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Analysis of The Effectiveness of KCL Polymer on Reactive Clay Formation in The 26 Section of A Field FA1

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ABSTRACT - In geothermal well drilling, a primary challenge is clay swelling, particularly in reactive clay formations, where drilling success is largely determined by the type of drilling fluid used. Although gel polymer mud is commonly preferred, adding KCL polymer is often necessary to mitigate swelling in such formations. The study aims to evaluate the effectiveness of KCL-polymer mud in mitigating clay reactivity in the 26-inch borehole section of the FA1 well in a geothermal field. The methodology began with the methylene blue test to assess clay reactivity, followed by the formulation of gel polymer and various concentrations of KCL polymer muds. A linear swell meter test was subsequently conducted to compare the swelling reduction performance of each mud type. The methylene blue test results indicated a smectite content of 60 meq/100 g, confirming the presence of reactive clay in the 26-inch borehole. LSM test results showed that the Gel Polymer mud exhibited 25.78% swelling over 11 hours, indicating it was ineffective for such formations. In contrast, the 7% KCL Polymer mud significantly reduced swelling to 16.38% over 8 hours. This improvement is attributed to the substitution of Na^+ ions with K^+ ions, which neutralizes negative charges on clay surfaces and reduces the clay's water-holding capacity. The findings confirm that KCl Polymer mud is more effective in minimizing clay swelling in reactive geothermal formations.

Keywords: KCL polymer, gel polymer, swelling clay, reactive clay, linear swelling clay, polymer effectiveness

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INTRODUCTION

Wellbore instability is a significant obstacle that is frequently encountered during shale drilling operations. Research conducted by Samuel (2001), Chenevert et al., (1998), and Konate et al., (2020) reveals that more than 70% of challenges in shale drilling stem from shale stability issues (Peng et al., 2009). This instability results in substantial economic burdens by substantially increasing the time that not productive (Chenevert & Pernot 1998a; Samuel & Osisanya 2011; Konate & Salehi 2020a). Beyond its financial impact, wellbore instability can cause numerous operational issues, including pipe sticking, borehole collapse, slower drilling progress, and even the risk of losing the borehole (Santarelli et al., 1992; Chenevert & Pernot 1998b; Konate & Salehi 2020b).

Wellbore instability arises from a variety of factors, including mechanical, chemical, and human-induced causes (Wahyudi & Makmur 2004). These factors comprise both uncontrollable (natural) and controllable elements, as highlighted (McLellan 1996; Mohiuddin et al., 2001). While uncontrollable factors cannot be modified, controllable factors can be addressed to reduce their impact (Konate et al., 2024a).

Among the primary controllable factors is the chemical interaction between rock and drilling fluid (Kartini 2014; Konate et al., 2024b) The characteristics of the drilling fluid and the rock's composition play a critical role in this interaction (Konate et al., 2024b). Most shale formations contain a high concentration of clay minerals, and incompatibility between the drilling fluid and these minerals can result in clay swelling (Konate et al., 2024b; Suhascaryo et al., 2025). This swelling can cause significant challenges in drilling operations, including stuck pipes, restricted boreholes, borehole collapse, and complications in casing installation (Konate et al., 2024b).

The composition of clay minerals plays a critical role in contributing to shale instability. (O'Brien & Chenevert 1973) are among the prominent researchers who established a connection between wellbore instability and clay mineralogy. Research into understanding clay stability during drilling dates back to the 1960s. The charged nature and hydrophilic character of clay minerals are significant factor contributing to instability, which promotes swelling (Wilson & Wilson 2014). The two primary mechanisms of swelling are osmotic and crystalline (Zhang 2001). Crystalline swelling occurs over short distances and affects all varieties of clay minerals, whereas osmotic swelling is limited to specific types of clay. During osmotic swelling, clay may grow up to 20 times its initial volume, making it particularly problematic for shale drilling operations, as noted by (Anderson et al., 2010). Clays, including illite, smectite, and mixed clays (illite+smectite) are particularly concerning due to their high susceptibility to osmotic swelling (Lai et al., 2017). Emphasized that one of the primary reasons for shale instability during drilling is the osmotic swelling of Na-smectite, underscoring the significant challenges posed by smectite clays (Anderson et al., 2010). To ensure a stable wellbore during drilling, controlling clay swelling is essential.

