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Nanotechnology-based High Performance Drilling Fluid Solution Optimizes Well Construction through Enhanced Wellbore Stability.

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Abstract

The Napo formation poses one of the biggest challenges in the well construction process for many wells drilled in Ecuador. This is predominantly due to interbedded lithological bodies of shale, limestone and sandstone, influenced by earth stresses that can potentially lead to severe wellbore stability issues. This paper presents results of applying nanotechnology in a water-based drilling fluid to reduce rock-fluid interaction and minimize the risk of wellbore instability.

One of the main concerns for the operator, Frontera Energy, is to maintain wellbore stability (low pore pressure and moderate collapse pressure). Based on geomechanical models, a specific sealing strategy and fluid properties management program was required to drill different formations in one section with a single drilling fluid.

Design analyses were performed based on rock-fluid and fluid-fluid studies, through critical tests such as shale dispersion and erosion, linear swell meter, permeability plugging apparatus test, and filtration at high temperature / high pressure.

Initially, "S shape" wells were drilled but during the exploratory campaign it was deemed necessary to drill "J shape" wells to establish the field limits, achieving vertical displacements greater than 6000 ft. For the new challenges in the field, a nanotechnology-based high performance drilling fluid was designed and applied that helped meet the operator's needs, optimizing time and operational costs with minimal impact in well production and no formation damage.

Basin Characteristics

In Ecuador, the Napo Formation (Fm). rests in concordance with the Hollin Fm. Napo Fm. consists of shales and limestones with intercalated sandstones. The Napo Fm. is easily recognizable in seismic studies due to the presence of strong reflectors corresponding to limestone levels.

According to (Jaillard, 1997), the Napo Fm. is classified as a group and is divided into four members, which correspond to shallow water marine sequences (Rivadeneira, 1999). The Napo Basal Formation can be interpreted as a transgressive (Basal Sandstone) and regressive (T Limestone and T Sandstone) mega sequence, with maximum transgression occurring within the Napo Basal shales.

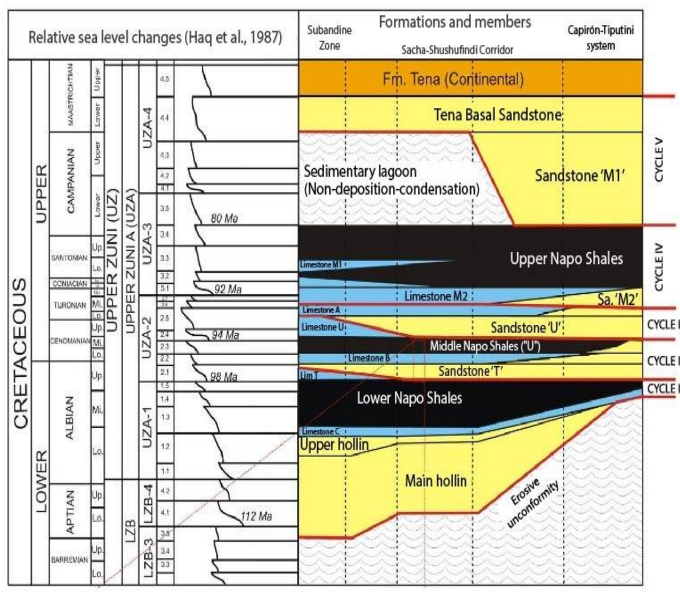

Figure 1 – Stratigraphic structure of the Ecuador Basin

The reservoir zones as shown in Fig. 1, include the Basal Tena, U, T and Hollín sandstones. These are intercalated with shales and limestones and are characterized as quartz and calcareous sands with contributions of Glauconite and Kaolinite.

The presence of sands intercalated with shales and limestones, combined with current compressive stresses caused by the uplift of the Andes Mountains, results in high collapse pressure values (see Fig 2). Geomechanical studies available for Frontera Energy fields indicates that the pore pressures in the reservoir sands are low. Consequently, the most significant risks include wellbore instability, geometric and differential sticking, and loss of circulation.

To control those risks, drilling fluid design requires, in addition specific fluid density, a specific sealing strategy and strict control of fluid properties to drill through the interbedded formation in a single section.

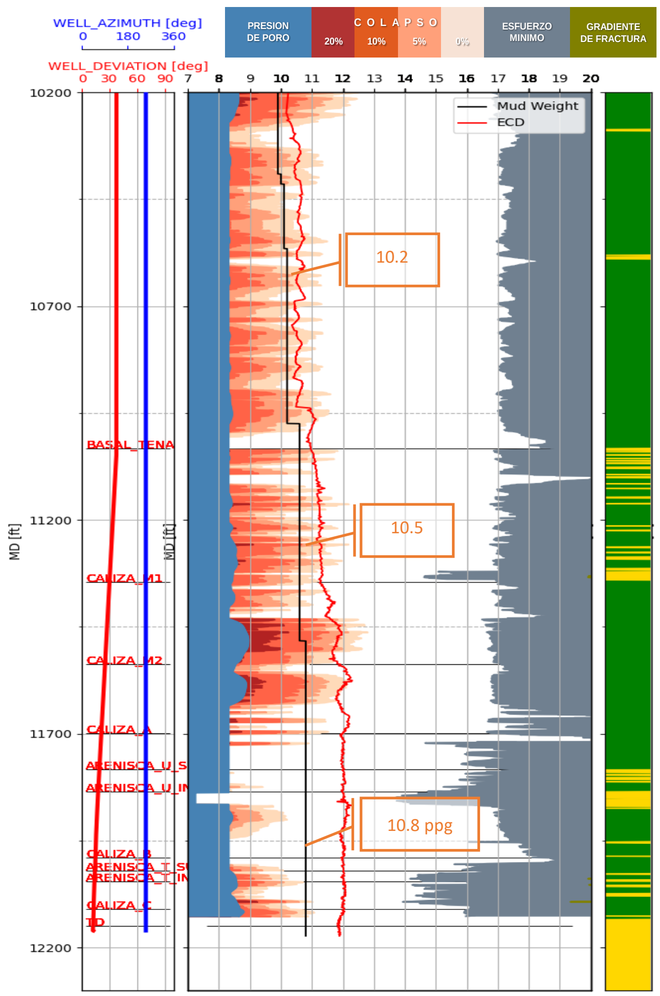

Figure 2 – Typical Wellbore Stability Mud Weight Window in the field. Property: Frontera Energy (Guio, 2024)

