Norwegian Ilmenite Solves Drilling Challenges & Enhancing Well Productivity

About Elkem

Elkem is one of the world's leading companies for the environmentally responsible production of materials. Its principal products are silicon, silicones, ferrosilicon, foundry alloys, carbon materials and microsilica. Elkem has four business areas and about 6100 employees.

Weight material is used to increase the density of the drilling fluid. It's an essential component to control downhole pressures. Barite has been the standard weight material for drilling fluids since the 1920's.

However, increasing challenges faced by the industry often require specialized drilling fluids. For these wells API barite may not be suitable. Thus, materials providing improved overall performance compared to API barite are required. Elkem was the first company to introduce micronized weight material to the oil and gas industry. In 1989 Elkem was granted the patent for the use of manganese tetraoxide (sold under the tradename Micromax®) as a microfine weight material for drilling and oil-well cementing fluids. Micromax has been used worldwide to drill and complete challenging wells. Over the last 20 years, Micromax® has ensured oil companies could drill wells that were not considered possible to drill with API barite.

Recently, Elkem recognized the growing need for a weight material capable of providing better fluid performance than barite and offering more added value to Operators and is less expensive than specialty weight materials. Elkem has developed an enhanced weight material that provides such a solution. This is Microdense ($FeTiO_3$). Elkem has developed Microdense with Titania, one of the largest producers of ilmenite in the world. Ilmenite is produced in huge quantities from Titania's plant in Hauge I Dalane, where more than 600 million tons of raw material is readily available, providing a low environmental footprint for the Norwegian oil and gas industry compared to other weight materials. As high-quality grade of barite resources - with a density of at least 4.20 SG - is diminishing globally, Microdense is a locally sourced weight material with no limitations of supply.

Dr. Mohamed Al-Bagoury
Scientific Advisor – Product Champion, Elkem Silicon Materials

"The Elkem oilfield laboratory in Kristiansand, Norway has extensively tested Microdense in a wide variety of applications"

Microdense® patented technology produces a 5µm material taken from well selected ilmenite ores. The production goes through several milling and refining processes. The unique technical features of Microdense, such as high density, micro-round particles, high hardness, less abrasiveness and acid solubility make it an optimal weight material for drilling and cementing fluids. Microdense has an improved environmental profile compared to API barite as it contains fewer heavy metals. Microdense is classified as a "green" product and is PLONOR listed.

The Elkem oilfield laboratory in Kristiansand, Norway has extensively tested Microdense in a wide variety of applications in non-aqueous and aqueous drilling fluids, spacer fluids and for oil-well cementing, of which some results are shown in this paper.

Microdense provides the operator with the following benefits:
1) Significant reduction in the non-productive time (NPT) by minimizing drilling challenges such as stuck pipe and barite sag. Comparing Microdense to API barite fluids, the Microdense fluids provide a reduction in ECD values thus lower the risks of fracturing pressure-sensitive formation hence losses to the formation and wellbore instability. These challenges create risks and the inability to complete a well.
2) Reduce operational time (OPT) by lowering overall fluid viscosity, thereby lowering frictional forces and associated challenges from such.
3) Higher rate of penetration (ROP) due to the improved hydraulics provided by the drilling fluid. This is due to the Microdense exhibiting a very small, narrow size particle distribution with a density of 4.6 SG – which again leads to fewer solids in the drilling fluids system as compared to API barite. These features allow lower viscosity fluids to be used, without compromising sag, with improved hydraulics as the outcome.

Ole Iacob Prebensen
Global Marketing Manager
Elkem Silicon Materials – Oilfield

6) Lower gel structure and fluid viscosity reduce swab and surge pressures, leading to reduced tripping time, resulting in cost savings for the Operator.
7) Enhanced logistics and powder handling, since Microdense - unlike micronized barite - is pneumatically conveyable. This saves time and money compared to handling of big bags and dealing with spike fluids, allowing safer operations.
8) Microdense fluids exhibit high return permeabilities leading to higher productivity. Its acid solubility enhances production, allowing this weight material to be used in the reservoir section.
9) Improved environmental profile as Microdense contains less heavy metals compared to API barite.
In this paper examples of testing and usage of Microdense in drilling fluids are presented. Acid solubility of Microdense will also be discussed.

