Cement Mixing: Better Understanding and New Hardware

In the lab, cement systems can be designed to perfection. But it is pie in the sky unless the same system can be reliably mixed at high volumes at the wellsite. Recently, mixing has become better understood, and the first radically new hardware in years has become available. Both developments will improve the competence of well completions.

Filling the casing-formation annulus with high quality cement must rank as one of the most crucial operations in the life of a well, in terms of production and safety. A poor cement job may result in costly remedial work such as squeezing to seal off unwanted producing zones, or the production of fluids channeling through a faulty cement sheath, jeopardizing production strategy and compromising safety.

Cement jobs may fail for reasons beyond the control of operator or contractor. Lost circulation, high temperature and other environmental problems can prove too much for current cementing technology. These tough cases apart, careful planning and proper execution can usually ensure satisfactory cementing. Planning involves the design and testing of the cement slurry in a specially equipped laboratory and fixing a pumping schedule that ensures successful placement of the slurry in the annulus.

Mixing turns out to be the key. Solid and liquid components of a cement slurry must be correctly combined at the wellsite to achieve properties established in the lab. Mixing chemically active ingredients is complex and hard to understand. Recent research has extended this understanding, and new field mixing technology is being deployed to create increasingly reliable slurries. This article reviews current understanding of cement mixing and describes a recent development in field hardware.

Mixing Recap
Cement slurries are created by mixing powdered Portland cement, water, and dry or liquid chemical additives. These additives are used to control slurry viscosity, fluid-loss control and setting time, permitting the slurry to do the best job for the given well conditions. Dry components—cement and dry additives—are usually blended at a bulk plant prior to being transported to the

In this article, VIP Mixer is a mark of Dowell Schlumberger.
1. For general reading on well cementing:
wellsite (right). Water and liquid additives are mixed at the wellsite, then mixed with the solids to form the slurry. The last step—mixing liquids and solids—is the crucial one.

The choice of liquid or solid additives remains a contentious issue. Certainly for offshore work, liquid additives are easier to handle—in fact, solids may be impractical for lack of space. But liquids are generally more expensive and are therefore less used onshore. Some operators believe, however, that dry ingredients never get blended thoroughly and that transport to the wellsite causes segregation of components. Another argument against solid additives is that once blended, slurry design changes are difficult and any unused solids may have to be discarded after the job. Liquid additives, mixed at the wellsite, are rarely wasted.

Some of these issues are affected by another choice, whether to batch- or continuous-mix the slurry. Batch mixing means mixing all ingredients in a large tank before pumping downhole; continuous mixing means mixing slurry “on the fly” as it is pumped. Batch mixing obviates the previous concerns about dry additives since everything is thoroughly mixed before pumping, but it requires space for tanks—again a problem offshore and even impractical onshore for cementing large casing strings—and can lead to some waste if all the slurry is not used. Batch mixing is mostly used for small cement volumes, such as for cementing liners, cementing through coiled tubing (CT) and squeeze jobs. Continuous mixing is more compact and produces no waste, but since it happens instantaneously is more difficult.

The cementer’s dream is to be able to continuous-mix slurry to the same quality as is routinely achieved with batch mixing. The goal with either method is to create a slurry with properties matching those measured in the lab during slurry design. A slurry’s most critical parameter is its unvaying density, but also important are plastic viscosity, yield strength, free water, fluid loss, setting time and compressive strength after setting. Pump rates depend on the job, but typically vary between 2 and 10 barrels (320 and 1,600 liters) per minute (bbl/min). Total volume pumped also varies but is typically hundreds of barrels. Cement density

Next, a centrifugal pump delivers the slurry to powerful triplex positive displacement pumps that push the slurry downhole.

More sophisticated jet mixers achieve better homogeneity and density control by regulating the flow of solids from the surge can with a remotely controlled gate and by recirculating some slurry through one of the jets. Density can be measured continuously using a radioactivity sensor on the pipe feeding the tripex pumps or intermittently by hand using a conventional mud balance.

The second type of traditional mixer uses a low-energy vortex to mix solids and liquids. Liquid is fed circumferentially into a vertical pipe, creating a helical flow on the pipe wall downward toward a mixing tub (next page, left). Cement and dry additives, fed via a smaller concentric pipe, are sucked to the pipe wall and mixed with the liquid. A little farther down, another concentric pipe feeds recirculated slurry into the mix.

