AADE-22-FTCE-013

Increasing Value Using a Specialized Weighting Agent for Challenging Operations in Oil and Gas Well Drilling

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Abstract
Since the advent of drilling fluids in the 1900's the weight material of choice has usually been barite. With significant changes to the oil and gas well drilling landscape in modern times the sustainable approach to drilling challenging wells has demanded other solutions, including replacing barite with alternative materials to enhance the fluid's performance and to improve production while reducing the total cost of operations. Challenges associated with formation damage, narrow equivalent circulation density (ECD) margins, high temperature high pressure (HPHT), slim hole, extended reach drilling (ERD) and deepwater wells have contributed to the development and utilization of alternative solutions. The success of these materials is dependent on the synergies they provide to improve operations where savings on the total cost of delivering the well can be realized.

The design and use of drilling and completion fluids strongly affects the performance and on-time delivery of the well and its productivity. The cost of the fluid can exceed 10% of the total authorization of expenditures (AFE) cost. Whilst barite has historically been a cheap and widely available option it is not always fit-for-purpose. Micronized ilmenite has now been extensively used to solve problems and offer greater value to operators. This paper demonstrates some of these successes, where a balanced approach to performance, cost and sustainability of the drilling fluid helped improve overall AFE and delivered greater value to the operator.

Introduction
There has been significant interest and use of specialty weight materials in the past 15-20 years. This has been driven both by a diminishing availability of API 4.20 S.G. material and a need for more useful materials to provide EDC management, sag control, reduced or remediable formation damage etc. Whilst barite still dominates use at around 7.5 million tonnes per year, we now see increasing use of <4.00 S.G. material at the low quality end and micronized barite etc. at the high end. API SC13 is working on a standard to define specialty barites more accurately, such that there will likely be the grades micro-fine, ultra-fine and fine ranging from D_{50} PSD's of around 1µm up to 16 µm. What we now see is a market driven by unit cost where users, who are uninterested in benefits other than density, go for the lowest cost to others requiring specific operational benefits leading to better fluid performance. The choice requires analyzing the value a product can provide in different applications and circumstances. We are looking at a "toolbox solution" and not a "one size fits all" . It is unlikely a 3.80 S.G. barite could provide a weighted fluid to, say, 16 ppg without a significant increase in both high- and low-end rheology. At 60 ^{0}F this may not cause problems for the operator, but at 300 ^{0}F it certainly would. Such types of problems may make it difficult or impossible to drill the well adding prohibitive non-productive time (NPT) and costs. Therefore, choosing a more expensive weight material, which provides improved performance to drill the well, creates higher value.

Micronized ilmenite was first used in 2015. Since then, over 100 wells have been drilled with it. These range from wells with low MW's of ±10.5 ppg to ultra-high mud weights of 18.8 ppg. They include the world's hottest geothermal well at a BHST of >930 ^{0}F to some of the world's longest horizontal wells at >47,000 ft. What is key to all of them is the recognition of the value this weight material provides to the operator, whether it is from minimizing NPT through to improved productivity and a better return on investment (ROI) for the operator. Specialty weight materials have often been assumed to be needed only for specialty situations such as HPHT wells, where the question asked is "Can we drill the well without it" to "How much financial gain (value) do we get from using this vs. cheaper alternatives?". However, we will see in the following case histories that low mud weights rather than high ones are more common where micronized ilmenite has been applied.

Case histories illustrating the Value of using micronized ilmenite vs. other weight materials

1) Arabian Gulf Ultra ERD Wells

Background

This operator wished to increase production in a large oilfield by at least 50%. This required drilling ultra ERD wells past 25,000 ft along hole depth (AHD) in a cretaceous limestone reservoir. Lower wellbore contact would not permit production increases of >50%.

Previous water-based muds (WBM's) and non-aqueous fluids (NAF's) experienced both excessive ECD's, resulting in serious losses, and severe torque and drag preventing further progress past 25,000 ft AHD. This meant that target production was not being achieved and the well costs were increasing.

The value drivers for these wells were:

- Maximize reservoir contact for **increased production**
- Reduce Torque and Drag to improve ROP and tripping speed
- Reduce ECD to reduce losses and **NPT**
- Improve ROP and **reduce daily costs**
- Minimize sag to reduce **NPT**

Micronized ilmenite was proposed as the weight material to reduce fluid rheological properties to reduce ECD's. This would enable reduced losses and provide more available hydraulic horsepower at the bit for improved ROP. Also, lower gels would permit faster tripping and casing running speeds.

