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Mahakam Success Story in Drilling and Wireline Logging by Utilization of Engineered Water Based Mud in High Reactive Clay Formation

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Abstract. In Tunu, Tambora and Handil field of Mahakam area, the production section layer is categorized into two types, which are shallow zone and main zone. Both zones are having highly reactive clay, proven by XRD test, which is one of the challenges in drilling operation. It has been a best practice for many years in Mahakam area to drill the reservoir section with Synthetic Base Mud (SBM) to encounter the reactive clay formation. The SBM system leads to the other technical requirement such as environmental policy, in its practice require a highly cost of waste treatment to be in compliant with the regulation.

In the challenge of the SBM restriction, the Water Base Mud (WBM) system is expectedly to be the answer. The WBM might not perfectly equal to the SBM in term of fluid performance. However, with the accurate engineering design, we can have the optimum WBM designed in line with operational needs while promoting efficiencies. The project has been conducted to replace the SBM for drilling both shallow and main zone wells, started with the study of the cutting from each zones, and the mapping of drilling fluid formulation which is technically and financially reasonable. There are 3 types of WBM system used in the project, for shallow zone the WBM system are KCl Polymer and Polyamine system. While for main zone, due to the high temperature environment, the HT-Polyamine system was utilized.

The engineered solution has been successfully implemented in both shallow and main zone. Especially in shallow well, total of 35 wells have been drilled with WBM system, and cost effective is proven especially in batch wells drilling operation. While in Main zone, the HT-Polyamine WBM system is had shown its capability for drilling reservoir, and the cost reduction is proven to plunge down to 18% compared to SBM system. Those cost reductions will be more when including the elimination of SBM waste management cost. This success is also one of key answer to the more stringent policy in environment in the future, specifically in the zero cutting discharge regulation. Replacement of SBM with WBM. Successfully Drilling and Wireline Logging with Water Base Mud in high reactive clay formation

Keyword: Well Construction; Drilling Fluid; Water Based Mud

1 Introduction

Tunu, Tambora and Handil is a giant gas field located in the Mahakam Delta, Indonesia. More than 1000 wells have been drilled since 1991 to produce multi-layer sandstone reservoirs deposited in a deltaic environment, dominated by distributary channels and mouth bars [4]. Nowadays, they have a typical well architecture to drill into shallow reservoir and main zone reservoir section.

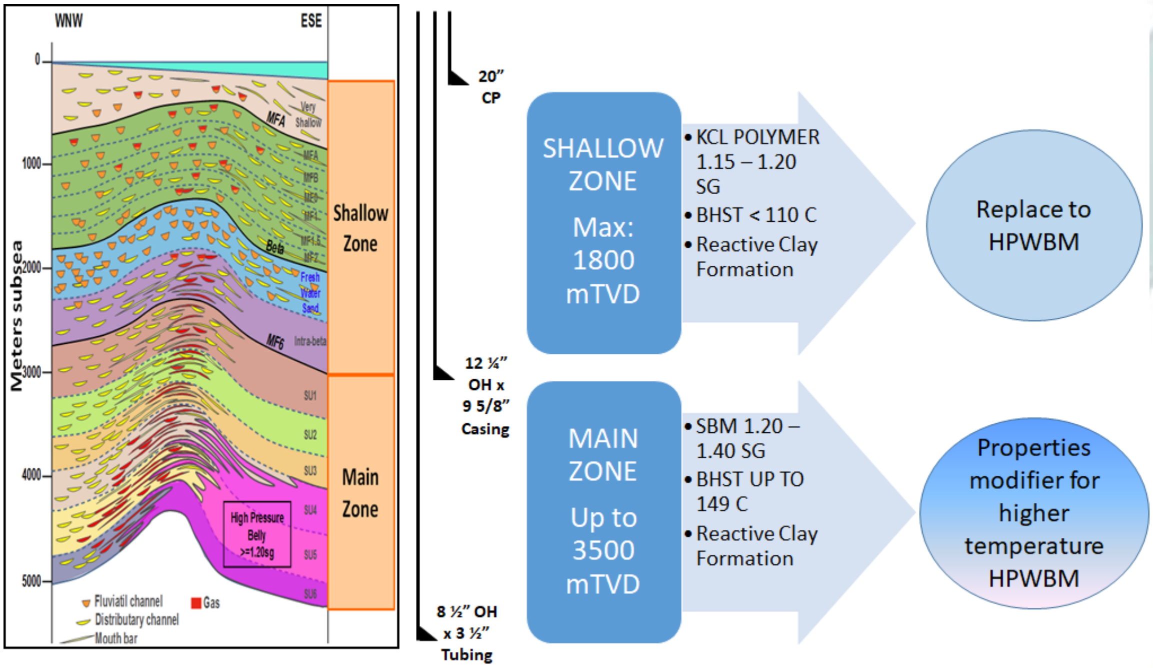


Figure 1. Delta Mahakam Typical Architecture for Shallow and Main Zone

The common drilling fluid to drill reservoir zone was Synthetic Base Mud (SBM), which is exhibiting excellent well bore stability due to oil wet property, however, its high cost resulting from low aromatic base oil and associated waste management [2]. The project has been conducted to replace the SBM for drilling both shallow and main zone wells. The evolvement of High Performance Water Base Mud (HPWBM) technology helped to identify a fit for purpose drilling fluid capable to deliver near SBM drilling performance with cost effective environmental compliance with local regulations [2].