This research concentrates on the 26" track, utilizing Gel polymer mud and KCL Polymer to evaluate their efficacy in drilling operations within reactive clay formations (Liu et al., 2015). KCL Polymer serves to regulate the chemical reactions within the shale layer, therefore impeding the rate of clay formation (Miranti et al., 2014; Wardani 2017). KCL dissociates into K^+ ions and Cl^- ions, K^+ ions will substitute for Na^+ ions, forming stronger interaction with water than those between Na^+ ions and water, so that the repulsive force between ions in water decrease and strengthens the bond between the plates (Doi, Ejtemaei & Nguyen 2019; Xiang et al., 2020) .

The attraction intensifies due to the presence of K^+ ions, leading to an increased water release of from the clay and its exit from the system (Hamid & Rangga Wastu 2017a). The degree to which swelling clay is reduced is contingent upon the polymer and KCL content of the liquid phase of the mud (Hamid & Rangga Wastu 2017b).

Two methods were used in this study: the first method is the methylene blue test (MBT) to determine the clays's sensitivity, which helps identify the type of mineral in track 26". Cation exchange refers to the mechanism by which positive ions neutralize negative ions associated with clay particles (Ramadhan 2016).The unit of CEC is Meq/100 grams. When a blue ring appears on the filter paper, the MBT test has reached its endpoint. Mineral clay can be categorized into four distinct classes, specifically:

Table1. Mineral Clay (Herianto 2015)

Mineral	CEC (Meq/100gr)
Montmorillonite /Smectite	60-130
Kaolinite	3-10
Illite	10-40
Attapulgite	10-35

The second method employed the LSM (Linear Swell Meter) test to monitor the expansion of swelling and reaction of the clay sample. Intending to assess the swelling and reactivity of clay minerals extracted from well cuttings in contact with drilling mud (Fann Instrument Company., 2018).

The Linear swell meter test results exhibit a curve demonstrating the correlation between time and the percentage of clay expansion. The duration of testing is not constrained; it depends onthe rate at which the sample reaches its maximum swelling, as depicted on the output graph, which indicates the endpoint of the sweeling (Diba et al., 2019).

The objective of this research is to analyze the effectiveness of KCL polymer mud in suppressing the swelling of reactive clay in the 26-inch section formation of Well X in a geothermal field. Specifically, this study aims to determine the optimal KCL concentration in the polymer mud formulation that provides the best inhibition of clay reactivity, based on methylene blue test (MBT) and Linear swell meter (LSM) results.

The results of this analysis are expected to serve as a basis for recommending an appropriate drilling mud system to minimize the risk of borehole instability caused by swelling clay and to ensure smooth drilling operations in formations with high reactive clay content.

METHODOLOGY

This research employs quantitive, correlational approach, integrating data from laboratory tests. The process is shown in Figure 1.

According to Figure 1, the study focuses on gel polymer and KCl polymer mud samples used in reactive clay formations with geothermal fields. Secondary data includes operational reports, such as daily drilling and mud reports. Meanwhile, primary data were obtained through a series of laboratory tests, namely the methylene blue test to determine cation exchange capacity and the linear swell meter test to measure the rock's swelling potential.

The research procedures commenced with the preparation of materials and laboratory equipment. The materials used for the MBT include clay samples ground to 200 mesh, sodium pyrophosphate, sulfuric acid, hydrogen peroxide, distilled water, and a methylene blue test. The methylene blue test procedure began by mixing 1 gram of the ne clay sample into a 150 ml Erlenmeyer ask containing 25 ml of sodium pyrophosphate.

Subsequently, 1 ml of sulfuric acid and 15 ml of hydrogen peroxide were added, and the mixture was heated to boiling. After boiling, the solution was cooled to room temperature, and 10 ml of distilled water was added. Titration was performed by adding the methyline blue solution dropwise to the erlenmeyer flask on a magnetic stirrer. After each 1 ml addition, a drop of the suspension was transferred onto filter paper using a clean pipette. The titration was terminated, and the total volume was recorded upon the appearance of a light blue halo (the "blue ring") surrounding the drop on the filter paper.

