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It's Not Your Grandfather's Ilmenite

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Abstract

Ilmenite, iron titanate ($FeTiO_3$), with a specific gravity of 4.5–5.1 was introduced into the Norwegian drilling industry as a locally available weight material in 1979 and 1980 to compete with barite ($BaSO_4$) with a specific gravity of 4.2. Ilmenite is harder than barite and would be expected to have less tendency to grind down which apparently accounted for the observation that fluid properties were easier to control. Abrasion was identified to be a large problem during this first field trial, caused by the relative coarse material used. In 1993 a field test was conducted using a finer material. This material, despite being contaminated with other minerals, performed better although surface equipment wear was found to be an unacceptable operational problem. A cleaner more refined product with tighter specifications was tested in 1999 in a KCl/polyglycol WBM to drill a 12 ¼ inch interval. The results from this field trial were so convincing that this grade of ilmenite has been used as the weight material in this field since the summer of 2000. Differences in fluid properties have not been noted relative to barite nor has there been evidence of sag despite the higher specific gravity of ilmenite. Abrasion in surface equipment and mud transfer lines has been reduced to levels below that observed with barite and abrasion in dry bulk transfer lines has been reduced to levels comparable to barite. This paper summarizes experience with this ilmenite material to date, reviews the chemical & physical properties of the material, grind specifications, environmental advantages, effects on fluid properties and abrasion measurements and results.

Introduction

Previous field trials using ilmenite indicated that a relatively high degree of abrasion was apparent. This was the major limitation of ilmenite as a commercial alternative to barite. New grinding techniques and tighter specifications have eliminated this problem, and ilmenite is therefore a fully acceptable alternative to barite as weight material. Statoil and Phillips Petroleum Company Norway (PPCoN) have proved this in their operations on the Norne and Ekofisk fields.

History

Since the first well in 1979/1980 ilmenite has been applied in several drilling operations in the North Sea. The ilmenite used during the initial wells was a fairly coarse ground material compared to the presently used ilmenite. The physical properties of the material compared to barite are listed in Table 1. According to Blomberg et al (1), the drilling fluid properties were easier to control compared to drilling fluids with barite. This is caused by the reduced tendency of ilmenite being ground down to finer materials. Consequently there is a lesser need for fluid dilution. During the drilling operations, excessive wear on different types of equipment was observed. This abrasion was believed to be a result of the relatively coarse ilmenite material. Although the abrasion was understood to be a result of the particle size distribution rather than the material itself, no further field evaluations were conducted until the early nineties.

A second field trial was conducted in 1993 using a material with tighter particle size distribution compared to the tests in the 80s. The ilmenite for the trial in 1993 was produced from waste tailing material from the ilmenite ore site. The particle size distribution used was aimed to be equal, or comparable to the one used for barite. Since the source for the material was the waste tailing, the content of quartz was relatively high and the material itself therefore more abrasive. During the field test the weight material did perform well after it was blended with the drilling fluid. However, according to Sunde (2), an unacceptable wear of the surface equipment was observed, primarily in the dry bulk handling system.

Development work

Based on industry demand for more environmentally acceptable drilling fluid components combined with the experience from the early field trials, a project to revitalise ilmenite as an alternative weight material for drilling fluids was initiated. A major part of this project was to identify and solve the abrasion-related challenges relative to particle size distribution and material source. A series of tests was performed using high-grade ilmenite concentrate with different particle size

distributions. Tests were conducted at laboratory scale to identify the optimum particle size distribution relative to abrasion. The selected particle size distribution should give low abrasion values combined with best possible drilling fluid properties. This particle size distribution was then tested in large-scale flow loops to verify the findings. The method used for small scale, wet process abrasion tests was the API abrasion test method (3). For simulated air transport testing a simple single point sandblasting test was used.
Abrasion testing using the API method indicates abrasion similar to barite for the ilmenite material as long as the maximum particle size is kept below 45 micron. The same conclusion was drawn from the other test methods. Concentration of fines, (particles less than 1 micron) had no significant effect on the abrasion results. The recommended particle size distribution for drilling fluid grade ilmenite compared to barite is found in figures 1 and 2 respectively.
Full scale wet process testing was conducted using a high-pressure pump rig up. A water based drilling fluid was prepared and adjusted to the same density with ilmenite and barite. The wear on a mild steel plate used as a nozzle at high flow rates was measured as a comparison of abrasion. Results of this test verified the conclusion from the small scale testing that abrasion is similar for the different fluids.
Abrasion of the dry bulk handling system was reported as one of the major problems on the field trial in 1993. To get a good overview of abrasion effects a flow loop was prepared using standard 5” tubing, bends of various angles and valves made from different alloys from different suppliers were included. A total of 500 MT of ilmenite and 500 MT of barite was blown through the loop, and wear was measured on the bends and valves. Results again indicated similar properties for the two materials (figure 3).