2 Methodology

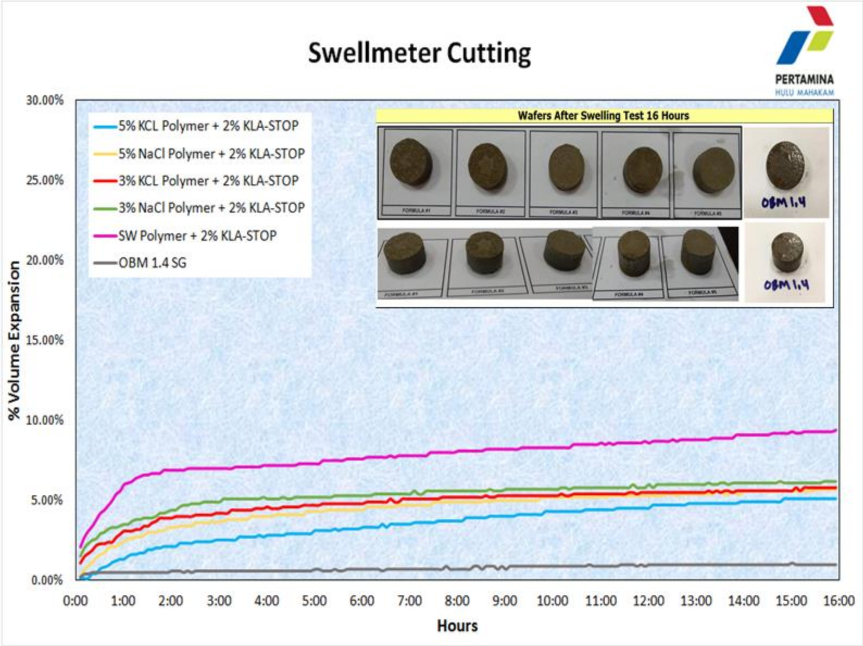
The project is started by identifying risk in changing SBM into WBM in the wellbore. Clay inhibition is a property that have to determine in certain well in interaction with drilling fluid. The following flowchart shows the methodology for identifying the feasibility of HPWBM in replacing SBM with imitation of clay inhibition.

Figure 2. Methodology Flowchart for Identifying Feasibility of HWPBM

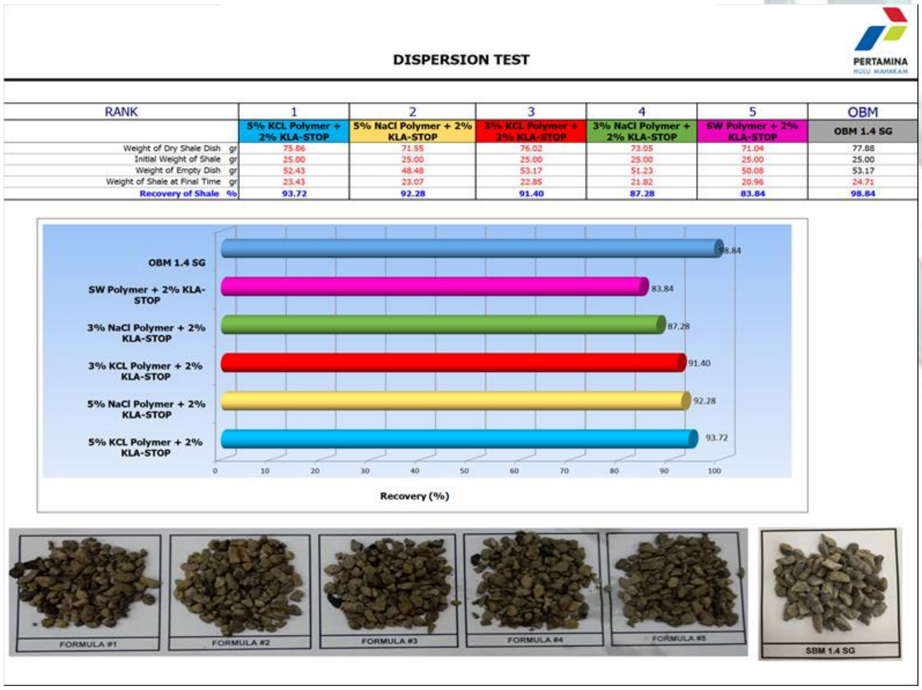
There are 3 types of WBM system used in the project, for shallow zone the WBM system are KCl Polymer and Polyamine system. While for main zone, due to the high temperature environment, the HT-Polyamine system was utilized. Aluminum polymer can reduce viscosity and filtration rate, and can effectively inhibit the hydration expansion of clay. Amino polyols had a little effect on the viscosity, gel strength and filtration of drilling fluid, but it had a good shale inhibition. This drilling fluid has good properties in rheology, filtration, inhibition and anti-contamination [3]. The following tests were carried out on different cuttings samples collected from the aforementioned formations when exposed to different drilling fluids formulations [2]:

1. Linear Swelling Test: Linear Swelling test is designed to determine shale hydration or Dehydration. The test is demonstrating the inhibitive effects of the mud designed on the shale swelling. Lower percentage volume expansion indicates higher inhibitive mud
2. Shale recovery / Dispersion Test: Dispersion test method is also used to develop new shale stabilizers with improved performance characteristics in “inhibitive” water-based drilling fluids. High recoveries contents indicate inhibitive fluids
3. Accretion Test: Accretion test is designed to gives a comparative assessment of the chemical factors in the drilling mud that affect performance. Cuttings with a critical water content (at their sticky or plastic limit) are more prone to agglomeration and sticking to mild steel bar under the deformation force applied than drier or more hydrated cuttings
4. Bulk Cutting Hardness Test: The Bulk Cuttings Hardness test is designed to give a rapid assessment of the hardness of shale cuttings, which in turn is related to the inhibiting properties of the drilling fluid. London Clay (reference) typically give hardness values in the range 5 to 30 inch pounds in a poorly inhibiting mud system, rising to 80 - 130 inch pounds in a highly inhibitive mud