Experiments & Materials
Micronized ilmenite

> “Microdense fluids exhibit high return permeabilities leading to higher productivity”

4) Unlike API barite, Microdense particles resist mechanical degradation due to its hardness. Degradation of API barite leads to fluid deterioration hence increasing dumping and dilution. Microdense will extend the longevity of the fluid as the amount of disposed drilling fluids and associated cost is reduced.
5) Permits higher flow rates due to lower and improved rheological properties. As an outcome improved hole cleaning is obtained, allowing operational time savings.

A well selected area of ilmenite quality ores is used in this work. These ilmenite ores go into several processing steps by means of crushing, milling and refining to gain the micronized $FeTiO_3$. To assure highly quality product, standardized characterization methods such as particle size, specific gravity, magnetite content are in place.

Figure 2 show the particle size distribution of milled ilmenite measured using laser diffraction using

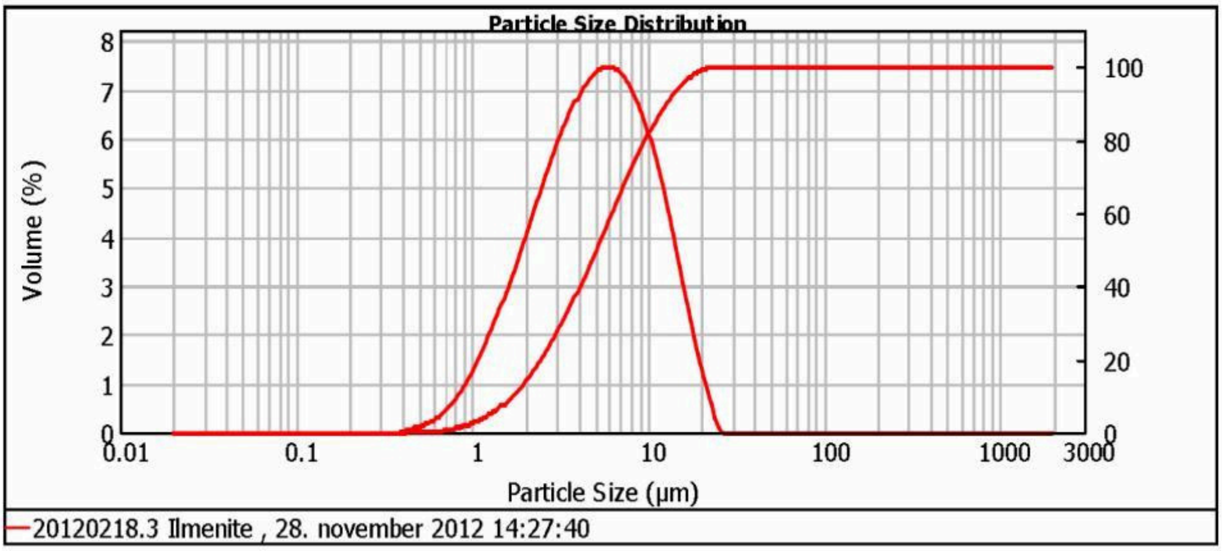

Figure 2: Particle size distribution of milled ilmenite (D10=1.7µm, D50=5µm & D90=12.6µm).

Test Results	Unit	Microdense Before Hot Rolling	Microdense After Hot Rolling	API Barite Before Hot Rolling	API Barite After Hot Rolling
Density	SG	1.92	1.92	1.92	1.92
Plastic Viscosity	cP	23	25	34	36
Yield Point	$lb/100ft^2$	5	5	8	1
Gel Strength 10 sec.	$lb/100ft^2$	3	3	5	2
Gel Strength 10 min.	$lb/100ft^2$	5	6	13	5
VSST	ppg	0.150	0.308	0.250	0.500
Filter Cake Thickness	inch	0.23	0.27	0.20	0.23
Volume of Filtrate	cm^3	3.1	3.5	1.7	2.2

Table 1: Properties of 1.92 SG non-aqueous fluid that heat aged at 204˚C for 16 hours.

a refractive index of 2.8. The average size (D50) is 5µm and the D90 is less than 13µm.