Drilling fluid properties were tested for different drilling fluid types with barite and ilmenite as weight material. For ilmenite, a series of different particle size distributions was evaluated. The effect of changing size distribution of the ilmenite was of low significance on viscosity measurements. This indicates that the fines from ilmenite have less effect on the viscosity properties than the fines from barite. This can be due to the differences in surface activities and total surface areas.
A stability test of particle size with respect to shear was performed. A sample of drilling fluid was mixed on a high shear Silverson mixer for 7 hours at constant temperature and the change in particle size monitored after 5 and 7 hours. This data shows that the barite size range is shifting to more fines, while the particle size curve for ilmenite is almost unchanged. The surface area of the particles was initially 1 m^2/gram for ilmenite and 4 m^2/gram for barite. After mixing, the surface area was 1,05 m^2/gram for ilmenite and 6,9 m^2/gram for barite. The test results are presented in figure 4 and figure 5.

Drilling fluid properties for oil and water based drilling fluids are attached in table 2.

Field trial
The first field trial of the new product was performed on a well in the Norne area in an environmentally sensitive area of the North Norwegian North Sea.
The performance of the drilling fluid with ilmenite as weight material was very similar to the properties with barite. No operational problems were encountered or reported. Based on previous history of ilmenite, a detailed abrasion measurement programme was conducted on the rig site. Metal thickness of piping and bends on rig surface was measured before and after the operations, including monitoring of pump pistons and liners. Wear on drilling motors, MWD equipment and logging quality was also evaluated with no adverse effects reported.

Based on the performance of ilmenite in the field trial and its environmental properties, it was decided that the remaining wells in this field should be drilled using ilmenite. To date a total of 6 wells has been drilled in the Norne area using ilmenite as weight material both in oil based and water based drilling fluids. The product has been used on three different drilling installations.
No problems have been reported with respect to the performance of ilmenite as weight material.

Abrasion
Abrasion was the major hurdle for further use after the trial wells in the 80s and 90s. For the initial wells on the Norne field a series of tests were performed to evaluate the abrasion tendency compared to what was seen with barite. These results are reported in more detail by Fjogstad (4) and Saasen (5). The conclusions from these measurements were that the abrasion seen on the rig systems was as low or lower than seen using barite. The only exception being the dry bulk systems in the initial trial well. Investigations into this indicated that the more condensed particle size distribution of the ilmenite compared to the distribution of barite, as seen on Fig 1, requires less air to fluidise.
This is further supported by the fact that despite the higher specific gravity of ilmenite, the bulk density is lower than for barite (1,9 Vs 2,1) indicating different packing of the solids. Using the same air pressure on the rig therefore results in an increased transportation velocity giving increased wear. Reducing the air

pressure by 30-50% reduces the transportation rate in metric tonnes to the level of barite. The abrasion rates after the reduction is lower compared to those obtained with barite. The reduced air pressure for the bulk handling system has been one of the major focal points when the product is introduced to new rigs to eliminate the risk of erosion in the dry bulk system. A list of the relative abrasion values associated with ilmenite compared with barite for the Norne wells can be found in table 4.

Production quality

Since particle size distribution is essential to the performance of ilmenite, it is imperative to have a production facility that gives a constant material quality. The feedstock for the weight material production is the standard ilmenite feed stock used by the pigment industry for TiO_2 production. Quality requirements with respect to the chemical composition of the material are strict for the processes to be able to run with a constant quality of the end product without alterations of the production parameters. Chemical composition of the material has been tested and logged for decades, and is very well mapped for the entire ore body at the mine.

