Cuttings Volume Measurement: A key Tool for Borehole Cleaning and Stability Monitoring in Horizontal Drilling

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Abstract

The Vaca Muerta Formation, located on the western side of Argentina across Neuquén, Mendoza, and Río Negro, is one of most significant unconventional reservoirs of the world, rich in shale oil and gas. Its vast energy potential has led to rapid growth, increasing complexity in well construction, with horizontal sections often exceeding 5000 meters. This complexity increases the risks of borehole mechanical instability, emphasizing the critical importance of real-time monitoring and control of drilling operations. Effective borehole cleaning and stability assessment are essential for reaching the planned total depth efficiently, minimizing stuck pipe risks, and reducing Non-Productive Time (NPT), particularly in horizontal wells.

Effective removal of drill cuttings enhances the Rate of Penetration (ROP) and improves drilling parameters. Conversely, stationary cuttings bed accumulation in the horizontal section can lead to drilling inefficiencies, including stuck pipes, erratic Equivalent Circulating Density (ECD), increased torque, and borehole instability. Real-time monitoring and quantification of borehole cleaning and stability conditions allow continuous optimisation of drilling and hydraulic parameters, ensuring maximum ROP while controlling downhole ECD and open-hole volume. Additionally, enables timely remedial actions and their effectiveness assessment.

This study presents the field application of real-time Borehole Cleaning and Stability Monitoring Service in over 60 wells in the Vaca Muerta Formation, Neuquén Basin. Using advanced Cuttings Volume Monitoring (CVM) equipment installed in front of each shale shaker to continuously measure drill cuttings recovery. These devices, combined with specialized monitoring software, accounted for drilling fluid coating and compared measured cuttings volume with theoretical drilled volume. This approach enabled early detection of trend deviations associated with the borehole cleaning and stability issues, allowing for prompt remedial actions to ensure drilling operations efficiency.

The CVM application granted significant results, helping operators drill efficiently within planned time and cost parameters. It minimizes the risk of stuck pipes and NPT related to borehole instability and poor hole cleaning. Even in extended horizontal sections, the service optimised ROP based on real-time wellbore conditions, reduced cleaning pill usage, limited circulation cycles at TD, and avoided unnecessary back-reaming or wiper trips, reducing Invisible Lost Time (ILT). Additionally, when running a Caliper Log was impractical due to high operational risks and costs, the CVM service provided a reliable alternative for effectively monitoring open-hole volume and estimating the average equivalent hole diameter in near real-time. This surface-based solution avoids the need to introduce tools into the hole, reducing stuck pipe and Loss in Hole (LIH) risk.

Introduction

Horizontal drilling in the Vaca Muerta Formation presents significant mechanical challenges, primarily due to borehole instability and, secondarily, due to inefficient cuttings removal, which leads to poor hole cleaning. The complex and heterogeneous lithology of the formation contributes to frequent wellbore collapses, torque and drag issues, presence of small amounts of cavings at surface, ECD increasing, coupled with the associated elevated pore pressures. These issues are aggravated in horizontal sections, where high inclination angles and extended lateral exposure make especially challenging to maintain efficient cuttings transport.

To tackle these challenges, this study introduces the field application and its advantage of using a quantitative and Real-Time Borehole Cleaning and Stability Monitoring approach. Applied in more than 60 wells across the Vaca Muerta Formation, this approach has provided continuous

insights into wellbore conditions, enabling timely remedial actions to minimize the impact of these events on drilling operations.
In the Neuquen basin, the application of real-time borehole cleaning and stability monitoring technology across multiple horizontal wells has enabled significant improvements in drilling performances. This approach has facilitated the optimisation of ROP, drilling and hydraulic parameters, and hole cleaning practices resulting in a notable reduction of total drilling time. Generally, this system was implemented in the build-up and horizontal sections, where borehole cleaning and stability issues were anticipated. Furthermore, the extensive application of sliding mode, to maintain the planned well trajectories, made more challenging the achievement of an efficient drill cutting removal. For this reason, real-time cuttings volume measurement played a crucial role in optimising drilling and mud parameters as well as in implementing appropriate and consistent hole cleaning practices to minimize the risk of mechanical stuck pipe and associated NPT.

Material and Methods
The relevance of real-time cuttings recovery monitoring is well known since the early 90's as it can provide key information regarding actual borehole cleaning and stability conditions, especially in highly deviated and extended reach wells. Initially, the cuttings measurement equipment (CVM machines) were simple and mainly helpful in identifying hole cleaning and/or stability issues. Over the years, the field experience combined with continuous R&D studies helped to significantly improve this technology to overcome all the factors influencing the drilling solids recovery and make the CVM equipment the most advanced, accurate and reliable technique for real-time, quantitative measurement of recovered drilling solids at rig site.
The pre-drilling phase involved a technical inspection of the drilling rig to obtain the proper measurements and design the installation according to the quantity and types of shale shakers, the available space and the availability of water, compressed air and electricity. A comprehensive technical report was then compiled, outlining the installation plan, and any necessary modification required to install the equipment. The CVMs were subsequently installed with the support of specialised personnel responsible for assembly, calibration and commissioning on the drilling rig. A CVM machine was positioned directly in front of each shale shaker (*Figure 1*) allowing continuous quantitative measurement of the total weight of drill cuttings returning to surface during drilling.

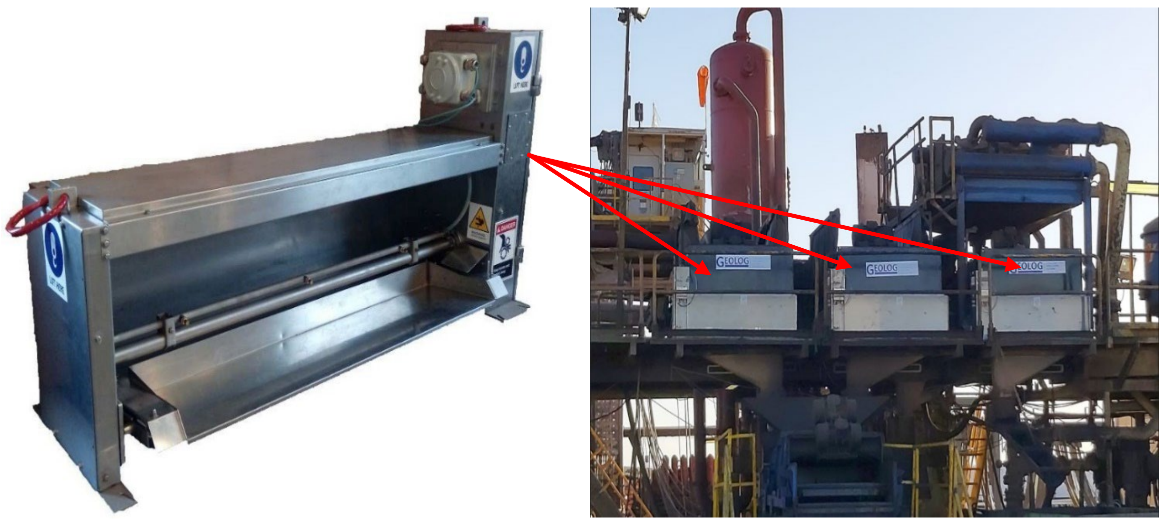

Figure 1 Example of latest generation of CVM machine and installation in front of shale shakers

