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Breakthrough Application of Encapsulated NaCl Polyamine High Performance Water Based Drilling Fluids System in Mahakam Field, Indonesia

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Abstract. Pertamina Hulu Mahakam (PHM), operating in Mahakam Field, has been drilling 321 wells for swamp operation and 73 wells for offshore operation. Surface section of the wells were drilled using conventional Potassium Chloride (KCl) Polymer System as inhibitive drilling fluids is needed to overcome reactive clay formation. Failed to overcome reactive clay might cause wellbore instability problems which will increase potential shallow gas hazard. However, in 2022, price of KCl has soared to highest level by 200% increased due to its scarcity. This is a consequence of ongoing political issue happened in Belarus. The challenge presented as alternative water-based system should be implemented to replace KCl Polymer System to maintain well cost economically.
Study of Encapsulated Sodium Chloride (NaCl) High Performance Water-based Mud (HPWBM) System has been executed as an alternative to KCl Polymer System. The basic idea is to replace shale inhibition method from using Potassium Chloride to Polyamine. Extensive laboratory testing was carried out to evaluate the performance of Encapsulated NaCl HPWBM and ensure it can generate similar or better performance compared to KCl/polymer system. Using cutting samples from Sisi field, KCl Polymer Mud and Encapsulated NaCl HPWBM with various concentration are prepared and tested to evaluate its inhibition performance. X-ray diffraction (XRD) and Cation Exchange Capacity (CEC) analysis were conducted to identify the type, relative amount, and reactivity of shale minerals present in sample.
Encapsulated NaCl HPWBM System has been applied successfully in 12 trial wells on offshore operation with total depth up to 1,800 meters. Through the implementation of Encapsulated NaCl HPWBM, dilution rate has vastly reduced by over 78% and hence, cost saving over $180K has been achieved. This has shown potential cost efficiency with more surface section to be drilled in this year.

Keyword(s): Drilling fluids; drilling; polyamine; drilling fluid chemistry; drilling fluid formulation; surface section; shale; inhibition

1 Introduction

Drilling shale sections has always been challenging. From studies in over the world, shale stability was a root cause of over 90% well-bore instability problem (Steiger and Leung, 1992). Drilling water-sensitive shale with water-based drilling fluids can be a difficult and costly operation. Problems caused by water adsorption on the clay such as bit balling, borehole washout, disintegration of cuttings, high torque and drag, wellbore instability and stuck pipe are troublesome to engineers.

Pertamina Hulu Mahakam has been implementing conventional Potassium Chloride (KCl) Polymer system to drill surface section of the wells. However, in 2022, the prices for KCl have been increasing up to 135% due to its scarcity. This happened as Belarus, one of the largest potassium chloride suppliers, has experienced obstacles in exporting, including to Indonesia. Hence, in order to support drilling campaign in Mahakam Field, an alternative water-based system should be implemented.

As sodium chloride (NaCl) is widely available, it was chosen as alternative to KCl as base brine to minimize osmotic effects. However, NaCl itself, provides less inhibition than KCl (Babajide, et al., 2016). Hence, polyamine and encapsulating polymer are added to the system to enhance the inhibition properties. This system is known as High Performance Water-based Mud (HPWBM). It provides inhibitions through mechanisms of clay inhibition (polyamines) and cuttings encapsulation. An extensive laboratory work was necessary to design concentration of polyamine in order to determine the optimum mud formulation that will be used to drill Mahakam Field.

2 Shale Inhibition Mechanism

Potassium chloride salt is frequently used in water-based mud design to inhibit reactive shale due to the ability of K^+ ions to replace the sodium ions. The swelling tendency of the shale is reduced significantly by the clay fixation property of K^+ cations along with its ability to lower hydration tendency of montmorillonite. Due to their small size, the K^+ ions can induce inhibition as they fit into the montmorillonite structure (Bourgoyne, 1986). Another inhibition mechanism is to use heavy brines to increase the water phase ionic concentration. This high ionic concentration reduces the hydration by minimizing the osmotic effect (Gomez and Patel, 2013).

