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The Use of a New Micronised Ilmenite to Successfully Drill Record ERD Wells – Case Histories

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Abstract
The paper AADE-12FTCE-12 described the development of a new, micronised ilmenite weight material to provide better ECD management & sag control in drilling fluids. This paper further describes its use to successfully drill & complete new wells including record ERD ones.

An operator has a field development programme comprising horizontal, ERD wells in cretaceous carbonates designed to increase reservoir contact &, thus, increase production. Using different WBM's & NAF's these wells could not get past 25,000 ft without serious fluid losses, high torque & drag & NPT.

A new fluid was required which would minimize ECD's, losses torque & drag, but would also minimize formation damage & be easy to remediate if required. This paper describes the design & use of a non-aqueous fluid weighted with micronised ilmenite to drill these wells. An oil based fluid was chosen to provide good lubricity & the micronised ilmenite was chosen to provide low ECD's with low solids levels & be soluble in acid. This fluid has now proved effective in obviating the previous problems & permitting the successful drilling & completion of these wells. These wells are now being drilled to >36,000 ft, increasing reservoir contact, improving productivity & with significantly reduced OPT & NPT.

Introduction
Barium Sulphate (barite) has dominated weight material usage for almost 100 years. This is primarily because it had a high density (*ca* 4.20sg), was available in large volumes (both in the USA & globally) & was cheap. However, the oil industry has been changing:

- There is a reduction in the availability of high quality 4.20 sg barite. Most US barite consumption is of 4.1 sg or less
- There has been an increase in well complexity with more ERD, deepwater, HPHT wells etc. These require better rheological control, lower sag, reduced formation damage etc

API barite does not meet the requirements for many of these wells & alternative weight materials were introduced to try & provide higher performance. Examples of such materials are Micromax®, WARP & Cesium Formate. These all offer high performance for particular applications but are also expensive.

Other materials considered & used were:

- Hematite (Fe_2O_3) – this offered high density at *ca* 5.0 sg, but was abrasive & paramagnetic. Finer grades, as sourced from the paints industry obviated the abrasiveness problem, but were also expensive
- Ilmenite ($FeTiO_3$) – Offered good density at 4.6 sg, but was abrasive
- Itabirite – this is a hematite chert & is highly abrasive
- Siderite ($FeCO_3$) – Has a density of 3.96 sg & often less in its mined form, so is light weight
- Celestite ($SrSO_4$) – Has a density of 3.95-3.97. Again it is light weight.

The advantages offered by these proposed weight materials were either less than that of barite or the material had significant disadvantages, such as abrasiveness, which precluded its possible use. These materials were generally milled to similar particle size distributions (PSD) as that of barite. What became apparent was that if the material was reduced in size benefits appeared. These were as follows:

- Lower plastic viscosities (PV) so lower downhole pressure losses (ECD)
- Lower static sag
- Lower abrasiveness

The obvious answer to finding a higher performance weight material seemed to be to reduce the PSD of barite. However, micronizing materials increases their surface area. This can increase their surface activeness. Micronising barite resulted in lower PV's, but as the solids content or temperature increased, so did the surface activity & this led to higher low-end rheology. This limited the use of micronised barite. Treated micronised barite evolved from this understanding. If the barite particles were coated with an inert material their surface activity was reduced & higher mud weights (MW) & temperature stability could be achieved. However, this resulted in much higher costs. Micronised barite has recently been used more frequently, but still suffers some other disadvantages which make it less desirable as a high performance weight material. These are:

- It is not soluble in oilfield acids so formation damage from solids invasion can only be remediated by fraccing or expensive chelate treatment. Soluble barium is highly toxic & represents a serious HSE hazard
- It is not pneumatically conveyable like API barite & must be supplied in bags, increasing mixing time & limiting most offshore use to providing it in a “spike” fluid
- Barite is a soft mineral at 3-3.5 Mohs. Continued use leads to particle size degradation to sub-colloidal size & the need to then dump & dilute. This reduces recycling efficiency & increases costs