Drilling fluid grade ilmenite requires a specific particle size distribution and tight quality control. Traditional ball mill technology will in most cases be unsuitable for the production because of wear and grinding loss. To mitigate this several grinding technologies have been evaluated and the most suitable technology identified was a jet mill with a sophisticated classification system included in the process. Jet Mill technology combined with proper classification equipment produces virtually no grinding loss and extremely tight product control. Detailed production quality controls are performed during the grinding process and the acceptance criteria are narrow. The process has been able to produce a very consistent quality with minimal wear on the equipment.
A log of production quality over a year is included as figure 6

Environmental evaluation

Documentation and evaluation of environmental properties of chemistry applied in drilling fluids are of increasing importance in most parts of the world. Ilmenite is considered to be an environment friendly alternative for weight material in drilling mud. In the North Sea area the concern of heavy metal contamination of weight material has been increasingly focused. A variety of studies have shown that heavy metal traces in weight material have a potential for biological uptake and subsequent effects (6).

Environmental regulations regarding the use and disposal of drilling chemicals in the North Sea region are set by the Oslo Paris Commission (OSPAR), which includes the countries with interests in the North Sea. Most common weight materials (ilmenite, barite, and $CaCO_3$) are found on a list of substances considered to pose little or no environmental risk, and subject to regulations not prioritised for action. There is however a requirement that the weight material in use has the lowest possible contamination of trace metal impurities, which is subject to regular control and documentation. In Norway, the State Pollution Control Authority (SFT) require the operating companies to have programs to survey the heavy metal concentration in weight material, and further to annually report the amount of heavy metals discharged. A concern was reported by SFT in 2001, regarding the tendency of increased discharges of heavy metals in connection with weight material discharges (7). The concern is mainly focused on the amount of lead, as Norway, along with the other OSPAR countries is obligated to reduce the discharges of prioritised pollutants including lead by 50% by the year 2005 (Esbjerg Declaration 1999, OSPAR).

The introduction of ilmenite as an alternative weight material in Norway has been welcomed positively by SFT and operators because ilmenite does not include any lead (<5 mg/kg) or barium. It further includes less concentration of most other heavy metals, reference made to table 5 and 6, showing concentrations of elements in both barite and ilmenite (4, 5)

The discharges of lead with weight material was reported to be more than 20 000 kg for the year of 2000, being four times higher than for 1999 (SFT, OLF 2001). The figure, if ilmenite had been used, would have been less than 1000 kg.

The even and narrow particle size distribution of ilmenite reduces the surface area of the ilmenite particles compared to barite. The reduced surface area has been calculated to be 4 times less for ilmenite. (1 m^2 pr gram for Ilmenite and 4 m^2 per gram for barite) This fact implies less need for coating chemicals in the mud to reach necessary specifications. The potential for reduced need for coating chemicals is equal to the reduced surface area. The operational experience to date is not sufficient to conclude this.

Studies have further showed that the heavy metal contamination of ilmenite is less soluble and has less bioavailability than for barite (8). The study has shown that flatfish fed with feed spiked with ilmenite and barite displayed no acute effects such as mortality or reduced feeding rate (growth). Fish exposed to barite showed increased concentrations of lead and barium in liver and blood. No such effects were observed for fish exposed to ilmenite.

These results are supported by the lower concentration of heavy metals associated with ilmenite and the fact that the elements are part of the element structure and therefore less soluble and bio-available.

The mining company, Titania, produces the ilmenite weight material used in the North Sea from the Tellnes ore. Titania's main product is ilmenite concentrate, a feedstock for the TiO_2 pigment industry. Tellnes ilmenite concentrate is produced from a hard rock ilmenite ore in South Rogaland, Norway. The concentrate contains approximately 94 percent ilmenite with the silicate hypersthene and plagioclase as the main accessory minerals.
TiO_2 pigments are applied in numerous different industries and products; examples are paint, toothpaste and food additives. These applications require a strict quality control and documentation of critical factors such as heavy metals. The strict quality assurance of the ilmenite concentrate ensures the quality of the weight material to be uniform and well documented.
The current mine was opened in 1960 and is able to supply high quality ilmenite with a stable element composition. The source is estimated to supply the same quality ilmenite for many decades.

A study was initiated to highlight the Life Cycle Properties (LCA) of utilising the local source of ilmenite. The study documented that the transport distance for the ilmenite weight material is 30 times less than for the presently used barite, hence reducing transport emissions (CO_2, NOx and SOx) from fuel consumption 30 times (9).

