AADE-19-NTCE-027

Micronized Weighting Agents for Ultra-High-Density Oil Well Cementing

Mohamed Al-Bagoury, Martin Urraca, Tarek Fattah, and Ben Wang, Elkem ASA

Abstract

Cementing across ultra-high-pressure zones (HPHT) is a detailed operation which requires highly stable cement slurries. Formulating heavy cement slurries can be a challenging process. These slurries must encompass a selection of compatible blend components. Cementing of HPHT, deviated and horizontal oil and gas wells need tailored low rheology cement slurries to minimize losses to the formation and provide proper zonal isolation.

Spherical micronized manganese tetraoxide (Mn_3O_4, with a density of 4.80 SG) has successfully been used to achieve stable high-density slurries. Using conventional weight materials like hematite make cement slurry design more challenging and decreases success ratio in the field. Continuous weight material development has resulted in a commercial availability and pneumatically conveyable, micronized ilmenite ($FeTiO_3$, 4.60 SG) with a d50 particle size of 5 µm. This product has lately been successfully used in the field as a weighting agent for drilling and spacer fluids.

This paper highlights test results of micronized ilmenite in cement slurries with various densities. Low viscosity fluid loss additive for ultra-high-density cement slurries were also used in these slurries. Micronized ilmenite has been tested as an aqueous slurry of 2.70 SG, delivering a one-month product stability. This liquid version can provide greater flexibility regarding logistics, and for remote cementing operations.

Introduction

Achieving zonal isolation across high pressure formations requires the use of weighting agents to reach the needed oil-well cement density. While barite is a commonly used weighting agent in drilling fluids, it has limitation for usage in oil well cementing. Barite has a lower density (4.2 SG) compared to ilmenite or hematite and has high-water demand (0.024gal/lb) to wet the surface, which leads to lowering compressive strength of a set cement. Hematite, ilmenite and manganese tetraoxide are the most suitable weighting agents. In certain cementing applications, i.e. HPHT horizontal wells and deep gas wells, the required cement slurry density can reach up to 2.80 SG (23.37 ppg). Oil well cement slurries weighted with hematite become unsuitable for these applications as gas migration, high settling and excessive viscosity can be the outcome when using hematite.

SPE-175194 paper by Al-Yami discussed the challenges of gas migration and cement failure for deep high-pressured gas wells. Settling of hematite was one of the most significant challenges when cementing these wells. The settling of cement column creates low density on the top and high density on the bottom of the cement column, which can lead to high fluid loss into the formation and poor cement bonding. Well integrity issues that occurred in the field were a consequence of hematite settling.

The introduction of a micronized weight material, manganese tetraoxide (Micromax, Mn_3O_4) in the early 1990 allowed the formulation of high-density slurries with low viscosities, contributed by the particle size of d50 of 1µm and particles circularity.

The small size of manganese tetraoxide allowed optimal particle packing, a well-established method in formulating high density inorganic pastes for construction and refractories applications. In these applications, cement is blended with sized aggregates and other additives, with certain mass ratios to obtain the optimal particle packing, assuring good flowability. This concept was adapted by the oil and gas industry to obtain high density cement slurries.

The modern high-density oil well cement slurries are generally composed of G-cement, silica flour, silica sand, sized weighting agents, and chemical additives with minimal contribution to the slurry viscosity.

Optimized rheological properties of the cement slurries can minimize cementing challenges including fluid loss control, gas migration, improper cement displacement etc. Improved rheological properties of cement slurries can be achieved by:

1. Optimal particle packing by using proper particle sizes of the different solid components within the blend.

The use of micronized weighting agent becomes an essential additive in size optimization, as the particle size of cement is normally in the range of 20-30 µm and silica sand has a particle size >100 µm.

2. Proper selection of chemical additives that do not contribute to an increase in viscosity, including fluid loss control agent, dispersant and retarder.

Hematite is still a commonly used weighting agent as it used to be readily available and has a high specific gravity, in the range of 4.60 - 5.30 SG. The main drawbacks of using hematite as a weighting agent in oil well cementing is:

1) Settling is a major issue for hematite due its large size >20 µm and its high density.
2) Cement slurry with hematite normally generate high plastic viscosity and low yield point, leading to high friction and low suspension.
3) Inconsistent quality is another major concern of hematite. In addition, the supply of high-quality hematite is diminishing, and shortage exists in certain regions of the world. Processing high-quality hematite from low-quality ores adds an additional production cost.

In certain areas, the availability and cost of hematite enable operators to continue using hematite for non-critical and less rigorous jobs: However, the characteristics of these slurries can still lead to poor cement placement and eventually lack of wellbore integrity.