Basis of Drilling Fluid Design

The fields where Frontera Energy operates in Ecuador are exploratory, and it has currently drilled a total of nine wells in two fields with similar lithological conditions.

During the exploration stage, various types of wells have been drilled, including vertical, S-shaped, and J-shaped wells, to maximize reservoir reach and enable comprehensive studies. Given the basin's conditions, geomechanical pre-drill models are being developed for each well. These models correlate data from previous drilling operations, enabling the design of density curves that have evolved from addressing 5% breakout with conventional drilling fluids to managing 20% breakout using nanotechnology-enhanced drilling fluids, achieved through a learning curve achieved through analysis of trips, cavings, calipers.

Traditionally in the area, the strategy for the drilling fluid used, was based on asphaltic materials (in this document referred as **WBM**), and achieving the required density in S-shaped wells. However, as the well design transitioned to J-shaped configuration, wellbore stability became a major challenge. As a result, it was decided to introduce High Performance Water Base Mud (in this document referred to as **HPWBM**).

A design analysis was performed based on Rock - Fluid and Fluid - Fluid studies, through tests such as Capillary Suction Time, Cation Exchange Capacity, Linear Swell Meter, Permeability Plugging Test, Rheology, Density and Filtration properties such as API FL, High Temperature High Pressure FL and compatibilities between the drilling fluid and the fluids present in the formation. As a result, HPWBM was introduced in combination with a nanotechnology wellbore sealant as a high-performance sealing product.

Due to the exploratory nature of the field, no core samples of the reservoir rocks were available. Consequently, the design did not include return permeability analysis (nevertheless, production data in the field suggest no formation damage). This document focuses on wellbore stability and sealing capacity, presenting values obtained from PPT and HTHP tests conducted during both the design and execution phases.

A comparison is provided between a conventional reservoir drilling fluid, such as Drill – N (**WBM**), and a Nanotechnology-based High-Performance fluid (**HPWBM**). The following table shows the materials used in each fluid.

Table 1. Materials Drilling Fluid for Frontera Energy

Product	WBM	HPWBM
Alkalinity Modifier	Yes	Yes
Bactericide	Yes	Yes
Viscosifier	Yes	Yes
Filtrate Controllers	Yes	Yes
Shale Stabilizers – Hydrocarbon Mix (Black Powder)	Yes	No
Shale Inhibitor	Yes	Yes
Asphalts (Black Powder)	Yes	No
Calcium Carbonate	Yes	Yes
Lubricant	Yes	Yes
Nanocomposite Agent	No	Yes

Using the designed fluids, several tests were performed in accordance with the API 13B-1 (API, 2023) Standard for water-based fluids, as shown in Figures 3-5. These tests followed various internal Work Methods and included evaluations with both fresh fluid and under stress conditions such as temperature, pressure and solids contamination to validate the performance of these fluids in the lithology to be drilled (Provider, 2024).

Permeability Plugging Test

The Permeability Plugging Test is used to evaluate the ability of a drilling fluid to form a semipermeable filter cake. This cake helps seal reduced-pressure intervals and prevents differential sticking. The test measures the fluid's effectiveness in creating a barrier that minimizes fluid loss in permeable formations.

"Set the permeability plugging test (PPT) volume, *V*PPT, expressed in milliliters, equal to two times the *V*30, the filtrate volume after 30 min, expressed in milliliters, as given in Equation (J.1):

$$VPPT = 2 \times V30 \quad (J.1)$$

Calculate the spurt loss, *V*1, expressed in milliliters, as given in Equation (J.2):

$$V1 = 2\,[V7.5 - (V30 - V7.5)] = 2(2V7.5 - V30) \qquad (J.2)$$

Where:

*V*7.5 is the filtrate volume after 7.5 min, expressed in milliliters.
*V*30 is the filtrate volume after 30 min, expressed in milliliters.

The filter media routinely used in these tests have half the filtration area of that used in the standard low-pressure filtration test. Doubling the filtrate volume compensates for this area difference." (API, 2023).

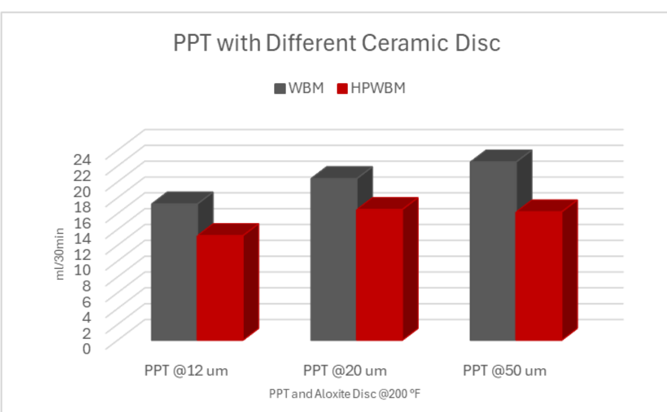

Figure 3 – Comparative PPT WBM vs HPWBM - Frontera Energy

From the planning phase, it is evident that with different Ceramic discs, the PPT yields better results with the nanotechnology based fluid. Given that these tests were run with the same particle size distribution, a conventional fluid is limited to covering the disc size for which it is designed (in this case, a 12-um disc). In contrast, a fluid such as **HPWBM** has the advantage of handling various pore throat sizes with results within the planned targets, which for the field execution is Total PPT < 18 mL/30min.