The actual weight of drilling cuttings, measured by CVM machines at shakers, is converted into volume by a monitoring software. This operation accounts for factors such as the amount of drilling fluid coating the cuttings, the fine solids lost through the shaker mesh (therefore not able to reach the machines weighing trays, for measurement), and the bulk density of drilled rocks. The measured cuttings volume is then continuously compared in real-time against the theoretical volume of the drilled hole (based on ROP and bit diameter). In this way, any deviation between actual and expected cutting volume (*Figure 2*), is therefore a direct indicator of borehole cleaning efficiency. Correlating these discrepancies with drilling and hydraulic parameters, the on-site CVM Specialist is able to provide timely operational recommendations and suggestions to the Client Representative in order to implement the proper corrective actions to mitigate the operational risks and avoid NPTs due to poor wellbore cleaning and instability.

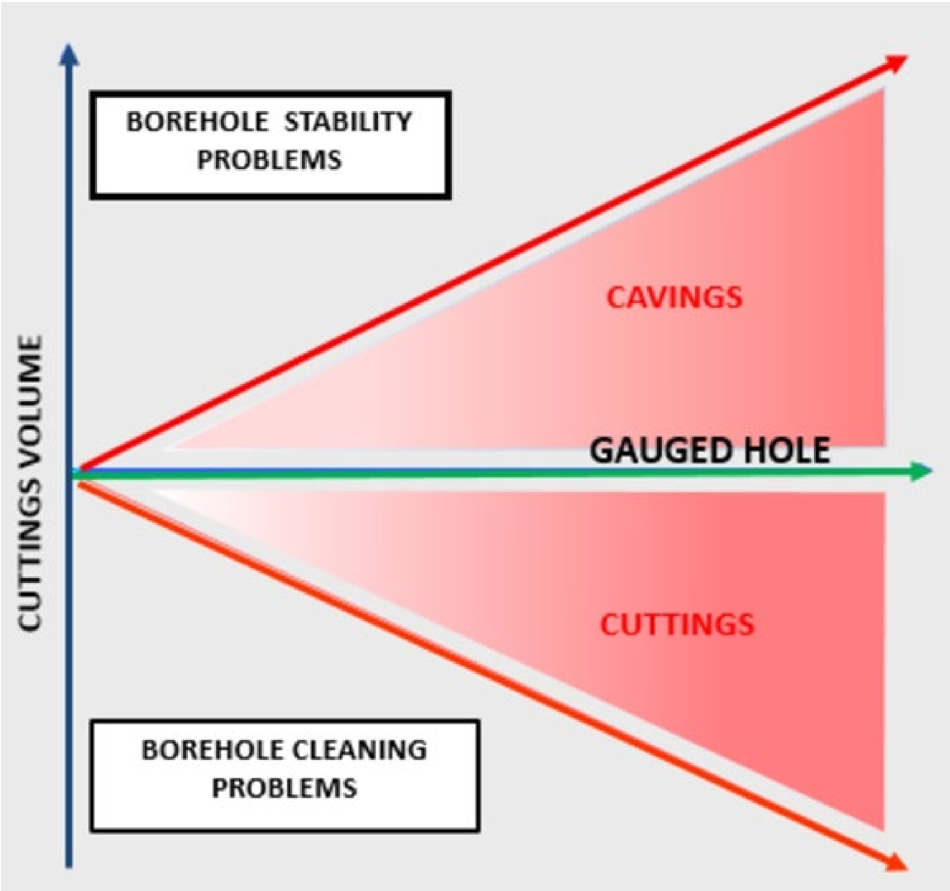

Figure 2 Cutting Flow Measurement working principal

The CVM machines are fully applicable for any mud system, including Water-Based Mud (WBM), Synthetic Oil-Based Mud (SOBM) and Oil-Based Mud (OBM). They are equipped with a pressurized water system designed to facilitate the removal of previously analyzed cuttings from weighing tray and ensure uninterrupted measurement. The mentioned system is operational only when drilling with water/based mud (WBM). Conversely, when a non-aqueous drilling fluid (OBM, SOBM) is utilized, the removal of cuttings occurs by gravity. The CVM are equipped with a rotating discharge mechanism that allows the fast dumping of cuttings once a predefined weight or time threshold set in the monitoring software has been reached.

The entire procedure always requires supervision by an on-site CVM Specialist to ensure an optimal operation of hardware and software, and data acquisition. The specialist is also responsible for continuously monitoring the recovery trend in order to identify any deviation from theoretical one and report it to Client representative. These information and recommendations provided in real-time, enables timely corrective actions to avoid NPT related to borehole cleaning and instability. In addition, the specialist, on a daily basis, provides to Client reports and logs, with expert interpretation of the data recorded.

Apart from identifying and mitigating the risk of NPT associated with borehole conditions, the dataset provided by the on-site CVM Specialist, enables the optimisation of the hydraulic parameters in terms of Cutting Carrying Index (CCI). These data also supports the assessment of effectiveness of borehole cleaning practices and remedial actions implemented to prevent NPT and reduce ILT. *Figure 3* below presents the main screen of software for real-time monitoring of Theoretical vs. Actual (Measured) cuttings recovery trends, highlighting how it could provide useful information for real-time decision-making.