Study in Mahakam Delta begin with sampling of clay cutting to define clay reactivity in the field. Cutting from shallow section as the most reactive clay formation (salinity 25,000 – 30,000 ppm) was collected. The sample was tested into 6 different fluids: 5 type of polyamine water based mud with variations of salt content, and SBM/OBM as benchmarking to compare the result to SBM Quality. Contractor perform clay reactivity by adding Kla-Stop [5]. Kla-Stop is additive is a liquid polyamine shale inhibitor used in polymer-based drilling and drill-in fluids. Shale inhibition is achieved by preventing water uptake by clays, and by providing superior cuttings integrity, so that water molecules will not penetrate and cause shale swelling. Kla-Stop has physical appearance as a colorless liquid [5]. The reactivity test result as follow:



<u>Figure 3. Cutting Swellmeter Test Result Showing the Blue Line (5% KCl Polymer + 2% Kla Stop) was Given the Best Result in WBM</u>



DISPERSION TEST

RANK	1	2	3	4	5	OBM
	5% KCL Polymer + 2% KLA-STOP	5% NaCl Polymer + 2% KLA-STOP	3% KCL Polymer + 2% KLA-STOP	3% NaCl Polymer + 2% KLA-STOP	SW Polymer + 2% KLA-STOP	OBM 1.4 SG
Weight of Dry Shale Dish gr	75.86	71.55	76.02	73.05	71.04	77.88
Initial Weight of Shale gr	25.00	25.00	25.00	25.00	25.00	25.00
Weight of Empty Dish gr	52.43	48.48	53.17	51.23	50.08	53.17
Weight of Shale at Final Time gr	23.43	23.07	22.85	21.82	20.96	24.71
Recovery of Shale %	93.72	92.28	91.40	87.28	83.84	98.84

Figure 4. Dispersion Test Result Showing the Blue Line (5% KCl Polymer + 2% Kla Stop) was Given the Best Result in WBM with Slightly Different Recovery Percentage than SBM

ACCRETION TEST

PERTAMINA HULU MAHAKAM

RANK	Formula	Weight of Initial Pipe (gr)	Weight of Initial Cutting (gr)	Observe Cutting Distribution			Weight of Pipe With Cutting (Gr)	Weight of Cutting on Pipe (gr)	% of Original Weight
				10 Minutes	20 Minutes	30 Minutes	After Drying		
1	5% KCL Polymer + 2% KLA-STOP	133.620	25	Random	Random	Random	134.11	0.49	1.96%
2	5% NaCl Polymer + 2% KLA-STOP	126.650	25	Random	Random	Random	127.15	0.50	2.00%
3	3% KCL Polymer + 2% KLA-STOP	126.650	25	Random	Random	Random	127.16	0.51	2.04%
4	3% NaCl Polymer + 2% KLA-STOP	126.560	25	Random	Random	Random	127.08	0.52	2.08%
5	SW Polymer + 2% KLA-STOP	126.560	25	Random	Random	Random	127.45	0.89	3.56%
OBM	OBM 1.4 SG	126.320	25	Random	Random	Random	126.37	0.05	0.20%

ACCRETION AROUND PIPE BEFORE DIPPING INTO 50/50 WATER/IPA SOLUTION and BASE OIL (BEFORE DRYING)

ACCRETION AROUND PIPE AFTER DIPPING INTO 50/50 WATER/IPA SOLUTION and BASE OIL (AFTER DRYING)

Figure 5. Accretion Test Result Showing the Blue Highlight (5% KCl Polymer + 2% Kla Stop) was Given the Best Result in WBM. As Showing in the Graph and Picture, SBM Result Showing Dominant Clay Inhibition in Accretion Test

BULK HARDNESS TEST

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5		3		1		4		2		OBM	
F#1. SW Polymer +		F#2. 3% KCL Polymer +		F#3. 5% KCL Polymer +		F#4. 3% NaCl Polymer		F#5. 5% NaCl Polymer		F#6. OBM 1.4 SG	
Number of Rotation	Torque (lbf-in)	Number of Rotation	Torque (lbf-in)	Number of Rotation	Torque (lbf-in)	Number of Rotation	Torque (lbf-in)	Number of Rotation	Torque (lbf-in)	Number of Rotation	Torque (lbf-in)
0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0
1.00	40	1.00	60	1.00	90	1.00	50	1.00	80	1.00	110
2.00	90	2.00	120	2.00	190	2.00	110	2.00	180	2.00	220
3.00	150	3.00	210	3.00	320	3.00	200	3.00	290	3.00	360
4.00	240	4.00	360	3.25	360	4.00	320	3.50	360		
5.00	360					4.25	360				