Polyamines have been recently used as shale inhibitors. By attaching strongly to the negatively charged faces of the clay, the positively charged amine particles dramatically reduce the water affinity of the shale. Due to the low molecular weight and small size, it is possible for these molecules to enter into the clay structure and inhibit both the internal and external hydration of reactive shale (Amanullah, 1993).

Multiple types of other additives are also used to control the invasion of fluids in natural or induce fractures, natural flow channels, or pores. Different types of asphaltenes, graphite, calcium carbonate, and other solid products with specific particle sizes are available to create an effective seal. The latest developments in sealing additives include nano particle products (Ji et al., 2011) and copolymers (Mehtar et al. 2010). Technological advances with the use of polymers for shale control include different types of polymeric products to control the dispersion of shale cuttings by encapsulating the clays and preventing contact with water. Most of these products prevent the invasion of water in the clay structures by an encapsulation mechanism.

3 Shale Characterizations of Mahakam Field

3.1 Mineral Composition and Content Analysis

Cutting samples that were taken from Sisi field with different depth, were provided for the X-ray diffraction (XRD) analysis. The result showed that shale in Sisi field is mainly composed of brittle mineral (Quartz) with average content 44.96% followed by illte with average content 23.55% as summarized in Table 1. It should be noted that the smectite has strong hydration and swelling properties, while illite and kaolinite do not show significant swelling when they come in contact with water (Boggs, 2003). In conclusion, the shale from Sisi field is typically brittle shale and has low to moderate hydration.

Table 1. X-ray diffraction results for whole sample analysis.

Minerals	Sample					
	1	2	3	4	5	6
Quartz	33 %	47 %	38 %	40 %	46 %	66 %
Illite/MICA	33 %	22 %	24 %	23 %	25 %	15 %

Kaolinite	20%	18%	11%	18%	13%	3%
Smectite equivalent*	6%	7%	5%	8%	8%	9%
Halite	3%	3%	3%	4%	6%	3%
Aragonite	0%	0%	16%	0%	0%	0
Siderite	2%	2%	2%	2%	2%	1%
Pyrite	2%	1%	1%	1%	1%	3%
Albite	0%	0%	0%	3%	0%	0%
Calcite	3%	0%	0%	0%	0%	0%

*Including illite-mixed layers.

3.2 Shale Reactivity

In order to determine reactiveness of clays, laboratory method called cation exchange capacity (CEC) analysis were conducted. Higher CEC value indicates higher reactivity and vice versa. Montmorillonite, the most reactive clay mineral, has CEC value ranging from 70-100 meq/100gr. The result of CEC analysis indicated that the samples have medium reactivity, showing values of 10 to 14 milliequivalents per 100 gr (Garcia et al., 2013).

Table 2. CEC Analysis Result

Minerals	Sample					
	1	2	3	4	5	6
CEC, meq/100 gr	14	12	10	13	14	11

4 **Laboratory Test of Fluids and Shale Interactions**

Laboratory tests hold a crucial step in the process of designing drilling fluids that will be exposed to the formations during drilling operation. A series of testing methods using different types of fluids should be conducted to evaluate the interaction between shale and drilling fluids. The tests which consist of dispersion test, accretion test, and swelling test, have been carried out using cutting samples of Sisi Field with drilling fluids. NaCl HPWBM with different concentrations of NaCl and polyamine were built and tested against conventional KCl/polymer system to evaluate the performance of each fluid with formations of Sisi Field. The designed formulations are as follows:

- 10% KCl/polymer
- 10% NaCl + 1% Polyamine
- 10% NaCl + 2% Polyamine
- 10% NaCl + 3% Polyamine
- 15% NaCl + 2% Polyamine
- 15% NaCl + 3% Polyamine

4.1 Dispersion Test

This test measures the dispersion tendency of the shale sample after being exposed to a drilling fluid. This test is carried out by rolling a pre-determined amount of sized shale cuttings in a hot rolling cell with the drilling fluid to be tested. After hot rolling the cell for 16 hours at 150 °F, the shale cuttings are recovered on a screen, washed, and dried in the oven for 24 hours at 105 °C. Then, the sample is weighted to determine the cuttings recovery percentage. The results are presented as the percentage of cuttings recovery. A high value of cuttings recovery percentage is indicative of high-quality inhibition against dispersion since a large amount of the cuttings does not disperse.