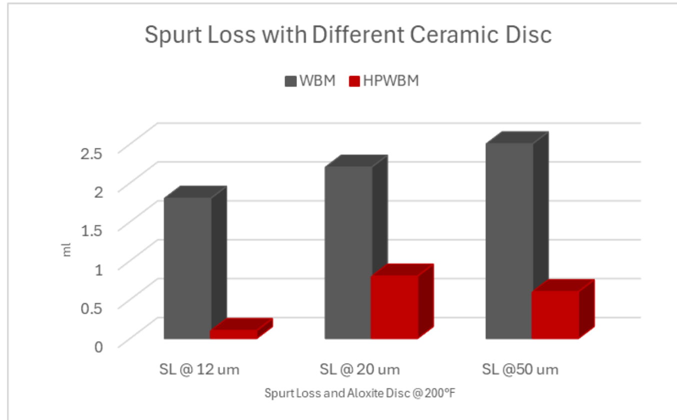

Figure 4 – Comparative Spurt Loss WBM vs HPWBM - Frontera Energy

Considering that the Spurt Loss is "The volume of fluid that passes through the filtration medium before a filter cake is formed" (API, 2023), the efficiency in filter cake formation can be determined when using nanotechnology. The disc variation does not significantly alter these instantaneous losses. On the contrary, the values are consistently less than 1 mL in the different discs tested for the fluid design.

High Temperature – High Pressure Filtrate Test

Measuring the HTHP fluid loss of a drilling fluid involves heating the fluid in a controlled environment to a temperature that is expected in the well. When test temperature is reached, filtrate volume and cake thickness is determined at a pressure differential to simulate downhole conditions (Mitchell, 2004).

"The filtrate volume should be corrected to a filter area of 45.8 cm^2 (7.1 in^2). HTHP filter cells usually have half the standard filter area 22.6 cm^2 (3.5 in^2), thus double the observed volume before reporting *V*f." (API, 2023).

The principle of controlling the filtrate with temperature and pressure is to monitor the invasion generated into the porous and permeable formation. As indicated in Fig. 5, the **HPWBM** is more efficient in filtrate control compared to conventional **WBM.** In addition to minimizing invasion into the reservoirs, its nano particle size characteristics help efficiently seal the micro and nano porosities of the shales, mitigating their stimulation by overbalance effects and pressure exerted on these rocks.

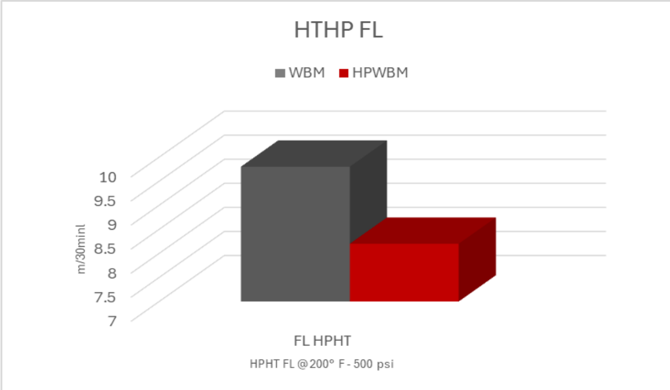

Figure 5 – Comparative HTHP WBM vs HPWBM Frontera Energy

Application Results: Field Properties

Nine wells have been drilled in Ecuador with Frontera Energy, the last four using **HPWBM** Nanotechnology. Based on mechanical conditions, only 2 wells of similar construction (S-shape) are comparable (Fig. 6). Well A was drilled with conventional **WBM,** and Well B was drilled with **HPWBM.** However, to evaluate the performance of the nanotechnology system, the wells drilled with **HPWBM** (Well C, D, E) will also be included. Table 2 shows a summary of the wells mentioned.