The procedure continued with the preparation of two types of mud samples: Gel Polymer mud and KCL Polymer mud. The Gel Polymer mud sample consisted of a mixture of water, bentonite, KOH, CMC-HV, PAC-LV, and XCD Polymer. In contrast, the KCL Polymer mud sample was composed of water, bentonite, KOH, KCL, CMC-HV, PAC-LV, and XCD Polymer. Subsequent testing was conducted using a linear swell meter (LSM) instrument. A prepared core sample was

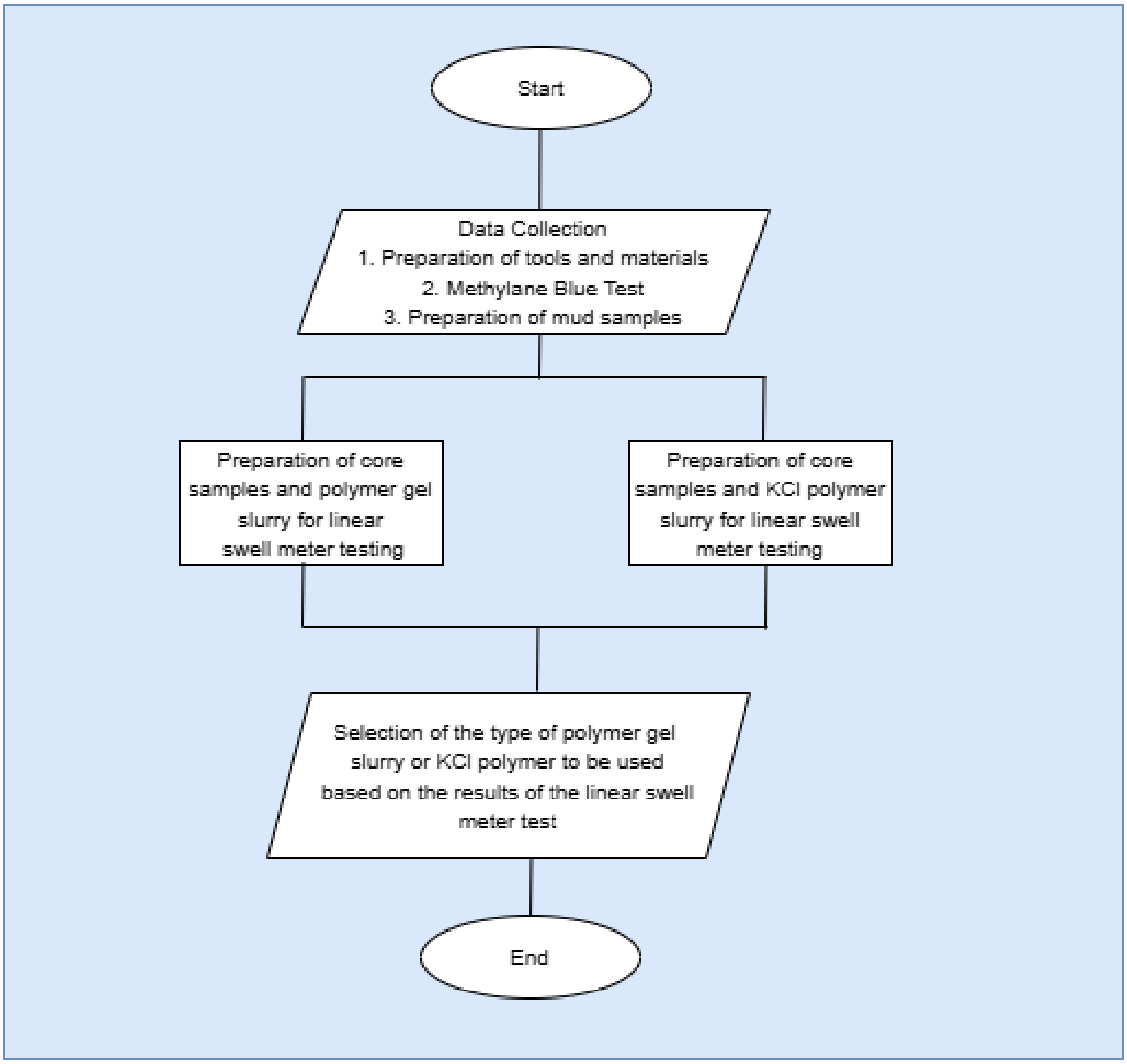

Figure 1. Research flowchart

inserted into a Teflon sleeve, capped with an acrylic disc, and mounted onto the core holder, which was then secured with a retaining clip. An evaporation dish was placed beneath the measuring head. The drilling fluid was poured gently into the dish until the entire surface of the core sample was completely submerged. The LSM instrument was then operated to monitor and record swelling development in real time, with the results displayed graphically over 16 to 24 hours. The outcome of this research is the selection of the mud type to be used, whether Gel Polymer mud or KCL Polymer mud, based on the results of the LSM (linear swell meter) test.

