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A Hart Energy Publication

May 2008

## Cementing

# Alternatives in low-density cement formulation

*Conventional neat cement can be used in the majority of drilling situations, but in special cases density adjustment is critical to successful well completion and long-term zonal isolation.*

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Several alternatives have been used to adjust cement slurry density. These methods can be used individually or in various combinations. The optimum means to adjust slurry density depends in part on the formation conditions of the well and logistics such as onsite availability of specialists, materials, and equipment and the service company's experience, hardware, and preferred practices.

Cement density is typically expressed in pounds-per-gallon or ppg (field units), with conventional unmodified slurries weighing between 15.6 and 16.4 ppg and reduced density material ranging down to as little as 5 ppg. Slurry density selection is based on factors that include pore pressure, fracture gradient, and length of the cement column. Depending on conditions, slurry density alternatives can be used alone or in concert to achieve the best combination of performance and economy.

**Density adjustment alternatives**

It is more common to reduce rather

than increase slurry density to achieve zonal isolation and protect the geologic structure. Several methods and materials are available for use individually or in combination for this purpose.

**Water extension.** The simplest means of achieving density reduction is to add water, along with extenders such as bentonite, sodium, or potassium silicates, or diatomaceous earth. This process is economical, but it degrades ultimate cement performance in proportion to the amount of excess added water. Slurry weight can be reduced to approximately 11.5 lbs/gal using water alone; further

density reduction with water results in unacceptable permeability, low compressive strength, and extended cure time.

**Extension with hollow beads.** Low-specific-gravity hollow ceramic beads (cenospheres) added to the slurry effectively displace water and cement components with tiny encapsulated air bubbles. They range in diameter from approximately 25 to 300+ microns. This method yields a homogeneous mix, and finished cement containing cenospheres have an increased strength-to-density ratio and lower permeability compared to water-extended slurry.

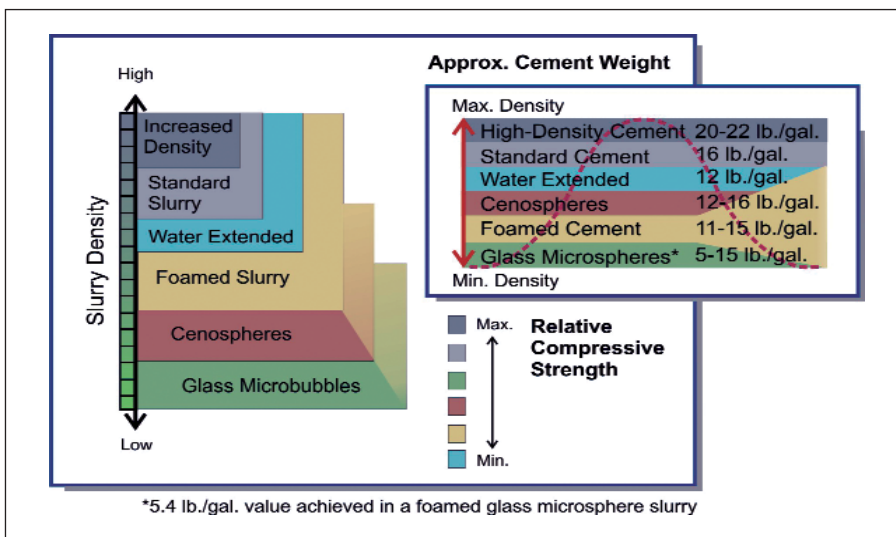


Figure 1. This graph shows the relative properties of cement density modification alternatives. These materials can be used in combination to achieve the required density and compressive strength. (Image courtesy of 3M)

Cenospheres are relatively inexpensive, but quality can vary from batch to batch, and availability can be an issue. This density reduction option has several limitations: the variability and unpredictability of cenosphere physical properties and the inability of this additive to tolerate the pressure levels that can be encountered in wellbore cementing. As a commodity rather than an engineered product, cenospheres do not have well-defined values or quality parameters. The material is commonly segregated by flotation rather than graded by size or other parameters, and those cenospheres that float are shipped for use in the field.

Nominal cenosphere density is 0.7 g/cc, but under minimal pressure of 500 psi, or more this value can increase to 0.85 g/cc, greatly reducing the functional value of the material as a slurry additive. Cenospheres also sometimes segregate partially by size during transport and handling, resulting in density variations in the slurry. In some oil producing areas there are environmental concerns associated with use of cenospheres in wellbore cementing.

