Atmospheric Foam Slurry Preparation

Procedure No.: WM-GL-HES-QM-433.030

Description

This procedure contains instructions for preparing atmospheric foam slurries for testing.

Equipment

Item	Specifications	Quantity
Variable speed mixer	a constant-speed mixer with variable speed capability as specified by API or a variable speed adapter used with a mixer without speed control	1
Waring blender (2-qt.)[a]	Part No. 100021755 (115-volt) Part No. 70.08550 (230-volt)	1
Sealable mixing container	(Eberbach Catalog No. 8520, VWR Scientific Catalog No. 58984-030 or equivalent); Fann No. E4013, SAP # 204429 see Figure 3.11, Page 3-56.	1
Multiple blade kit for the sealable mixing container	Part No.100072106; see Figure 3.11, Page 3-56.	1
Container of known volume	for determining density of foamed slurry	1 per mix
Scale	with accuracy to at least 0.1 g	1
Spatula	with a blade that is 4 in. or larger	1

[a]In most cases, a 2-quart (2L) mixer is required to contain the volume of unfoamed slurry.

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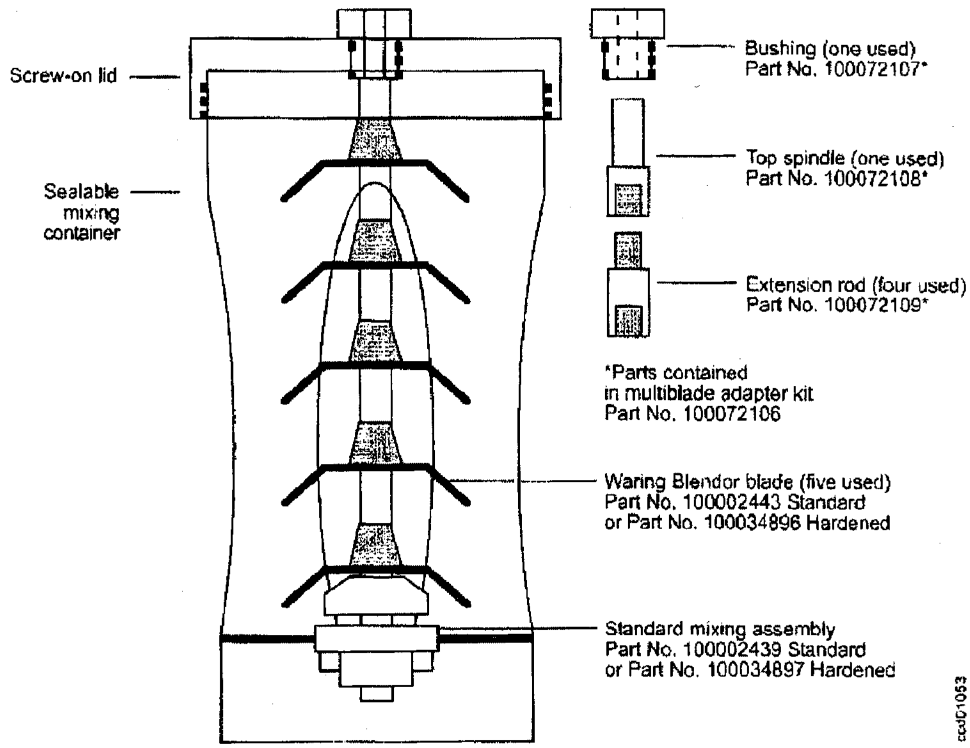

Figure 3.11—Multiblade blender for preparing atmospheric foam cement slurry

Important—Always prepare foam cement in a device suitable for foaming.

Procedure

Prepare an atmospheric foam slurry in a multiblade foam blender as follows:

1. Use the Microsoft Excel spreadsheet (located at http://halworld.corp.halliburton.com/internal/PS/cem/contents/Interactive_Tools/TECH/FoamCalc.xls) or the hand calculations outlined in Procedure 433.020 to calculate the necessary base slurry weigh-up values and the slurry and foamer/stabilizer weights to be added to the foam blender. The capacity of the multiblade foam blender is assumed to be 1170 mL, and the capacity of the MACS analyzer with the baffle plate removed is 1280 mL and the capacity of the special modified Mini-MACS foam slurry cup is 480 mL. If another system is used to prepare the final foam slurry, the volume of it must be determined and used in the spreadsheet or calculations.