The processed fluid residues resulting from drilling operations have shown that ilmenite can be recovered and is acceptable for re-use. The high SG and hardness of the ilmenite particles makes it well suited for reuse. Studies performed on ash generated by incineration of drilling waste have shown that a simple separation process can recover the ilmenite, and that it is suited for reuse (9).

Based on the reduced heavy metal content in ilmenite and subsequently in the generated drilling fluid waste and cuttings, contaminated with oil based drilling fluid, several operator funded projects have been initiated to investigate the potential uses and alternative deposits of this waste.

Occupational Hygiene

Working environment has a potential to be improved with the use of ilmenite. There is a lower percentage of fines (particles below 1 micron) in ilmenite compared to barite. This fact indicates a significantly lower number of fine particles, as the number of particles increases with decreasing particle size. The hard nature of ilmenite makes it less vulnerable for physical stress to form fines during the operational process. This indicates that handling and mixing of ilmenite will generate less dust than barite.

Ilmenite has a black colour that makes it much easier to detect compared with the grey barite, both in terms of free dust, leaks and as formulated mud. This fact makes prevention measures easier and more effectively implemented. Human exposure to skin and through inhalation is also easily detected and necessary preventative measures can be implemented at an early stage.

It is further documented (10) that the ilmenite concentrate does not include any free quartz, which is a classified carcinogen, subclass K3, according to Norwegian law.

Based on the history of the medical programs implemented by the mining company, no occupational hygiene effects such as dust lung, carcinogenic effects or allergic effects, have been reported from the 40 years of mine activities (Titania, 2001). This not only reflects the high focus on HS&E initiatives by the mining company, but also the low risk posed by ilmenite dust.

Field Introduction

One Norwegian Sector Operator with a past record of encouraging and using alternative drilling fluid related products and additives has field tested the ilmenite weight material as an alternative to barite.

The Operator's trial of ilmenite was for the following reasons:

1: To confirm that ilmenite would be acceptable on a platform rig location. Ilmenite qualified on a technical basis for use as an alternative product to barite and from marine and work environment perspectives. However the product is black in contrast to the light red and grey colour of barite. Typically rig areas are painted a grey colour to reduce the visual impact of barite dust beds on the deck. Although less ilmenite dust will result, it will nonetheless be obviously apparent owing to its black colour. The impact of this to a person is only psychological but nonetheless very apparent.

2: To comply with the Norwegian Pollution Control Authorities' challenge to introduce products with lower heavy metal contents. Ilmenite has less than 5 milligrams per kilogram versus barite that has typically between 50 – 1300 milligrams per kilogram. Only limited volumes of drilling fluids are discharged owing to the cuttings re-injection practices used by the operator, however some top hole sections are drilled with water based fluids and these are discharged.

3: To ensure that ilmenite functioned correctly in drilling fluid systems.

4: To confirm that ilmenite could be sourced and logistically supplied in a reliable manner. Ilmenite had only been used cautiously as a weight material in drilling fluids earlier and the trial period indicated that no obstructions to the supply were apparent. Ilmenite is mined and processed within 100 kilometres of the offshore supply base for the field. Barite on the other hand is mined over 3000 kilometres away and then processed in another region of Norway.

5: To determine that the ilmenite was compatible with the rig equipment facilities, e.g. bulk handling and storage systems, associated pumps and mixing lines.

Prior to the use of ilmenite offshore, a presentation was given to all involved drilling personnel on the respective drilling platform. This was to prepare the crew mostly for the product colour difference from barite. In addition, it was necessary to brief the crew on the technical differences of the ilmenite that would be apparent particularly relating to the bulk handling systems.

Ilmenite has now been used in two consecutive wells on the 2/4X platform. The rig crews have raised a number of observations and concerns relating to the use of ilmenite. Each of the observations and concerns have been documented and responded to. It was deemed imperative to address all the issues raised by the rig crews regardless of their significance. This tactic has helped maintain an open dialogue condition.

As expected, the greater numbers of concerns were a direct result of the black colour of ilmenite. These concerns included a) personal hygiene and that cleanliness was affected; b) and it was more difficult to clean the deck areas. However the particle size distribution and greater density of ilmenite reduces the consequence of these issues compared to barite.