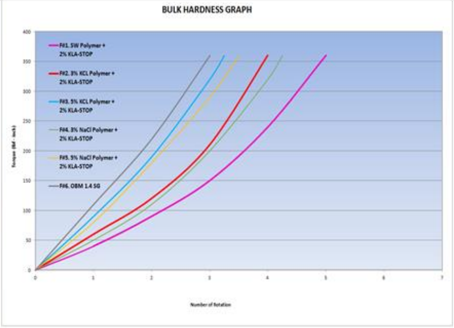

Figure 6. Bulk Hardness Test Result Showing the Blue Highlight (5% KCl Polymer + 2% Kla Stop) was Given the Best Result in WBM

In general, combination of 5% KCl polymer and 2% Kla Stop is adequate as "fit for purposes" drilling fluid for drilling in Delta Mahakam field. Some potential saving from Waste Treatment costs and cementing are considered due to existing dumping method of cutting ex SBM is cost around 250,000 USD/well. Strategy prior field trial was evaluated for having an optimization hole cleaning and prevent bit balling. Additional drilling strategy to maximize drilling performance such as:

- Dumped and Dilution method to maintain K+ ion and the MW.
- Pre-Hydrated Bentonite to strengthened the Mud Cake.
- 5- 10 kg /m3 of Soltex for shale stabilizer and reduce fluid loss
- Addition of Drilling Detergent to minimize surface tension of clay
- Be aware of water base mud contaminants source from: CO2, Cement, and Gypsum/Anhydrate.
- Strategy of HPWBM deployment in high temperature, additional chemical Dual-Flo HT [5] and IDCAP [5] may require.

Dual-Flo HT: Modified starch that giving fluid loss control and low end rheology modifier in high temperature [5].
IDCAP: a polymeric shale inhibitor that provides excellent cuttings encapsulation by adsorbing onto clay surfaces and forming a protective film that prevents cuttings from sticking to each other or to the shaker screens. IDCAP is formed in white powder which soluble in water [5].

3 Result and Discussion

3.1 Delta Mahakam Shallow Zone

In shallow well, total of 35 wells have been drilled with WBM system, and cost effective is proven especially in batch wells drilling operation. The utilization of HPWBM is well managed with concentration 3% Kla-Stop and 7% KCl polymer as base case, the concentration was evaluated from initial 2% Kla-Stop and initial 5% KCl polymer on first trial. The trial and error on field was in order to get robust operation.

One of example shallow well in Handil-Delta Mahakam is HBA-XXX, the well was utilized HPWBM in 8-1/2" section with no issue observed during drilling, good torque & drag parameter and robust in controlling mud properties. Wireline logging was performed in HBA-XXX with operation summary as follow:

- PT performed 8 attempts (8 good)
- FA performed 8 attempts (5 Oil, 1 Gas+Oil, and1 Oil+filtrate).
- Average additional 10 minute of pumping during FA compared to SBM

Logging was spent around 13 hours. Max BHST Recorded 66° C. In terms of cost evaluation, the implementation of HPWBM in Shallow well Delta Mahakam is giving state of the art to eliminate waste management for handling cutting ex SBM. However, the saving is promising as describe by the figure 7. The comparison is taken from shallow well in Delta Mahakam with same section (8-1/2") and interval depth around ±1000 meter. Include waste management cost, the saving of HPWBM system in average is 38% cheaper compare the utilization of SBM.

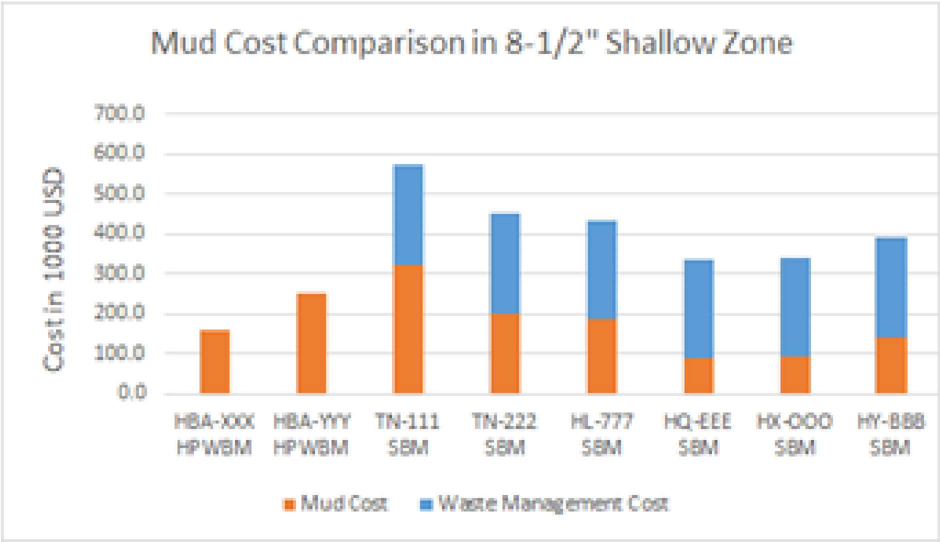

Figure 7. Cost Comparison for 8-1/2” HPWBM in Shallow Zone

3.2 Delta Mahakam Main Zone

HU-YYY was one of main zone reservoir well in Delta Mahakam-Handil. The well trajectory is S-shape semi 3D with maximum inclination 29° at 12-1/4” Section and drop to vertical in most 8-1/2” section, and turning from exit Conductor Pipe at 242°, then turning to 281° azimuths until TD.