2. Prepare the base slurry according to procedures found in the current edition of *API RP 10B-2/ISO 10426-2*. It will be necessary to prepare two batches of slurry in a 1-quart blender and thoroughly blend the two batches together before adding the slurry to the foam blender when the API/ISO mixing procedure is used.

   a. An option is to use a 2-quart blender. When the 2-quart blender is used, it should be stated since it is a deviation from the procedures in *API RP 10B-4/ISO 10426-4*.

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3. Add the proper weight of base slurry and foaming/stabilizing surfactants to the multi-blade foam blender. Place approximately one-half of the unfoamed slurry into the multi-blade foam blender, followed by the foaming materials and the remainder of the unfoamed slurry. Cover the hole in the lid bushing and shake the foam blender three to five times to distribute the foaming/stabilizing surfactants throughout the slurry.
4. Shear the foam in the foam blender with either of two methods:

- The instructions in the current *API RP 10B-4/ISO 10426-4* states to shear the slurry at 12,000 rpm for 15 seconds.
- Alternate procedures that have been used prior to the introduction of the API/ISO procedures and are still used by many are as follows. When procedures other than those specified by API/ISO are used, they should be identified.
    a. Shear at maximum speed for 15 seconds, or until there is an audible blender speed change which indicates a full container. The foam should be near the designed density when the foam blender container is completely full.
    b. Shear at maximum speed for 3 to 5 seconds and open the blender to examine the results. If it is not completely full, shear another 3 to 5 seconds and re-examine. Repeat this procedure until the foam blender container is full.
- After completion of the foaming, stop the mixer and remove the screw-on lid from the mixing container. There may be a slight pressure inside the mixing container if slurry foamed to fill the container in less time than used for foaming and caution should be exercised when removing the screw-on lid

For the foam slurry to be considered for use, the slurry should foam to the target density in 15 seconds or less (record the actual time required). If the target density cannot be achieved in 15 seconds, redesign the slurry or alter the foaming/stabilizing surfactant package to improve foamability. (See Procedure No. 433.010 on Page 3-47.)

5. Check the density of the foamed slurry as follows:
    a. Tare a container of known volume on a scale.
    b. Fill the container with the foam slurry and level the top of the foam with a spatula.
    c. Weigh the foam cement
    d. Calculate the specific gravity by dividing the foam weight by the container volume with the following equation:.

SG = foam weight (grams) ÷ container volume (mL)

FD = SG × 8.3454

Where:

SG = specific gravity of final foam cement slurry

FD = foamed density (lb/gal) of the cement slurry

8.3454 = weight (lb) of 1 gal of material at a specific gravity of 1.00

If the slurry is sheared longer than required to reach the target density, the resulting foam density may be up to 1 lb/gal (0.12 SG) less than desired. For stability testing purposes, a foam density slightly lower than the target density may not be of concern. If the foam prepared in this step is to be used for compressive-strength testing, it should be as close to the target density as possible. If necessary, discard the foam sample and repeat this step to obtain a more accurate foam density.

If the 15 second mixing procedure described in the current API RP 10B-4/ISO 10426-4 is used and the slurry density is lighter, the API/ISO procedure provides a method and example calculations to obtain a closer foamed density to the required density for a remix of the slurry. Sometimes, it may take more than 1 mixing test to obtain the required density.

Additional Resources

The following publication from the American Petroleum Institute (API) provides a quick reference source. To ensure you have the most recent edition, go to www.global.ihs.com/ and perform a search for: API RP 10B-2 or ISO 10426.

- **API RP 10B-2 (ISO 10426-2)**—*Testing Well Cements.*

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Atmospheric Foam Slurry Testing

Procedure No.: WM-GL-HES-QM-433.040

Description

This procedure provides instructions for testing foam cement specimens for foam stability, compressive strength, fluid loss, thickening time, and permeability at temperatures below 194°F (90°C).Testing of foam slurry above 194°F (90°C) should be performed with the MACS analyzer according to Procedure 433.080. Some of these procedures are now included in the current edition of API RP 10B-4/ISO 10426-4.