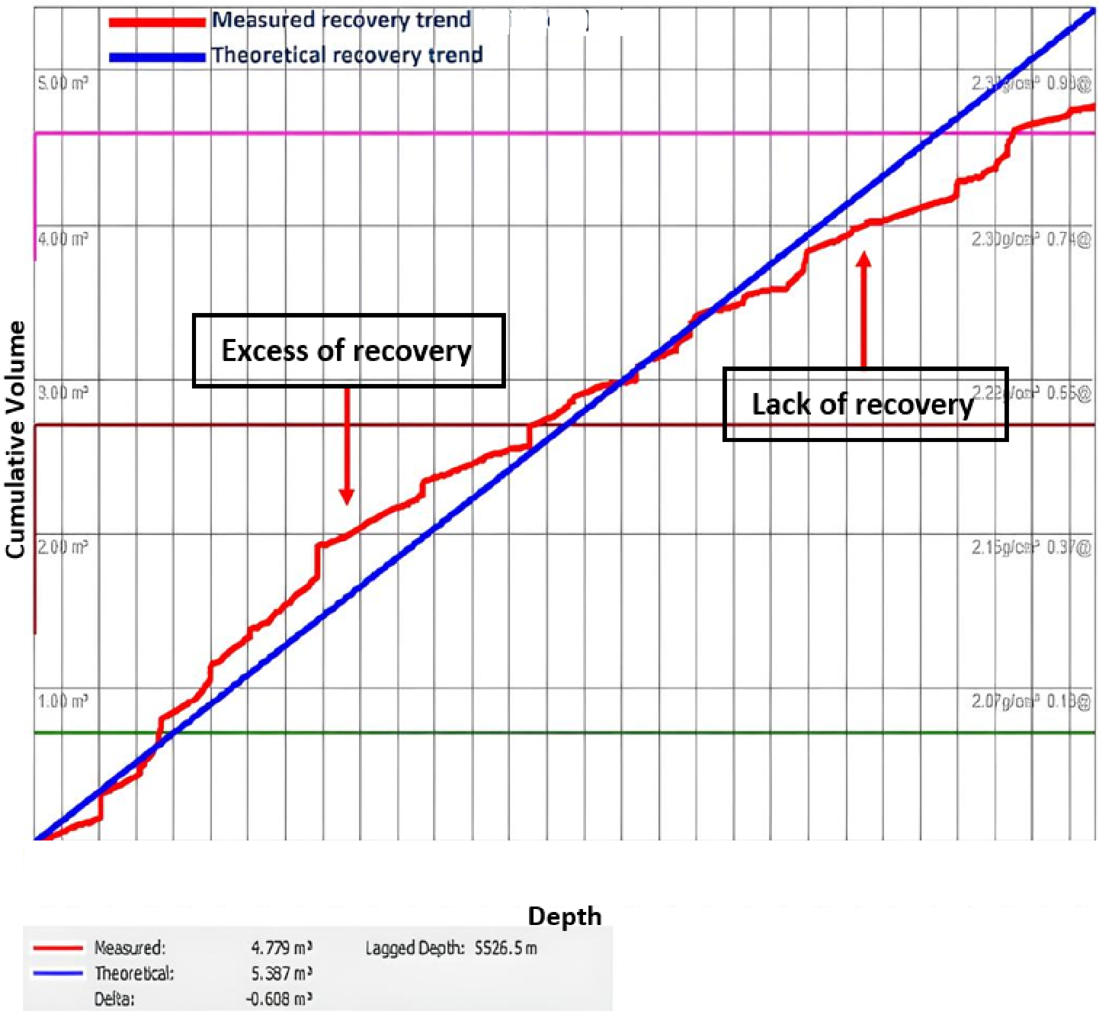

Figure 3 Measured vs Theoretical Cuttings Recovery and real-time decision making

Beyond its primary function, the CVM technology provided several additional benefits such as effective control of downhole ECD, critical in narrow-pore pressure margin environments, and an accurate open hole gauge indication while drilling, useful for cement volume estimation. The service, while ensuring the proper borehole cleaning, helped to reduce torque and drag and to provide early detection of caving and wellbore instability, enabling to undertake remedial actions timely and reduce stuck pipe risks.

The following *Table 1* summarizes the key parameters used for weight measurements (CVM Inputs), and to convert them into the volumes (CVM outputs).

Table 1: CVM Software input and outputs

CVM Inputs	CVM Outputs
Weight of the drilled cuttings	Computed cuttings volume
Density of the drilled cuttings	Measured cuttings volume
Mud coating on cuttings	Computed cuttings flowrate
Bulk density of cuttings (formation)	Measured cuttings flowrate
Mud Density	Volume recovery in %
Hole Diameter	Volume recovery - Excess / Lack of recovery
ROP	
Pump flowrate	
Lag-depth	
RPM	

Results

This section describes the results of the implementation of the CVM Technology across the Neuquen Basin, with a focus on unconventional reservoirs within the main members belonging to the Vaca Muerta Formation. Leveraging extensive field experience in more than 60 wells logged since 2016, the technology has been deployed in collaboration with major oil companies, successfully monitoring the horizontal sections greater than 5000 metres. The use of the CVM system enabled real-time optimisation of drilling operations, by providing continuous feedback on hydraulic and drilling parameters to maintain efficient borehole cleaning and prevent stuck pipe incidents, contributing to reduce the NPT. Additionally, the system facilitated the early detection of borehole instability, allowing for timely implementation of corrective actions. Continuous optimization of drilling parameters—such as ROP, flow rate, and RPM—combined with enhanced borehole cleaning practices, including circulation time, pipe reciprocation at connections, wiper trips, and cleaning mud pills, contributed significantly to reduce the ILT. These results demonstrate the CVM technology's value as a practical, field-proven solution for improving drilling efficiency and reducing operational risks in complex extended-reach horizontal wells.

Case Study A: Several Stuck pipe events and Borehole Instability – Induced NPT

A major operator in the Neuquén Basin faced recurring NPT due to stuck pipe incidents and borehole instability, particularly in the horizontal sections drilled through the Vaca Muerta Formation. To address these challenges, the operator decided to deploy the CVM technology in upcoming wells to facilitate continuous real-time, quantitative monitoring of borehole cleaning and stability during the drilling of the 8 ½" section. The technology was deployed in two wells located on the same multi-well pad, starting with Well X, followed by Well Y. According to their best practices, lessons learnt and lithological considerations, the operator utilized optimized drilling parameters, including Flow Rate, RPM, and ROP, along with a predefined hole-cleaning strategy which was subsequently enhanced and optimised based on real-time feedback from the CVM technology.

During drilling at a high ROP ranged between 60 to 70 m/h, a continuous decreasing trend in cuttings recovery was identified through real-time monitoring (*Figure 4*). This observation suggested an inadequate borehole cleaning conditions, which potentially increase the risk of stuck pipe and a subsequent NPT. Upon notifying the client, a prompt decision was made to stop drilling and initiate a bottoms-up circulation while reciprocating the drill string. This remedial action, executed in real time, significantly improved borehole cleaning efficiency. The CVM technology enabled direct and immediate feedback on the effectiveness of the cleaning procedures, validating the corrective measures taken. As a result, the operator was able to refine and establish optimal hole cleaning practices and drilling parameters tailored to the actual downhole conditions, thereby enhancing operational safety and performance while mitigating the risk of Loss in Hole (LIH) events.