RESULT AND DISCUSSION

Well FA1, with a 26-inch borehole interval at a depth of 29–453 m, is located in a geothermal field whose lithology is dominated by the Tondano Andesite Formation. The mineralogical characteristics of the Tondano Andesite Formation, which is rich in reactive clays (halloysite and allophane), become the strong scientific basis for applying a KCL polymer mud system. KCL polymer mud works through an inhibition mechanism, in which potassium ions (K^+) from KCL intercalate the clay mineral structure, preventing hydration and swelling. In contrast, the polymer acts as an encapsulant, coating the clay surface and cuttings to maintain stability (Altashah et al., 2025).

An offset well is a well drilled near a reference well and used to obtain information such as the mud materials to be used in each section, mud weight and mud type in designing well x. This test was conducted on rock samples from the offset well data located near well X, namely well FB1 in the 26" section. This analysis provides data on potential clay reactivity, which is then used to determine the drilling mud to use.

Table 2. Data offset well plan section 26”

Offset well	Depth (m)	MBT plan (meq/100 gram)
	235	71
Y	238	60
	241	60

Based Table 2, offset well data in the 26-inch section at the 235–238 meter interval, the planned Methylene blue test (MBT) results show values ranging from 60 to 71. This very high MBT value indicates a significant concentration of reactive clays, particularly from the smectite group (such as montmorillonite), which have a high cation exchange capacity (CEC) (Altun and Osgouei, 2014; Marsiyanto, Agusman and Badruzzaman, 2023). In drilling, a high MBT value indicates substantial potential for clay hydration and swelling when exposed to water-based drilling fluids (Asra, 2024).

This can trigger various operational problems such as bit balling, borehole wall instability (sloughing), and even stuck pipe (Altun and Osgouei, 2014; Mkpoikana, Dosunmu and Eme, 2015). Therefore, this offset well data serves as a critical reference in designing an appropriate drilling mud formulation (Marsiyanto, Agusman and Badruzzaman, 2023). To address such high clay reactivity, a strong inhibition mud system is required, such as KCL polymer-based mud or polymer gel, which can suppress swelling through ion-exchange mechanisms and the formation of a protective layer on the clay surface (Gaczoł, 2017; Huang *et al.*, 2021). K^+ ions from KCL have a suitable size to enter the clay interlayer and bind clay particles, while polymers form a protective coating that prevents water from reaching the clay surface (Mkpoikana, Dosunmu and Eme, 2015). This combination has been shown to provide a synergistic effect in reducing the interlayer spacing (d-spacing) of clay and suppressing swelling rates (Huang *et al.*, 2021). Thus, the use of offset well data enables more adaptive mud planning tailored to formation characteristics, thereby minimizing the risk of borehole instability. The Methylene blue test (MBT) is performed to ascertain the clay mineral content in this sample, with the intention of determining whether this formation is classified as reactive clay or not. The MBT (Methylene Blue Test) result are presented below.

According to Figure 2, the 26” track has a cation exchange capacity (CEC) of 60 meq/100 grams. This indicates that the prevailing structure in the 26" track is classified as smectic, as detailed in Table 1. Smectite along the 26” track is categorized within the argillaceous zone, exhibiting a weak to strong alteration level, which is primarily composed of altered minerals in the form of Fe clay or iron oxides with a percentage of 11-18%. The smectite clay present in this formation is reactive to fluids, so the sample tends to swell when absorbing liquid. If unaddressed, this swell may impede drilling operations and cause problem such as swelling clay. As a result, the incorporation of KCL as a mud additives is essential to prevent clay swelling and guarantee a seamless drilling process in the well.

Evaluating the swelling clay along a 26” track using two types of samples, namely Polymer gel and KCL Polymer, Utilizing rock core samples from the 26” track as testing material. During the testing procedure using the LSM instrument, data is documented for 17-24 hours to illustrate the percentage of core sample swell relative to the contact duration with the drilling mud. Testing for the initial sample was performed using polymer gel mud to assess clay expansion based on the rock core sample.