To overcome hematite drawbacks and provide the industry with cost efficient solution, a new micronized weighting agent has been developed. The criteria for the new weighting agent were as follows:

1) Minimize or eliminate settling within the cement slurries, avoiding cementing job failures and gas migration incidents.
2) Provide cement slurry with low plastic viscosity allowing for improved ECD management and thereby minimizing losses to formation.
3) Predictable quality to assure homogeneous and consistent blends. This include consistency in size and composition of the weighting agent.
4) Improve mechanical properties of set cement.
5) Readily availability and sustainable supply.

This paper will discuss the use of micronized ilmenite as a weighting agent for high density oil well cementing.

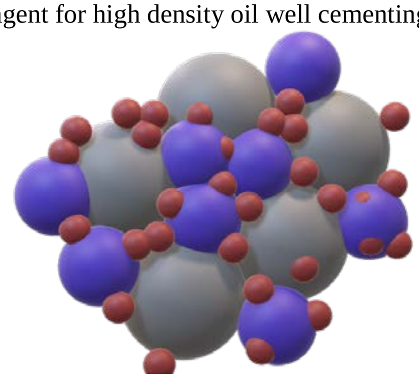


Figure 1: Illustration of particle packing of cement slurry

Experiments

Chemicals

Table 1 shows the properties of weighting agents used in this paper. G-cement is supplied by Dyckerhoff (fineness is 326 m²/kg). Latex, latex stabilizer and polymers as fluid loss additives, Silica sand (120 µm) silica flour (23 µm), Microblock, dispersant, retarder and silicone defoamer were also used in the slurries.

Table 1: Typical properties of weighting agents.

Weighting agent	Micromax	Micronized ilmenite	Hematite
Chemical formula	Mn_3O_4	$FeTiO_3$	Fe_2O_3
Density (SG)	4.85	4.65	4.95
Absolute volume (gal/lb)	0.0247	0.0257	0.0242
d50 (µm)	1	5	10 – 30
d90 (µm)	5	13	100
Shape	spherical	round	irregular
Water demand (gal/lb)	zero	zero	0.0023
BET (m^2/gm)	2 - 3	1.6	ca. 0.7

Micronized ilmenite

Ilmenite ($FeTiO_3$) with a size in the range 15-30 µm was previously used as weighting agent for oil well cementing, drilling fluids and spacer fluids in the North Sea. Recently, a 5µm ilmenite was developed and applied in the field to reduce the setting rate and improve the viscosity of drilling fluids.

Table 2 shows the main chemical composition of micronized ilmenite characterized by using x-ray diffraction (XRD). Micronized ilmenite is mainly composed of $FeTiO_3$. The material has a high circularity of > 0.85 assessed by particle imaging analysis. This contributes to lowering cement slurry viscosity. Figure 2 shows the particle size distribution (PSD) of 5 µm ilmenite measured using laser diffraction analysis.

Table 2: Chemical composition for micronized ilmenite.

Element as metal oxides	FeO	TiO_2	MgO	Al_2O_3	SiO_2	MnO	CaO
Content wt.%	46.21	44.42	4.39	0.72	2.88	0.30	0.35

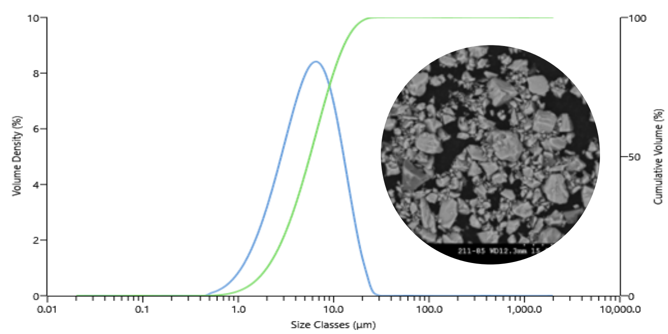


Figure 2: Particle size distribution of 5µm ilmenite.

Equipment

The following standard oil well cementing equipment was used: a constant speed mixer, HPHT fluid loss system at various temperatures with a differential pressure of 1000 psi, Fann 35 viscometer, HPHT consistometer, SGSA, BP settling test tube and HPHT thickening time tester. Cement tests were conducted according to API Recommended Practice 10B-2 (ISO 10426-2).

Results & Discussions

As the density of cement slurries increases, the ratio of weighting agent to cement should increase to maintain the slurry flowability. Figure 3 shows the required amount of micronized ilmenite to increase the density of latex cement slurries up to 2.40 SG. The zero-water demand for ilmenite, and the particle size of 5 µm and the particle roundness allow formulations of cement slurries with improved rheological properties even at low dosage of weighting agent. Latex as fluid loss and gas migration control additive is prohibited in certain regions such as the North Sea. Alternative options for HPHT cementing are synthetic fluid loss additive combined with Microblock for gas migration control. Micronized ilmenite works both in latex and non-latex systems.