Equipment

Item	Specifications	Quantity
Sealable mold	2-in. cube mold with a cover clamped to the top OR plastic cylinder mold with sealable top	1
Graduated cylinder (glass)	250 mL, 100 mL TC, 50 mL TC, or widemouth 100 mL TC	1
Stability test device	See Figure 3.12, Page 3-62	1-2

Procedure

Foam Stability Test for Slurry at Ambient Conditions

To check the foam stability at ambient conditions using the preferred stability curing methods, perform the following steps:

1. Pour the foamed slurry into the standard 250-mL graduated glass cylinder that is used for free fluid testing.
2. Cover the cylinder to prevent drying or dehydration of the sample.
3. Place the cylinder on a countertop and check the slurry periodically over a 2-hour period for changes in appearance, noting such changes as free fluid, streaking, solids settling, bubbles concentrated in specific area, thixotropic properties, etc.

If the 250-mL cylinder is not available, use one of the following stability curing methods:

- Perform the above test in a smaller graduated glass cylinder. Standard 50-mL to contain (TC), standard 100-mL TC, or widemouth 100-mL TC cylinders will suffice.
- Perform the above test in an open-top sample container or in a plastic container with a lid. Inspect the top surface at the end of the 2-hour test period. If the open-top container is not covered, some drying may occur, resulting in a small decrease in height.

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4. After 2 hours, perform the following density measurements:
   a. Remove small portions from the top, middle, and bottom of the sample with a large syringe with a Tygon tube attached.
   b. Transfer the slurry to a smaller graduated cyclinder to determine the weight of a known volume.
   c. Calculate the density using the equation on Page 3-57.

Table 3.1—Signs of Foam Instability When Prepared at Various Temperatures

Appearance	Unset Slurry at Ambient Temperature	Set Specimens
More than a trace of free fluid	X	—
Bubbles on surface or bubble coalescing (breaking, enlargement, merging	X	X
Excessive column-height reduction	X	X
Signs of density segregation (streaking or dark coloration from top to bottom)	X	X
Large variations in density between top and bottom of sample	X	X

Set Foam Stability Tests

The temperature increase during cement curing causes expansion of the gas phase. To prevent this expansion, a cell with a clampable lid is required for curing foam at elevated temperatures. The following sections describe two curing methods. Method 1 is sufficient for curing foam slurry at temperatures below 150°F (65°C). Method 2 is specially designed to prevent excessive foam expansion at temperatures up to 194°F (90°C). Method 2 can be used at any temperature less than 194°F (90°C).

Method 1 for Test Temperatures < 150°F (65°C)

Check the foam stability of set foamed cement by performing the following steps:

1. Cure samples until they are set for density gradient measurement throughout the sample.
2. Use a nongreased, covered, 2-in.-diameter × 4-in.-tall cylinder or any appropriate covered container.
3. Cure samples at ambient conditions or in a heated waterbath (maximum temperature of 150°F) by clamping the lids of the curing container to prevent foam expansion.
4. Cut or break the samples into sections, mark each section's location within the sample, from the top to the bottom, and measure the specific gravity of each section.

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Caution—DO NOT cut the specimen with a saw that uses water. The specimen can absorb water, changing the density of the specimen. Large variations in density from the top of the sample to the bottom are an indication of instability (See Table 3.1, Page 3-60).

To determine the specific gravity by the Archimedes principle, perform the following steps.

1. Place a beaker of fresh water on a scale and tare it.
2. Place the specimen into a loop of fine string or thread, and suspend it in the water to measure the volume of the specimen (V). The volume of the specimen (mL) will equal the weight of the water displaced by the specimen when it is suspended in the water.

Important—Determine the weight of the specimen being suspended in the water quickly to prevent the specimen from absorbing water and giving erroneous results.

3. Lower the specimen to rest on the bottom of the beaker of water to obtain the actual weight of the specimen (W).
4. Determine the specific gravity (SG) with this equation: ($W \div V = SG$).
5. Determine the slurry density with this equation: ($SG \times 8.33 =$ lb/gal).