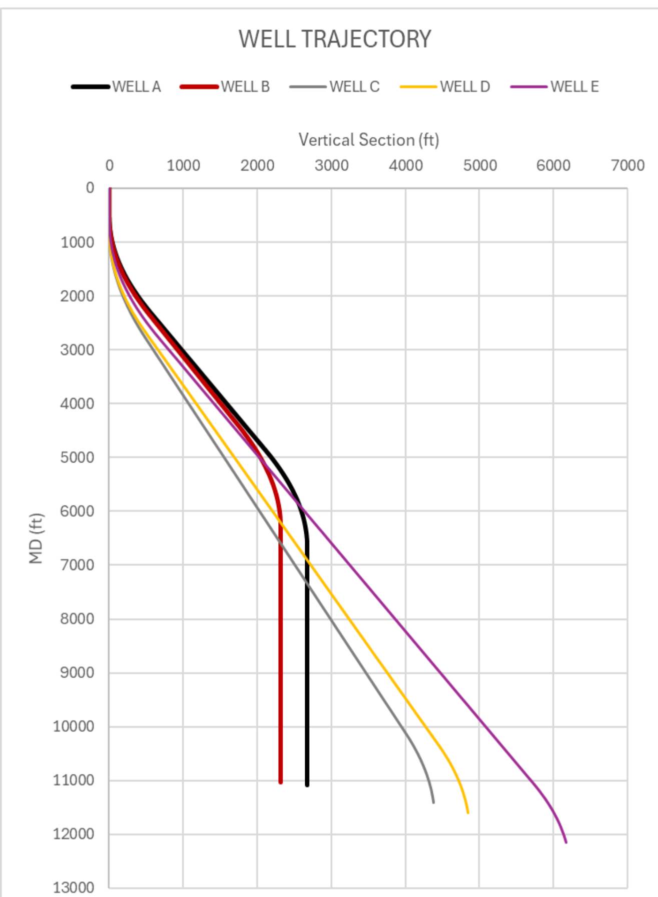

Figure 6 – Trajectory Frontera Energy Wells

Table 2. Well and Drillign Fluid Type

WELL	DRILLING FLUID	TRAJECTORY
A	WBM	S-Shape
B	HPWBM	S-Shape
C, D, E	HPWBM	J-Shape

Density

The density curves were designed based on updated geomechanical models (supplied by a third-party company contracted by Frontera) for each well in execution. Figure 7 shows the density values executed in each of the wells mentioned in this document.

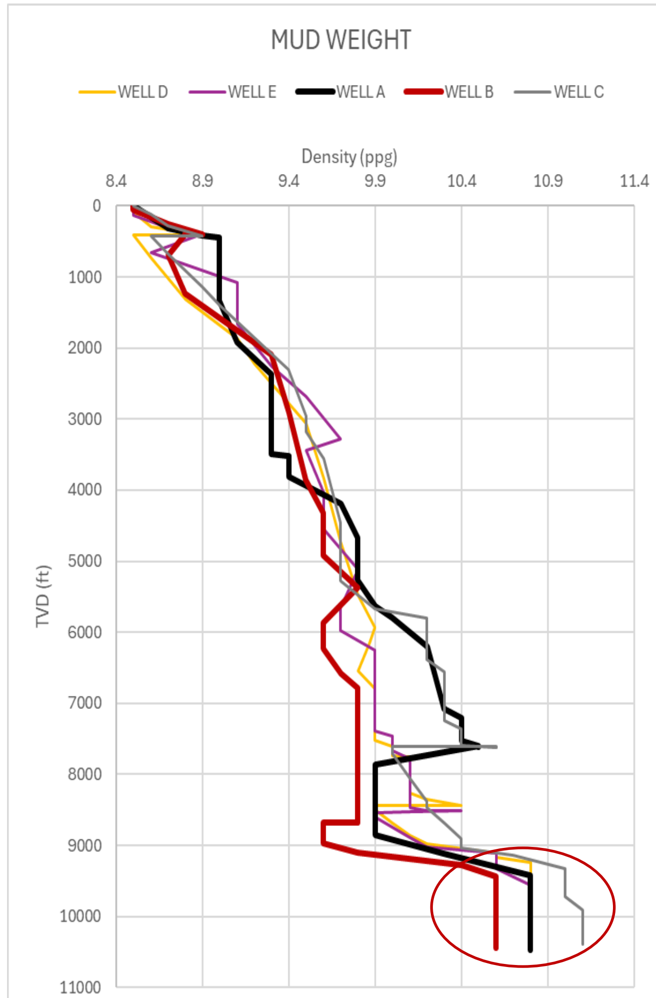

Figure 7 – Density Curve Execution Frontera Energy Wells

In the reservoir section, the use of Nanotechnology in well B improved wellbore stability, allowed for handling a lower density compared to well A. Additionally, in wells with higher angles and displacements (J-shape wells), the stability provided by the **HPWBM** allowed drilling this reservoir zone with a density similar to that of a S-shape well, considering that its inclinations ranged from 28 to 47 degrees.

The fluid density management for drilling the wells was supported by a design with strong rheological and filtration properties, compensating through sealing and hole cleaning. This allowed breakout-tolerant densities of 15% in the J-shape wells and 20% in well B, compared to 5% in the Well A.

PPT – Spurt Loss

Laboratory equipment was available in the field to follow-up on the PPT in the wells. These tests were carried out under the following conditions: Temperature: 200°F, pressure differential: 1000 psi, and with 12 um Ceramic discs.