Dispersion test result showed that 10% KCl/polymer exhibits only 74.44% cuttings recovery. On the other hand, NaCl HPWBM with 10% NaCl + 3% Polyamine provides 91.24% cutting recovery while the highest is possessed by 15% NaCl + 3% Polyamine at 97.64%.

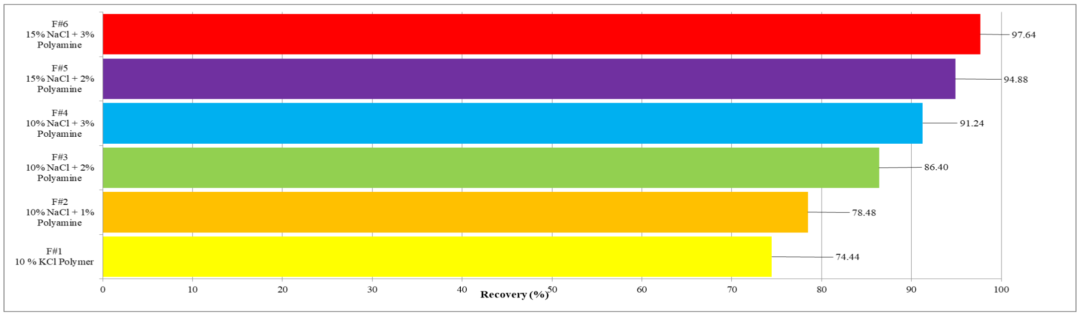

Figure 1. Dispersion Test Result

4.2 Accretion Test

This test measures the sticking tendency of hydrated shale cuttings to the metal surfaces. The accretion is affected by the type of shale formation, drilling fluid, lubricity, and rate of penetration. The test starts by filling a hot-rolling cell with the drilling fluid to be tested and shale cuttings. A steel bar is placed inside the cell and the cell is rolled for a period of time. After that, the steel bar is taken out and the cuttings that are adhering to the bar are gently washed, dried and weighted. The results are presented as the percentage of the cuttings that adhere to the steel bar during the test time. A high value of the cutting's percentage is indicative of high tendency for accretion which indicates poor quality of accretion inhibition. From the result on Figure 2, NaCl HPWBM (10% NaCl + 3% Polyamine) provides better inhibition in term of accretion compared to KCl/polymer. Meanwhile, 15% NaCl + 3% Polyamine performs the best among other formulation which is 0.20% cuttings adhered onto the steel surface.

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	Before drying	After Drying		
F#1 10 % KCl Polymer	130.42	25	Random	Random	Random	131.75	131.02	0.60	2.40%
F#2 10% NaCl + 1% Polyamine	131.59	25	Random	Random	Random	132.93	132.04	0.45	1.80%
F#3 10% NaCl + 2% Polyamine	123.65	25	Random	Random	Random	124.45	124.02	0.37	1.48%
F#4 10% NaCl + 3% Polyamine	130.39	25	Random	Random	Random	131.04	130.61	0.22	0.88%
F#5 15% NaCl + 2% Polyamine	132.82	25	Random	Random	Random	133.51	133.01	0.19	0.76%
F#6 15% NaCl + 3% Polyamine	124.62	25	Random	Random	Random	125.21	124.67	0.05	0.20%

Figure 2. Accretion Test Result

4.3 Swelling Test

The objective of this test is to measure swelling tendency of the shale sample after being exposed to a drilling fluid. In this test, a natural or outcrop shale sample of a specific dimensions or a reconstituted shale pellet can be placed into a linear swelling tester after filling the tester reservoir with the drilling fluid to be tested. When the shale pellet comes in contact with the drilling fluid, it starts to swell. Swelling is measured by measuring the increase in the sample volume or the linear expansion of the sample. The results are presented as a plot of swelling percentage against time. A high value of ultimate swelling percentage is indicative of poor inhibition quality of the drilling fluid against swelling (Stephens et al., 2009).