Other issues included a) increased solids debris sticking inside the wellhead hanger area and in the riser; b) related bulk handling equipment motors were overloaded. Analysis of the debris samples from the wellhead and riser indicated that ilmenite was not the cause for the sticky condition. And again the particle sizes distribution of the ilmenite enables ilmenite to be more free flowing than barite and therefore could not negatively impact motors or gear assemblies.

Drilling fluid properties were stable and comparable to barite in the wells where ilmenite was used as weight material.

Conclusions

By using an improved particle size distribution and source of material, combined with stringent quality control during production, ilmenite has proven to be a technically acceptable alternative as weight material for drilling fluid applications. Previous abrasion related concerns have been mitigated.

The environmental properties make it well suited for use in areas with strong environmental focus, and also improves the occupational hygiene because its colour makes it easier to detect. The potential to reuse cuttings and waste generated from the drilling process will be increased if ilmenite is used as weight material. Several factors play a role here; the major one being reduced content and bio-availability of heavy metals including extremely low barium content.

The transport emissions from the weight material supply have been reduced 30 times compared to the use of barite in the North Sea.

Ilmenite production has a proven history of steady quality, with consistent properties.

Field tests have proven that ilmenite is a fully viable alternative as weight material.

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Nomenclature

WBM = Water Based mud
OBM =Oil based mud
API = American Petroleum Institute
MT = Metric Ton
MWD = Measurement While Drilling
SG=Specific Gravity

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Table 1 – Physical and chemical properties of Barite and Ilmenite

	Formula	Specific gravity (g/cm^3)	Hardness MohsScale
Barite	$BaSO_4$	4,2-4,5	2,5-3,5
Ilmenite	$FeTiO_3$	4,5-5,1	5-6

Table 2 – Drilling fluid properties of oil based drilling fluid with barite and ilmenite

	Base	Barite	Ilmenite	Barite	Ilmenite
sg	**0.95**	**1.3**	**1.3**	**1.62**	**1.62**
600	39	68	62	97	90
300	26	42	40	59	56
200	19	32	31	45	43
100	13	21	21	31	30
6	5	8	8	12	12
3	4.5	7	7	11	11
Gels 10"	6	9	9	13	14
Gels 10 '	10	16	15	21	20

Table 3. Water based Drilling fluid properties

		Barite fluid	Ilmenite fluid
Density	g/cm^3	1,55	1,55
600 rpm	Dial reading	94	69
300 rpm	Dial reading	64	46
6 rpm	Dial reading	8	6
3 rpm	Dial reading	6	5
Plastic Viscosity	cp	30	23
Yield Point	Lbs/100 ft^2	34	23
API fluid loss	ml/30min	2,7	3,3

Table 4 a Wall thickness and relative abrasion in high pressure pipe system

Date	Weight material	Pipe thickness (mm)	Relative abrasion
24.01.99	Ilmenite	17,6	0,03
16.02.99	Barite	17,6	0,79
29.04.99	Barite	17,0	0,11
02.07.00	Ilmenite	16,7	0,09
21.12.00		16,5	

Table 4 b Wall thickness and relative abrasion in low pressure pipe system

Date	Weight material	Pipe thickness (mm)	Relative abrasion
24.01.99	Ilmenite	12,3	0,00
16.02.99	Barite	12,3	0,47
29.04.99	Barite	12,0	0,15
02.07.00	Ilmenite	11,5	0,11
21.12.00		11,4	

Table 5 – Chemical composition of typical sample of Tellnes ilmenite concentrate.

Element	Concentration
TiO_2	44.33 %
Fe tot.	35.12 %
SiO_2	2.61 %
CaO	0.24 %
MgO	4.29 %
Al_2O_3	0.60 %
MnO	0.31 %
K_2O	0.02 %
Na_2O	0.03 %
P_2O_5	0.018 %
Cr_2O_3	0.075 %
V_2O_3	0.17 %
S	0.048 %
Zn	150 ppm
Cu	19 ppm
Ni	140 ppm
Co	110 ppm
Cd	< 10 ppm
Pb	4 ppm
Hg	0.006 ppm
Th	0.6 ppm
U	< 0.2 ppm

Table 6 - NS-4770 analysis of selected metal leachates from ilmenite compared with barite limits recommended by The Norwegian Oil Industry Association (OLF) (6) and barite (Norbar 2000) (5). Ilmenite analysis by West Lab, 1997.