Results

The new fluid was a low toxicity oil-based mud (LTOBM) weighted to a mud weight of 10.8 ppg with micronized ilmenite and an internal phase of $CaBr_2$ This was displaced at the 9 5/8" shoe prior to drilling the horizontal reservoir section. The rheological properties were now run significantly lower than the offset wells with PV's of less than 20 cP vs. *ca* 30 cP for the offset wells. This was important as the equivalent mud weight (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.

It proved critical to being able to maintain the PV at this lower level to both:

- Prevent losses
- Increase flow rates for hole-cleaning optimization

Table 1 Planned vs actual - Micronized Ilmenite Properties

Test	Planned	Actual- minimum	Actual - maximum
Mud weight (SG)	1.30	1.30	1.33
PV (cP)	ALAP +/- 21	14	16
YP (lb/100 ft²)	+/- 16	14	18
6 rpm (lb/100 ft²)	6 – 9	6	9
ES (Volt)	>700	525	950
LSYP	+/- 7	5	7
HTHP free water (mls)	0	0	0
OWR	70 / 30	70 / 30	80 / 20
Solids %	-	14.5	15

The ECD comparison is seen in Fig. 1 below. The red line is the ECD for the last well drilled with a LTOBM weighted with $CaBr_2$ and $CaCO_3$. The blue line shows the significantly reduced ECD with the micronized ilmenite weighted LTOBM.

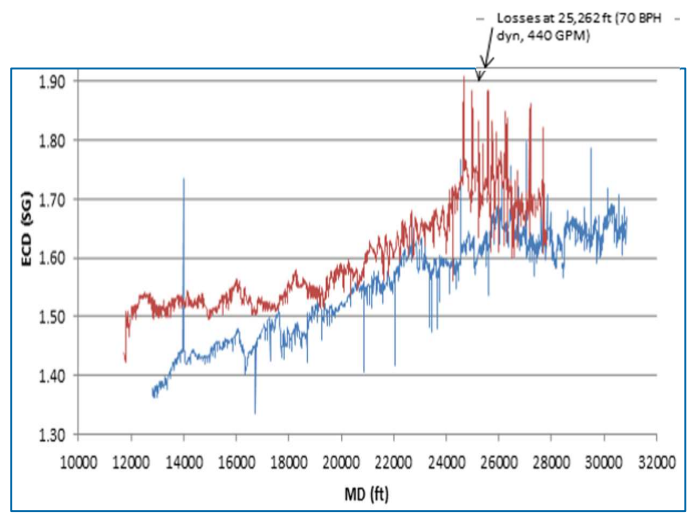

*Fig. 1-ECD's – Old LTOBM vs. Micronized Ilmenite LTOBM (*AADE-18-FTCE-055)

Because of the lower ECD's, pump rates were able to be increased (vs. offsets) from 400 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 (*Fig 1*) This higher pump rate and 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 and drag on the offset wells had been high, and a huge problem. Friction factors were around 0.20. This reduced ROP and increased tripping time. The new micronized ilmenite fluid had a significantly lower friction factor of 0.10, which contributed to the excellent ROP and savings in operational time. 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.

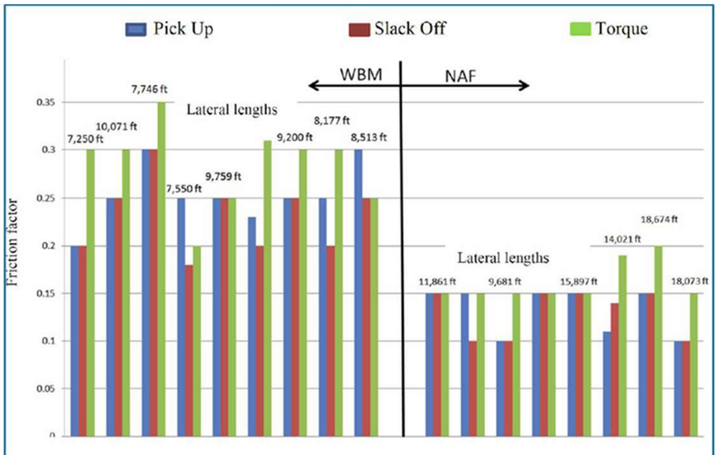

Figure 2—Friction Reduction Comparison Between RDFWBM & RDFNAF whilst Drilling Reservoir Laterals

Fig 2-FF's – Old LTOBM vs Micronized Ilmenite LTOBM (AADE-18-FTCE-055)

In *Fig 2* above the Pick-up and Slack-off weights are shown alongside Torque readings. The early WBM's used are on the left and NAF readings on the right. The last readings on the right show the first well drilled (to 31,000 ft) with micronized ilmenite. Whilst switching to a NAF made improvements, using the micronized ilmenite fluid made the greatest progress.