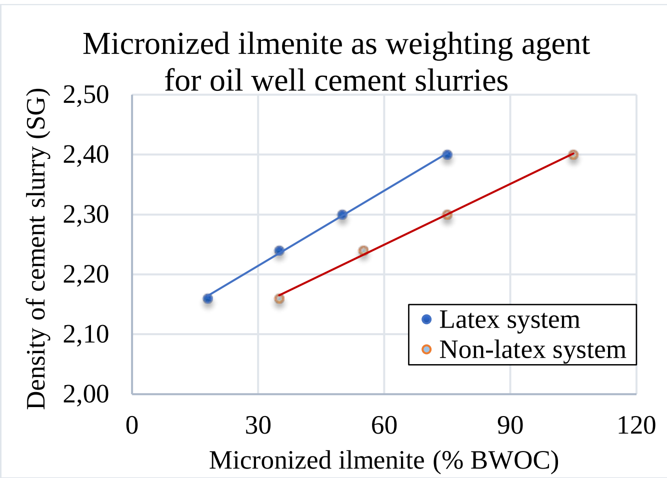


Figure 3: Dosages of micronized ilmenite to increase the density of OWC slurry.

Hematite quality

To formulate a high-density cement slurry with high robustness, the quality assurance of each individual cement slurry additive is essential. The use of optimized particle packing model requires high consistency for the particle size distribution. To illustrate the impact of the particle size of hematite in cement slurry properties, three commercially available hematite grades were tested. Figure 4 shows a large difference in particle size, as well a size distribution. The average particle size (d50) can vary from 10 to 50 µm. As there is no oilfield specification with respect to particle size of hematite, inconsistent quality and particle size exist in the market.

Figure 5 shows the effect of the particle size of hematite on viscosity in 2.24 SG cement slurries. The wide particle distribution complicates the cement slurry design. In cement densities above 2.20 SG, some of hematite grades were not mixable due to its low density and particle size distribution. Inconsistent hematite quality may lead to cement failure in the field.

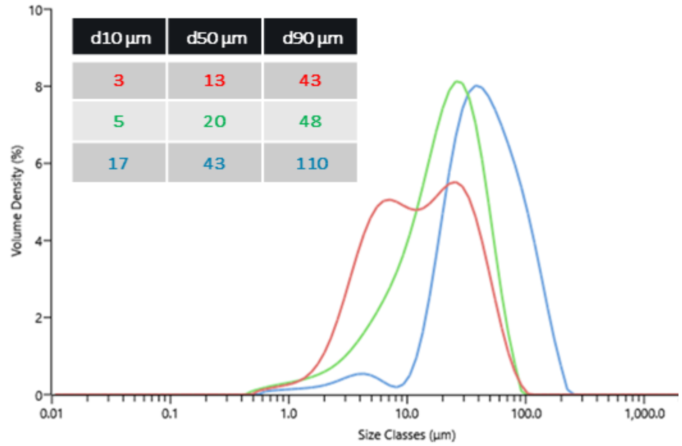


Figure 4: Particle size distribution of three hematite samples. PSD for each sample is indicated in the table.

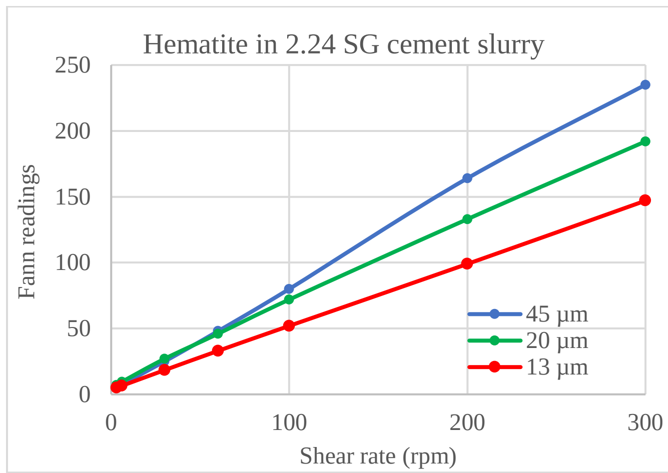


Figure 5: Effect of hematite quality on the viscosity of cement slurry.

In addition to the variations in PSD, hematite can contain large amount of impurities (up to 10 wt %) such as magnetite or silicates. These impurities occur naturally in hematite ores. Figure 6 shows the SEM of a hematite sample with impurities. Pure hematite has a density of 5.30 SG with red color, but as the impurities content increases in volume, the specific gravity is reduced, and the material become black colored (figure 7). In addition to magnetite, some hematite sources contain large amount of micro-quartz and silicate phases as shown by XRD scan in figure 8. This is called high-silica low grade hematite, a common grade sourced in China. This sample with a high quartz content had a density of merely 4.70 SG.