HU-YYY started with clean out 20” CP at 105 mMD/mTVD. Continue with 12-1/4” phase drilled with KCl Polymer WBM from CP shoe to 1499 mMD / 1385 mTVD, set casing 9-5/8” and cemented. HPWBM is implemented in the last section 8-1/2”, with mud weight was planned 1.21 SG from start drilling to well TD at depth 3329 mMD / 3212 mTVD. Drilling fluid program was stated as follow:

Mud Type: HPWBM - 7% KCl Polymer + 3.5% KLA STOP
Section depth: 3329 mMD / 3212 mTVD
Section Length: 1830 m
Inclination: 12˚ - 0˚
Maximum BHST (as per TDP) = 124.5 degC

Mud Properties Requirement for 8 ½" in hole as below:

- MW : 1.21 SG
- PV : ALAP
- YP : 20 - 25 lbs/100ft²
- R 6 : 9 - 11
- R 3 : 8 - 10
- Gel Strength (10s / 10m) : 8 - 12 / 16 - 24
- LSRYP : ≥ 8 lbs/100ft²
- API FL : ≤ 6 mL/30 mins
- HPHT FL : ≤ 6 mL/30 mins
- pH : 9.5 – 10.0
- LGS : < 5 %
- **Total Hardness : < 200 mg/L**
- Chloride (Cl-) : > 34,971 mg/L
- **KLA-STOP Concentration : 3.5% v/v**

Mixing procedure and instructions:

Sequence	Additive	Concentration		Function	Maintained Properties
		ppb	kg/m3		
1	Seawater	as required		Base Fluid	As required
2	SODA ASH	0.30	0.86	Ph / Hardness Control	Total Hardness <500 mg/l Maintain pH 9.5 - 10.0
3	POTASSIUM CHLORIDE	25.60	73.03	Stabilize Formation Water	Cl- > 34,971 mg/l
4	KLA-STOP	3.50 % v/v		Shale Inhibition	3.5% Volume shall be added to the fluid
5	POLYPAC UL	2	5.7	Fluid Loss Control	Maintain between 2.85 to 8.6 kg/m3
6	DUAL-FLO HT	2	5.7	Fluid Loss Control - HT	Maintain between 2.85 to 8.6 kg/m3
7	DUOVIS	1.25 -1.50	3.57 -4.28	Viscosifier	Increase LYRP >8
8	IDCAP D	3.5	9.98	Shale Encapsulator	IDCAP D shall be adjusted by observing the quality of the cuttings at the shaker
9	Fracseal Fine	2.5	7.1	Bridging Material	adjust accordingly from simulation
10	CaCO3 Fine	6	17.1	Bridging Agent	adjust accordingly from simulation
11	CaCO3 Medium	4	11.4	Bridging Agent	
12	CaCO3 Coarse	10	28.5	Bridging Agent	
13	BARITE	as required		Weighting Agent	to adjust MW as necessary
Additional	SOLTEX	6.00	17.00	Shale Stabilizer	Stabilize shale section. Soltex shall be added up to 17 kg/m3
Additional	G-SEAL/G-SEAL PLUS	10.00	29.00	Reduce Torque and Drag	G-SEAL sweeps can be added into the system to reduce T&D.
Additional	STARGLIDE	1.0 - 3.0 % v/v		Lubricant	Required to reduce torque, drag and differential sticking, only if necessary
Additional	DRILLING DETERGENT	2.0 - 4.8 l/m3		Reduce Clay Surface Tension	Required to reduce the tendency of bit balling. 1-2% v/v concentration.
Additional	SOLACIDE	0.5 - 1.0 l/m3		Fluid Loss Control	5.7 - 20 kg/m3
Additional	DEFOAM-A	0.10	0.30	Base Fluid	As required