Element	Barite (average 2000) mg/kg	Barite recommendation OLF (1995) mg/kg	Ilmenite mg/kg
Cr	11,6	<50	53
Mn	1436	-	66
Fe	7240	-	21860
Co	<1	-	21
Ni	1	<15	69
Cu	100	<150	25
Zn	85,7	<1000	27
Cd	0,6	<5	<0,5
Hg	<0,6	<5	< 0,005
Pb	623	<1000	<5

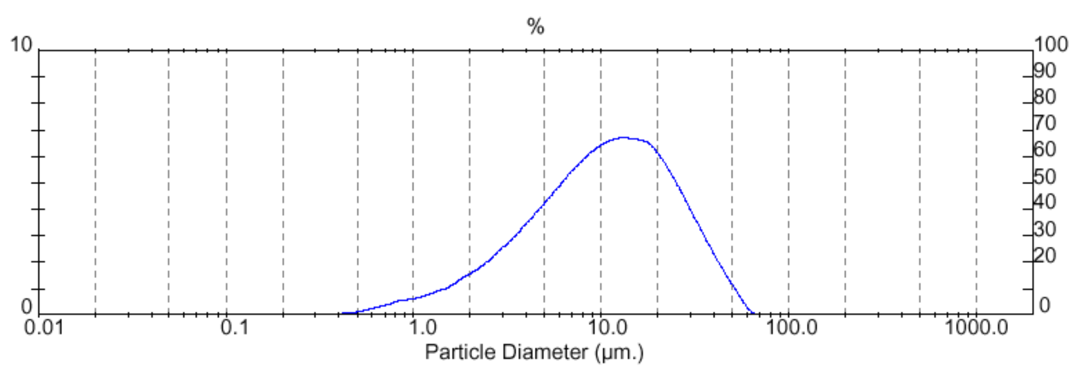

Fig 1- Particle size distribution of Drilling Fluid Grade Ilmenite

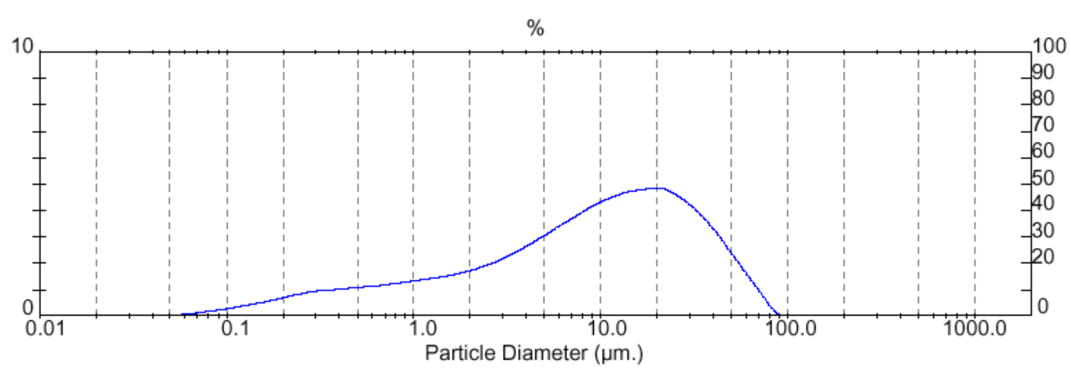

Fig 2- Particle size distribution of Drilling Fluid Grade Barite