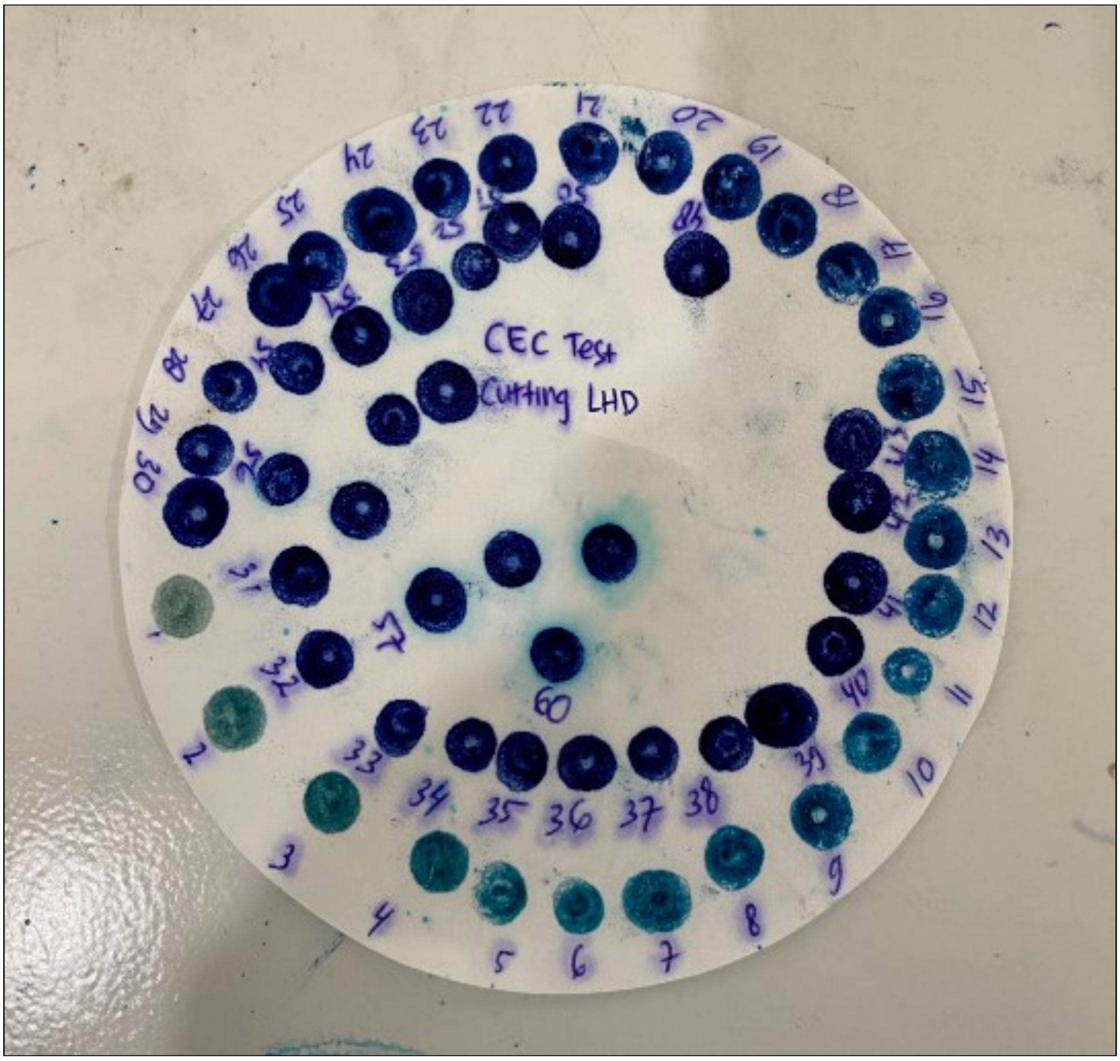

Figure 2. Result of the methylene blue test

The clay swell results from the contact between the rock core sample and the polymer gel mud sample are presented below.