The mineralogical composition of the ilmenite sample was analyzed using the X-ray diffraction (XRD). Microdense is mainly composed of (FeO, MgO) TiO_2 (> 94 percent by weight).

The material also contains < 3 percent by weight silicate phases such as orthopyroxene (Mg, Fe) SiO_3, plagioclase

(($NaAlSi_3O_8$)($CaAl_2Si_2O_8$)), and biotite. The morphology of Microdense was studied using scanning electron microscope and particle imaging analyzer. The material has a high circularity of > 0.85, which contributes to lowering the viscosity of its dispersions. The total specific surface area of 1.6 m^2/g was measured by the Brunauer-Emmett-Teller (BET) method.

Use of Microdense in drilling fluids

Below are examples of the use of Microdense as weight material in both aqueous and non-aqueous drilling fluids. High density fluids (1.6 - 2.3SG) with a high loading of weighting agents were selected to demonstrate the enhanced properties from this weighing agent.

Microdense – laboratory testing in non-aqueous drilling fluids

The papers SPE165184 & SPE 155331 reported the extensive laboratory testing of Microdense in non-aqueous drilling fluid. The performance of Microdense was compared with other weight materials such as API barite and Micromax. The main conclusions and recommendations of testing Microdense in oil based system were as follows;

1. Microdense can be successfully used as a weight material in aqueous and non-aqueous drilling fluids in a wide density range, and is well suited for conventional and challenging drilling operations.
2. The specific surface area and the fineness of micronized material should be taken into consideration when formulating new fluids. Generally, Microdense requires less amount of viscosifier to be suspended. For dispersion purposes, slightly more dispersant and wetting agent is needed when compared to API barite.
3. Microdense fluids show good filtration properties using organophilic lignite - with or without synthetic polymer such as styrene-butadiene polymer. A thin filter cake and a small filtrate volume were obtained under static and dynamic conditions at 150°C and 500 psi.
4. Microdense shows low dynamic sag (< 0.3), which makes it suitable for challenging drilling operations such as HPHT, narrow pressure margin drilling and extended reach wells.
5. This weight material provided very lower plastic viscosities (PV) compared to API Barite.

“Microdense fluids show good filtration properties using organophilic lignite”

As an example (Table 1) properties of two drilling fluids are listed, one weighted with Microdense and another with API barite. The plastic viscosity and dynamic sag (VSST) for Microdense is significantly lower than for API barite. Even if it can be challenging to control filtration loss for fine and monomodal particle size distribution, the dynamic filtration was

“Microdense has been tested at ultra-high densities”

in the acceptable range (<5ml) for Microdense fluid. Added particles in the form of sized Calcium Carbonate or any other wellbore strengthening material have not been used in the fluid formulation to assist in the fluid loss.

Microdense has been tested at ultra-high densities. In Table 2 a 2.30 SG non-aqueous fluid with Microdense was heat aged at 200°C for 64 hours, whereas in the second fluid a 2.20 SG with a mixture of Microdense (23%) and API Barite (77%) was tested and heat aged at 175°C for 16 hours.

Both fluids exhibit low rheological properties with non-progressive gel structure, minimal sag potential and good electrical stability. Still the Microdense stand-alone fluid at 2.30 SG outperforms the mixed weighting agent fluid at 2.20 SG, with excellent plastic viscosity, hence low high-end readings, even at higher density. Fluid loss at 175°C and filter cake thickness is regarded as very good. Microdense allows for cost efficient low viscous fluids, and sag resistance.

