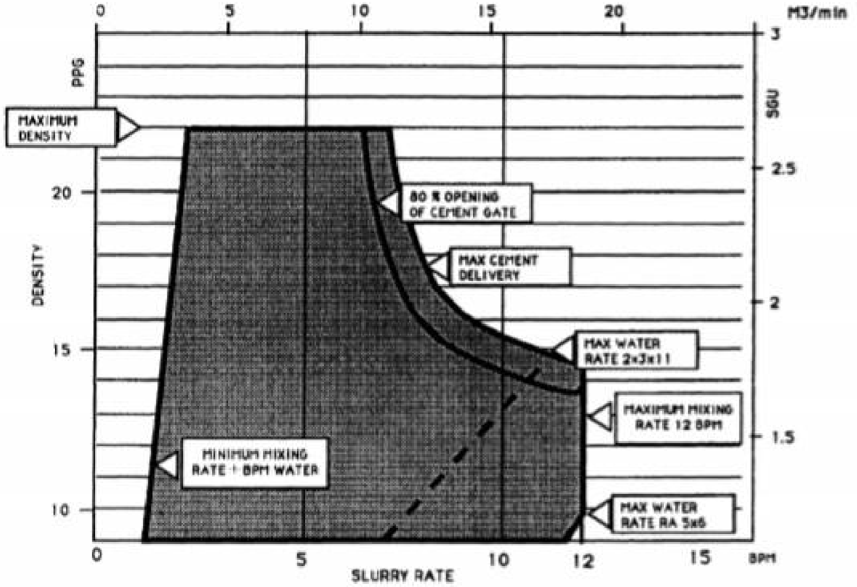

Fig. 8. Mixing capabilities of the VIP Mixer unit.

When the mix water is delivered to the header tank by a 2 x 3 x 11 centrifugal pump (RB 23), the maximum mix-water rate is limited to 7 bbl/min. A dotted line on the chart in Fig. 8 represents this limit.

The maximum slurry rate corresponds to the rate at the mixer discharge port. The length and size of the discharge line affects this rate (e.g., an 11-bbl/min maximum rate is observed for 20 ft of four-inch discharge line run from the mixer discharge port to the slurry tub).

For a given cement system, the maximum slurry density depends on several factors. The two main factors are the slurry plastic viscosity and the solids-to-liquid volumetric ratio. The maximum plastic viscosity is 600 cp at 0.2 lbm/gal above the desired slurry density. The maximum solids-to-liquid volumetric ratio is between 1.0 and 1.2. If this ratio is greater than 1.0, then the slurry rheology must be checked in the laboratory.

The accuracy of the slurry-density control is ±0.1 lbm/gal.

Some of the mixing limitations of the VIP Mixer unit presented earlier (e.g., maximum slurry density) may be exceeded providing new cement technology is applied. For further information on the required cement technology to exceed these limitations, contact your Regional Cementing Specialist.

4.1.5 Batch Mixer

A batch mixer is basically a cement mixer with one or two large mixing tanks. It enables a slurry volume up to the volume of the mixing tanks to be mixed before the slurry is pumped down the well. Once mixed into the tanks, the slurry can be circulated (see *SECTION 2.C.4—MIXING TECHNIQUES* for restrictions on slurry circulations times) and agitated, and its density adjusted until a homogeneous slurry with the desired density is achieved. The final slurry is delivered to the pumping unit by the batch mixer and then pumped down the well.

Dowell has several batch-mixer models. Some of the differences between the models are

- mixing tank sizes (ranges from a single 25-bbl tank to twin 100-bbl tanks [200 bbl total])
- power source and type
- skid or trailer mounted
- capability to monitor slurry density.

All batch-mixer models can

- pick up mix fluids from remote sources and meter them
- meter dry cement
- meter and pump discharge fluids
- recirculate the slurry back to the tanks.

For additional information, refer to the *DOWELL EQUIPMENT CATALOG.*

4.2 Pressurized Mud Balance

Densitometer measurements are used to achieve the correct slurry density during a continuous-mix cement job. If air entrainment within the slurry is present, then the densitometer measurement will be lower than the actual slurry density. The pressurized mud balance is used to validate the densitometer measurement. For batch-mix jobs, it is normally used to make all density measurements.