Therefore, this leaves only hematite & ilmenite from the existing, known weight materials that might be suitable for micronisation to improve performance &, perhaps, limit the downsides seen with micronised barite. Both hematite & ilmenite are very hard at >5 Mohs. This results in materials that are highly abrasive when their PSD is high. However, extensive testing on non-micronised ilmenite determined that abrasion was reduced to less than that of API Barite by eliminating the coarse particles; specifically, by keeping the particle size of ≥45µ to <1.5% *w/w*. The removal of coarse particles & the maintenance of low, narrow PSD’s provides materials with lower abrasiveness than API barite. The biggest difference between micronised hematite & ilmenite is in the cost. This is likely a result of processing costs for micronised hematite being more than for micronised ilmenite.

Micronised Ilmenite

The ilmenite used to produce this micronised weight material comes from an open-cast mine in Norway. The ore body contains magnetite, which was responsible for the magnetic interference seen when ilmenite was introduced to the market in the 1980’s. Reduction of the magnetite content removes this undesirable effect. The ore is crushed & then dry milled & classified to produce a weight material with the following properties:

SG ~ 4.6 approx. 10% denser than 4.20 sg API barite
D50 ~ 5 µ
D90 ~ 13 µ
BET ~ 1.6 m2/gr
>45 µ particles kept below 1.5 *w/w*%. Minimising the coarse particles reduces abrasion to less than API barite
Magnetite content of <0.3 *w/w*%. to prevent magnetic dampening – no interference with logging tools etc
PLONOR rated and an excellent HSE profile. It has a lower heavy metal content than barite. It is not mobile, does not persist or bioaccumulate & has no ecotoxicity. It has no regulatory risk phrases. Studies have further shown that the heavy metal contamination of Ilmenite is less soluble and bio-available than for Barite **.** **“**The study showed that flatfish fed with fish feed spiked with ilmenite, 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.”
It is pneumatically conveyable unlike other micronised weight materials & is compatible with existing oilfield infrastructure & practices.

An analysis by a major operator of using ilmenite in Norway showed that it resulted in:

- Reduced sag potential
- Improved hole-cleaning
- Longer lifetime of the drilling fluid
- Land-based cuttings handling
  - Burning with barite problematic because of
  - Burning with ilmenite straightforward
  - Less heavy metals from ilmenite if deposited
- Better shaker screen performance
  - Improved sand tolerance

Laboratory testing of this micronised ilmenite has shown that it performs significantly better than 4.20 sg API barite & better than equivalent particle sized micronised barite & with the advantages of being acid soluble & pneumatically conveyable. (Tables 2&3)

Case Histories

An operator had initiated a redevelopment plan to increase oil production by 50% by drilling ERD, horizontal drain holes through a cretaceous limestone reservoir. The success of the programme depended upon being able to maximise the horizontal sections through the reservoir & increase wellbore contact. Throughout the programme both WBM’s & LTOBM’s had been tried. However, using either of these fluids resulted in ECD’s exceeding the fracture initiation pressure (FIP) & incurring significant mud losses. Using an inner phase of CaBr2 in a LTOBM to reduce ECD’s & with graded CaCO3 as a bridging & weighting agent still resulted in significant mud losses & torque & drag. Pushing the wellbore length beyond 25,000 ft AHD proved difficult. As the field development plan was predicated on AHD’s of nearer 35,000 ft this meant many more wells would need to be drilled or production targets would not be met; either a major increase in cost or a failure to fully recover value from the field.

The new LTOBM was prepared to a MW of 10.8 ppg with an inner phase of CaBr2 & displaced at the 9 5/8” shoe. The rheology was run significantly lower than the offset wells (Table 5) with PV’s less than 20 cP vs *ca* 30 cP for the offset wells. This was important as the EMW at which losses occurred on the offset wells occurred at around 14.1ppg. Maintenance of low PV’s to keep the ECD below this EMW was critical. As drilling continued the PV’s reduced to an average of around 15 cP.