If the cementer’s goal remains continuous rather than batch mixing, then neither of these continuous mixing techniques is wholly satisfactory. First, chemical engineers believe that neither technique mixes slurry as thoroughly as is achieved in the lab during slurry design, possibly compromising downhole slurry properties. Second, it takes considerable skill to control the slurry’s density, its most critical property. Recirculation facilitates density control, but events move quickly during continuous mixing, and density fluctuations while pumping are inevitable (next page, below right).

**Research**

Mixing involves both mechanical and chemical processes. The mechanics are relatively well understood. Ideally, each cement particle should get wetted by the fluid, be forcibly separated from other particles clinging to it—in a process called deloeculation—and be kept separate from its neighbors as the cement hardens. Deloeculation is achieved by shearing a stream of solid cement particles with fast moving liquid, such as provided in conventional field mixers by a jet or rotating fluid stream. In the lab, cements are mixed in a kitchen-type blender with blades revolving at high speed to provide shear energy.

Throughout the deloeculation process, the cement grains and liquid are reacting chemically. As soon as the grains and liquid meet, silicate and aluminate compounds begin precipitating in the liquid. Much later, they link up and create hard cement.2

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Continuous jet mixing. Liquids issuing from jets into a mixing bowl suck down solids contained in a surge can. The mixed slurry exits to a slurry tub, from which it is delivered by a centrifugal pump to the powerful triplex positive displacement pumps that push it downhole. More sophisticated jet mixers allow recirculation of the slurry both to the mixing bowl and the tub, and have a remote-controlled gate regulating solid feed and a densitometer on the feed to the triplex pumps to continuously monitor density. These improvements provide better mixing and control of slurry density.

Low-energy vortex mixing. Liquid is fed circumferentially into a vertical pipe and mixes with cement solids fed through an inner concentric pipe. The mix is joined by recirculated slurry entering through a second concentric pipe, then passes through a baffle to a centrifugal pump.

Slurry density control during a cementing job. The first half of the job was mixed continuously; density fluctuates by 1 lbm/gal. The second half of the job used batch-mixed cement; density is uniform. Density fluctuations are detrimental to cement quality, affecting almost all slurry properties. (From Grant et al, reference 12.)
This process, called hydration, happens in two distinct stages. The first stage is rapid, occurring in a matter of minutes during mixing. Then, in a so-called induction period, precipitation slows down for several hours. During this time, the still liquid slurry is pumped downhole into the casing-formation annulus. After a few more hours, the second stage begins: Precipitation picks up and the cement hardens.

Hydration history determines many of a cement's most important design parameters, such as viscosity and yield strength during the induction period, thickening time and compressive strength after setting. But what determines hydration history? Obvious factors are the type of cement, the range of additives and their relative proportions, but also crucial is how the cement is mixed.

Like the big bang, which apparently lasted a fraction of a second yet goes a long way to explaining the current state of the universe, so the first few minutes of mixing predetermine how hydration evolves. Like cement hydration, page 4.

How mixing affects hydration, though, is still poorly understood. Precipitation of hydrates would certainly occur in a stationary mixture of cement particles and water, but imparting shear energy through stirring, jet mixing or whatever technique is used, appears to accelerate the process. This probably happens because embryonic crystals can be formed by chance collisions between molecular clusters of precipitate, in a phenomenon called contact nucleation. If the mixture is stirred vigorously and for an extended period, collisions are more likely to occur and hydration gets off to a better start.

Mixing energy and duration are also essential for wetting and deflocculation. Wetting is no mean feat. At typical pumping rates, the dry cement powder presents a surface area equivalent to 7,000 tennis courts every minute. Failure to wet this huge area results in agglomerations of grains and a lumpy slurry. The principle behind mixing is to create a turbulent flow that shears the agglomerations into smaller pieces.

In a theory developed by Soviet physicist A.N. Kolmogoroff, turbulent flow can be modeled as the superposition of a spectrum of different sized eddies on an average flow. In a mixer, the largest eddies are the size of the mixing blades. The size of the smallest eddies can be predicted using his theory from the density, viscosity and volume of fluid being mixed and the amount of power applied to the mixing. For a given amount and type of fluid, Kolmogoroff's theory shows that as power increases, the smallest eddy size gets smaller.