Method 2 for Test Temperatures < 194°F (90°C)

1. Prepare a foam stability curing device with the materials shown in Figure 3.12, Page 3-62.
2. Apply primer/cleaner and glue PVC parts together.

Note—The example shown in Figure 3.12, Page 3-62 is constructed with the recommended length-to-diameter ratio outlined in the API sedimentation test procedure (4:1 to 8:1). Other diameters may be constructed as desired, assuming the ratio remains within the recommended range.

3. Apply Teflon® tape to the brass fittings.
4. Prepare the foam slurry according to Procedure 433.030.
5. Pour a sample of the foam into a foam stability test device to the top of the threaded collar as shown in Figure 3.12, Page 3-62.
6. Insert the brass reducer until it is completely tight. Foam should totally fill the 1/4-in. opening.
7. Insert the brass plug until it is completely tight.

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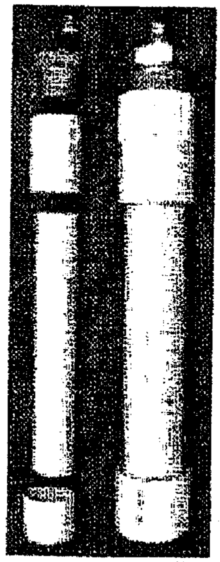

Figure 3.12—Foam stability test device showing individual components, left, and sealed, right

8. Place the samples vertically into a heated waterbath or oven and cure until they are set.
9. Cut the curing device into multiple sections (3 sections are recommended). Carefully cut PVC longitudinally along each segment and remove the sample from the PVC.
10. Inspect the sample for signs of instability.
11. Mark the sections from the top to the bottom. If the samples are to be used for compressive-strength determination, ASTM recommends that the samples be cut with a 2:1 length-to-diameter ratio.
12. Determine the specific gravity of each section by the Archimedes principle, as described in the previous test.

Caution—DO NOT cut the specimen with a saw that uses water. The specimen could absorb water, changing the density of the specimen. Large variations in density from sample top to bottom indicate instability (see Table 3.1, Page 3-60).

Compressive Strength Tests

The compressive strength of foam slurry created in the multiblade foam blender may be tested with the following procedure:

1. Pour the atmospherically prepared foam cement into a sealable mold.
   - For curing foam samples at low temperatures [<150°F (65°C)], cells such as nongreased 2-in. by 4-in. plastic cylinders or standard 2-in. cube molds (with lids or covers clamped in place) may be used.

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- For tests performed at temperatures above approximately 150°F (65°C) but less than 194°F (90°C), place the foamed slurry into a sealed container such as the example shown in Figure 3.12, Page 3-62, to prevent expansion out of the curing molds.

2. Place the sealed mold into an atmospheric water bath.
3. Cure the specimen and determine its strength according to API specifications.

The following tables show the typical effect foaming will have on a cement's compressive strength.

Table 3.2—Compressive Strength (psi) of Foam Cement Cured at Atmospheric Pressure

Density	65°F		100°F		140°F	
lb/gal	12 hr	24 hr	12 hr	24 hr	12 hr	24 hr
(Base Slurry: Standard Cement + 2.0% $CaCl_2$, Mixed at 15.6 lb/gal)						
10	130	220	370	630	510	870
8	70	190	230	530	250	430
6	40	100	150	230	160	340
4	10	50	60	110	70	110
(Premium Cement + 2.0% $CaCl_2$, Mixed at 16.4 lb/gal)						
10	60	160	130	400	150	570
8	40	80	110	200	120	200
6	20	50	90	90	50	90
4	10	20	10	30	10	30
(Premium Plus Cement + 2.0% $CaCl_2$, Mixed at 14.8 lb/gal)						
10	50	410	260	1,280	650	1,250
8	70	240	260	350	650	650
6	50	120	150	180	120	150
4	10	30	60	80	50	70

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Table 3.3—Compressive Strength (psi) at High Temperature Cycling Test (550° to 100°F) for Steam Injection Conditions

Curing Time	Foam Cement Density 10.0 lb/gal 11.5 lb/gal 13.0 lb/gal		
(Base Slurry: Fine Premium Cement + 40% SSA-1 + 3% Lime, Mixed at 15.4 lb/gal)			
20	1,210	1,680	2,260
100[a]	1,630 (2.4 md)[b]	1,550 (1.0 md)[b]	2,440 (0.94 md)[b]
160[c]	1,240	2,020	2,430

[a]Cycled from the 550°F curing temperature to 100°F two times.