The shakers were dressed with API 325 mesh screens, which were the finest available. Two high volume centrifuges were used. One was able to handle feed rates of ca 100 gpm, but the other only 20-35 gpm due to equipment problems. The MW differential between feed mud & effluent was approximately 0.2 ppg.

Because of the lower ECD's, pump rates were able to be increased (vs offsets) to 480 gpm at an EMW of 13.9 ppg. On offset wells the pump rates had to be reduced from 440 gpm to 400 gpm to control losses (Figure 1) This higher pump rate & the lower solids content of the mud resulted in an average drilling rate of 1500 ft/day vs 1200 ft/day for offset wells. A 25% improvement. Minor losses occurred, but were eliminated in a slight reduction in pump rate to control the ECD below 14.2 ppg.

Torque & drag on the offset wells had been high & a problem. Friction factors were around 0.20. This reduced ROP & increased tripping time. The new micronized ilmenite fluid had a significantly lower friction factor of 0.10, which contributed to the excellent ROP & savings in operational time. Lighter weight LTOBM was used to prevent the increase in solids resulting from the faster ROP & inadequate centrifuge performance.

The first well drilled with this new micronized ilmenite fluid reached approximately 31,000 ft. Subsequent wells are now being drilled to *ca* 36,000 ft. The wells are completed using a NaCl/NaBr fluid at 11.1 ppg. This contains lactic acid precursors to remediate any damage & stimulate the reservoir. Losses on displacement have been minor. Productivity has significantly improved. On 2 wells the lactic acid precursors were not pumped & the production was double that of the offset wells.

It is important to note that these wells were not HTHP, but had MW's of around 11 ppg & BHST's of around 220^0F & show that the use of speciality weight materials is not confined to extreme well conditions. The use of micronised ilmenite offers another important tool in the fluids toolbox providing solutions for drilling that focus on adding value.

Until now, 8 wells have been successfully drilled. One of the characteristics of the use of micronized ilmenite is how well it recycles. Because it is hard with a hardness of *ca* 5 Mohs, the particles, unlike barite hardly degrade in size (Figure 3). Thus, low end rheology remains low & less dilution is required. The result of this is not only cheaper maintenance costs, but better preserved properties & more mud saved & re-used. A significant benefit to the operator. On these wells, the initial volume of ilmenite used was 155 MT. Since then less than 50 MT has been used per well.

Recommendations

More efficient solids control equipment is needed. With a D_{50} PSD the micronized ilmenite will mostly go through the centrifuge effluent & back to the circulating system. Efficient, high volume centrifuges operating in total discharge mode can make the management of this fluid more effective. Very fine shaker screens, such as API 425, can be used. This fluid has a much lower rheology which facilitates better fluid pass through & better separation of the drilled cuttings.

Micronised particle fluids have not just low PV's, but the low end rheology does not need to be as high as with API barite because there is very low sag. This enables running higher pump rates for both hydraulic horsepower to improve ROP & for faster annular velocities to clean the hole. These wells had no hole-cleaning problems.

Conclusions

The value drivers for using micronized ilmenite in these wells were:

- Maximise reservoir contact for increased production
- Reduce torque & drag
- Reduce ECD to reduce heavy losses
- Non-damaging or easily remediable
- Reduce NPT
- Reduce OPT
- Minimise sag
- Good ROP

All of these drivers were successfully met.

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Nomenclature

API = American Petroleum Institute
CTD = Coil Tubing Drilling
ECD = Equivalent Circulating Density
ERD = Extended Reach Drilling
EMW = Equivalent Mud Weight
FIP = Fracture Initiation Pressure
GPM = Gallons Per Minute
HPHT = High Pressure High Temperature
HSE = Health, Safety & Environment
LGS = Low Gravity Solids
LTOBM = Low Toxicity Oilbase Mud
MT = Metric Ton
MWD = Measurement While Drilling
OBM =Oil based mud
PSD = Particle Size Distribution
PV = Plastic Viscosity
SCE = Solids Control Equipment
SG = Specific Gravity
TTRD = Through Tubing Rotary Drilling
WBM = Water Based mud
YP = Yield Point