Testing Microdense and comparing this proprietary product to API barite at more conventional densities like 1.60 SG shows similar properties; lower high-end values and similar low-end readings, all of which contribute to added values to Operators as listed above.

Test Results	Unit	Microdense Heat aged 200°C 64 hours		23% Microdense, 77% Barite Heat aged at 175°C for 16 hours	
		Before Heat Ageing	After Heat Ageing	Before Heat Ageing	After Heat Ageing
Density	SG	2.30	2.30	2.20	2.20
600 rpm	lb/100ft²	82	88	96	100
300 rpm	lb/100ft²	42	47	54	55
200 rpm	lb/100ft²	28	33	40	39
100 rpm	lb/100ft²	16	20	26	24
6 rpm	lb/100ft²	3	7	8	6
3 rpm	lb/100ft²	2	6	7	5
Gel Strength 10 sec.	lb/100ft²	3	7	8	7
Gel Strength 10 min.	lb/100ft²	3	10	9	13
Plastic Viscosity	cP	40	41	42	45
Yield Point	lb/100ft²	2	6	12	10
Fluid loss at 175°C	mls	4	4.5	4	4
Filter cake	mm	1	1	2	3
Static Sag	-	-	0.519	-	0.505
Electrical Stability	mV	435	621	728	878

Table 2: Properties of 2.30 SG and 2.20 SG non-aqueous fluids

Test Results	Unit	Microdense Heat aged 150°C 16 hours Before Heat Ageing	Microdense After Heat Ageing	Barite Heat aged at 150°C for 16 hours Before Heat Ageing	Barite After Heat Ageing
Density	SG	2.10	2.10	2.10	2.10
600 rpm	lb/100ft²	100	98	125	156
300 rpm	lb/100ft²	54	53	70	87
200 rpm	lb/100ft²	41	40	51	62
100 rpm	lb/100ft²	23	21	27	34
6 rpm	lb/100ft²	6	4	5	5
3 rpm	lb/100ft²	5	3	4	4
Gel Strength 10 sec.	lb/100ft²	5	3	5	4
Gel Strength 10 min.	lb/100ft²	8	5	5	7
Plastic Viscosity	cP	46	45	55	69
Yield Point	lb/100ft²	8	8	15	18
Sag Factor	-	-	0.520	-	0.530

Table 3: Properties of 2.10 aqueous drilling fluids

“The contribution from Microdense will ensure less non-productive time”

Using Microdense as the weighting agent at these densities will enable Operators to obtain lower pump pressures for the same flow rate as for API barite, and lower the ECD values. These features should contribute to reduce downhole losses, increase tripping speeds due to the nature of the rheological properties, and if needed; obtain the same ECD with increased flow rate. The latter will assist in improved hole cleaning.

In general, the contribution from Microdense will ensure less non-productive time (NPT) and thereby contribute to reduced overall operational cost for the Operators.

Microdense – laboratory testing in aqueous drilling fluids

So, is Microdense suitable for aqueous drilling fluid? Test results at 2.10 SG provides the same overall results as for non-aqueous drilling fluids with regards to fluid properties. As shown in Table 3, the rheological properties exhibit the same trendline with very low PV values for Microdense, at similar low-end readings. Even if YP values are reduced and low-end values are low, the buoyancy of the fluid will greatly assist in hole cleaning at this density, thus these values are of low interest.