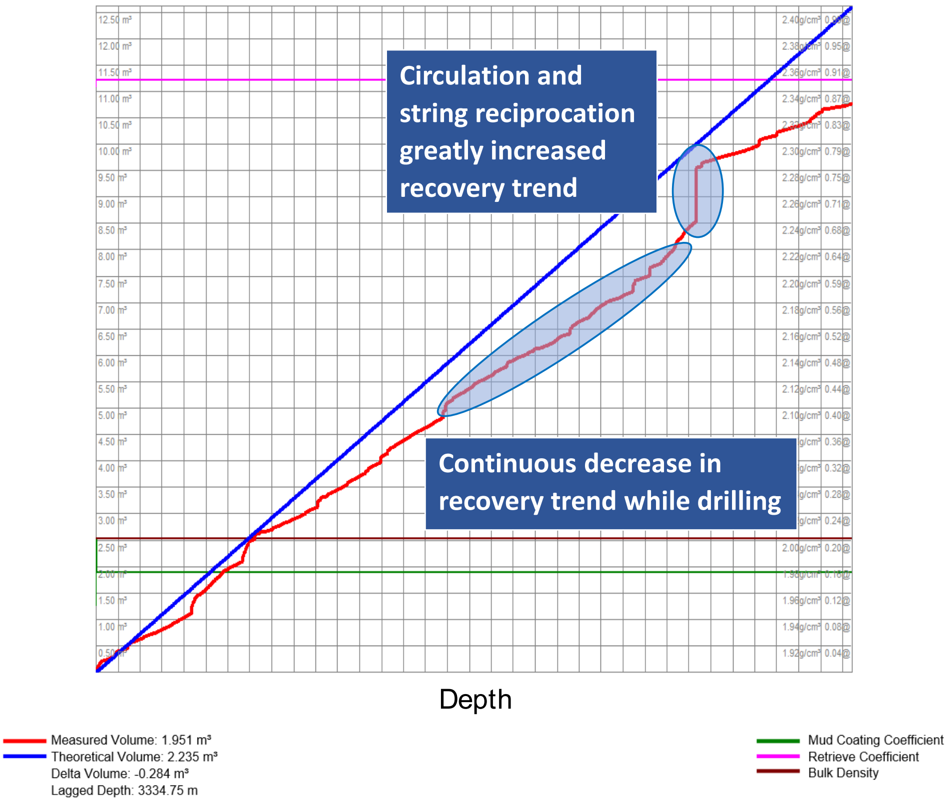

Figure 4 CVM plot depth based - Theoretical Vs Actual recovery

The CVM technology was initially deployed in well X, after which the lessons learnt, recommendations, and enhancements were applied to well Y, drilled in the same PAD, resulting in a reduction of approximately 6.17 days (36%) compared to the projected schedule, and 3.92 fewer days (26%) than in previous well X. The average Rate of Penetration (ROP) achieved was 56% faster than the projected rate, while Well X recorded an ROP that was approximately 42% faster (*Figure 5*). These outcomes highlight the effectiveness of the CVM system in enabling real-time drilling optimization, contributing to faster and safer well completions, and significantly reducing NPT.

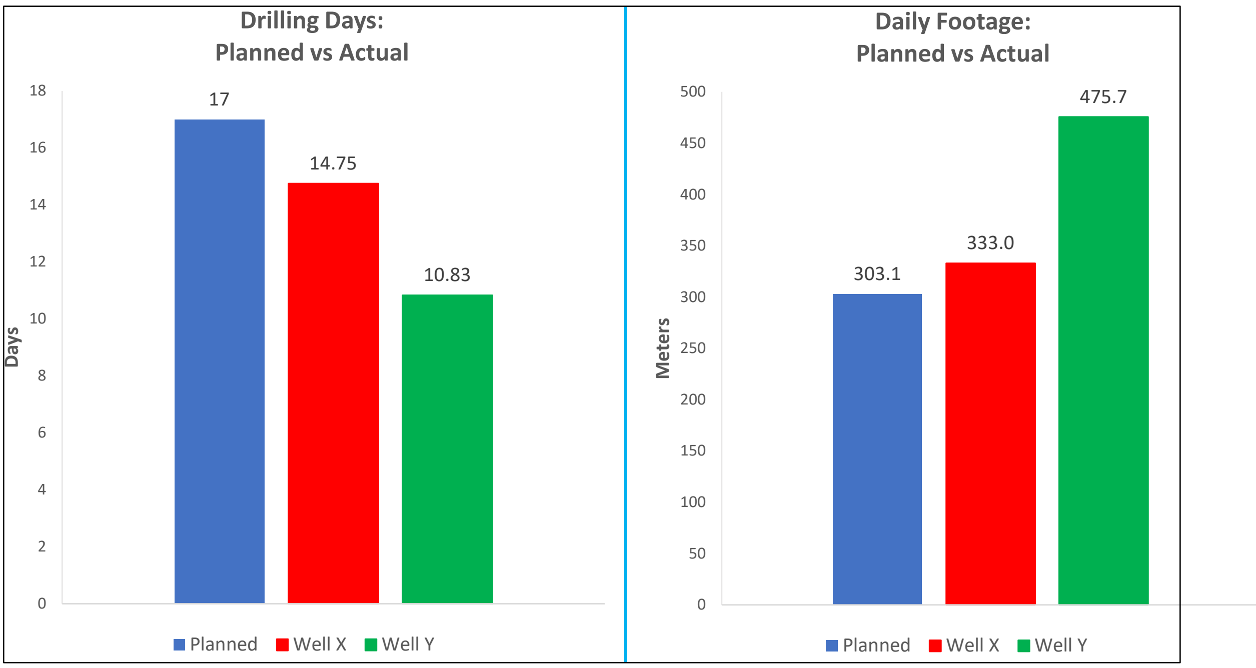

Figure 5 Drilling days and meters per day charts: planned vs actual (Planned, Well X, and Well Y).

The drilling and hydraulic parameters established during drilling Well X were carefully optimised to ensure effective borehole cleaning while maintaining high operational performance. The flow rate range was adjusted to 480 – 560 GPM, increasing both the lower and upper limits to enhance cuttings transport. Rotary speed was maintained within an optimal range of 80 to 130 RPM, balancing drilling efficiency with hole-cleaning requirements. These optimised parameters were subsequently applied to Well Y, where the implementation, combined with increased ROP around 45 to 50 m/h, enabled both wells to reach Total Depth (TD) ahead of schedule. This outcome clearly demonstrates the efficacy of real-time parameter optimisation in enhancing drilling efficiency and operational reliability.

In parallel, continuous real-time monitoring of borehole cleaning conditions enabled the client to fine-tune cleaning practices prior to pipe connections. Specifically, back-reaming and reaming were optimised to one full stand every three drilled stands—an improvement over the original plan of one every two. Similarly, the frequency of cleaning pills was reduced, with one pill pumped every three stands instead of two. These adjustments yielded measurable savings in time and costs, further validating the effectiveness of this technology in supporting data-driven decision-making and operational optimisation, and providing useful lessons learnt for upcoming wells.