References

1) SPE 11085 - Evaluation of Ilmenite as Weight Material in Drilling Fluids - Blomberg, N. E., Melberg, B., Boe, A., Jacobsen, E. A.,Aarrestad, S – 1982 SPE ATCE New Orleans

2) SPE 61042 - Field Trial of Alternative Weight Material with Improved Occupational Hygiene and Environmental Performance – A.Fjogstad, Baker Hughes Inteq, A.Saasen, Statoil, R.Hagen, Titania, P.B. Tanche-Larsen, R. Ree, H. Melgren, Baker Hughes Inteq, E. Rostad and H. Hoset, Statoil - SPE International Conference on Health, Safety, and the Environment in Oil and Gas Exploration and Production held in Stavanger, Norway, 26–28 June 2000.

3) SPE 65000 - High-Density Invert-Emulsion System with Very Low Solids Content to Drill ERD and HPHT Wells - Nicora, L. F., Pirovano, P. (Lamberti S.p.A.); Blomberg N. (Blomberg Agenturer AS), Taugbol K. (Saga Petroleum ASA) - International Symposium on Oilfield Chemistry, Houston 13-16 February 2001.

4) SPE 71401 - Application of Ilmenite as Weight Material in Water Based and Oil Based Drilling Fluids - A. Saasen, SPE, H. Hoset, SPE, E.J. Rostad/Statoil, A. Fjogstad, O. Aunan/Baker Hughes Inteq,E. Westgård/ Transocean SedcoForex, P.I. Norkyn/Titania A/S - 2001 SPE Annual Technical Conference and Exhibition held in New Orleans, Louisiana, 30 September–3 October 2001.

5) AADE-02-DFWM-HO-40 - It’s Not Your Grandfather’s Ilmenite - Arild Fjogstad, Per-Bjarte Tanche-Larsen, and Morten Løkken, Baker Hughes Inteq, Reagan James, Phillips Petroleum Company Norway - 2002 AADE Fluids Conference, Houston.

6) Minimising the Environmental Effects of Drilling Operations - Ilmenite, Alternative weight material with improved environmental performance - Morten Løkken, Per-Bjarte Tanche-Larsen, Arild Fjogstad, Baker Hughes INTEQ - IBC’s 10th Annual conference, 4-5 March 2002

7) R. Farestveit et al, 1994, Statoil report, "Biologisk Tilgjengelighet av Tungmetaller i Baritt og Ilmenitt"

8) SPE 167937 - Alternative Drilling Fluid Weighting Agents: A Comprehensive Study on Ilmenite and Hematite - Tehrani, Ahmadi, M-I SWACO, Cliffe, Angleika, M-I SWACO, Hodder, Michael H, M-I SWACO, Young, Steven, M-I SWACO, Lee, John, M-I SWACO, Stark, James, M-I SWACO, Seale, Suzanne, M-I SWACO, a Schlumberger company

Table 1: Comparison of Properties of Micronised Ilmenite vs API Barite

Property (Typical)	API Barite	Microdense®
Density (g/cm^3)	4.2	4.6
Mean PSD -D_{50} (µ)	15 - 20	5
Hardness (Moh's scale)	3.0 - 3.5	5.0 - 5.5
Abrasivity (relative)	1	0.3 - 0.4
Shape	Angular	Round