A pressurized mud balance, cleaned and calibrated, has an accuracy in the order of ±0.2 lbm/gal.

Additional information on the pressurized mud balance can be found in *API SPECIFICATION 10* and Section 210.10 of the *SENSOR ENGINEERING MANUAL*.

4.2.1 Operational Procedure

The procedure for measuring the density of a slurry is

1. Ensure the sample cup is dry or rinse it with slurry.
2. Fill the sample cup on the end of the balance arm with slurry up to a level slightly below the upper edge of the cup (see Fig. 9).
3. Properly place the lid on the sample cup by pushing it downward until its outer skirt comes in contact with the upper edge of the sample cup.
4. Screw the threaded cap completely onto the sample cup.
5. Rinse the piston with slurry.
6. Fill the piston with slurry (see Fig. 10).
7. Place the piston end on the valve of the lid and completely fill the sample cup with slurry by forcing the piston rod inward (see Fig. 11). During multiple measurements, try to apply approximately the same force on the piston when pressurizing the sample cup.

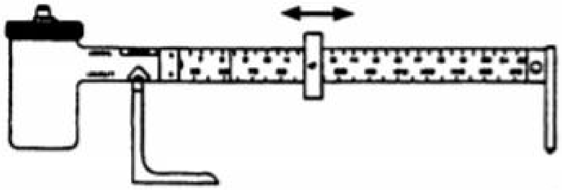

Fig. 13. Balance arm and read slurry density.

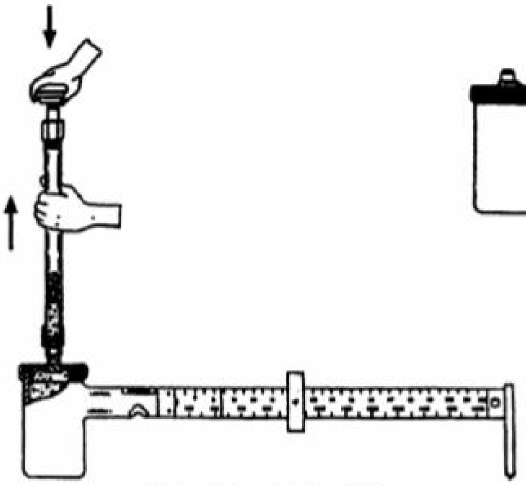

Fig. 12. Close valve on lid.

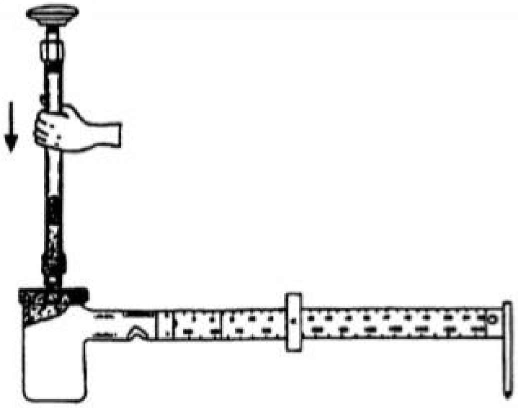

Fig. 14. Release pressure inside sample cup.

8. Shift the valve into the closed (upper) position by maintaining force on the piston rod while simultaneously lifting the piston off the valve (see Fig. 12).
9. Rinse and thoroughly dry the balance arm and sample cup before placing it on the fulcrum.
10. Move the rider along the balance arm (see Fig. 13) until the level on the balance arm indicates it is balanced (the bubble is centered and stable).
11. Read the slurry density on one of the scales on the arm.
12. Place the piston end on the valve and pull up on the piston rod to release the pressure inside the sample cup (see Fig. 14).

4.2.2 Calibration

The pressurized mud balance is calibrated by

1. following steps 1 to 7 in Subsection 4.2.1—Operational Procedure
2. moving the balance arm to the water density position (8.32 lbm/gal)
3. adjusting the amount of lead shot in the end of the balance arm (the end opposite the sample cup) until the arm is balanced
4. repeating this procedure to verify that the pressurized mud balance is correctly calibrated.