[b]Values in parentheses ( ) are air permeabilities of the specimens.

[c]Cycled from the 100°F curing temperature to 100°F three times.

Fluid-Loss Testing

Fluid-loss testing is not recommended for atmospheric-prepared foam cement slurries. Rather, the fluid loss of the base unfoamed cement is normally used to predict the fluid loss of the foamed cement slurry since the foamed slurry typically yields less fluid loss than the same unfoamed slurry. If a fluid loss is to be determined on the base unfoamed slurry; prepare the base unfoamed cement slurry according to API/ISO recommendations. After API /ISO mixing, stop the mixer and add the proper amounts of foaming/stabilizing surfactants and gently blend with a spatula until the surfactants are thoroughly mixed into the slurry and a uniform slurry is obtained. If there is any foaming or air entrainment in the slurry, place a few drops of defoamer into the slurry to remove as much as possible before placing the slurry into the atmospheric or pressure consistometer's slurry cup for conditioning.

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Note—Accurate fluid-loss tests can be performed on a foam slurry by using modified fluid loss cells and preparing the slurry under pressure in a MACS analyzer. The fluid-loss values that result from foamed slurries prepared in this manner are typically less than the fluid-loss values obtained from the base unfoamed slurry.

Figure 3.13 shows the typical effect foaming will have on a cement's fluid loss properties.

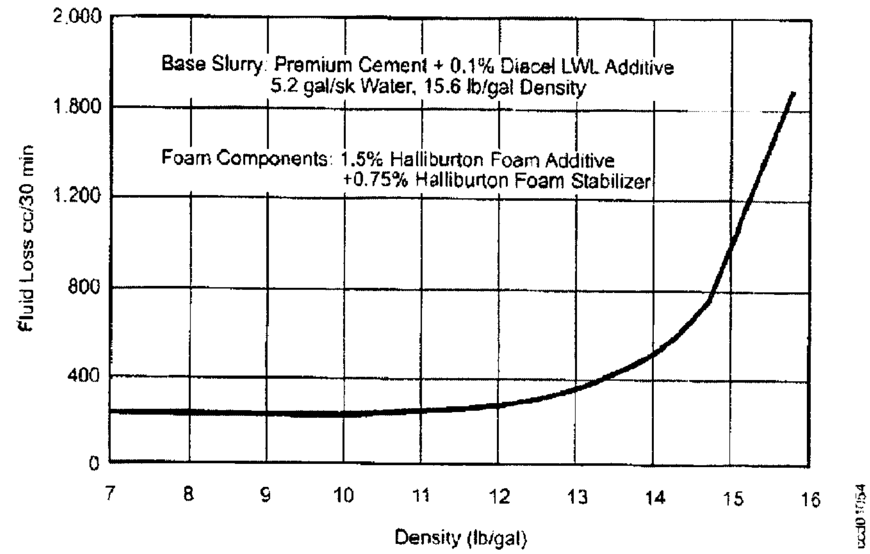

Figure 3.13—Fluid-loss properties of foam cement at various densities (80°F and 1,000 psi)

Thickening Time

Because nitrogen is an inert gas, it does not affect the thickening time of a cement slurry; therefore, the thickening-time test is usually performed with a standard HPHT consistometer or Mini-MACS analyzer.

Prepare the base unfoamed cement slurry according to API/ISO recommendations. After API/ISO mixing, stop the mixer and add the proper amounts of foaming/stabilizing surfactants and gently blend with a spatula until the surfactants are thoroughly mixed into the slurry and a uniform slurry is obtained. If there is any foaming or air entrainment in the slurry, place a few drops of defoamer into the slurry to remove as much as possible before placing the slurry into the consistometer's slurry cup. The defoamer will not affect the thickening time results, but it can help prevent oil contamination from the consistometer's pressurization oil that could affect the thickening time results.

Place the unfoamed slurry into the standard HPHT or Mini-MACS slurry cup, and determine the thickening time with the standard API/ISO or specific well condition test schedule.

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