High magnetite content might cause logging interference. Low purity hematite causes gelation of cement slurry and delays the development of compressive strength, both critical factors in cementing operations.

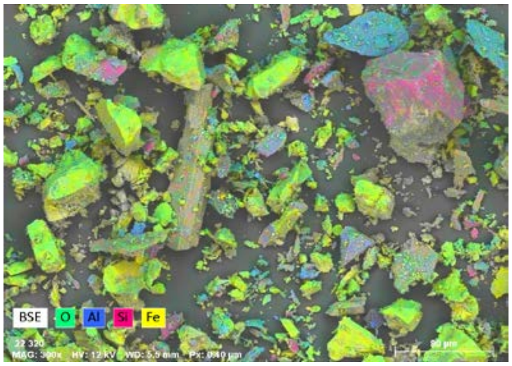


Figure 6: SEM scan of hematite sample

High grade hematite low grade hematite

Figure 7: appearance of hematite samples

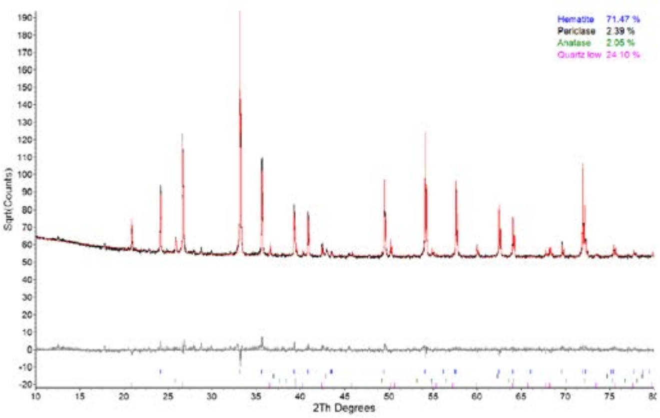


Figure 8: XRD of hematite sample contains 24 % quartz

2.24 SG HPHT cement slurries weighted up with 5 µm ilmenite and 25 µm hematite

Latex based cement slurries were formulated for comparison of micronized ilmenite versus hematite. As illustrated in table 3, the plastic viscosity at 90 °C of the 5 µm ilmenite slurry (180 cP) was significantly lower than the slurry containing 25 µm hematite (232,5 cP). The yield point and 6 and 3 rpm readings were higher for the micronized ilmenite sample, ensuring better stability and less settling. The improved rheological profile from using micronized ilmenite in the cement slurry compared to hematite provides the following operational advantanges: reduced pump pressure, lower ECD and less settling. Settling occurred in the hematite slurry at temperature of 90 °C. Using micronized ilmenite eliminates the need of anti-settling agents in order to stabilize cement slurries. This is beneficial as usage of anti-settling agents increase the viscosity at surface and mixing in the field can be difficult due to the product high viscosity and stickiness. Cement slurries exhibit thermal thinning behaviour at elevated temperatures which increases settling potential. Therefore, thermally activated polymers are an option for maintaining surface viscosity at downhole conditions. However, as the activation mechanism including hydration of these in-situ polymers depend on several parameters, avoiding settling can not be guaranteed.

All cement slurry designs presented in the paper had a fluid loss of <50ml /30min (as per the API Fluid-loss Test). This is the API recommended value for liner and slimhole applications and for areas with potential for annular flow.

Table 3: 2.24 SG cement slurries formulated with 1.5 gps SBR-latex, 0.15 gps latex stabilizer, 0.3 gps retarder, 0.5 % BWOC FR, 35 % BWOC silica sand, and 35 % BWOC weight material.

Tests	5 µm ilmenite		25 µm hematite	
Temperature	20 °C	90 °C	20 °C	90 °C
300 rpm	292	192	>305	235
200 rpm	210	133	221	164
100 rpm	119	72	116	80
60 rpm	80	46	74	48
30 rpm	48	27	43	25
6 rpm	23	9.5	16.3	7.5
3 rpm	18.4	7.0	12.4	5.4
PV (cP)	259.5	180	-	232.5
YP lb/100ft^2)	32.5	12	-	2.5
Settling	no	no	no	yes

2.30 SG HPHT cement slurries weighted up with 5 µm ilmenite and 25 µm hematite

Table 4: 2.30 cement slurries formulated with 1.5 gps SBR-latex, 0.15 gps latex stabilizer, 0.3 gps retarder, 35 % BWOC silica sand, 50 % BWOC weight material, 0.5 % BWOC dispersant for hematite and 1.0 % BWOC dispersant for 5µm ilmenite.