5 PUMPING

Once mixed, the slurry must be pumped down the well and displaced using one or two high-pressure pumps. A centrifugal pressurizing pump supplies the slurry to the high-pressure pumps. Two graduated displacement tanks (normally 10 bbl each) are used to measure the displacement.

A unit containing the high-pressure pumps, centrifugal pressurizing pump and displacement tanks is referred to as a pumping unit. If a cement mixer is also mounted on it, then it is referred to as a cementing unit.

High-pressure pumps consist of a power end and a fluid end. The power end transmits the power from the power source (e.g., diesel engine and transmission) to the fluid end.

Table 2 presents the performance ratings of different power end and fluid end combinations. The performance curves for the available combinations of power end, fluid end, and power source for a particular unit exist, usually in its operator's manual. Because each set of curves is for one specific combination and Dowell pumping equipment has dozens of combinations, they are not reproduced in this manual.

6 DATA ACQUISITION

As a minimum standard, the density, rate and pressure during a cement job will be recorded.

Dowell has two data acquisition devices for cement jobs. They are

- PACR* unit
- PAC unit.

Both units display and record the density, pressure and rate during the job, as well as other job parameters if desired. For additional information on either of these units, refer to the respective user's manual.

TABLE 2
PERFORMANCE RATINGS OF DIFFERENT POWER END/FLUID END COMBINATIONS

Series Group Pump Power End	Fluid End	Plunger (in.)	Maximum psi	Maximum bbl/min[a]	Gear Shift	bbl/Rev. Pinion	bbl/Rev. Main
5-in. stroke PG series 4.32 ratio, internal gears 300 rpm max. at main shaft 1296 rpm max. at pinion shaft	TSO	2½	20,000	2.5		0.00171	0.0074
	TRO	3	15,000	3.0		0.00245	0.0106
	TGO	3¾	10,000	5.0		0.00384	0.0166
	TLO	4½	7,000	7.0		0.00553	0.0239
	THO	5	5,500	9.0		0.00681	0.0295
6-in. stroke PT series 3.00 & 5.14 ratio, 2 speed Sier bath reducer (external) 340 rpm max. at main shaft	MMO	3	20,000	3.0	Low		0.0127
	MMO	3	14,500	4.5	High		0.0127
	MFO	3¾	18,000	4.5	Low		0.0199
	MFO	3¾	9,500	7.0	High		0.0199
	MEO	4½	12,000	6.5	Low		0.0286
	MEO	4½	6,500	10.0	High		0.0286
	MDO	5	10,000	8.0	Low		0.0342
	MDO	5	5,500	12.0	High		0.0342
	MNO	5¾	7,500	11.0	Low		0.0467
	MNO	5¾	4,000	16.0	High		0.0467
	MJO	6¾	5,500	15.0	Low		0.0644
	MJO	6¾	3,000	22.0	High		0.0644
	MPO	7¼	4,500	17.0	Low		0.0742
	MPO	7¼	2,500	25.0	High		0.0742

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AUXILIARY CEMENTING EQUIPMENT

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1 INTRODUCTION

Three pieces of equipment that are primarily used on a cement job or obtain information for a cement job are

- squeeze manifold
- opposing chokes
- Downhole Circulating Temperature Probe (DCTP).

This equipment is not always used on a cement job and is therefore classified as auxiliary cementing equipment.

A squeeze manifold is primarily used on squeeze cementing operations to change the circulation direction and control the slurry placement. Opposing chokes provide slurry homogeneity to "critical" cement systems. The circulation of a DCTP is one method for determining a maximum circulating temperature.

2 SQUEEZE MANIFOLD

A squeeze manifold is primarily used on remedial cement or matrix acid jobs. It allows the direction of the well circulation to be quickly changed without disconnecting and reconnecting the treating lines. It also enables backpressure to be applied to control the placement of a cement slurry.