For deflocculation, eddies of all sizes are required, each shearing agglomerations about its own size. In a kind of chain reaction, large eddies break up large agglomerations of grains, then smaller eddies break the remnants into smaller components. To completely disperse slurry, the size of the smallest eddy must approach the dimensions of an individual cement grain, around 30 microns (µm). Calculations show that conventional lab blenders can put out enough power to reduce the smallest eddy size to around 60 µm, and in practice this seems enough to achieve complete deflocculation.

But power is only half the story. The Kolmogoroff theory does not indicate how long the power must be applied. In experiments performed at DS laboratories at Saint-Étienne, France, Benoit Vidick filled in this missing information. Using a lab blender,

3. The length, \( L \), of the smallest eddy is given by:
\[ L = \frac{\rho^2}{\mu V} \]
where \( \mu \), \( \rho \) and \( V \) are the fluid's viscosity, density, and volume, respectively, and \( P \) is mixing power.


5. Next cement is cement mixed with water with no additives.

6. Mixing energy, \( E \), per slurry mass, \( m \), is expressed as:
\[ E = \frac{\rho a^2}{m V} \]
in which \( k \) is a constant determined experimentally, \( a \) is eddy speed, \( t \) is mixing time and \( V \) is the volume of slurry being mixed.

7. Yield stress is the lowest stress under which a non-Newtonian fluid like cement slurry will flow.
Vidick mixed a neat 15.8-lbm/gal (1.9 g/cm³) slurry using different speeds and durations. He then filtered the resulting mixtures through a sieve designed to pass wetted and dispersed grains but to catch unwetted agglomerations. Not surprisingly, as he blended faster and longer, fewer agglomerations appeared on the sieve—time varied between 15 and 50 seconds, blender speeds between 3,000 and 12,000 rpm.

A first criterion for good mixing appeared when the speed and mixing time data were combined into one parameter—mixing energy per mass of slurry (below). As long as at least 2 kilojoules of mixing energy were applied for every kilogram of slurry (kJ/kg), nothing remained on the sieve and deflocculation could be considered complete. A certain mixing energy per mass seems to be required for deflocculation irrespective of what is being mixed. Experiments using barite and water showed that a similar criterion holds for a different solid, and experiments with cement and alcohol showed that it also holds for a liquid other than water. Vidick also discovered that the cutoff value depended on slurry density. For the 15.8-lbm/gal slurry of the experiments, it was around 2 kJ/kg, but it was less for lighter slurries and more for heavier ones.

Measurements of another slurry's plastic viscosity mimicked its sieve results (left). Approaching the 2-kJ/kg cutoff, viscosity decreased rapidly as the mixture deflocculated; past the cutoff, the deflocculated slurry's viscosity decreased only slightly. Most other cement properties follow the same trend of rapid change before the cutoff and flat response afterward (below, left).

Plastic viscosity measurements also revealed that even if enough energy had been applied to pass the sieve test, it was still worth continuing the mixing for a few tens of seconds because this reduced viscosity even more (below). This emphasizes that cement mixing does not end with deflocculation, as it would if the components were chemically inert. Continued mixing enhances hydration and as a result induces further changes in slurry properties.

For this reason probably, mixing time dramatically affects a slurry's yield stress. In further experiments, Vidick mixed slurries containing dispersants—many field slurries have dispersants—using four combinations of mixing speed and duration: 6,000 and 12,000 rpm, and 15 and 50 seconds. He

- Percentage of a neat 15.8-lbm/gal Class G slurry remaining on a sieve after mixing at different blending speeds and times (top). The bottom graph shows the same data but with speed and time combined into one parameter—mixing energy per mass of slurry. A cutoff around 2 kJ/kg indicates the transition between incomplete and complete deflocculation of the slurry. (From Vidick, reference 4.)

- Thickening time and fluid loss for different slurries, both leveling off once enough mixing energy has been applied to completely deflocculate the slurry. (From Vidick, reference 4.)