Case Study B: Cuttings Volume Monitoring Performance

In this case, a client deployed the CVM technology to monitor borehole cleaning and wellbore stability during drilling an extended-reach horizontal section. The objective was to ensure efficient hole cleaning while drilling at high ROP, and to proactively manage the risks associated with cuttings accumulation and instability. As shown in *Figure 6*, the CVM technology system provided continuous, real-time monitoring of actual surface cuttings recovery versus theoretical one, facilitating the early detection and quantification of a decreasing cuttings recovery trend during drilling with high ROP. In addition, the system validated the effectiveness of cleaning practice adopted prior to connection (back-ream and ream) and was able to define in real time the maximum allowable ROP, with the utilized hydraulic and drilling parameters, maintaining at the same time a proper borehole cleaning.

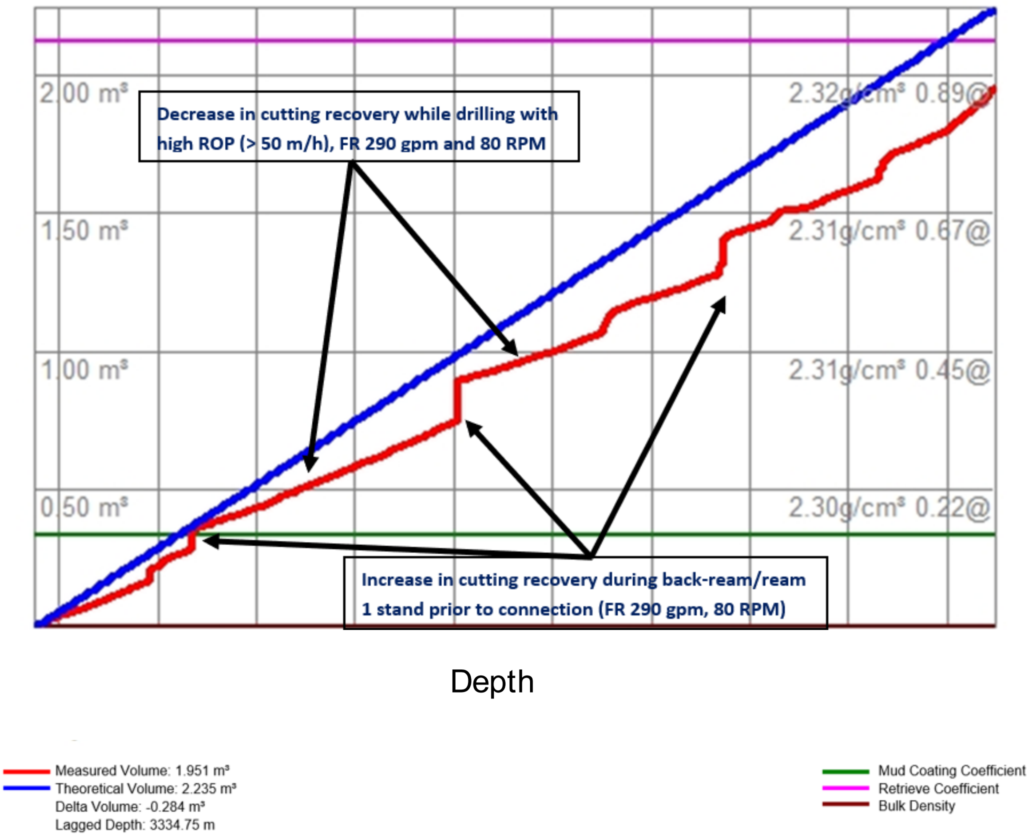

Figure 6 CVM plot depth based - Theoretical Vs Actual recovery – Cleaning Practices

Specifically, *Figure 7* demonstrates that when drilling at a pre-established flow rate and RPM, as defined in the well plan based on previous lesson learnt, while sustaining an ROP above of 45 to 50 m/h, is observed a noticeable tendency to decrease in cuttings recovery, which impact on the borehole cleaning efficiency.

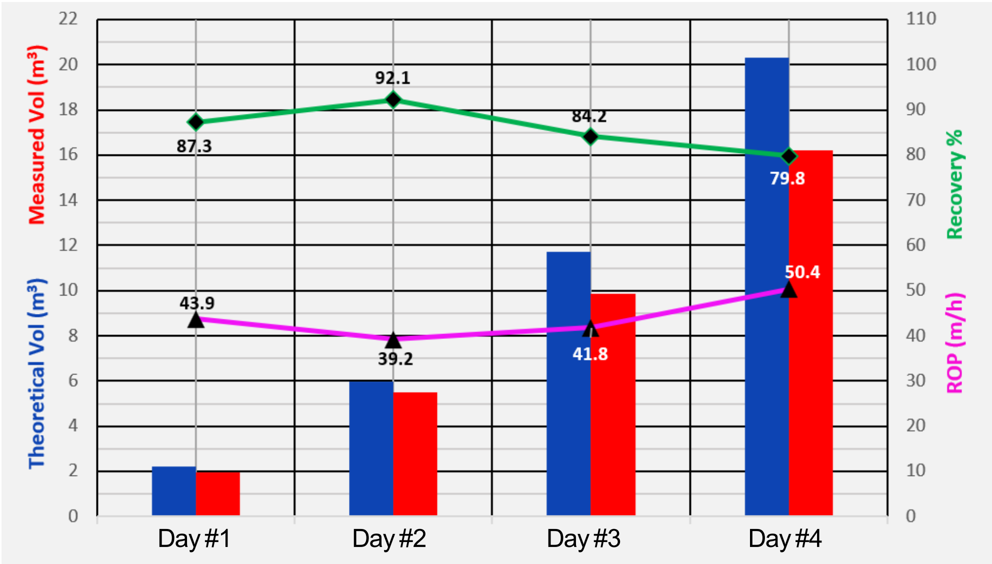

Figure 7 Correlation between Cuttings Recovery Percentage and ROP

An additional significant benefit of the CVM technology is its ability to support the Client in optimising the cleaning pills program during drilling, quantifying and evaluating their efficiency (*Figure 8*), and providing the volume of cuttings recovered before, during and after the event, together with the time spent performing this operation.

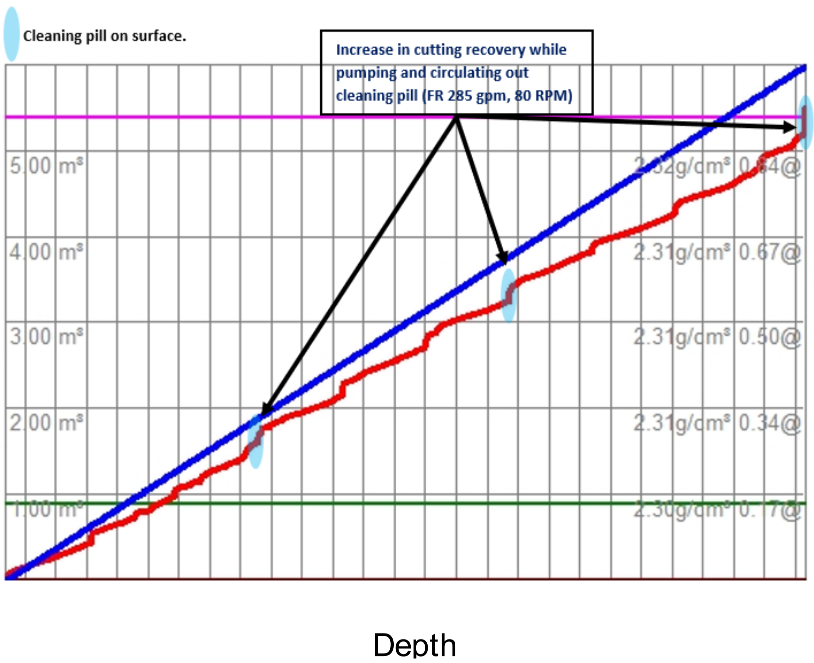

Figure 8 CVM plot depth based - Theoretical Vs Actual recovery – Cleaning pills efficiency