Figure 1 illustrates a typical squeeze-manifold configuration for reverse circulating a well. By closing the open valves and opening the closed valves, circulation down the tubing and up the annulus is possible. By partially closing the last open valve before the circulating fluid goes to the rig tank or pit, backpressure is applied which enables the circulation of fluids of different densities (e.g., cement slurry and fresh water) to be controlled.

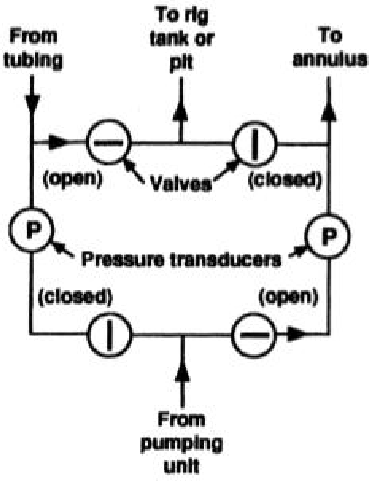

Fig. 1. Typical squeeze-manifold configuration.

The components of the squeeze manifold must be the integral type and pressure rated to 15,000 psi working pressure. The pressure transducers are removed from the squeeze manifold during storage and shipment.

Complete information on the integral squeeze manifold can be found in the *DOWELL TREATING EQUIPMENT MANUAL*.

3 OPPOSING CHOKES

3.1 Introduction

Good slurry mixing, such as obtained in the laboratory with a Waring blender under API conditions, can only be achieved in the field if sufficient mechanical energy is supplied to the slurry so that the cement grains are well dispersed and no longer agglomerated in large flocs. Such powerful mixing breaks the bonds between the grains to yield a perfectly homogeneous slurry. Only when all individual cement grains are well dispersed can they be completely water-wetted for hydration, the efficiency of additives maximized and the slurry stability improved.

The homogeneity of a slurry mixed at the correct density can be improved by pumping it through a high-pressure choke, thus achieving more predictable slurry properties in accordance with the slurry design. The choke system is recommended for mixing all GASBLOK*, WELBOND* and SALTBOND* slurries, as well as other dispersed slurries.

3.2 Description

The choke system consists of a high-pressure manifold with a set of two opposed chokes and a fullbore bypass (see Fig. 2 to 6).

The main hazard when pumping through a choke is plugging, which can result in an extremely rapid and excessive pressure buildup. To reduce such hazards, and to reduce pipe erosion, two chokes in an opposed configuration are mandatory. Frequent inspection for wear of the treating equipment downstream from the chokes is mandatory.

All types of steel chokes do not offer sufficient resistance to slurry erosion. Chokes made of hardened steel must be used for extended pumping times.

3.3 Pumping Through Chokes

Chokes are the simplest mechanical devices which can be used with standard equipment to charge the slurry with the level of energy required to obtain good homogenization.

Pumping through chokes generates a pressure drop given by the formula:

$$P = 0.24\frac{Q^2 \times \rho}{N^2 \times C_d^2 \times D^4} \qquad (1)$$

where

P = pressure drop (psi)
N = number of chokes
Q = total flow rate through N chokes (bbl/min)
ρ = fluid density (lbm/gal)
C_d = choke discharge coefficient (dimensionless)
D = choke diameter (in.)

and

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4 DOWNHOLE CIRCULATING TEMPERATURE PROBE (DCTP)

4.1 Introduction

The Downhole Circulating Temperature Probe (DCTP), coded D894, can measure the maximum circulating temperature in wellbores ranging from 100 to 300°F (38 to 149°C) to within an accuracy of approximately ±5°F (±2.8°C). It does not record the depth at which the temperature was obtained, which may be at the bottom of the hole or somewhere up the annulus (see *SECTION 7.H.1—CEMENTING TEMPERATURES*). Its application requires no specialized equipment and does not interfere with normal well-completion procedures.

A standard DCTP can withstand pressures up to 12,000 psi before deformation and leaking occurs. For the special order DCTP, the pressure limit equals 20,000 psi. These pressure limitations have been determined under laboratory conditions; actual field applications for a standard DCTP indicate that the maximum exposure pressure should be 9000 psi.

The DCTP density can be altered between 10.3 and 23.0 lbm/gal with small lead shot. The special order DCTP has a fixed density of approximately 24.0 lbm/gal.