- Plastic viscosity of a neat 15.8-lbm/gal neat Class G slurry versus mixing time for various values of mixing energy/slurry mass. A certain mixing time is essential for complete deflocculation, whatever the energy/mass imparted to the mixture. (From Vidick, reference 4.)
then conditioned the slurry for 5 to 80 minutes in a machine called an atmospheric consistometer. (A consistometer gently stirs slurry to maintain its suspension.) While mixing speed and time in the consistometer clearly affect yield stress, most of the variability comes from the difference between 15 and 50 seconds in mixing time (above).

Before every job, cements are tested in the lab using procedures established by the American Petroleum Institute (API) and described in their specification 10 document. These include explicit directions on how to mix the regulation 600 milliliters of test slurry. You start with the liquid in the blender, turn it up to 4,000 rpm and then add the solids over a 15-second period. You then turn blender speed up to 12,000 rpm and mix for 35 seconds. This provides 5.6 kJ/kg of mixing energy to the slurry, more than 2.5 times the cutoff Vidick found to ensure defloculation. It also provides sufficient mixing time. What remains in doubt is whether it reflects actual mixing conditions in the field.

Jacques Ortban and colleagues, also at the DS Saint-Étienne facility, showed that jet mixers alone provide barely 20 percent of the energy per slurry mass imparted by the API test, well below the defloculation cutoff. Only by adding the shear energy provided by recirculating centrifugal pumps and perhaps a little as the slurry is pumped downhole by the triplex pumps, does the total energy per slurry mass reach levels required to defloculate all the cement grains. Continuous mixing may never attain the API specification 10 energy levels.

Batch mixing is a different story, particularly with small slurry volumes used for squeeze jobs or coiled-tubing operations. In these cases, energy is supplied over an extended period and can total far more than that provided by API procedures. In experiments simulating the batch mixing of small slurry volumes and then pumping these through coiled tubing, as much as 11 times the API energy levels were imparted. This resulted in dramatic and possibly dangerous changes in cement properties compared with API lab measurements. Thickening times, for example, were reduced to 20 percent of their lab-measured values.

One reason for this larger reduction is that much of the mixing took place within the coiled tubing itself, due to fluid friction, imparting energy to the slurry much more slowly than achieved with the API mixing procedure. When the lab mixing procedure was slowed down to mimic the mixing taking place in the tubing, lab and field results matched well.

Also in doubt are some API lab tests made on the slurry, for example, the thickening time test. This is performed in a consistometer at downhole pressure and temperature. As the consistometer gently stirs the slurry, resistance to stirring is measured. Initially, while the slurry is still liquid, resistance is low and constant, but when the slurry thickens, resistance increases. Thickening time is variously defined, but it basically measures the elapsed time for this increase to occur.

Recently, R.P.A. Van Kleef and J.P.M. van Vliet at the Koninklijk/Shell Exploration and Production laboratories in Rijswijk, The Netherlands criticized the consistometer test as not properly representing field condi-

\[
\begin{align*}
\text{Densities} & = + 0.4 \text{ lbm/gal} \\
\text{Design} & = + 0.8 \text{ lbm/gal}
\end{align*}
\]

**Table 1: Time to reach 500-psi compressive strength for ten slurries of varying density. Poor density control induces dramatic variations in slurry properties, particularly when liquid additive systems are used. (From Grant et al., reference 12.)**

<table>
<thead>
<tr>
<th>Solid additives</th>
<th>Liquid additives</th>
</tr>
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<tbody>
<tr>
<td>H+FLA+DIS³</td>
<td>H+FLA+DIS¹</td>
</tr>
<tr>
<td>H+FLA+DIS²</td>
<td>H+R³</td>
</tr>
<tr>
<td>H+R²</td>
<td>H+R¹</td>
</tr>
<tr>
<td>H+FLA+DIS¹</td>
<td>H+R³</td>
</tr>
<tr>
<td>H+R²</td>
<td>H+R¹</td>
</tr>
<tr>
<td>H+FLA+R³</td>
<td>H+FLA+R³</td>
</tr>
</tbody>
</table>

**Codes:***

- H: Class H cement
- FLA: Fluid loss additive
- DIS: Dispersant
- R: Retarder

**1 140°F (60°C)**

**2 160°F (71°C)**

**3 180°F (82°C)**

*Oilfield Review*
Throughout the test, the consistometer shears the slurry, giving it mixing energy. In the field, practically no shear is imparted after mixing, particularly when the slurry is pumped down large casing strings. The difference is much longer thickening times in the field compared with those predicted by the standard API test. The Shell researchers are calling for more realistic tests.