Figure 8. Drilling Fluid Program for HU-YYY

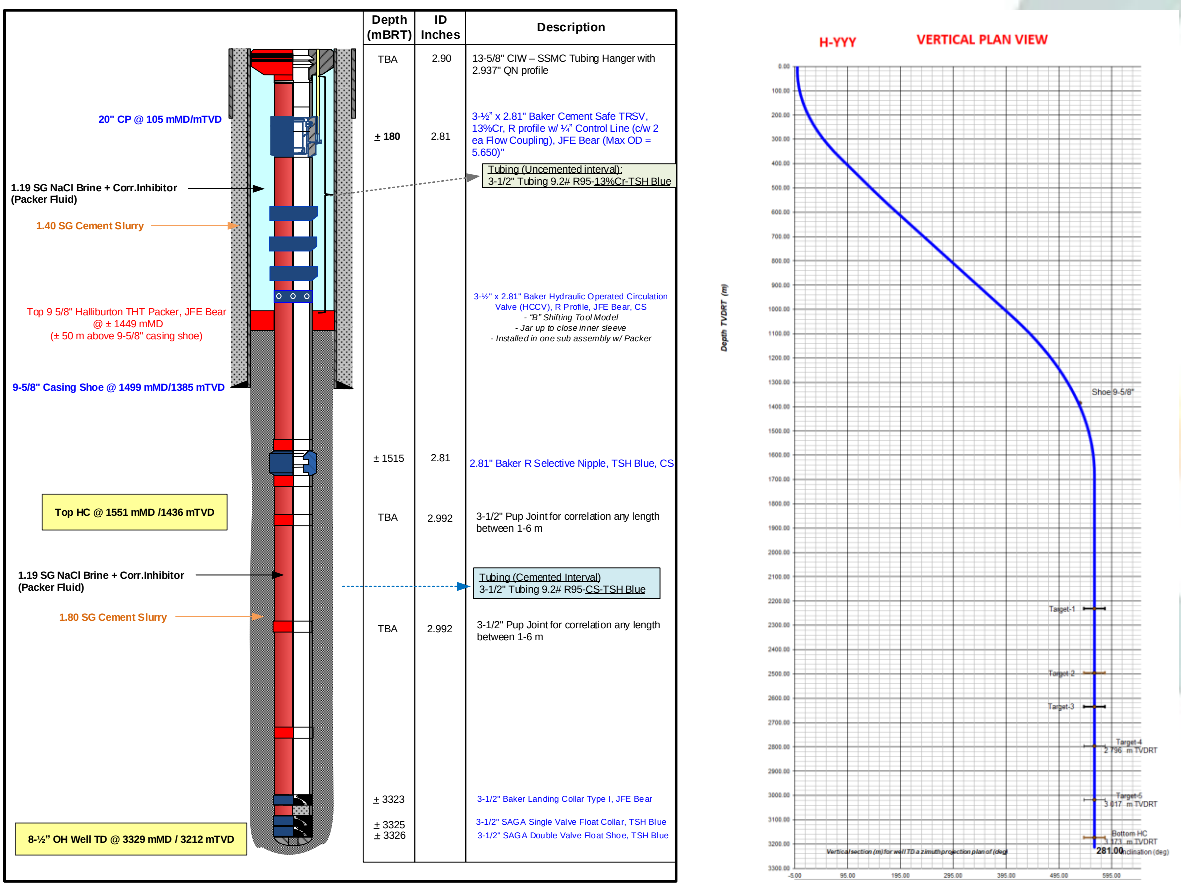

Figure 9. Well Schematic and Vertical Plan view for well HU-YYY

Drilling 8-1/2" was sorely smooth, drilling loads showing consistence parameter during drilling and no excessive drag. Cutting transport was also proven by seeing the parameter on figure 10. On bottom torque as per simulation 27 klbs.ft – 21 klbs.ft. No issue during drilling and pulling out BHA, however pulling out BHA was done by pumping out of hole and backreaming. No mud loss observed during drilling, pulling out, and electric logging.

In terms of mud properties control and monitoring, there was no issue risen. Mud weight was controlled robustly at 1.21 SG, mud rheology was also controlled well with YP initially at start drilling at 19 lbs/100ft2, as the temperature increased the rheology was increased to maximum 25 lbs/100ft2 as per plan. HPHT fluid loss was measured at this section with excellent result at 6 ml/30mins for most of the section. Another parameter maintained was pH that controlled at 10.4 – 9.5, the parameter is controlled by addition Soda Ash. The success key is achieved by Kla-Stop concentration at 3.5% volume and K+ by adding KCl, K+ concentration was maintained at 45,000 mg/L or 8%. During drilling maximum temperature out at surface was recorded at 71°C. During drilling Hi-Vis sweep was pumped periodically to enhance hole cleaning