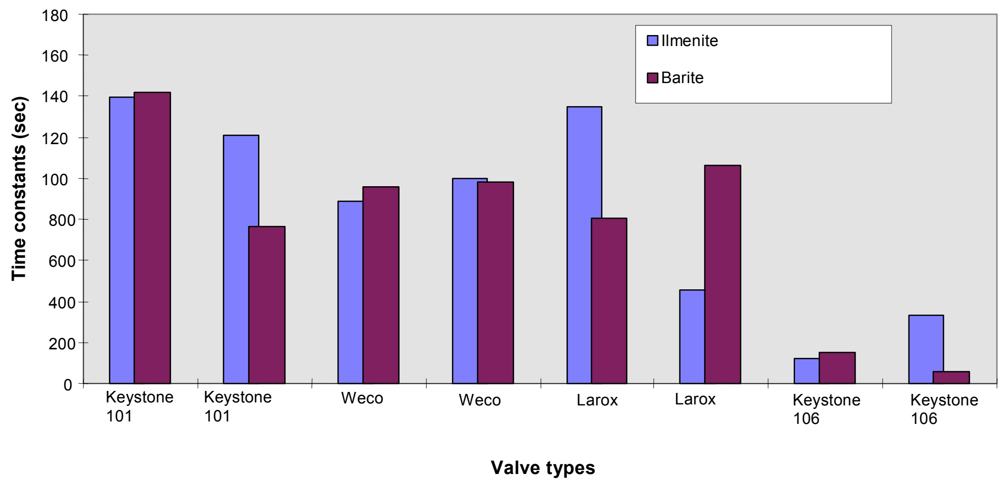

Fig 3- Dry bulk testing of ilmenite and Barite on standard oil field valves. All valves tested in parallel. High number indicates good resistance to wear and leakage.

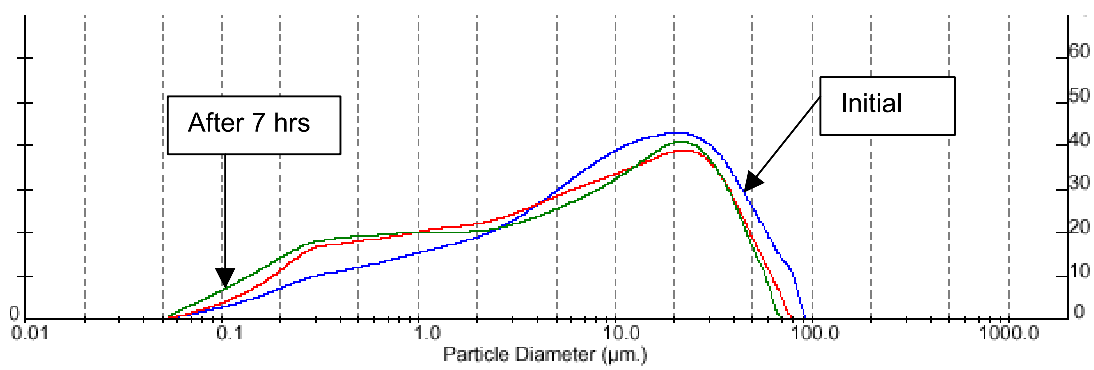

Fig 4- Change in particle size of barite with shear

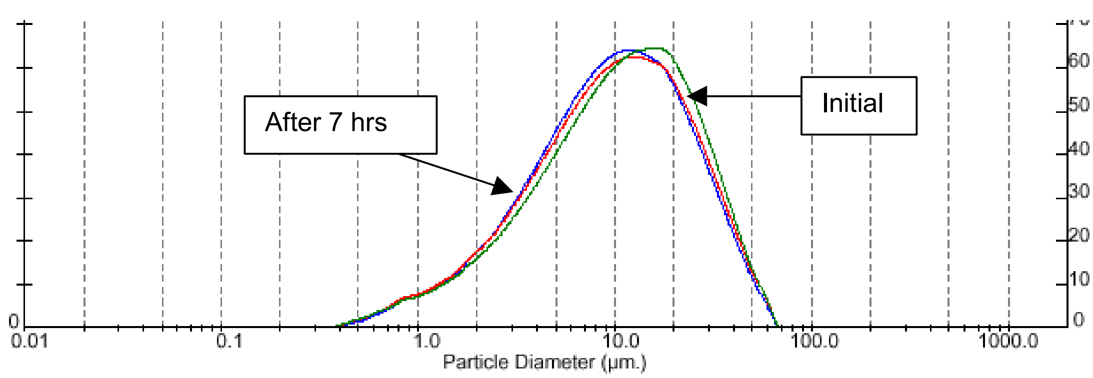

Fig 5- Change in particle size of Ilmenite with shear

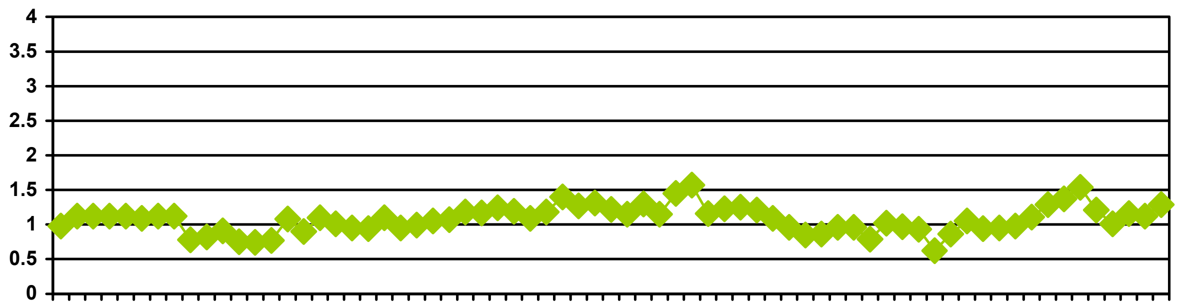

Figure 6 - Weight % >45 micron in production.