The implementation of micronized ilmenite in the RDIF composition also allowed the use of breaker systems with organic acid precursors since this product is acid soluble and allows the operator to remove the RDIF filtercake to improve production.

Productivity has significantly improved, and the production rate is double that of the offset wells.

It is important to note that these wells are not HTHP but had low MW's of around 10-11 ppg and bottom hole static temperatures (BHST's) of around 220 ^{0}F and show that the use of specialty weight materials is not confined to extreme well conditions. Over 50 of these wells have now been successfully drilled.

Value

The value drivers for these wells were:

- Maximize reservoir contact for **increased production**
  Wells now exceeding 36,000 ft for increased wellbore contact Successful use of breaker systems to remove filtercake. Production has increased by approximately 100%
- Reduce Torque and Drag to improve ROP and tripping times
  The FF has been reduced from 0.20 to 0.10-0.15. ROP has been increased by an average of 25% resulting in days of cost savings.
- Reduce ECD to reduce losses and **NPT**
  ECD's were reduced such that there were no losses, and the pump rate was increased to 480 GPM to improve hydraulic horsepower and hole cleaning.
- Improve ROP and **reduce daily costs**
  3 days on average saved per well
- Minimize sag to reduce **NPT**
  No sag observed

2) South East Asia HPHT Wells

Background

These wells, drilled by several operators, are positioned offshore Sarawak. They are HPHT with MW's up to 18.5-19.0 ppg and BHST's of 275-300 ^{0}F. They are vertical wells drilled to +13,000 ft. These have been exploration or appraisal wells. Previous wells used different types of barite, but suffered from high rheological properties, ECD induced losses and sag problems. Moving the barite weighted SBM to a 50:50 mix of barite and Mn_3O_4 enabled a fluid able to drill these wells without fluids related NPT. However, the first operator was interested in reducing costs on these wells and tested micronized ilmenite as a substitute for the Mn_3O_4, since the density window was not as narrow as initially predicted.

The value drivers for these wells were:

- The micronized ilmenite-based HPHT fluid must meet the fluid's rheological properties requirement for the well. The margin between the pore pressure and fracture gradient of well #1 was only 0.6 ppg. Based on the hydraulic simulations, it was imperative that the PV of the mud be kept below 55 cP to control the ECD of the well while drilling and thus prevent losses
- The ilmenite-based HPHT fluid must remain stable with no risk of sagging at a static period of 4-5 days to enable successful wireline logging operations

Results

Previous wells using the 50:50 barite and Mn_3O_4 weighted synthetic based mud (SBM) system had been successful. Up to 11 HPHT wells had been drilled. For these wells, the application of Mn_3O_4 was the main weighting material in the HPHT fluid system. With an S.G. of 4.80 and D50 of 1 µm, this material helps to reduce the overall solids content in the fluid system. This in turn minimizes the ECD and reduces the risk of loss circulation typically observed in a narrow margin HPHT well. However, as part of the initiative to reduce well cost, there was a need to investigate possible alternatives to lower the fluids' expenses while at the same time maintaining good performance. Therefore, micronized ilmenite was tested as a fit for purpose weighting material in the HPHT fluid system as the sag values for micronized ilmenite are significantly lower compared to API barite (Al-Bagoury, Nasr-El-Din, and J, 2013). The potential savings due to this change-out can go as high as 30% cost reduction in fluid spending.

As can be seen in *Table 2* the properties of the ilmenite fluid, even whilst being used as a 50:50 blend with barite, matches the required properties for these wells.

Table 2 Mud properties of the first well drilled

Mud weight	16.6 ppg	17.0 ppg
OWR	82 / 18	84 / 16
Readings at 120 ²F		
600 / 300 rpm	115 / 68	128 / 78
200 / 100 rpm	53 / 33	58 / 38
6 / 3 rpm	11 / 9	12 / 11
Plastic viscosity (cP)	47	50
Yield Point (lb/100 ft²)	21	28
10 sec. gel (lb/100 ft²)	12	15
10 min. gel (lb/100 ft²)	29	35
ES (Volt)	750	810

Over 12 wells have now been successfully drilled using the new system.