The special order DCTP requires 4 to 6 weeks lead delivery time.

4.2 Description

The DCTP consists of a temperature indicator housed inside a 3/8-in.-diameter sphere (or jacket).

4.2.1 Temperature Indicator

Six different temperature indicators, each with a unique 50°F (28°C) application range that overlaps the next indicator's range, are available (see Table 1). Each temperature indicator contains six small squares. Each square is labeled with its activation temperature and represents a 10°F (5.6°C) temperature increment.

A square turns from off-white to black when its activation temperature has been reached. The activation of a square occurs within ±1°F of its labeled temperature, resulting in a temperature measurement having an accuracy of approximately 5°F (2.8°C).

The indicator selection is dependent on which 50°F (28°C) measurement range best suits the estimated maximum circulating temperature. In some situations, the correct choice would be to increase the measurement range by simultaneously running two sets of DCTPs with each set containing a different indicator (e.g., 6MA-160/71 and 6MA-190/88).

TABLE 1
TEMPERATURE INDICATORS AND THEIR MEASUREMENT RANGES

Temperature Indicator	Measurement Range	
	°F	°C
6MA-100/38	100 to 150	38 to 66
6MA-130/54	130 to 180	54 to 82
6MA-160/71	160 to 210	71 to 99
6MA-190/88	190 to 240	88 to 116
6MA-220/104	220 to 270	104 to 132
6MA-250/121	250 to 300	121 to 149

Example

The 6MA-130/54 temperature indicator has a measurement range of 130 to 180°F. Its six squares are labeled 130, 140, 150, 160, 170 and 180°F. After well circulation, the 130 and 140 squares are black and the other squares are off-white. This means the maximum circulating temperature can be as low as 139°F (-1°F accuracy for the 140°F measurement) and as high as 150°F (1°F below 150°F activation with +1°F accuracy applied). Taking an average of these two temperatures, the maximum circulating temperature equals 144.5°F.

4.2.2 Sphere (or Jacket)

The DCTP sphere (or jacket) is constructed of a lightweight material that has been machined into two halves. These halves are epoxyed at the threads and then screwed together to provide a water-tight seal under downhole pressure conditions. The standard DCTP (12,000-psi pressure limit) has a magnesium jacket. The special order DCTP (20,000-psi pressure limit) has a stainless steel jacket.

4.3 Density Adjustment

The density of the standard DCTP (magnesium jacket) can be altered between 10.3 to 24.0 lbm/gal by placing small lead shot inside the jacket with the temperature indicator (see Table 2). This permits the DCTP to be weighted to a density equal to or slightly less than the carrier fluid (not more than 1.0 lbm/gal lighter) for maximum recoverability in a predictable time frame.

- dead spots in the flow path (e.g., washouts, cellar)
- pipe eccentricity
- DCTP mechanical damage (damaged DCTPs will probably not be recovered).

The DCTPs will circulate with the carrier fluid if the DCTP density is equal to or slightly less than the fluid density (not more than 1.0 lbm/gal lighter). Below 10.3 lbm/gal, the DCTP density cannot be matched to the fluid density.

Field studies have shown that it is possible to circulate DCTPs which are slightly heavier than the carrier-fluid density provided

- the circulation rate is sufficient and consistent
- the fluid has adequate gel strength
- a viscous pill is used to transport the DCTPs.

The DCTPs are collected at the shale shaker or the return line. A simple, yet effective, catch basket can be constructed of 1/4-in. mesh screen which is precut to the desired shape, molded and then tie-wired together. To provide an indication when the DCTPs can be expected at surface, the carrier fluid can be tagged with a dye.

Once retrieved and using pliers, the halves of the DCTPs are unscrewed or the DCTPs are popped open by deforming the DCTP at its seam. The indicator is removed and the temperature is read. If the seam is damaged during the circulation allowing fluid to infiltrate the DCTP, then the windows of the temperature indicator are often turned by this infiltration, and the DCTP measurement is invalid.