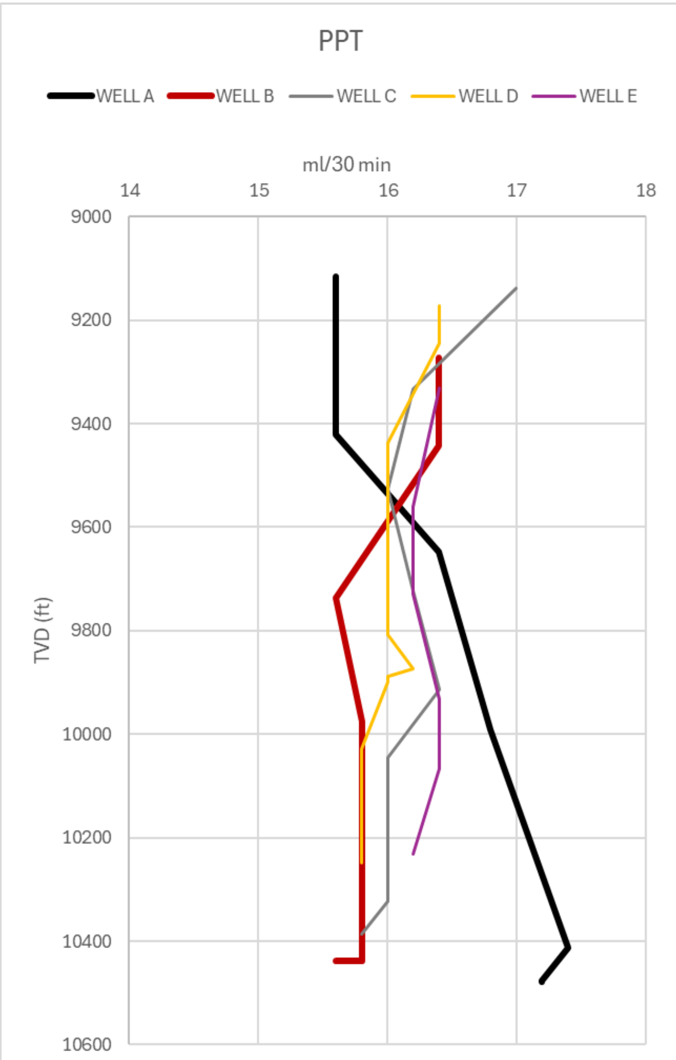

Figure 8 – PPT Execution Frontera Energy Wells

The trend of the PPT during well execution showed that when **HPWBM** is used, lower values are obtained compared to **WBM**. Given the nature of the stratigraphic column, with the presence of shales and limestones, black powder materials, such as asphalts, are used in the conventional fluid, agents that increase formation damage probability.

As shown in Fig. 8, the use of nanotechnology (**HPWBM**) has contributed to the decrease of PPT values, despite not using black powder materials, obtaining on average lower PPT values comparing Well B vs Well A. The efficiency in sealing through the total PPT is evident when using Nanotechnology, decreasing by up to 1.5 ml/30 min in this case and eliminating the need for asphaltic materials for wellbore stability.

Similarly, Spurt Loss with **HPWBM** is more than 50% lower (at well TD) than with the **WBM**, helping to minimize the invasion of drilling fluid into the formations. This also minimizes damage to the formation and, in this specific lithological column, to the shale layers, controlling the loss of overbalance and the stimulation of the rock through the transmission of pore pressure. (Fig. 9)

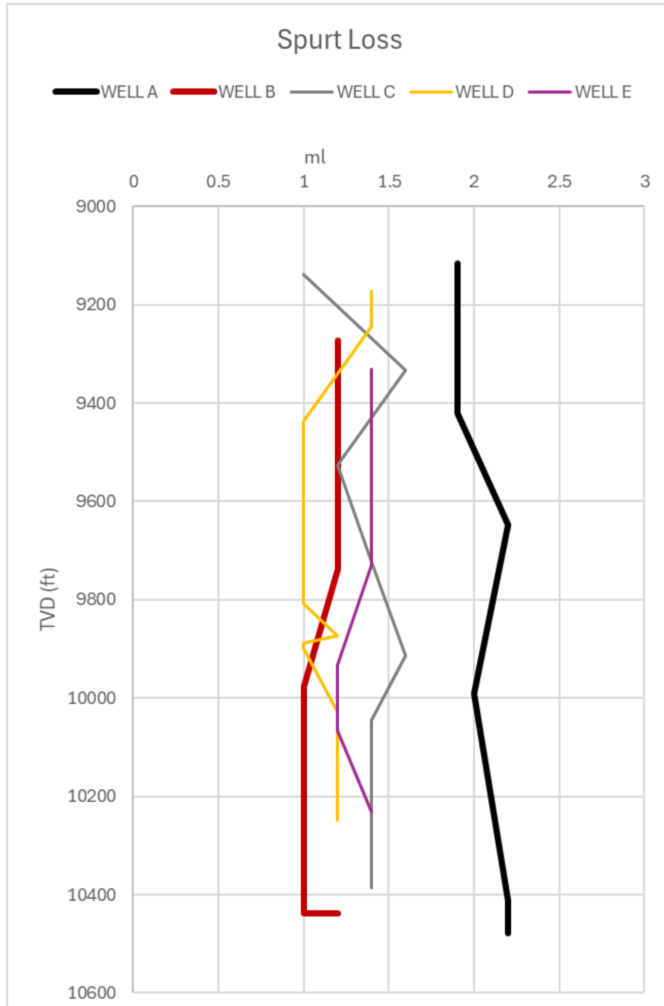

Figure 9 – Spurt Loss Execution Frontera Energy Wells

As for the instantaneous fluid loss, the values decrease by up to 50% in the **HPWBM** (Well B) compared to **WBM** (Well A), demonstrating the ability a quick sealing for the formation.
The comparison between well A (**WBM**) and well B (**HPWBM**) shows how replacing black power products with

nanoparticle-based not only mitigates formation damage but also provides better filtration properties, controlling formation invasion and avoiding shale hydraulic stimulation. The **HPWBM** is 50% more efficient in sealing capacity by having lower total values compared to the **WBM**.

HTHP

The HTHP tests performed in the field under temperature conditions (200°F) and pressure differential (500 psi) were applied in the reservoir section. Figure 10 shows the behavior of the wells, comparing well A and well B. Better results from filtration tests were seen when using the nanotechnology sealant.