These examples show that numerous challenges remain in understanding slurry mixing. Perhaps the most important is creating more realistic lab tests that simulate field mixing equipment and pumping conditions. The challenge for designers of field equipment, meanwhile, has been slurry density—guaranteeing a fixed density irrespective of pump rate. Density has a dramatic effect on almost all slurry properties and may therefore dictate success or failure for well cementation (see related articles in this issue).

**Density Control**

W.H. Grant and colleagues of Chevron Services Company highlighted the density problem in a 1989 study of liquid cement additives. Using liquid additives poses special dangers if density control is poor. Suppose slurry is being pumped with too low a density (a similar argument applies for too high a density). This occurs because too much liquid is being mixed and means the concentration of additives relative to cement weight is too high, compromising slurry properties. The situation is slightly better for dry additives. At least then, the proportion of additives to cement stays constant because both are premixed and added together to the liquid.

Grant and colleagues found properties varying dramatically as they changed a variety of different slurries' densities by adding more or less liquid (previous page, bottom). Especially vulnerable, as expected, were the liquid additive systems. Further experiments at Saint-Etienne have confirmed how sensitive slurry properties are to density. Everything seems to be affected, from rheology to free water to thickening time (above, right). As a result, DS began an engineering program to design a radically new continuous-mixing technique that could control density.

Recent experimental data from Dowell Schlumberger showing variation of slurry properties with density, for a high density system (left) and a normal density system (right).

to within 0.2 lbm/gal (.02 g/cm³) below. Now, three of the mixers, called VIP mixers, are operating in North and South America and the Middle East, and ten more will become available in 1991.13 How is such
good density control achieved?

There are two secrets. One is applying
process control to the mixing process, a fea-
ture that most service companies are
already retrofitting to their traditional mix-
ers. The other is mixing the slurry in a
closed constant-volume environment: If you
know the exact volume being mixed and
the slurry density is not quite right, then it is
an easy matter to calculate the right amount
of solids or liquids needed to achieve the
right density.

The new device uses a rapidly turning
impeller within a circular chamber to create
a liquid vortex into which the solids are
mixed (next page, top). Liquid is gravity-fed
into the chamber; solids are metered
through a hydraulically operated gate from
a surge can above. The slurry exits sideways
from the chamber, enters a conventional
recirculating tube and is then fed to the
triplex pumps by a centrifuge.

The pressure in the vortex varies from
atmospheric at the liquid/air interface to 60
psi at the chamber wall; this high pressure
jects the mixed slurry. The shape of the eye
of the vortex is practically independent of
slurry density and pump rate, achieving a
constant mixing volume. The size of the eye
is easily sufficient to let all air accompany-
ing the cement powder escape upward, an
important feature. Air trapped in slurry
changes the slurry properties, affects the
pumping downhole and makes measuring
slurry density, D_{slurry}, with a radioactive
densitometer clamped on the exit pipe
highly unreliable.

The densitometer, which measures to an
accuracy of 0.1 lbm/gal (.01 g/cm³), is one of
four sensors that control the new mixer’s
performance. The other three are a flowme-
ter measuring liquid flow into the mixer,
Q_{water}, a sensor below the surge can mea-
suring the area of the gate opening, A, and a
weight measurement of the surge can that is
translated into a dry cement pressure at the
gate, p. These measurements are fed into a
processing unit installed on the pump truck
that controls slurry density as follows (next
page, bottom):14 From the Q_{water} measure-
ment and the operator choice of D_{slurry}, the
computer calculates the rate at which dry
cement, Q_{cement}, should be added to main-
tain the correct density—the only other vari-
able it needs for this calculation, dry cement
density D_{dry cement}, is input by the operator.
The computer then calculates the gate
opening area that will provide this dry
cement rate. This is derived from Q_{cement}
and surge-can cement pressure as:

\[ A = \frac{k Q_c}{\sqrt{p}} \]

in which k is a constant. Then, the com-
puter signals the hydraulic actuator to shift
the gate to the correct position. This hap-
pens ten times a second.