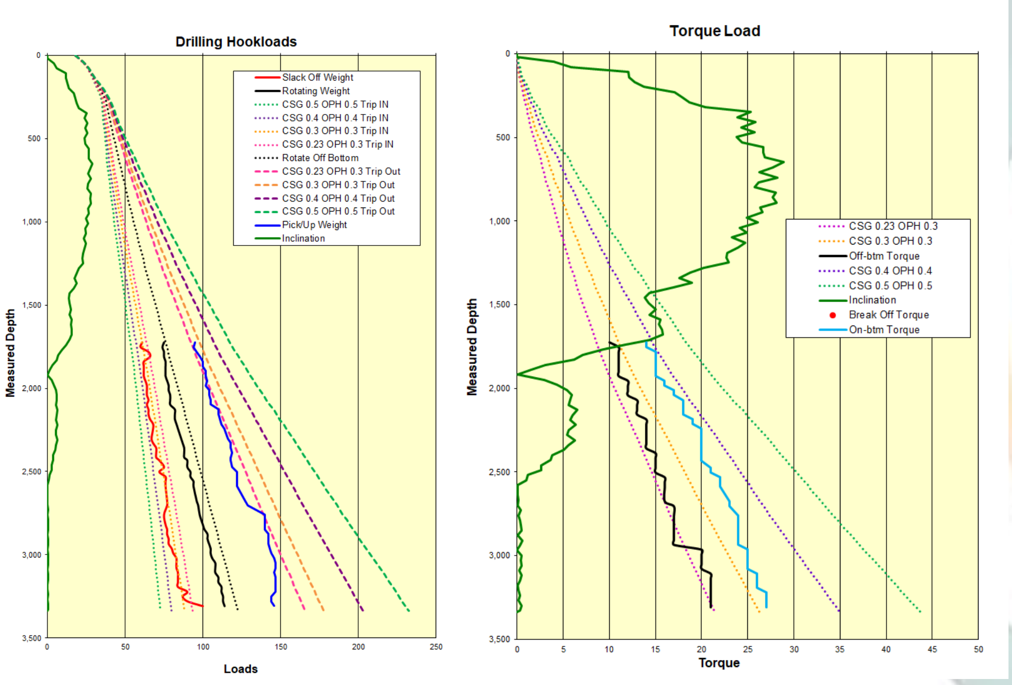

Figure 10. Torque and Drag recording for HU-YYY 8-1/2" section

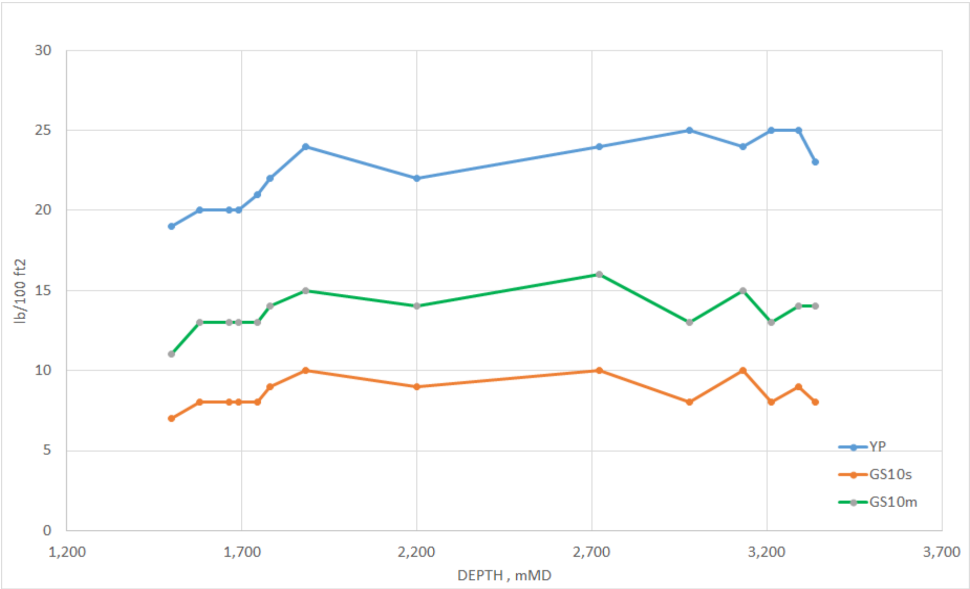

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Figure 11. Mud Rheology Monitoring during Drilling

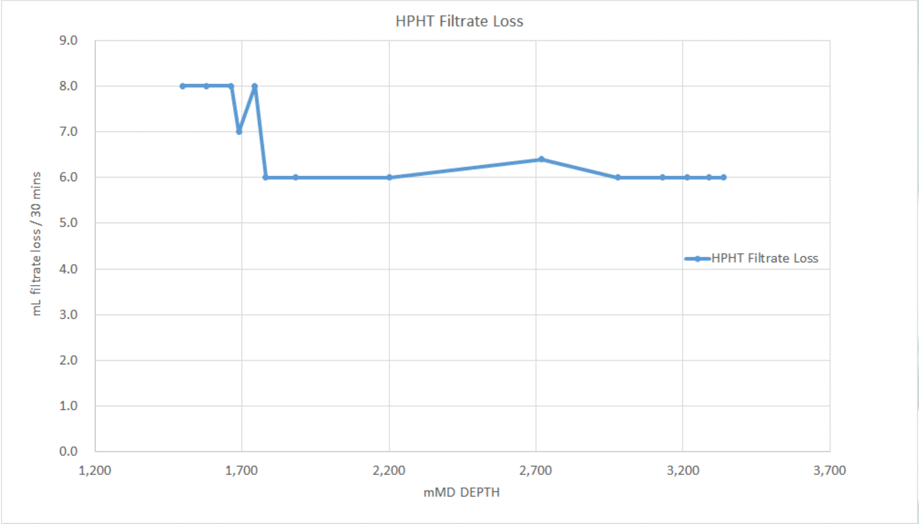

Figure 12. HPHT Filtrate Loss Monitoring during Drilling

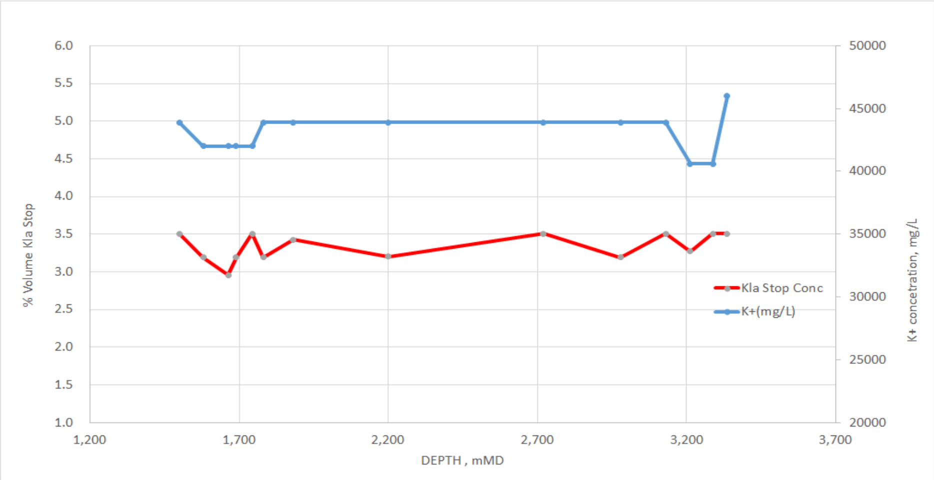

Figure 13. Kla-Stop and KCl Concentration Monitoring during Drilling


Figure 14. Drilled Cutting Appearance from Shale Shaker

After drilling and pulling out of hole BHA, electric logging was performed smoothly with result of operation as follow:

Program	Actual
21 pressure test	21 attempt, all good
16 fluid analysis	12 attempt, 1 cancelled
Cable tension simulation: 6932 lbs	Cable tension actual: 6700 lbs

Table 1. Operation Summary for Electric Logging in HU-YYY

Temperature reading Max BHST: 123.42°C at 3177.3 mWL/ 3052.9 mTVD. MW: 1.21 SG from logging tool sensors (homogeneous). Cumulative time to perform electric line logging was 20 hours. The operation continues with running 4.5" tubing with MTGL (mono trip gas lift). Cementing job was performed without any issue, no losses during cementing, expected TOC was reached as per design. Overall, well HU-YYY was completed in 14.06 days with NPT 5.48% where the NPT was not contributed from drilling fluid.