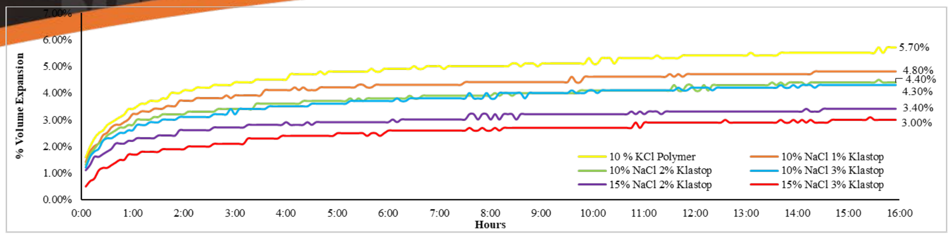

Figure 3. Swelling Test Result

Figure 3 shows the swelling data for cutting samples of Sisi Field, which were exposed to five different fluids. After 16 hours of exposure to these fluids, the highest swelling percentage was observed by using 10% KCl/polymer which is 5.70% volume expansion. Meanwhile, NaCl HPWBM (10% NaCl + 3% Polyamine) shows 4.30% volume expansion (24.6% lower than 10% KCl/polymer) and the lowest swelling percentage is shown by 15% NaCl + 3% Polyamine.

5 Field Applications

Field trials were immediately deployed in order to solve scarcity of KCl. First application was done on Sisi and Nubi Field, offshore East Kalimantan. NaCl HPWBM will be used to drill 16” section with interval length range from 800-1000 meters and high inclination (45° to 75°). The novel polyamine shale inhibition system was expecting to require less dilution volume and provide better cutting integrity on the scalping and primary shakers.

After conducting several lab tests, 10% NaCl + 3% Polyamine was chosen instead of 15% NaCl + 3% Polyamine as 10% NaCl + 3% Polyamine is able to perform better than previous mud system (KCl Polymer). Moreover, 10% NaCl + 3% Polyamine provides better cost efficiency compared to 15% NaCl + 3% Polyamine as it uses lesser concentration of NaCl. The drilling fluids formulation and program using NaCl HPWBM (10% NaCl + 3% Polyamine) are described as follows.

Table 3. Drilling Fluids Formulation

Additive	Function	Concentration (kg/m³)
Seawater	Base Fluid	As required
NaCl	Shale Inhibition	10 - 15 wt%
Xanthan Gum	Viscosifier	3.2 - 8.5
PAC Low Viscosity	Fluid Loss Control	4.5 - 12.8
Polyamine	Primary Shale Inhibitor	2.5 - 3 % v/v
Barite	Weighting Agent	As required
Soda Ash	pH/Hardness Control	1.42 - 1.6
Biocide	Biocide	0.24 - 1.25
Encapsulating Polymer	Encapsulator	5.7 - 11

Table 4. Drilling Fluids Program

MW	1.08 SG - 1.17 SG
PV	ALAP
YP	24 - 30 lbs/100ft²
R6	12 – 16
R3	10 – 15
Gel Strength (10s/10m)	10 – 15 / 12 – 30
LSRYP	8 - 14 lbs/100ft²
API FL	≤ 8 ml/30 mins
pH	9 –10
LGS	< 5%
MBT	< 28.5 kg/m3
Polyamine	2.5 – 3% v/v
NaCl	10 – 15% by weight

During drilling the sections, NaCl HPWBM has provided great inhibition as integrated cuttings could be observed on shakers and no sticky cuttings were observed. Figure 4 shows the condition of cuttings on the shakers. Solid control performance was maximized by sizing up shakers’ screens to API 120 and running two centrifuges to reduce solids percentage and maintained mud weight throughout drilling. 0.19-1.5 kg/m3 of encapsulating polymer had been added to reduce dispersion degree and maintain LGS percentage in the system. Through these practices, the dilution rate for NaCl HPWBM is lower (0.25-0.5m3/meter drilled) compared to KCl/polymer (1.12-2.94m3/meter drilled).