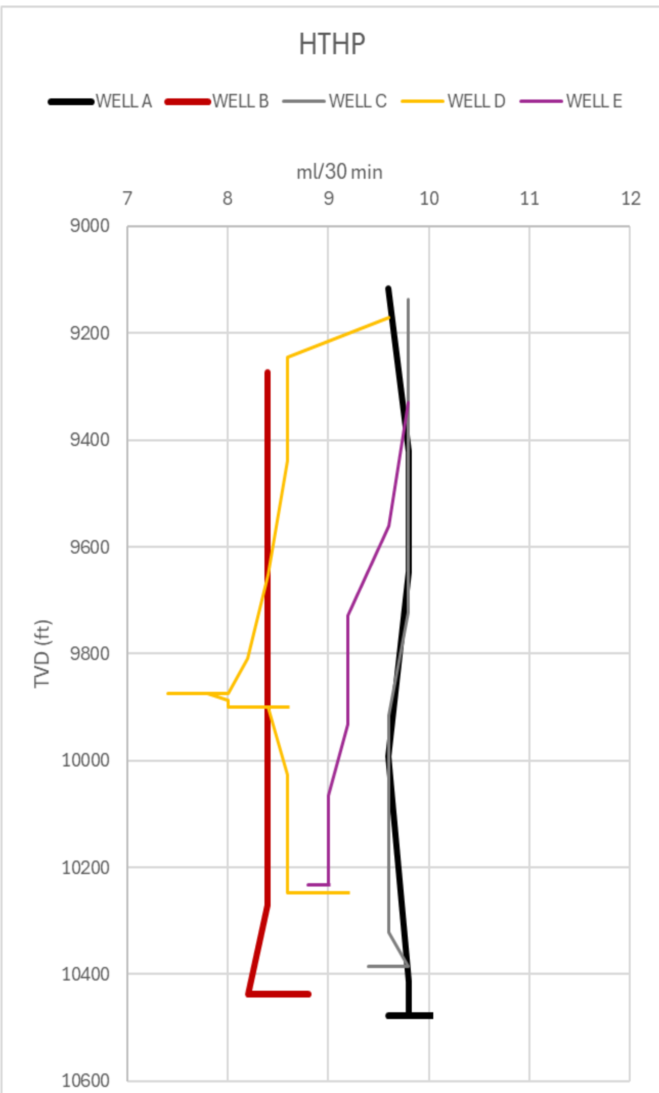

Figure 10 – HTHP Execution Frontera Energy Wells

Application Results: Operational Conditions

This section provides a comparative analysis of caving, pipe trip behavior, and Liner running when using a **WBM** (Well A) vs. a **HPWBM** (Well B).

Caving Analysis

The cavings analysis was carried out by a third-party company contracted by Frontera Energy, which has also modeled the geomechanical behavior of its fields. This company conducted a study on the "Prediction of collapse pressure in wells through a pore-elastic geomechanical model" (Guio, 2024). Therefore, the information below is referenced from this study.

In well A, with **WBM**, reactive behavior was observed in part of the shale formations, showing overburden and excessive collapse of material during drilling. Surface samples of cavings reached up to 37 mm in size, with an excess of up to **20%** of the formation material observed. (Fig. 11).

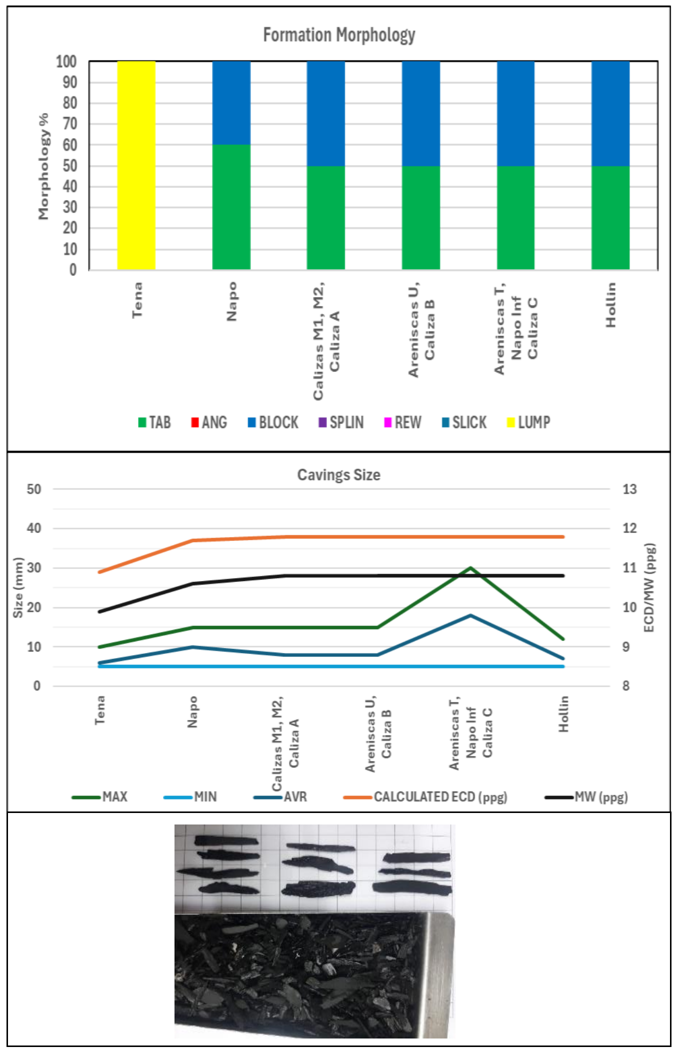

Figure 11 – Data Collection Cavings Well A. Ingeodata - Frontera Energy Wells

In contrast, Well B, which used **HPWBM,** showed a very stable behavior in part of the shale formations, with no evidence of overload or excess material at the surface. This good stability is corroborated by surface samples, which showed no sizes larger than 13 mm and excess material that reached a maximum of **10%**. (Fig. 12).