Mud phase cost at 8-1/2" section was 259,003 USD. This cost is quite similar with typical Handil well in reservoir section 8-1/2" open hole that drilled with SBM. However, the advantage of not using waste management cost was giving the difference. Comparison well HF-XXX and HF-SSS was drilled with SBM in main reservoir section. Compare to HF-SSS wells, the mud cost of HU-YYY was 20% cheaper.

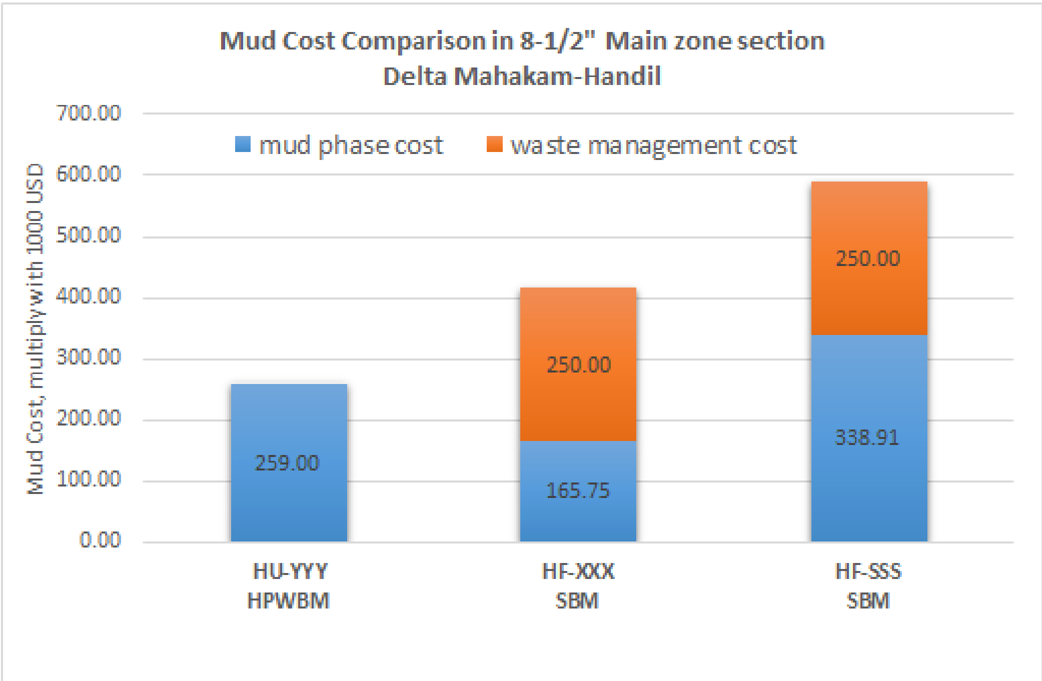

Figure 15. Mud Cost Comparison for 8-1/2" Section in Main Zone

Some application was gained by mud engineer as best practice for HPWBM implementation:

Laboratory Practice	When determining the % KLA-STOP in the system, make sure all reagent is not contaminated and all apparatus are cleaned. Also, titrate with precision.
Hardness	Pre-treat seawater with soda ash prior to drilling (100 mg/l). If possible, spraying shale shaker is done by drill water instead of sea water.
Alkalinity	Various alternative, either caustic potash or lime can be used besides soda ash. The key is to maintain pH at 9.5 – 10.5
Gel Strength	It is essential to maintain the initial gel strength >6 to provide a thixotropic fluid. However, when the 10 min gel strength is >2x the 10 sec gel, it indicates a need for treatment to reduce the gel.
Solid Control Equipment	Optimization solid control for reducing MBT (below 25 kg/m3)
Inhibition	Monitor cuttings condition at the shakers. Cuttings shall be discrete,

	firm and dry inside.

Table 2. Best Practice in Handling HPWBM on Site

In Main zone, the HT-Polyamine WBM system is had shown its capability for drilling reservoir, and the cost reduction is proven to plunge down compared to SBM system. Those cost reductions will be more when including the elimination of SBM waste management cost. This success is also one of key answer to the more stringent policy in environment in the future, specifically in the zero cutting discharge regulation.

4 Conclusion

- Replacement of SBM with HPWBM. Successfully Drilling and Wireline Logging with Water base Mud in high reactive clay formation without operational or wellbore issue on several shallow wells Mahakam Delta, and already successfully initiate for main zone.
- 7% KCl and 3 % Kla Stop as base case in both shallow and main zone of Delta Mahakam. Additional IDCAP 3.5 ppb and Dual-Flo HT 2 pbb in main zone may require to overcome high temperature issue on mud properties and enhancing clay reactivity.
- Current practice to maintain K+ above 55,000 mg/l is proven as a robust strategy to prevent swelling issue
- Considering the cost and operation complexity, Hi-Density pill is only recommended in a well with inclination > 40°
- Confirmed savings, and the value is more attractive on batch wells

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