Tests	5 µm ilmenite		25 µm hematite	
Temperature	20 °C	90 °C	20 °C	90 °C
300 rpm	310*	233	320*	268
200 rpm	224	165	223	186
100 rpm	130	89	114	84
60 rpm	88	58	71	50
30 rpm	55	33	40	27
6 rpm	27	12.2	15.1	8.3
3 rpm	21	8.9	12	5.7
PV (cP)	270	216	309	276
YP (lb/100ft^2)	40	17	11	-8
Settling	no	no	no	yes
Free water, ml	<1		6	

*) Extrapolated value

The cement slurry with 5µm ilmenite showed lower viscosity profile after cement conditioning. The PV of the 5 µm ilmenite cement slurry was 216 cP compared to 276 cP for 25 µm hematite. The yield point for 5 µm ilmenite cement slurry (17 lb/100ft^2), providing improved suspension characteristics without settling. To the contrary, the 25 µm hematite slurry had large amount of free water (6 ml) and settling was observed in the viscosity measuring cup. To minimize free water in hematite slurries, an anti-settling agent needs to be added, which will further increase in the overall rheological properties. Using the micronized ilmenite eliminates the need for an anti-settling agent.

Non-latex 2.30 SG HPHT cement slurry weighted up with micronized ilmenite

Micronized ilmenite was used to weight up non-latex HPHT cement slurries with densities of 2.20 and 2.30 SG. To assure the optimum dispersibility of the weighting agent, 1.0 % BWOC dispersant was used. Microblock was used as a gas migration additive in conjunction with a HPHT fluid loss additive. Both slurries showed good stability with no settling and a free water content of less than 1 ml. Since polymeric fluid loss additives increase the viscosity of cement slurries, micronized ilmenite concentrations were adjusted to 45 and 70 % BWOC for 2.20 and 2.30 SG slurries, respectively.

Table 5: HPHT cement slurries formulated with 0.3 gps fluid loss additive, 0.5 gps Microblock, 0.5 %BWOC retarder, 20 % silica flour, 15 % BWOC silica sand, and 1.0 % BWOC dispersant. For 2.20 and 2.30 SG slurries micronized ilmenite 45 and 70 % BWOC were used, respectively.

Tests	2.20 SG		2.30 SG	
Viscosity readings	20 ˚C	85 ˚C	20 ˚C	85 ˚C
300 rpm	229	214	>305	292
200 rpm	162	149	262	196
100 rpm	87	81	149	101
60 rpm	55	51	98	61
30 rpm	31	28	58	30
6 rpm	10.9	7.6	24	6,5
3 rpm	7.8	5.1	20	4,1
PV (cP)	213	199.5	NA	286.5
YP (lb/100ft^2)	16	14.5	NA	5.5
Settling	no	no	no	no
Free water, ml	<1			<1

Ultra HPHT cement slurry

When formulating ultra-high-density oil well cement slurries with hematite, challenges related to excessive PVs, settling and gas migration are encountered. The shortcoming of hematite in ultra-high-density cement slurries has led to poor zonal isolation in the field, including gas migration which again has led to remedial cement jobs [Al-Yami, SPE-175194-MS].

The introduction of Micromax has eliminated these challenges. Common practice in obtaining superior high-density cement slurries is done by using of Micromax as the weighting agent [Johnston et al., SPE-24976-MS].

Tests were conducted to evaluate the usage of 5 µm ilmenite in an ultra-HPHT formulation. Table 6 shows a 2.40 SG cement slurry formulated with 75 % BWOC of 5 µm ilmenite and 25 µm hematite. The 300 reading for hematite was out of measuring scale. Thus, the PV value must be extrapolated. The PV for ilmenite was calculated at 255 cP at 90°C, which can be undesirable in applications where there is a narrow pressure window. Above these conditions, Micromax is the single solution for overcoming these challenges.

Table 6: cement slurries with a density of 2.40 SG formulated with 1.5 gps SBR-latex, 0.15 gps latex stabilizer, 0.3 gps retarder, 35 %BWOC silica sand, and 75 %BWOC weight material. 0.5 %BWOC dispersant for hematite and 1.1 %BWOC dispersant for 5 µmm ilmenite.

Tests	5 µm ilmenite		25 µm hematite	
Viscosity readings	20 ˚C	90 ˚C	20 ˚C	90 ˚C
300 rpm	>305	257	>305	>350
200 rpm	263	171	>305	230
100 rpm	150	87	162	107
60 rpm	100	55	101	65
30 rpm	61	30	57	35
6 rpm	28	10,8	21	11
3 rpm	21	7.4	15.3	8
PV (cP)	NA	255	NA	NA
YP (lb/100ft^2)	NA	2	NA	NA
Settling	no	no	no	yes

PV's can be reduced by increasing the amount of ilmenite from 75 % to 100 % BWOC, or by applying the particle packing model. In narrow ECD windows, slim-hole or long horizontal cementing operations, the spherical 1µm Micromax is essential in designing low rheology cement slurries.