Value

The value drivers were:

- Meet rheology requirements of PV of < 55 cP to control ECD and reduce losses
  This has been achieved. The first well had problems with losses when insufficient emulsifier and wetting agent was added to the fluid during weighting up. Since then, these wells have been drilled with zero to slight losses saving 25-30% of the fluid cost
- Maintain stability and mitigate sag for up to 5 days logging
  This has been successfully accomplished on all wells

3) Sakhalin Ultra ERD Wells

Background

Sakhalin Ultra ERD wells are drilled with low mud weights of 10-11 ppg SBM's. These wells comprise many of the longest horizontal wells ever drilled. They are designed to maximize reservoir contact to optimize productivity. So even with the extraordinary wellbore lengths being drilled, increased production needs longer reservoir horizontals. The original NAF's were upgraded to new low ECD ones using micronized barite instead of API barite. However, the desired AHD's were not being achieved and the previous max step-out of 33,563 ft, had losses.

The fracture initiation pressure (FIP) was 17.7 ppg and needed ECD's well below that for prevention of losses. Also, sag causing increased drag and consequent slow running times for tripping and running completion screens. Running times of ±14 days were standard.

The value drivers for these wells were:

- Drill longer horizontals to maximize reservoir contact for **increased production**
- Minimize sag to reduce torque and drag to improve **tripping and completion times**
- Reduce ECD to reduce losses and **NPT**

Results

The same SBM system was used to drill the well, but micronized barite was replaced with micronized ilmenite.

This well was pushed to 44,780 ft MD with micronized ilmenite vs. 33,563 ft which used micronized barite. Approximately 11,000 ft further reach.

The ECD was lowered by 1.13 ppg at TD compared to the micronized barite SBM, with a 500 gpm flowrate, 325 mesh shaker screens and no losses.

It took eight days rig time to drill and run the completion screens with the micronized ilmenite compared to 14 days (best time) with micronized barite.

There was a mud density variation recorded of 0.15 ppg with micronized ilmenite compared to 1.30 ppg with micronized barite after being static for 72 hours in the well.

All operations were achieved under arctic conditions.

Fig 3 clearly shows the difference in ECD for the micronized ilmenite fluid (black line) vs. the micronized barite one (yellow highlighted dots) the dotted red line marks the FIP and losses occurring above 17.7 ppg

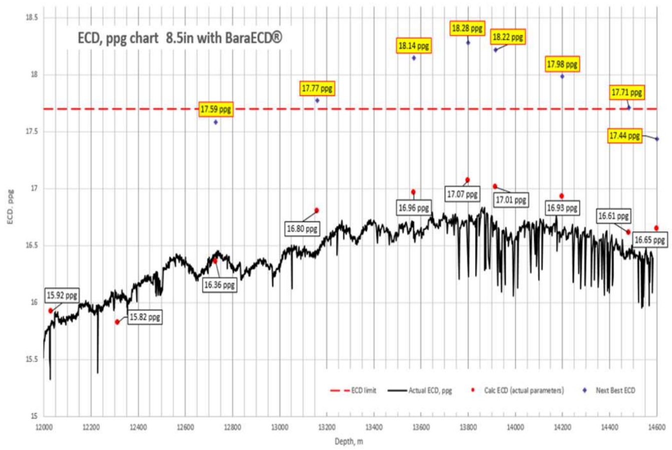

Fig-3 Actual ECD's with Micronized Ilmenite vs Offset Wells with Micronized Barite (Halliburton case study H013676 07/09 2020)

Value

The value drivers for these wells are:

- Drill longer horizontals to maximize reservoir contact for **increased production**
  Using the micronized ilmenite resulted in an increased horizontal of 11,000 ft. This was the longest well ever drilled from a land rig
- Minimize sag to reduce torque and drag to improve **tripping and completion times**
  Drilling and completion time improved by six days compared to offsets
- Reduce ECD to reduce losses and **NPT**
  There were virtually no losses vs. the offset wells

4) **Guyana Deep Water Wells**

Background

Guyana and the surrounding area are the biggest play to be discovered for many years. The wells are in deep water of 5-6000 ft.

Like all deepwater wells ECD management is critical to prevent losses. Micronized barite had been used previously, but there were still losses. Because of the long hole sections more fluid is required on these wells and losses manageable on shallow water operations require larger volumes to handle when in deepwater operations.

Micronized barite had previously been used, but there were still losses and barite may induce irreversible formation damage. Barite sag has also been a problem in these wells when using micronized barite.

The nature of deepwater drilling requires large circulating volumes to operate. Mixing and maintenance prefer a trouble-free pneumatic transfer of the weight Micronized ilmenite is pneumatically conveyable & was used to facilitate mixing.

The reservoir would require pressure maintenance from both seawater and gas injection. The reservoir drill-in fluid (RDIF) must be able to be cleaned up before injection to prevent plugging and reducing injectivity.