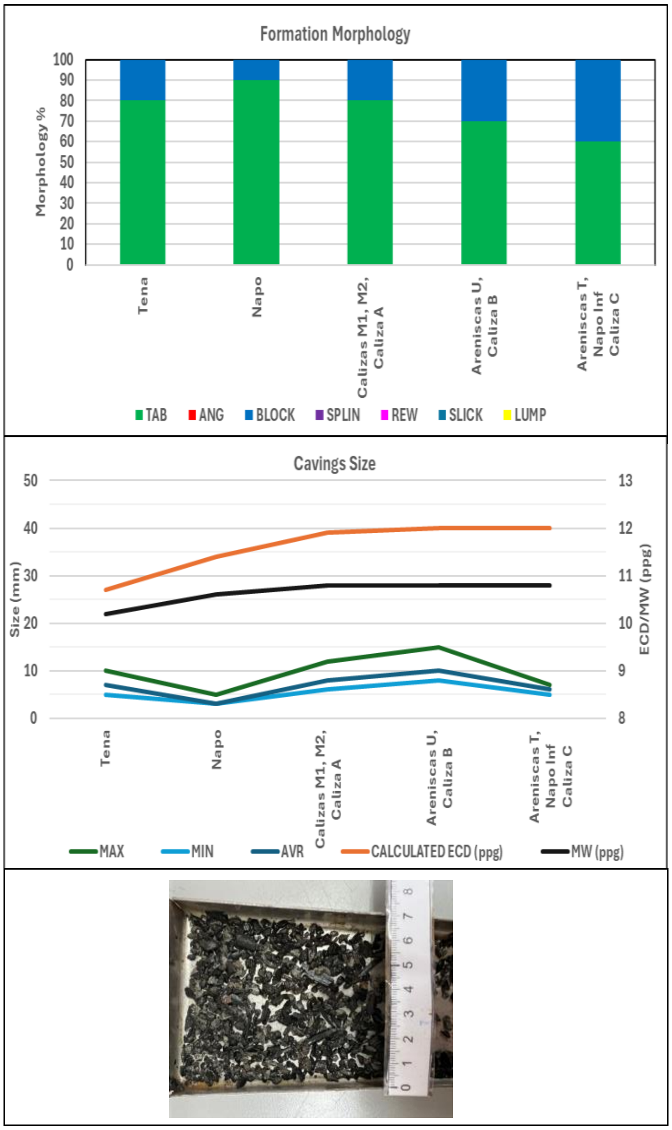

Figure 12 – Data Collection Cavings Well B. Ingeodata - Frontera Energy Wells

It is relevant to highlight the significant changes in the caving size behavior between the two wells. The average size decreased from **37 mm to 13 mm,** and excess material dropped from **20% to 10%.** This improvement indicates better hole quality and, therefore, better stability, all these parameters positively impacting hole cleaning conditions. Additionally, in well B, with the same stratigraphic column, drilling was done with a density of 10.6 ppg, while in well A, it was drilled with 10.8 ppg.

BHA Tripping and Liner Run in Hole

During well execution, tripping speed was monitored as an indicator of hole quality and stability. S-shape wells A and B demonstrate that the speed in well B increased by **108%,** reducing operating times.

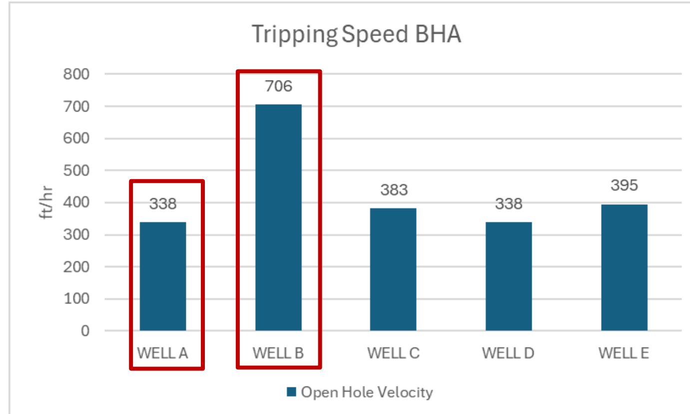

Figure 13 – Data Collection Tripping Speed. Property of Frontera Energy.

Similarly, when comparing wells C, D and E (Type J wells with angles up to 47 degrees) to Well A (Type S), their execution times were equal to or higher than those of well A. This indicates that, despite the complexity of well construction, pipe trips times were not affected.

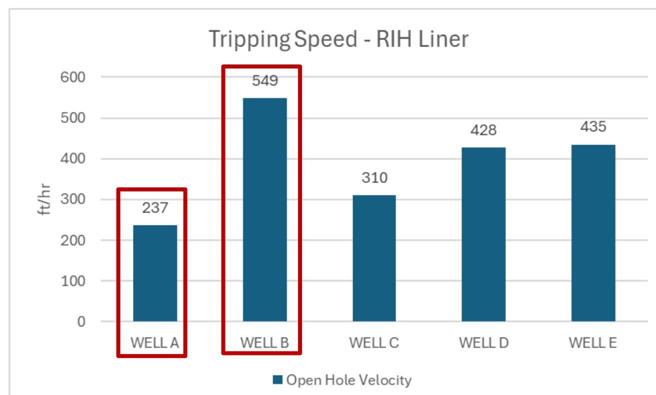

Figure 14 – Data Collection Tripping Speed. Property of Frontera Energy.

Consistent with the improved BHA trip behavior, the Run in Hole behavior of the reservoir section liner also showed substantial improvement. The speed increased by **131 %**, successfully reaching the casing point and performing the cementing operations to satisfaction. Wells C, D and E also showed higher values in the Liner Run in hole speed, which ratifies the performance of using fluids with Nanotechnology.
In summary, the improvement in the Liner run behavior in well B is attributed to excellent wellbore stability. The trip was performed only with elevators, no issues during Liner Run in hole, facilitated using **HPWBM** and good operational practices to maintain wellbore stability.