Ultra HPHT 2.70 SG oil well cement using Micromax and micronized ilmenite

Table 7 shows the properties of ultra HPHT (2.70 SG) cement slurry designed with a blend of Micromax and 5µm ilmenite - each with 80 % BWOC.

This simple ultra-high density and gas-tight cement slurry design demonstrates the improved effect on rheological properties when using micronized weighting agents, in combination with effective dispersant and low-viscosity fluid loss additive such as latex.

Table 7: Ultra HPHT oil well cement 2.70 SG weighted up with Micromax and 5µm ilmenite - each with 80 % BWOC. Latex 2.5 gps, equal to 0.85 gps blend, silica sand 25 % BWOC and silica flour 10 % BWOC and dispersant 1 % BWOC were used.

Viscosity readings	20 ˚C	90 ˚C
300 rpm	395*	206
200 rpm	273	142
100 rpm	136	75
60 rpm	82	50
30 rpm	43	31
6 rpm	11.3	14.4
3 rpm	7.6	12
PV (cP)	388.5	196.5
YP (lb/100ft^2)	6.5	9.5
Settling	no	no
Free water, ml	zero	
SG @ room temp	2.70	
Fluid loss @ 135°C, ml	32	

*) Extrapolated value

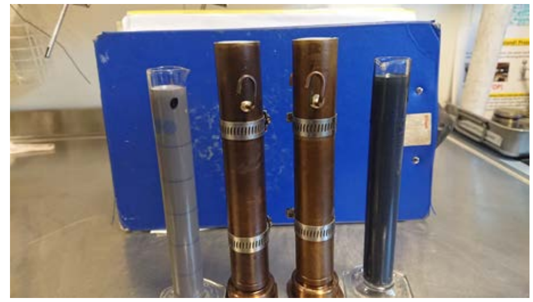
Stability of cement slurry (settling test)

As previously discussed, settling of cement slurry can lead to major cementing issues such as gas migration, cement failure and well integrity. Severe settling can occur in horizontal, deviated and HPHT cementing operations.

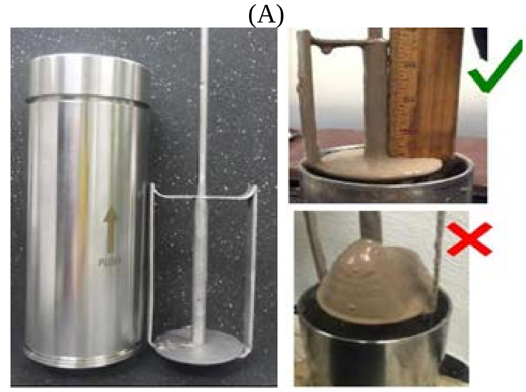
There are two common methods for measuring slurry stability:

1. API free water test method.
2. BP settling tube method.
3. Dynamic settling using HPHT consistometer

API free water test method is a good tool to discard cement formulations with high free water. However, it does not provide accurate estimation for the settling at downhole conditions. A BP research team found that the API free water test method was inaccurate in assessing the settling potential at downhole conditions [Greaves and Hibbert, Oil & Gas Journal, 1990]. The BP method assesses the static settling potential once the cement has been placed in the annulus. The dynamic settling using a HPHT consistometer assesses the settling potential when cement slurries are in motion in low flow and downhole conditions [Doan et al 2016]. Figure 9 a and b show the BP tubes and measuring cylinders for assessing settling of cement slurries.



(A)



(B)

Figure 9: BP copper settling tube to assess settling under HPHT conditions (A) and HPHT consistometer (B)

According to Stokes' Law, micronized particles have lower settling velocity compared to larger particles such as hematite. The concept of using micronized weighting agents to minimize barite sag in drilling fluids has been proven in the field to be very successful. Minimizing barite sag using suspending agents was not a straightforward approach.

When comparing settling rates for micronized ilmenite and hematite, several cement slurry densities were tested at HPHT conditions.

Table 8: Settling test results of 2.30 SG cement slurries weighted with 5 µm ilmenite and 25 µm hematite.

Settling parameters	5µm ilmenite		25µm Hematite	
System	latex	Non-latex	latex	Non-latex
Density of OWC	2.30 SG	2.30 SG	2.30 SG	2.30 SG
Density top (SG)	2.29	2.29	2.28	2.28
Density bottom (SG)	2.32	2.30	2.36	2.35
ΔSG	0.03	0.01	0.08	0.07
Free water (%)	1%	1%	4.9%	2.5%

Table 8 shows the comparative settling testing for latex and non-latex 2.30 SG cement slurries at 150 °C. The thickening time was adjusted to approximately six hours. Slurries with 25 µm hematite showed high settling with large amount of free water - up to 5 % compared to 1% for micronized ilmenite slurries. This large amount of free water can cause gas migration problems and cement failures since it leaves 5 % of the targeted zone with poor cement properties. The difference in densities (-delta SG) was 0.08 and 0.07 for hematite compared to an average of 0.02 for micronized ilmenite. The density of bottom layers for hematite slurries increased by 0.05 SG. In horizontal cementing, such hematite slurries are not suitable as it can jeopardize well integrity.