Microdense in aqueous kill fluid

Test Results	Unit	Micromax / Microdense Kill Fluid Heat aged 80°C 16 hours Before Heat Ageing	After Heat Ageing	Micromax / Microdense Kill Fluid Heat aged 80°C 16 hours Before Heat Ageing	After Heat Ageing	Micromax / Microdense Kill Fluid Heat aged 80°C 16 hours Before Heat Ageing	After Heat Ageing
Density	SG	2.50	2.50	2.75	2.75	3.00	3.00
600 rpm	lb/100ft²	82	68	123	101	230	184
300 rpm	lb/100ft²	45	39	68	56	121	100
200 rpm	lb/100ft²	32	29	48	40	84	69
100 rpm	lb/100ft²	18	18	29	24	47	40
6 rpm	lb/100ft²	3	7	7	8	9	10
3 rpm	lb/100ft²	2	6	5	6	8	8
Gel Strength 10 sec.	lb/100ft²	3	6	5	6	10	9
Gel Strength 10 min.	lb/100ft²	4	7	13	8	29	21
Plastic Viscosity	cP	37	29	55	45	109	84
Yield Point	lb/100ft²	8	10	13	11	12	16
HPHT Fluid Loss	mls	11.6	10	15	6	10	8.5

Table 5: Properties of 2.50 – 3.00 SG Micromax / Microdense Kill Fluid in sodium chloride brine.

"The high-density kill fluid met the Operators requirements, showing the feasibility of the Microdense at extreme densities"

An Operator requested a kill fluid at extreme density of 3.00 SG, with low viscosity to be used in a gas field. Previously API barite was used up to 2.24 SG, but above this density it became very viscous and un-pumpable. A series of tests were conducted in a simple fluid formulation with a low-viscosity modified starch, an acrylic based HPHT dispersant in a saturated sodium chloride brine solution using 50 /50 mixture of Microdense and Micromax as weight materials. . The concentration of starch was kept constant, regardless of density. The bottom hole temperature was below 100°C, allowing heat ageing to be performed at 80°C. The desired fluid properties are highlighted in Table 5:

The high-density kill fluid met the Operators requirements, showing the feasibility of the Microdense at extreme densities. This mixture of weight materials provided the Operator with a suitable kill fluid, that was regarded as a cost-efficient solution.

Ilmenite solubility in HCl

The solubility of ilmenite in mineral acids such as sulphuric (H2SO4) or hydrochloric (HCl) acids is a widely used industrial process to gain titanium dioxide pigment. The solubility of ilmenite is extensively studied in literature. The dissolution mechanism of ilmenite in HCl can be drawn as follows:

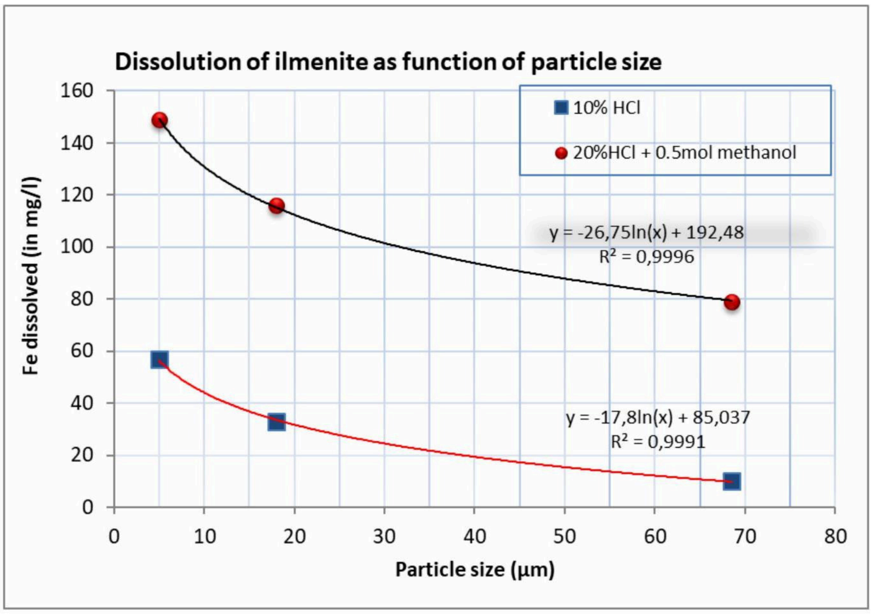

Figure 3: Dissolution of ilmenite as function of particle size

"This high dissolution rate is of great advantage when acidizing is considered"