**Foam extension.** While standard slurry has an unadjusted density of around 15.8 lb/gal, properly foamed material density can be reduced to approximately 12 lb/gal. Industry experience demonstrates that the best practice is to foam the base slurry with no more than 25% gas content. The resulting foamed mixture has a higher compressive strength than water-reduced cement.

While the presence of gaseous bubbles in the cement matrix reduces its weight and improves flow characteristics, such a mixture can lack homogeneity and can vary in density along the column. Effective foaming can be complex and requires careful control to achieve the desired results. This process also relies on immediate availability of the required equipment, along with experienced personnel.

**Extension with glass microspheres.** High-strength glass microspheres are now widely available. Hollow glass microspheres are typically between 10 and 90 microns in diameter and do not tend to segregate by size, remaining evenly distributed in transportation and storage and stable in a slurry mixture.

The smaller size of glass microspheres

compared to ceramic cenospheres results in tighter cement, having an equivalent volume of entrapped air but with closer spacing. Glass microspheres have substantially greater pressure tolerance than alternative cenosphere materials, making low-density cement using glass microspheres particularly useful in the higher pressures encountered in deepwater drilling wells or locations having longer cement columns. Equipment required for use of glass microspheres is typically simpler and less costly than for foaming.

Multistage cementing is used in some locations to isolate the pay zone in areas of weak formation. Unfortunately, the stage tools used to divide upper and lower zone cementing in this process can have a high failure rate, and a field malfunction can prevent drillers from cementing the second stage. The potential risks and expenses associated with multistage cementing can be minimized or avoided; however, by using a hollow-glass sphere, low-density slurry to cement a long interval in a single stage.

It is possible to reduce cement density by using a combination of water and hollow glass microspheres to reach approximately 8 lbs/gal, and then foam the mixture to approximately 25% nitrogen content to achieve an ultimate density as low as 5.4 lb/gal, and still retain necessary physical properties.

Using glass bubbles alone, a conventional neat cement slurry can be adjusted incrementally to very low density. This level of adjustment is not possible with foam alone without an unacceptable loss of cement properties. Additionally, foamed cement can be difficult to proportion in small quantities, while a properly designed cement mixture using hollow glass microspheres can be simpler to formulate and more consistent in density as well as homogeneity, regardless of volume. The mechanical properties of lower density cement made with hollow glass microspheres alone are excellent, and industry experience confirms its performance.

An SPE technical paper on beaded lightweight cements reported that a properly designed hollow glass sphere slurry has the highest strength-to-weight ratio and lowest permeability of any cement design. It also develops com-

pressive strength more quickly, thereby reducing costly wait time.

### High-temperature applications

Steam injection calls for cement that can tolerate the stresses imposed in this cyclic process, which include high temperature and thermal cycling. Heavy oil zones with weakened underground rock formations add another challenge to low-density cement formulation. If the cement is sufficiently light to circulate as intended but cannot withstand down-hole conditions (for example, a 550°F or 287.5°C steam extraction environment) the resulting seal can be compromised.

A lightweight slurry capable of maintaining a seal under such demanding conditions, which include elevated temperatures as well as the presence of corrosive carbon dioxide gas, was formulated for use in a Middle East region where heavy oil exists in shallow areas of weak limestone and where steam injection is required.

Water-extended cements were not suitable for this task, and the permeability and porosity of foam adjusted cement made it unsuitable as well. Lightweight base slurry was required to reach the target density, withstand rigorous conditions, and make it possible to place pipe swiftly. The lowest available specific gravity additive was needed to minimize the amount of non-cementitious material in the slurry, and glass microspheres were selected as the density reduction agent. Use of 0.32 specific gravity hollow glass microspheres reportedly allowed for a higher cement-to-additive ratio, and resulted in a slurry weighing only 8.5 lb/gal, with the necessary thermal integrity.

Ultra-lightweight glass spheres with crush strength as high as 18,000 psi have been shown to resist the elevated wellbore pressures that are encountered in challenging drilling conditions.

Additionally, slurries made with hollow glass microspheres are simple to formulate and pump. The international use of high-strength hollow glass microspheres singly and in conjunction with other cement density reducing methods has increased substantially over the past several years as service providers gain experience with this density control option. **ENR**