High density cement plug with micronized ilmenite

A cement plug with a density of 2.16 SG was prepared using 30 % BWOC silica sand, 30 % BWOC 5 µm ilmenite and 0.4 % dispersant. The plug showed low plastic viscosity of 86 cP at 85°C.

Table 9: 2.16 SG cement plug with 30 % BWOC 5µm ilmenite

Viscosity readings	20 °C	85 °C
300 rpm	135	86
200 rpm	88	58
100 rpm	47	30
60 rpm	27	19
30 rpm	13	10
6 rpm	3	4
3 rpm	2	3
PV (cP)	132	84
YP (lb/100ft^2)	3	2
Free water, ml	zero	
SG @ room temp	2.16	

This plug developed a compressive strength of ca. 10.000 psi after 24 hours. This compressive strength was measured using both destructive (-crushing cement cubes) and non-destructive (-SGSA equipment) methods. The cubes were cured at a pressure of 3000 psi and temperature of 120 °C. SGSA was measured at the same conditions with a ramp up period of 120 minutes. Figures 10 shows thickening time for a 2.16 SG cement plug. Table 10 shows the compressive strength after 12, 24 and 46 hours. Table 11 illustrates the compressive strength measured by the destructive method. Compressive strength was higher for the destructive method compared to non-destructive method.

Table 10: Compressive strength of 2.16 SG cement plug measured by SGSA at 120 °C and 3000 psi.

Compressive strength (psi) at 120 °C and 3000 psi		
12 hours	24 hours	46 hours
5513	6300	6592

Table 11: Compressive strength of 2.16 SG cement plug with Microdense 30 % BWOC. The cubes were cured in a HPHT curing chamber at 120 °C and pressure of 3000 psi.

Time	Samples	Mpa	psi	Average
After 24 hours	Cube 1	62	8990	9367
	Cube 2	67.2	9744	
After 7 days	Cube 1	68.6	9947	10281
	Cube 2	59.2	8584	
	Cube 3	84.9	12311	

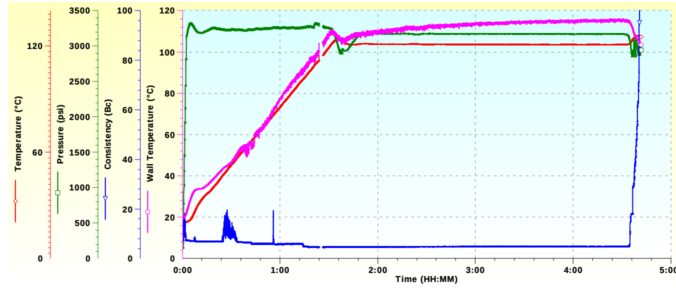


Figure 10. Thickening time curve of 2.16 SG cement plug with 30 % BWOC 5 µm ilmenite

Handling of micronized ilmenite

It is anticipated that micronized ilmenite will provide a stable dry blend with the cement without segregation, which is drawback when using hematite.
In addition, micronized ilmenite – a pneumatically conveyable weighting agent - can improve handling while being premixed with mix water and forms a stable slurry. Table 12 shows the properties of 80 wt % micronized slurry in water. The slurry was easy to mix and maintained stable for at least two weeks. This liquid version can provide greater flexibility regarding logistics, specifically for remote cementing operations.

Table 12: 5µm ilmenite slurry in water

Solid content	Density	pH	Plastic viscosity	Yield point
%	SG		cP	(lbs/100ft^3)
80	2.6	8.2	172	28

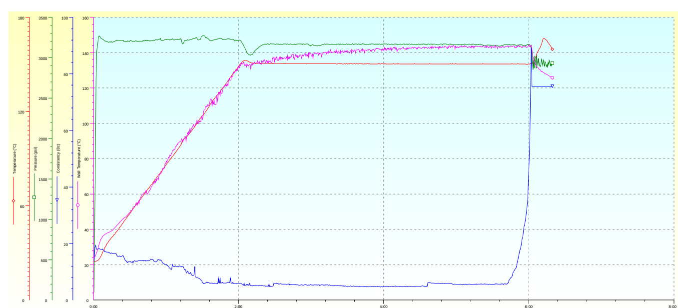


Figure 11: Thickening time curve of 2.16 SG cement slurry with 5µm ilmenite at 150 °C and 3000 psi.