$FeTiO_3 + 4\ HCl \rightarrow TiOCl_2 + FeCl_2 + 2H_2O$

Since HCl is commonly used in stimulation, the solubility of Microdense in HCl was investigated under various conditions of acid concentrations and temperatures. It was found that Microdense has an improved rate of dissolution compared to the coarser ilmenite grades used in the past. The higher the acid concentration and /or the higher the temperature, the higher the dissolution rate of ilmenite. Figure 3 show the dissolution of Fe ion in HCl at 82°C as a function of particle size. The reaction was monitored by Inductively Coupled Plasma (ICP) technique. The dissolution of ilmenite is a power function of particle size. This high dissolution rate is of great advantage when acidizing is considered.

Case Histories:

A Middle East operator was drilling extended reach development wells to increase production. The Operator had previously faced serious torque and drag problems combined with high friction factors, high ECD's and downhole losses. Consequently, this Operator was unable to drill the 8.5in. hole past 7620 mMD to achieve the desired higher production rate.

The Operator was looking for a reservoir drilling fluid that would increase the horizontal lengths to maximize reservoir contact, reduce torque and drag and reduce ECD to avoid heavy losses. The fluid needed to be non-damaging and remediable.

A non-damaging Microdense non-aqueous reservoir drilling fluid (RDF) was field trialed. The Operator drilled these wells to a new record of 9420 mMD without any fluid related or operational problems. Rate of penetration was improved by 25% compared to offset wells, friction reduction of at least 100% were obtained, and has been one of the key developments in being able to drill and complete these extended laterals.

allowing the Operator to achieve the strategic goal of increasing production rate by around 40% in total from this field development. The success of this project has resulted in the operator extending the project for a further six years.

A second Operator used Microdense at ultra-high density in a sodium chloride polymer drilling fluid. This well encountered high pressures zones, requiring an unplanned density increase from 1.71 SG to 2.35 SG. The Operators drivers for using Microdense were; reduce solids content, the ability of Microdense to be acidizable in the occurrence of stuck

"Microdense is a very efficient weight material for drilling conventional, technically challenging and expensive wells"

Losses to the formation were dramatically reduced; all of which saving three days per well on average versus offset wells excluding NPT. Average flow rates were increased from 1500 lpm to 1800 lpm allowing improved hole cleaning and smooth tripping operations. The Operator reported that the actual deployment of the 6 5/8" lower completion was excellent, requiring no rotation of the drillpipe running string as the friction factors were dramatically reduced in this record length well. This was accomplished by the lubricious non-aqueous RDF and good hole cleaning after reaching total depth.

Due to the extended reach of the reservoir sections, these wells have increased production rate by close to 100% compared to previous wells,

pipe, to reduce ECD, and to enable higher density increase compared to API barite - still maintaining fluid specifications. Despite the unplanned increase in density, all properties were maintained and the well successfully drilled to total depth. These applications of Microdense illustrates the value of using this non-damaging and novel weigh material.

Conclusion:

Microdense is a very efficient weight material for drilling conventional, technically challenging and expensive wells, providing great value and cost savings to Operators. Microdense contributes in reducing non-productive time through eliminating drilling problems such as downhole losses, stuck pipe, sag, and enhances

The acid solubility of Microdense increases productivity. Furthermore, the pneumatic conveyance of Microdense is a great benefit for offshore applications compared to other specialty or micronized weight materials. Thus, this Norwegian produced weight material exhibits unique value and an environmental classification well suited for the Norwegian Continental Shelf.

Acknowledgments

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“Norwegian produced weight material exhibits unique value and an environmental classification”

1. Al-Bagoury M. and Steele C., Oil well drilling fluids, oil well cement composition, and slurry of weighting material comprising ilmenite, patent WO2013009187.

2. Al-Bagoury M. and Steele C., A New, Alternative Weight Material for Drilling Fluids, SPE-151331.

3. Al-Bagoury M., Micronized Ilmenite - A Non-Damaging Non-Sagging New Weight material for Drilling Fluids, SPE-169182.