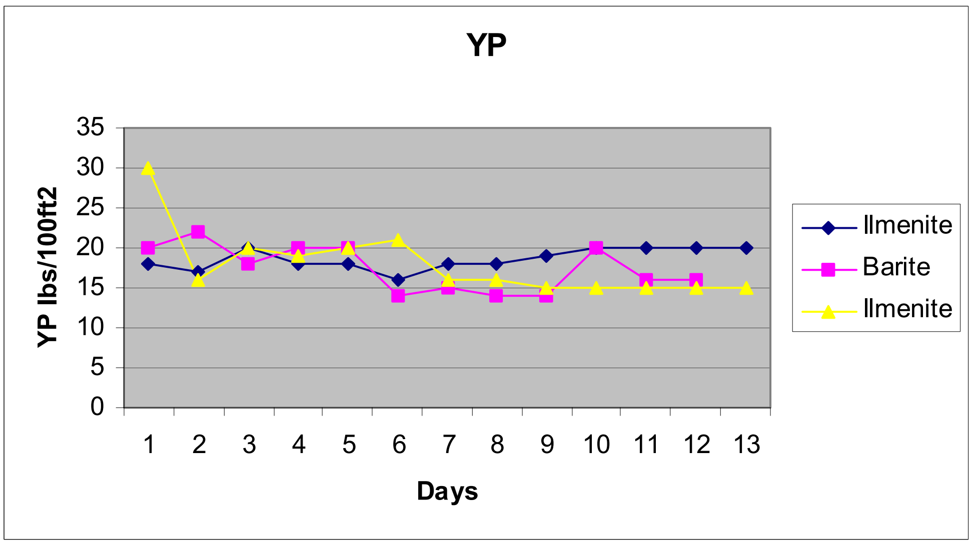

Figure 7 a - Comparison of the Yield Point for Barite and Ilmenite weighted fluids

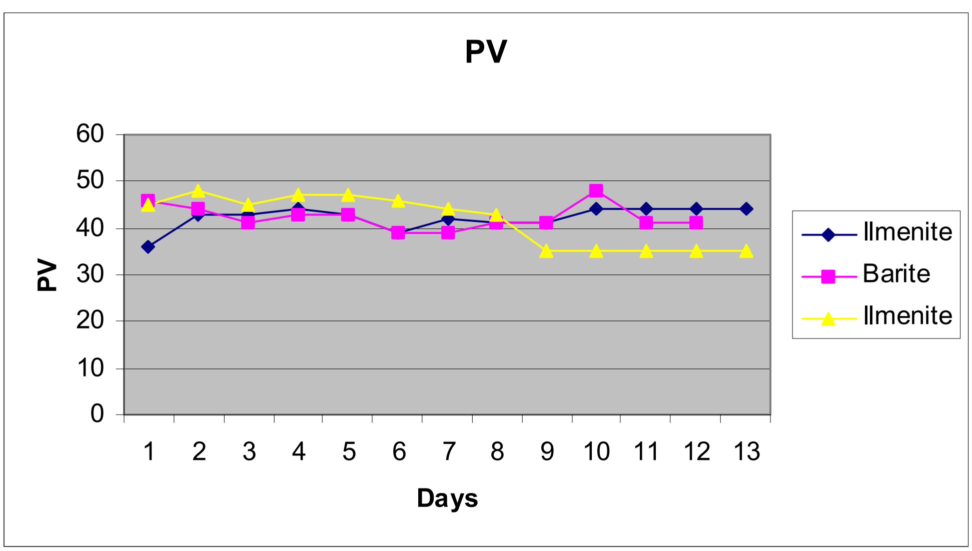

Figure 7 b - Comparison of the Plastic Viscosity for Barite and Ilmenite weighted fluids