4.6 Ordering Instructions

the DCTP Kit (Item Code 101777-000) contains

- DCTP jackets, male and female halves
- small bristled brushes for applying the epoxy
- epoxy, resin and hardener
- specified range of temperature indicators
- supply of No. 4 and No. 8 lead shots
- detailed set of fabrication and operations instructions.

Each Kit contains enough materials to prepare 50 DCTPs. The temperature ranges can be mixed, but are supplied ONLY in multiples of 10 (e.g., 10, 20, 30). A special order for partial Kits (e.g., 30, 80, 140 DCTPs) will be processed by the Product Center at its discretion.

The density of the special order DCTP has a minimum density of 23.6 to 24.0 lbm/gal.

The specifications for the DCTP jackets have been rigidly set, and samples from each lot are subjected to a quality-control check. However, periodic checks of DCTP densities (loaded with a 6MA indicator and lead shot) are recommended.

TABLE 2
STANDARD DCTP (MAGNESIUM JACKET) DENSITY RANGES

Lead Shot		Typical Density (lbm/gal)
No. 4	No. 8	
0	0	10.3 to 10.8
0	1	11.8 to 12.2
0	2	12.9 to 13.3
1	0	14.6 to 15.2
0	4	15.6 to 16.0
1	2	16.7 to 17.5
2	0	18.0 to 18.4
3	0	21.4 to 23.0

4.4 Preparation

1. Select a male and female half of the DCTP jacket and ensure that the threads match.
2. Prepare a small amount of epoxy (supplied with the DCTP Kit). Using a small brush (supplied with the DCTP Kit), coat the male thread of the DCTP jacket.
3. Fold the temperature indicator so it will fit in the jacket and place it and the lead shot in the female half of the jacket. Gently tamp the temperature indicator until it does not interfere with the threads.
4. Screw the jacket halves together and wipe away any extruded epoxy from the seam. A DCTP coated with epoxy will lead to an erroneous result, because the well pressure will falsely turn the windows of the temperature indicator.

Plan at least one hour for the assembly of 10 DCTPs.

NOTE: The epoxy resin consists of a resin and a hardener which are blended together in equal quantities. This provides ample working time, but requires the DCTP preparation at least six hours before the circulation to allow the epoxy to harden. Varying the hardener-to-resin ratio will shorten or extend the working time and prejob waiting period. SAFETY GLASSES AND THIN RUBBER GLOVES SHOULD BE WORN WHEN HANDLING EPOXY.

CAUTION: Care must be taken when storing the temperature indicators or the DCTPs prior to their application. Storage in confined areas subject to rapid temperature increases (e.g., car trunks, truck cabs) will turn the windows of the temperature indicators if the temperature exceeds the lower limit of the range.

4.5 Application

The DCTP can be used anytime the flow paths of the wellbore allow the passage of a 3/8-in.-diameter sphere. The best time to run the DCTP is when the static and circulation conditions before cementing can be emulated, resulting in the measurement of the most realistic maximum circulating temperature. This best time may be during the wiper trip or when the drilled hole is cleaned prior to logging or running casing.

When circulating the DCTPs through drillpipe, it may be necessary to remove the drill-bit jets to permit their passage. **Bit rotation must be stopped long enough to allow the DCTPs to pass through the bit and past the drill collars.**

When circulating the DCTPs down the casing, the tolerances of the ball or flapper valves in the float equipment must be known. For liner cement jobs, the DCTP applications may be limited by the tolerances in the liner hanging equipment.

Field applications have shown that even when the wellbore conditions are ideal and the density of the DCTPs equals the mud density or is not more than 1.0 lbm/gal lighter, the retrieval percentage of the DCTPs at surface will seldom exceed 50%. Depending on the well conditions, 20 to 50 DCTPs are recommended per application. Poor hole conditions require more DCTPs per application, and a lower recovery percentage can be expected. Field experience and drilling and completion practices will quantify the number of DCTPs necessary per application in a given area.

The DCTP recovery depends on

- density difference with the fluid
- fluid rheology
- circulation rate

- dead spots in the flow path (e.g., washouts, cellar)
- pipe eccentricity
- DCTP mechanical damage (damaged DCTPs will probably not be recovered).

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