A key further advantage of implementing the CVM technology was the continuous real-time comparison between the theoretical (computed) CFR trend, calculated based on the lagged ROP, against the actual CFR measured at the surface. As illustrated in *Figure 9*, a strong synchronization was observed between theoretical and measured CFR, indicating that the well was drilled with optimal flow rates and drilling parameters under real-time conditions.

Consequently, the cuttings were effectively transported to the surface together with the drilling fluid validating the accuracy of the hydraulic model in real-time and preventing solids accumulation downhole. Consequently, were reduced the risks of the stuck pipe and was defined an efficient hydraulic regime that ensured an adequate CCI while maintaining a stable and controlled ECD downhole.

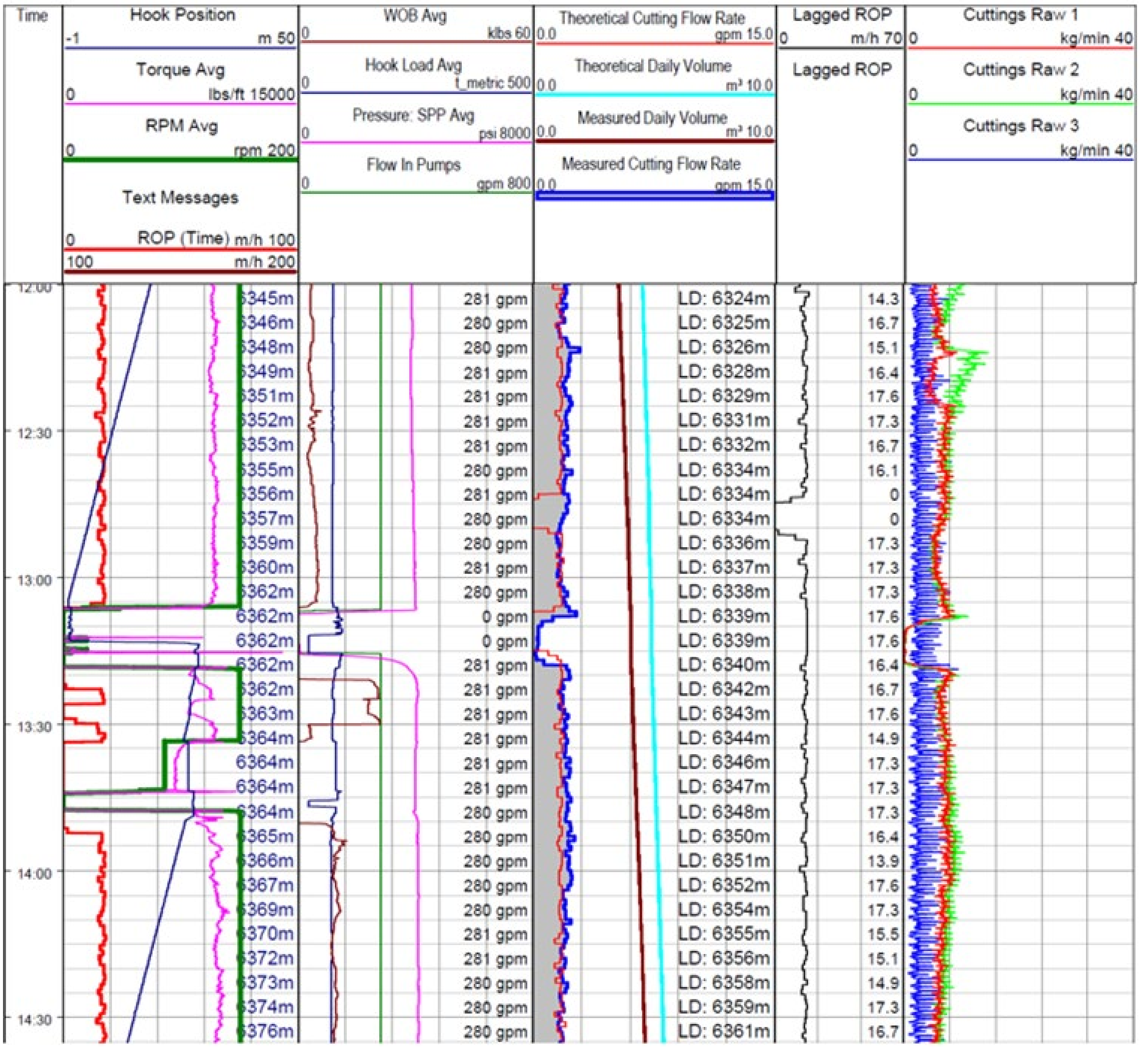

Figure 9 CVM Log time based – Theoretical Vs Actual CFR

At the well TD, the instructions stated in the drilling plan required the circulation of 4.5 cycles of bottom up to ensure adequate borehole cleaning. However, the data recorded by the CVM system clearly indicated that the well was already clean after just two circulation cycles. Following the second bottom-up cycle, the CFR gradually decreased until it stabilized at the cutting generation friction factor (*Figure 10*), and the cuttings volume recovered during the following two cycles, was almost negligible (a few hundred litres). The CVM Specialist on-site promptly detected in real-time this reduction in measured CFR and immediately notified the Client's representative about the actual borehole cleaning conditions, suggesting that the well was properly clean and the circulation could be interrupted. Despite this recommendation, the Client decided to proceed with the original plan and circulate the remaining 2.5 cycles of bottom-up. If the circulation had been stopped immediately after the second bottom-up reached the surface, it would have been possible to save over 3 hours of rig operational time and associated costs (ILT reduction).