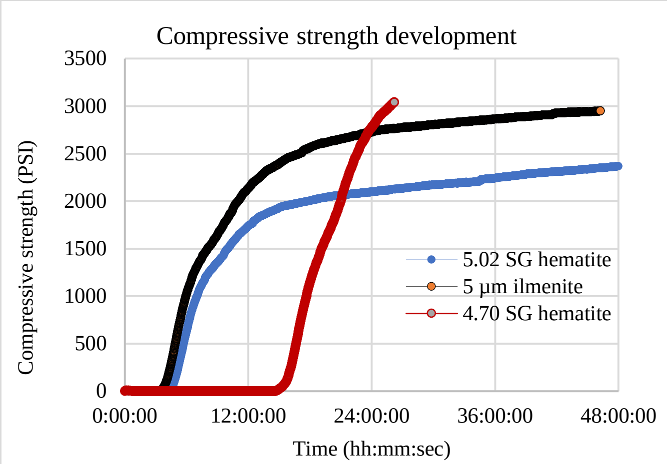


Figure 12: SGSA curve of 2.30 SG cement slurry with 5 µm ilmenite (black), 5.02 SG hematite (blue) and 4.70 SG hematite (red) at 135°C and 3000 psi.

Figure 11 shows an example of the thickening time curve for a 2.16 SG cement slurry with micronized ilmenite, where the short transit time of less than 10 minutes is displayed. Figure 12 depicts the compressive strength development for a 2.30 SG cement slurry weighted with 5 µm ilmenite, 4.70 and 5.02 SG hematite slurries. The 5 µm ilmenite slurry shows rapid and higher early compressive strength compared to the hematite slurries. In addition, the low-grade hematite 4.70 SG showed significant delay in strength development of more than 12 hours compared to the other samples. Extending the wait on cement is undesirable.

Conclusions

Micronized ilmenite provides stable cement slurries with low or no settling, which assure long-term well integrity and avoid cement failures. The usage of micronized ilmenite in cement slurries will improve zonal isolation in oil wells. Gas migration incidents are thereby greatly reduced, assisting in safe and predictable cementing operations. Avoiding remedial treatment contributes to substantial cost savings and a reduction in non-productive time.

The low water demand, small particle size and roundness of micronized ilmenite allows for formulation of high-density cement slurries. Micronized ilmenite improves the rheology of cement slurries, especially the plastic viscosity, leading to a reduction in pump pressure. Due to improvement in ECD values, losses to the formation during cement jobs are greatly reduced.

Micronized ilmenite provides quality predictability, as the chemical and physical properties of the material are well controlled through its manufacturing process and a rigorous Q&A control. Micronized ilmenite provides homogeneous dry blends with cement and it can be premixed with mix water. The resulting set cement mechanical properties are superior in quality and performance when compared to hematite- based cement blends.

There is unlimited high-quality raw material available to produce micronized ilmenite at the production site.

Acknowledgments

The authors would like to thank Elkem ASA for permission to publish this paper. The authors would like to acknowledge the Elkem oilfield lab personal in Kristiansand, Liv Hilde Birkeland, Jorunn Øvsthus and Grace Rutuku Andersen, for their great contribution.

Nomenclature

API RP = American Petroleum Institute Recommended Practice
gps = gallon per sack. One sack is 94LB (42.2kg)
BWOC = By Weight of Cement
SEM = Scanning Electron Microscopy
BHCT = bottom hole circulating temperature
SGSA = Static Gel Strength Analyzer
HPHT = high pressure and high temperature
SG = specific gravity (g/cm^3)
ppg = pound per gallon
psi = pounds per square inches
rpm = revolutions per minute
°C = temperature in Celsius

References

1. Johnston N.C. and Senese M.: SPE-24976-MS “New Approach to High-Density Cement Slurries for Cementing High- Pressure, High-Temperature Wells.” European Petroleum Conference, Cannes, France, Nov 16-18, 1992.
2. Al-Yami, A. S.: SPE-175194-MS “An Innovative Cement Formula to Mitigate Gas Migration Problems in Deep Gas Wells: Lab Studies and Field Cases.” SPE Kuwait Oil and Gas Show and Conference, Mishref, Kuwait, October 11-14, 2015.
3. Greaves C., Hibbert A.: Test Improves Measurement of Cement Slurry Stability Density, Oil & Gas Journal 12/1990 https://www.ogj.com/articles/print/volume-88/issue-7/in-this-issue/drilling/test-improves-measurement-of-cement-slurry-stability.html
4. Doan A. A., Kellum M. G., Cardenas I.: AADE-16-FTCE-44 “Using Large Cellulose Particles to Improve High-Temperature Cement Slurry Stability” 2016 AADE Fluids Technical Conference and Exhibition, Houston, Texas, April 12-13, 2016.
5. Al-Bagoury M. and Steele C.: “Oil well drilling fluids, oil well cement composition, and slurry of weighting material comprising ilmenite”, patent WO2013009187.