Figure 4. Cuttings observed on shakers

Concentration of polyamine was monitored during drilling to mitigate shale swelling problem. NaCl HPWBM was built with the concentration of 10% NaCl + 3% polyamine prior to drilling. The concentration of polyamine decreased to 2.6 % v/v after 80 - 100 m drilling progress and maintained at minimum concentration of 2.5%. The concentration was tracked per depth as shown on Figure 5. On the other hands, the NaCl concentration were keep at minimum 10% to minimize osmotic effect and reduce the hydration.

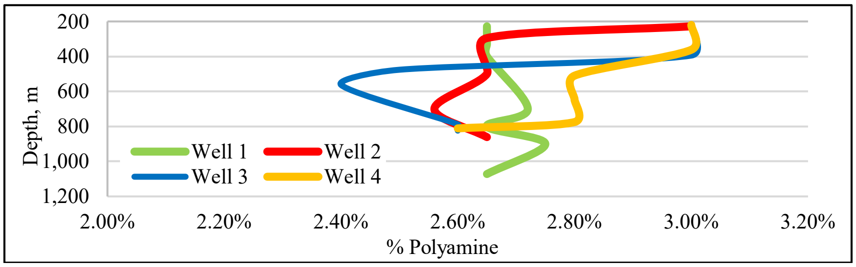

Figure 5. Concentration of polyamine tracked per depth

6 Drilling Performance Evaluation

To date, there have been 11 sections of 10 wells drilled by Pertamina Hulu Mahakam in offshore East Kalimantan using NaCl HPWBM system. The list of wells and their respective hole sections is given in Table 5.

These sections were drilled in Sisi and Nubi Fields. The average ROP is 46.69 m/hr, similar when using KCl polymer system (40-50 m/hr). Casing can be run smoothly without any held up. No major HSE and drilling related issue (bit balling, swelled cutting, etc) were encountered during drilling campaign using NaCl HPWBM. Through the utilization of NaCl HPWBM in these well, due to lower dilution rate, cost for drilling fluids had been reduced by more than $120K per section compared to utilization of KCl polymer system. Moreover, scarcity of KCl can be mitigated while continuing drilling campaign in Mahakam Field.

Table 5. List of Wells and Hole Section Drilled using the NaCl HPWBM System

	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Well 8	Well 9	Well 10	Well 1
Section	12.25"	16"	16"	16"	16"	16"	16"	16"	16"	16"	8.5"X 9.5"
Open Hole Interval (meter)	564	1066	844	633	561	1304	608	591	728	984	342
Maximum Inclination	66.75	26.64	73.46	67.81	63.07	65.13	55.00	25.00	73.77	47.37	74.00

Average ROP (m/hr)	38.10	38.60	50.90	62.00	36.20	57.10	41.40	41.90	61.00	49.80	36.60

7 Conclusions

- Encapsulated NaCl HPWBM system has been applied successfully as an alternative mud system in offshore East Kalimantan, Indonesia, where traditionally surface and intermediate sections were drilled using a 10 to 12% KCl/polymer system.
- No major HSE and drilling related issue were encountered during drilling campaign using NaCl HPWBM. Average ROP during drilling is 46.69 m/hr. Dilution rate was significantly lower than KCl/polymer system. Cost saving more than $120K per section had been achieved and scarcity of KCl can be mitigated by implementing NaCl HPWBM system.
- Recommended formulation for Encapsulated NaCl HPWBM system was 10% NaCl + 3% polyamine as it is able to perform better than KCl Polymer while provides better cost efficiency. Minimum concentration of 2.5% polyamine is maintained to ensure good inhibition.
- Cutting integrity on shale shakers was significantly better and no sticky cutting observed.

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