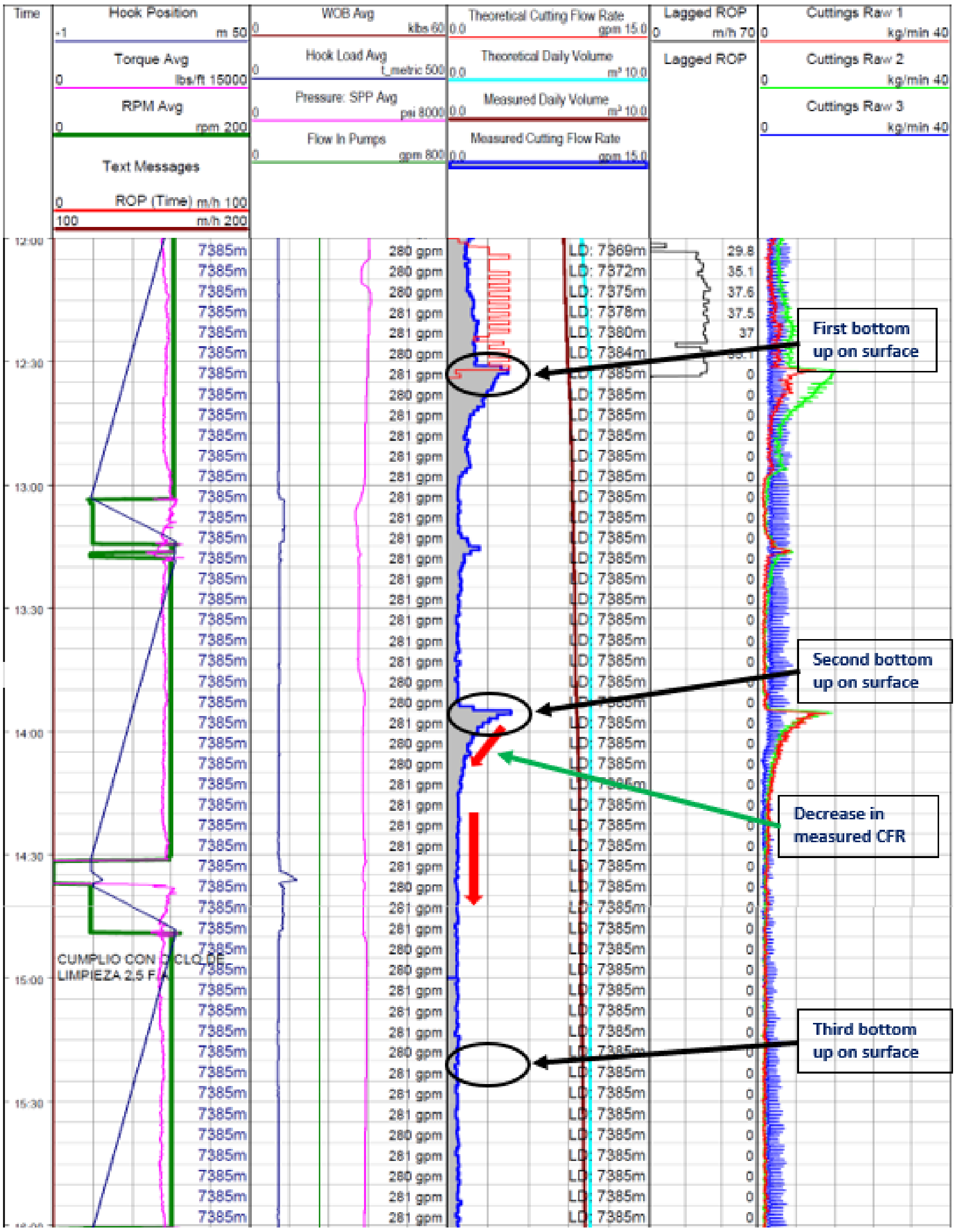

Figure 10 CVM Log time based – Circulations bottoms up

Case Study C: ROP Optimisation

The following case study presents the results of deploying the CVM technology in a MWP, which includes around eight (8) horizontals wells, in the Neuquen Basin, Argentina. By consistently using the best practices and integrating the acquired lessons learnt, the client successfully refined drilling parameters and hydraulic conditions throughout all the wells included in the campaign. The CVM system played a crucial role in facilitating data-driven decision-making, improving operational consistency and drilling efficiency. A key achievement was the ability to maximise the average ROP maintaining effective hole-cleaning conditions (*Figure 11*). Rather than seeking an excessively high ROP, which could result in a substantial volume of cuttings and complicate the cleaning operation. Hole-cleaning practices were systematically reviewed, monitored, and communicated in real time throughout the operations. This proactive approach allowed for the identification and mitigation of invisible lost time (ILT), contributing to overall process optimisation. As a result, all wells in the campaign were drilled ahead of schedule, delivering significant time and cost savings for the client.

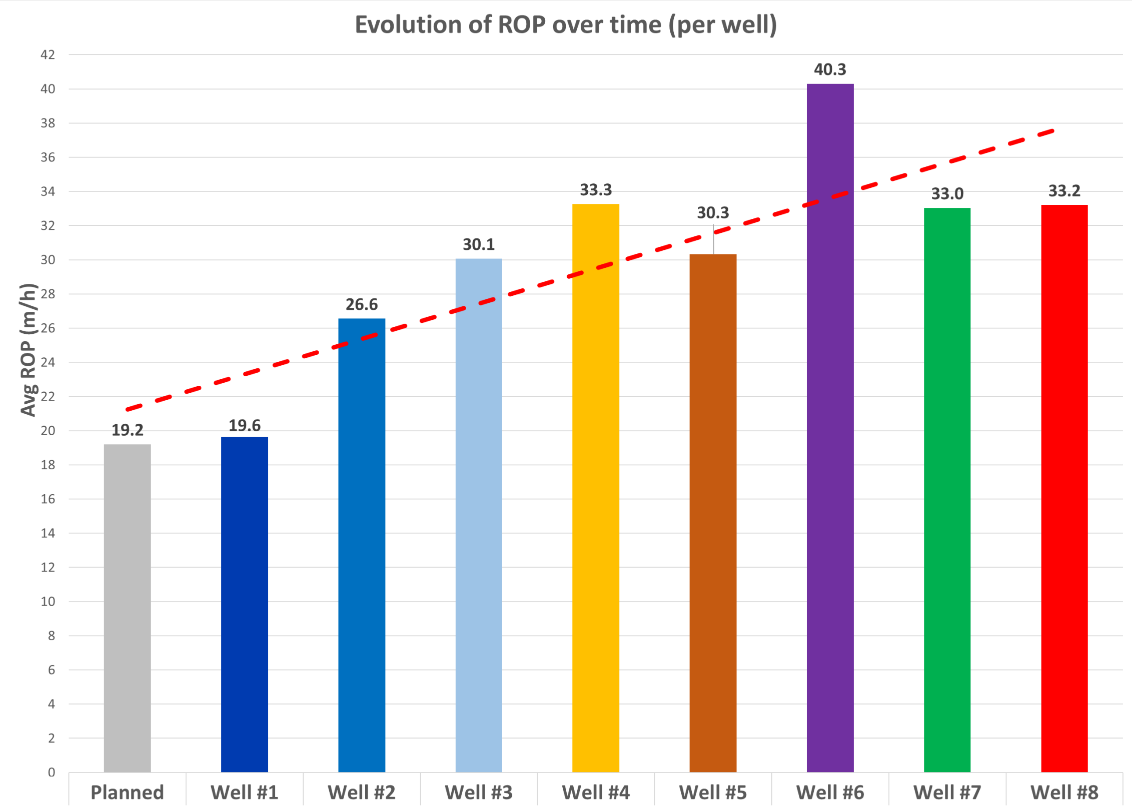

Figure 11 ROP Optimisation

Case Study D: Estimating Equivalent Borehole Diameter using CVM Technology

A client drilled an extended-reach horizontal well in a technically challenging environment, where borehole instability and high operational risk rendered the deployment of a conventional caliper log impractical. Additionally, the cost implications associated with running wireline tools in such conditions further discouraged their use.