Table 2: Micronised Ilmenite vs 5µ Barite in 12.5 ppg LTOBM

	Material	Mixing Time	Micronised Barite		Micronised Ilmenite	
1	EDC 99-DW	**0**	208.9	257.9	208.9	257.9
2	Primary Emulsifier	**5**	13	14.1	13	14.1
3	Secondary Emulsifier	**5**	10	10.4	10	10.4
4	Organophilic Clay	**10**	6.4	3.2	6.4	3.2
5	Lime	**5**	9	4.1	9	4.1
6	Filtration SBR	**5**	1.9	1.9	1.9	1.9
7	Filitration Lignitic	**5**	17	9.4	17	9.4
8	CaCl2 brine (21g CaCl2, 79g water)	**5**	139.6	123.5	139.6	123.5
9	Micronised Barite 5µ	**15**	356	84.8		
10	Microdense	**15**			339	73.7
TEST RESULTS			**BSHA**	**ASHA at 350 F 16 hrs**	**BSHA**	**ASHA at 350 F 16 hrs**
RHEOLOGY: Temp /°C			50	50	50	50
	600 rpm		78	75	69	72
	300 rpm		46	39	42	43
	200 rpm		35	33	32	33
	100 rpm		24	22	21	21
	6 rpm		9	8	8	7
	3 rpm		8	7	7	6
	Gels 10''		10	10	7	8
	Gels 10'		14	13	11	12
	Plastic Viscosity		**32**	**36**	**27**	**29**
	Yield Point		14	3	15	14
	HTHP Fluid Loss @ 150 C		2ml	4ml	2ml	6ml
	Filtercake		1mm	1mm	1mm	1mm
Electrical Stability			568	590	571	544
SAG	Density - Top			1.42		1.48
	Density - Bottom			1.62		1.5
	Sag Factor			**0.533**		**0.503**

Table 3: Micronised Ilmenite vs 5µ Barite in 14.5 ppg LTOBM

	Material (in gr)	Microdense		Micronised Barite	
1	EDC 99-DW	498		488	
2	Viscosifier	10		10	
3	Primary Emulsifier	40		40	
4	Secondary Emulsifier	5		5	
5	Lime	20		20	
6	Filtration Control	4		4	
8	Water	194		189	
9	Calcium Chloride	24		23	
10	CaCO3 5µ	65		65	
11	CaCO3 50µ	65		65	
12	MicroDense	878			
13	Microfine Barite			878	
TEST RESULTS		**BHR**	**AHR**	**BHR**	**AHR**
TEMPERATURE / °C			150		150
RHEOLOGY: Temp /°C		50	50	50	50
	600 RPM	55	83	69	86
	300 RPM	31	46	38	47
	200 RPM	22	33	27	35
	100 RPM	13	19	16	20
	6 RPM	3	3	4	3
	3 RPM	2	2	3	2
	Plastic Viscosity	24	37	31	39
	Yield Point	7	9	7	8
	Gels 10''	2	4	4	4
	Gels 10'	3	5	5	6
FILTRATION: Temp	Temperature		150		150
	HTHP Fluid Loss		3.4		2.8
	Filter cake		6		5
Dynamic sag VSST			0.160		0.230

Table 4: 16 ppg LTOBM Micronised Ilmenite vs API Barite

Material (in gr)	MicroDense		Barite	
EDC 99-DW	243		243	
Viscosifier	3		6	
Primary Emulsifier	30		15	
Secondary Emulsifier	25		15	
Lime	30		28	
HT FLA	23		25	
Water	25		25	
Calcium Chloride	8		8	
Micronised Ilmenite	700			
Barite			740	
	BHR	AHR	BHR	AHR
TEMPERATURE / °C		204		204
PERIOD STATIC AGED		16		16
RHEOLOGY: Temp /°C	50	50	50	50
Plastic Viscosity	23	25	34	36
Yield Point	5	5	8	1
Gels 10''	3	3	5	2
Gels 10'	5	6	13	5
HTHP Fluid Loss @150 deg C	3.1	3.5	1.7	2.2
Filter cake	4	3	3	2
Static Sag		0.508		0.521

Table 5: Summary of Fluid Properties Through Reservoir Interval

AHD ft	MW ppg	PV / YP cP & lb/100ft2	6 & 3 RPM	HPHT FL mls/30 min	ES mV	OWR
12837	10.8	22/11	7/6	8	490	70/30
13540	10.8	20/14	8/7	6.4	486	71/29
16939	10.8	21/13	8/7	6.6	610	70/30
18727	10.8	23/11	8/7	6.8	700	70/30
21860	10.8	19/14	8/7	6.8	823	76/24
23280	10.8	20/17	8/7	6.6	867	77/23
25850	10.8	18/20	8/7	6.6	943	79/21
27402	10.8	15/19	8/7	6.4	950	79/21
29094	10.8	16/14	6/5	6	930	80/20
30903	10.8	14/15	6/5	6	935	79/21