Cost Benefits

To perform a cost-benefit analysis of using **HPWBM** versus **WBM**, a comparative exercise of the average trip costs for

BHA and liner was conducted. This allowed to quantify the benefits achieved both technically and financially.

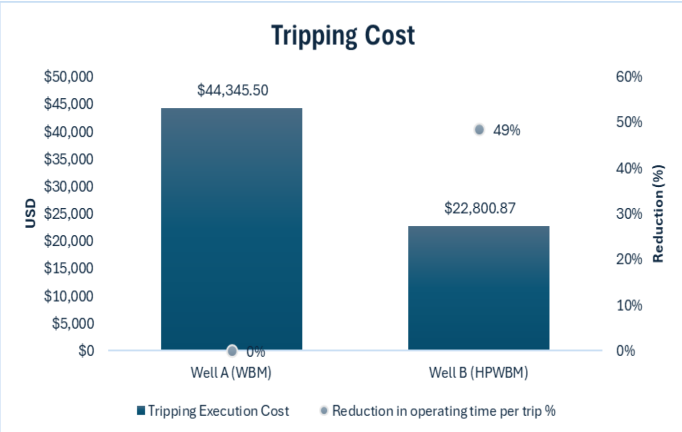

Figure 15 – Exercise Cost with BHA trip. Property of Frontera Energy.

Fig. 15 shows an exercise related to the cost of tripping time for Well A (44K) and the same for Well B (22K), standardizing average operating hour cost (USD) and average section length (ft) for the 2 cases, which means that the associated costs during the BHA to surface trip in the two wells have been reduced by almost 50%.

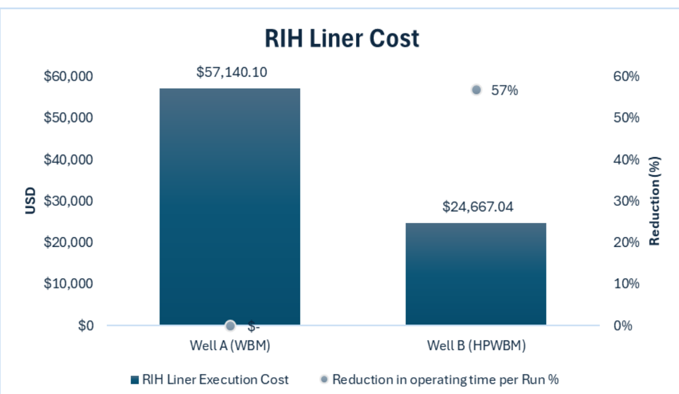

Figure 16 – Exercise Cost with RIH Liner. Property of Frontera Energy.

Similarly, for the liner run, shorter execution times led to a saving of approximately USD$33K in well B compared to well A, representing a 57% reduction in operating cost (Fig. 16).

This paper focuses on showing the results and operational benefits of using nanotechnology enabled **HPWBM** versus conventional **WBM**. Therefore, the financial analysis is limited. The specific cost of each fluid is not provided, as this is customized per field and client. However, it should be mentioned that the cost difference between **HPWBM** and **WBM** used for these wells does not exceed 10% per barrel.

It is also worth mentioning that, although not discussed in this document, other operational benefits associated with costs were observed, such as: reduce logistics for solids disposal, reduced water consumption, and reduced cement slurry volumes. Also, the reduced time can also be associated with a decrease in carbon footprint, water consumption, energy consumption, and consumables related to solids control equipment, mud pumps, etc.

Limitations

To apply nanotechnology-based compounds, it is crucial to consider water quality and the time and order of mixing.

Water quality: Water with low hardness, salinity, neutral pH and low presence of surfactants should be used to ensure fluid effectiveness.

Mixing time and order: The large surface area of nanotechnological compounds requires sufficient free water for good dispersion. This implies following a specific order of preparation, which can increase logistics and operational times.

Conclusions

- ❖ The geomechanical model developed for the field is a tool that has contributed not only to define the fluid density but also to identify operational risks that complement variables to be considered in the fluid design.
- ❖ A robust set of tests, with fluid-fluid, rock-fluid interaction analysis, has led to a customized fluid design that meets technical specifications and operational expectations, a set of numerous tests accompanied the selection of products according to the lithology of the field and its geomechanical and well design conditions.
- ❖ It was evidenced the HTHP, PPT and Spurt Loss values reduced by an average of 50% when using **HPWBM** compared with **WBM** across different ceramic discs under the same tested conditions and design.
- ❖ The use of **HPWBM** allows drilling with lower density values, reducing risk such as differential sticking and formation damage.
- ❖ In conclusion, improved wellbore stability was achieved with the use of nanotechnology **HPWBM**, as evidenced by decreased caving volume from 20% to 10%, cavings size reduced from 37 to 13 mm, and increased tripping speed with BHA and Liner.

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Nomenclature

API = American Petroleum Institute
API FL = Filtrate LHLP - API
BHA = Bottomhole Assembly
FL = Filtrate
Ft = Feet
HPHT = High Pressure High Temperature
HPWBM = High Performance Water Based Mud
J Shape = Well Trajectory with Tangent Deviation
PPA = Permeability Plug Apparatus
PPT = Permeability Plug Test
RIH = Run in Hole
S Shape = Well Trajectory with S Deviation
VPPT = Total Volume Permeability Plug – in
USD = United States Dollar
WBM = Water Based Mud

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