The constant k is determined by an auto-
calibrating scheme also implemented by the
computer. Knowing what is going into the
mixer, both liquid and dry, and the volume
of the mixing chamber, the computer cal-
culates an expected density for the slurry. It
then compares this with the actual density
measured by the densitometer. If there is a
discrepancy, it assumes the dry cement flow
calculations is in error and attributes the
error to an incorrect value for k. It calculates
a new k value to get agreement and then
uses this updated value in its gate position
calculations. Autocalibration of k recurs

Density Control in Cementing Operations,” paper
SPE 21330, presented at the SPE Latin American
Petroleum Engineering Conference, Rio de Janeiro,
Brazil, October 14-19, 1990.

cess Control of Slurry Density: Impact on the Field
Performance of Cement Systems,” paper SPE 21687,
presented at the SPE Production Operations Sympo-
sium, Oklahoma City, Oklahoma, USA, April 7-9,

Oilfield Review
Two systems of process control that keep slurry density on track. The primary control (top) uses changes in water flow into the mixing chamber to regulate cement flow from the surge can. This operates 10 times a second. The secondary control—k calibration—compares the slurry densitometer reading with density calculated from knowing what is entering the mixer. Differences are used to recalibrate the constant k, needed to determine dry cement flow.

New constant-volume vortex cement-mixing system. Cement and dry additives are fed from a newly designed surge can through a hydraulically operated gate into a closed circular chamber. Liquids enter the chamber from below, fed by gravity. A high-speed impeller creates a liquid vortex within the chamber that mixes solids and liquids at high energy levels. The vortex pressure ejects mixed slurry to a tub.

Slurry density is precisely regulated by a process control system using four measurements: water flow into the chamber, slurry density measured by a densitometer, surge-can weight and surge-can gate position. Required density is input by the operator using a remote panel on the pumping truck.
Density control using the new vortex continuous mixer under varying flow rates. A yard test (top) shows that step changes in flow rate do not seem to affect slurry density, which stays within the design specifications of ±0.2 lbm/gal. A field example (bottom) shows perfect density control over a 2-hour period under erratic flow rate changes caused by the fluid containing bulky lost circulation material.

Density control of a conventional low-energy mixer (top) versus the new continuous vortex mixer pumping a similar slurry. The horizontal band indicates the ±0.2 lbm/gal design specifications of the slurry.

Density and slurry rate operating conditions for the new vortex mixer.

Every 5 seconds, providing flow through the mixer is steady.

This process control reacts quickly, keeping density amazingly on track as slurry flow rate changes (above, left). This is because the primary control is the water flow measurement, not the density measurement. Each time the slurry flow rate changes, the input liquid flow rate adjusts instantaneously—because the chamber has constant volume—triggering an immediate change in cement supply. If the cement supply were controlled by the densitometer measurement, a considerable lag would occur between a necessary change in cement supply and its effect on slurry density. Nevertheless, as a backup, density may be controlled in this fashion if the main process control method fails. A second backup permits the operator to input a density value, measured using a mud balance, to recalibrate k.

In field tests, the process-controlled vortex mixer has provided unparalleled density control compared with traditional continuous mixing systems. Statistics from five jobs involving 10,000 sacks of cement show that over 96 percent of the slurries were within 0.2 lbm/gal of the design value. Certainly, comparisons with densities mixed by conventional mixers provide ample proof that this technology has advanced the state of the art (above, right). For the operator, the new machine is far easier to use than a conventional mixer. Design density is punched into the computer and is maintained by the process control automatically whatever the triplex pump rate. The mixer handles a range of flow rates and slurry densities covered in most field operations (above, right).
Another benefit is that the mixing energy is higher than with conventional mixers, bringing us nearer the deloeculation cutoff found by Vidick.

A crucial part of the mixer’s development has been ensuring a smooth, controllable flow of cement from the surge can into the mixing chamber. In a complete redesign of the conventional surge can, the sides have been made steeper and are fabricated using shiny stainless steel to prevent cement powder sticking. At the bottom, air is injected to create a fluidized cement pad to keep powder moving (below).