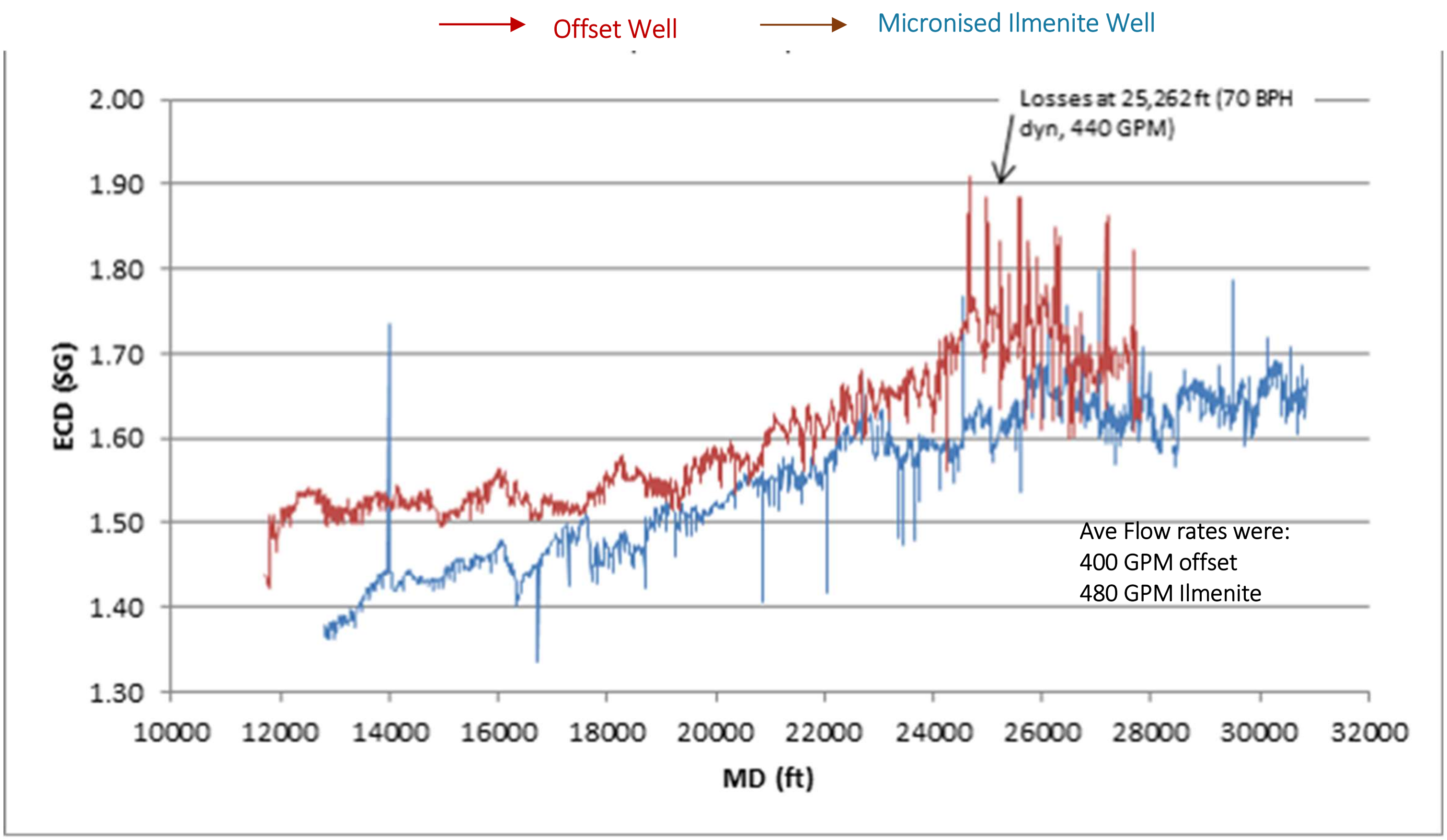

Figure 1:ECD Comparison Between Microdense & Offset Well