To address this, the operator implemented the CVM technology as an alternative solution. Leveraging real-time data on cuttings volume recovered at surface, the CVM system enabled the estimation of the equivalent borehole diameter, as illustrated in *Figure 12*. Furthermore, it facilitated a more accurate estimation of the cement volume required after casing run, reducing the risk of overestimating the cement slurry requirements. The implementation of the CVM contributed to enhanced cost control, serving as an effective complement when conventional tools are not viable.

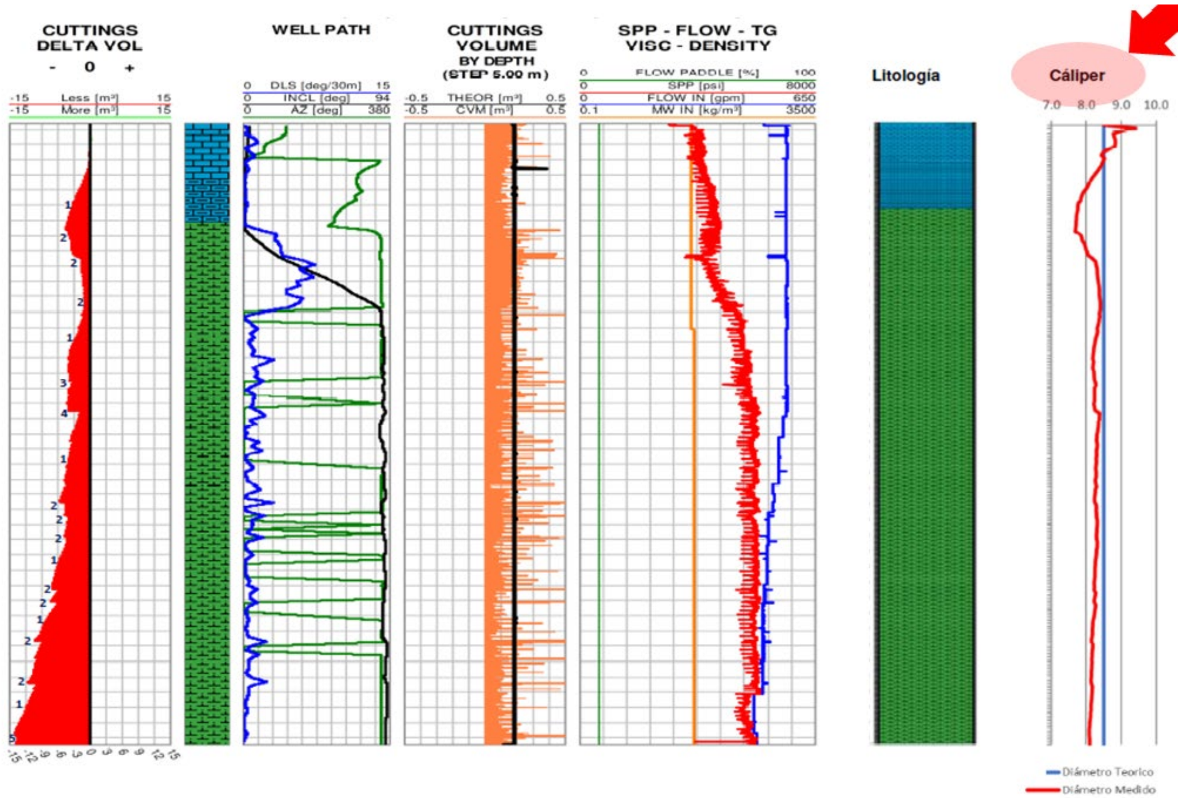

Figure 12 Cement Volume Estimation – using CVM

Conclusions

- The implementation of the CVM Technology in the Vaca Muerta Formation significantly improved drilling performance by enabling the real-time monitoring and optimization of key drilling parameters including ROP, RPM and Flow rate. In well X these parameters were optimized for improved borehole cleaning and drilling efficiency. When applied to well Y, they contributed to reaching TD ahead of schedule. Furthermore, real-time data allowed the fine-tuning of cleaning practices, including reducing the frequency of back-reaming and cleaning pills, leading to measurable time and cost savings. As a result, drilling time on well Y was reduced by 36% compared to plan, with a 56% increase in ROP over projections. These outcomes underscore the effectiveness of CVM technology in improving drilling efficiency, reducing NPT, and supporting data-driven decision-making across multi-well operations.

- The continuous real-time comparison between theoretical and actual cuttings flow rates (CFR) enabled by the CVM system, provided critical validation that drilling was performed under optimal hydraulic conditions. This ensured effective cuttings transport to surface, avoiding solids accumulation downhole and thus lowering the risk of stuck pipe while maintaining proper borehole cleaning and stable ECD. In addition, the CVM indicated that the well was adequately cleaned earlier than planned in the program potentially savings rig operational time. This demonstrates the technology's effectiveness in supporting timely and cost-efficient decision-making during drilling operations.

- The application of the CVM technology in a multi-well drilling campaign enabled consistent improvements in drilling performance through real-time optimization of hole cleaning practices and drilling parameters. This helped to reduce NPT and facilitates timely, and cost-effective project execution.

- The CVM technology also offered a reliable alternative to the conventional caliper logging, particularly in challenging and high-risk environment such as extended-reach horizontal wells. By enabling real-time estimation of equivalent borehole diameter and supporting accurate cement volume calculations, CVM enhances cost control and risk mitigation where the use of downhole tools is operationally constrained or economically unfeasible.

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List of Abbreviations (Nomenclature)

CCI: Cutting Carrying Index
CFR: Cutting Flow Rates
CVM: Cutting Volume Monitoring
ECD: Equivalent Circulating Density
ILT: Invisible Lost Time
LIH: Lost In Hole
MWP: Multi Well Pad
NPT: Non-Productive Time
OBM: Oil Based Mud
ROP: Rate Of Penetration
RPM: Revolution Per Minutes
SOBM: Synthetic Oil Based Mud
TD: Total Depth
WBM: Water Based Mud

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