Comparisons between lab and field mixing show that in most cases the new system is mixing slurry to near API laboratory standards. One test involved a 16.4-lbm/gal (1.9 g/cm³) Class H slurry containing liquid additives—retarder, fluid-loss additive, dispersant, and antifoam agent (see “Class H Cement with Retarder, Fluid-loss Additive, Dispersant and Antifoam Agent,” above, right). Slurries having a range of densities around the design value were prepared in the lab using actual solid and liquid components obtained and reserved for lab use during the field trial. API mixing procedures were followed. Then rheology was measured, both immediately after mixing and, according to API specifications, after 20 minutes of stirring in an atmospheric consistometer. Similar tests made on slurry mixed by the new mixer at pump rates of 4 and 7 bbl/min provided viscosity and yield values consistent with lab results.

In a second slurry—a light mixture of Class H cement, dry bentonite and antifoam agent—the new mixer performed satisfactorily at 7 bbl/min but did not match the lab results at 10 bbl/min (see “Class H Cement/Fly Ash (35:65) + Bentonite + Antifoam Agent,” above). In comparison, a conventional recirculating jet mixer failed to match the lab results at either pump rate.

This new mixer will vastly improve cement slurry quality. The next steps will be physically integrating the mixer with the pump unit and providing additional computer control. Meanwhile laboratory research in the mixing process continues. Cement mixing poses surprising scientific and technical challenges, but the industry is addressing them. The benefit for the industry is safer wells requiring less remedial work. —HNE

<table>
<thead>
<tr>
<th>Old Surge Can</th>
<th>New Surge Can</th>
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<tr>
<td>Flow of cement from traditional surge can (top) and from newly designed surge can (bottom). Each surge can is initially full and then allowed to empty. Rate of emptying is plotted against remaining weight of cement in the can.</td>
<td>The old design gives erratic flow, and flow stops entirely when cement mass drops below about 300 kg. The new design gives smooth flow that continues to zero cement mass.</td>
</tr>
</tbody>
</table>

| Class H Cement with Retarder, Fluid-loss Additive, Dispersant and Antifoam Agent |
| --- | --- | --- | --- | --- |
| Mixing Environment | Density (lbm/gal) | Plastic viscosity (cp) | Yield stress (lb/100 ft²) | Plastic viscosity (cp) | Yield stress (lb/100 ft²) |
| Lab | 16.1 | 50 | 1 | 61 | 3 |
| VIP at 4 bbl/min | 16.3 | 62 | 3 | 68 | 4 |
| Lab | 16.5 | 74 | 4 | 98 | 5 |
| Lab | 16.2 | 77 | 4 | 91 | 5 |
| VIP at 10 bbl/min | 16.4 | 78 | 4 | 102 | 3 |
| Lab | 16.6 | 78 | 5 | 113 | 5 |

| Class H Cement/Fly Ash (35:65) + Bentonite + Antifoam Agent |
| --- | --- | --- | --- | --- |
| Mixing Environment | Density (lbm/gal) | Plastic viscosity (cp) | Yield stress (lb/100 ft²) | Plastic viscosity (cp) | Yield stress (lb/100 ft²) |
| Lab | 12.8 | 11 | 35 | 13 | 37 |
| VIP at 7 bbl/min | 13.0 | 11 | 44 | 13 | 42 |
| Lab | 13.2 | 13 | 58 | 16 | 49 |
| Lab | 12.8 | 11 | 58 | 13 | 37 |
| VIP at 10 bbl/min | 13.0 | 13 | 18 | 14 | 21 |
| Lab | 13.2 | 13 | 58 | 16 | 49 |
| Lab | 12.8 | 11 | 35 | 13 | 37 |
| Recirc. jet mixer at 7 bbl/min | 13.0 | 12 | 19 | 12 | 21 |
| Lab | 13.2 | 13 | 58 | 16 | 49 |
| Lab | 13.0 | 10 | 37 | 10 | 49 |
| Recirc. jet mixer at 10 bbl/min | 13.2 | 13 | 15 | 12 | 26 |
| Lab | 13.4 | 19 | 65 | 12 | 94 |

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