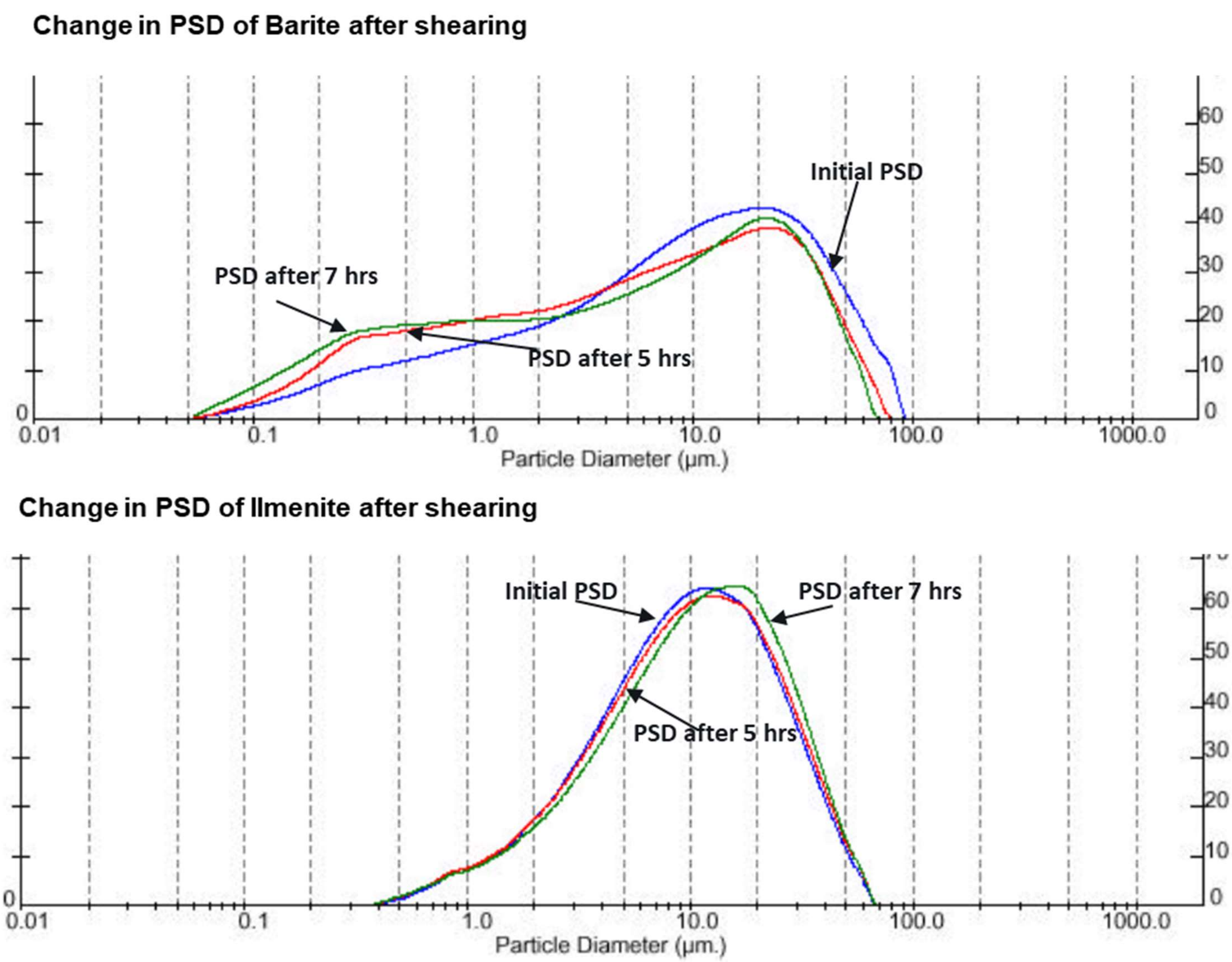

Figure 2: The Difference in Effect of Shearing on Ilmenite vs Barite