The value drivers for these wells were:

- Minimize sag to improve **tripping and completion times**
- Reduce ECD to reduce losses and **NPT**
- High productivity and ability to clean up RDIF filter cake such that **injectivity will occur** below FIP

Results

The wells are batch-drilled, with the top- and intermediate-hole sections first, then the reservoir sections. This facilitates more effective use of the RDIF.

The RDIF used was a low ECD SBM with micronized ilmenite as the weigh material. The micronized ilmenite is pneumatically conveyable which facilitated weight-ups, pills etc. by using the drillship silos; it has been used in more than 16 wells without issues and without fluids related NPT.

These wells are low mud weight with around 11-11.5 ppg. Even at these low MW's ECD reductions compared to using barite are around 0.7 ppg (*Fig 4*). The micronized particles exhibit less sag than barite, so lower low-end rheological properties can be used without causing problems. This permits higher flow rates. Over nine wells have now been drilled without losses or sag problems.

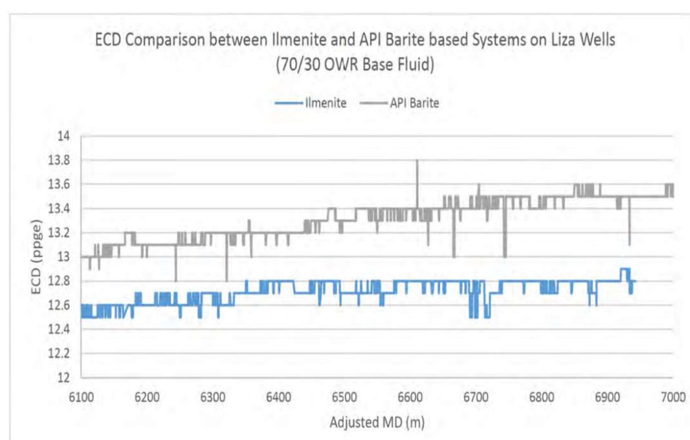

Fig-4 Actual ECD's with Micronized Ilmenite vs Offset Wells with Micronized Barite (OTC-31230)

The implementation of micronized ilmenite in the RDIF composition allowed the use of specialized breaker systems with organic acids, since this product is acid soluble, it enables the operator to remove the filtercake (*Fig 5*) and start the injection of seawater without flowing the wells back

Fig-5 Comparison showing Micronized Ilmenite filtercake before & after acid breaker treatment (OTC-31230)

Value

The value drivers for these wells are:

- Minimize sag to improve **tripping and completion times**
  There have been no sag problems and tripping and completion times are improved
- Reduce ECD to reduce losses and **NPT**
  Rheological properties have been maintained at lower levels and ECD's have been successfully kept below FIP with a reduction of ±0.7 ppg
- High productivity and ability to clean up RDIF filter cake such that **injectivity will occur below FIP**
  A couple of production wells were connected to the existing FPSO have achieved the expected production. Lab tests have been run giving successful formulations to achieve breaker efficiency enabling >50% injectivity below FIP. However, the injection wells will not start until another FPSO is in use

Conclusions

The primary reason for the use of weight materials in drilling and completion fluids is to maintain wellbore integrity. However, the use of a weight material brings with it benefits and drawbacks. Choosing the right one for a particular application provides benefits and adds value. From the four case histories described here there are recurring benefits such as improved rheological properties providing low ECD's with reduced or zero losses etc. What we have seen in these case histories is added value such as improved production or reduced costs by eliminating time to complete an operation e.g., tripping or running casing or completions. The specialty weight materials are more expensive than barite, but as shown here, the extra value that is provided far outweighs the extra cost.

Acknowledgments

The authors would like to thank Elkem Silicon Products for permission to publish this paper. The authors would also like to thank all those colleagues involved in the project, particularly the laboratory personnel.

Nomenclature

AHD = Along Hole Depth
API = American Petroleum Institute
ECD = Equivalent Circulating Density
ERD = Extended Reach Drilling
EMW = Equivalent Mud Weight
FF = Friction Factor
FIP = Fracture Initiation Pressure
GPM = Gallons Per Minute
HPHT = High Pressure High Temperature
LTOBM = Low Toxicity Oilbase Mud
MT = Metric Ton
MW = Mud Weight
NAF = Non-Aqueous Fluid
NPT = Non-Productive Time
OBM =Oil based mud
PPG = pound per gallon
PSD = Particle Size Distribution
PV = Plastic Viscosity
RDIF = Reservoir Drill In Fluid
ROI – Return On Investment
SBM = Synthetic Based Mud
SCE = Solids Control Equipment
S.G. = Specific Gravity
TD = Total Depth
WBM = Water Based mud
YP = Yield Point

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