According to Figure 3, the polymer gel sample exhibits swelling until the 11th hour, with a swelling percentage reaching 25.78% and achieving stability. This indicates that a higher percentage of clay swelling correlates with a longer duration of swelling. This is because of the polymer gels' capacity to incorporate substantial quantities of water. When the polymer gel interacts with reactive clay, the sample attracts water molecules into its structure. This results in hydrophilic clay absorbing water, which can lead to the occurrence of swelling clay. The application of polymer gel under reactive clay- forming conditions is inadvisable due to its tendency to induce clay swelling; consequently, a new mud sample is required for use with the addition of polymer KCL.

Figure 4 demonstrates how the clay swelled at varied KCL concentrations, revealing distinct effects for each concentration. Results showed that the concentration of 3% KCL, 5% KCL, 7%, 8% KCL were 22,36%, 20,07%, 16,38% and 18,24% respectively. Different clay swelling results were obtained across four of KCL concentrations, reflecting varying reactions between the KCL concentrations and the clay samples used. Nevertheless, if we look at it the 7% KCL concentration the most effective results, as it

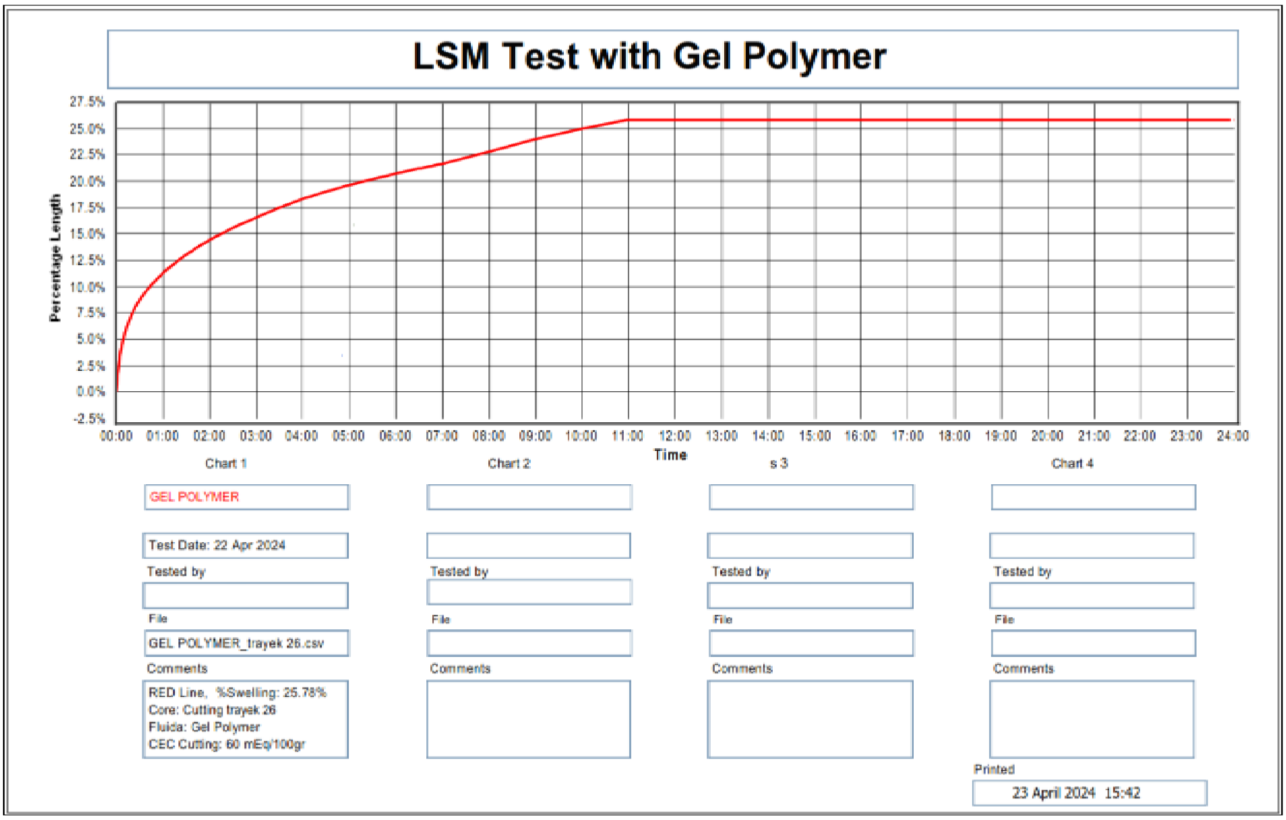

Figure 3. The result of mud gel polymer on clay swelling

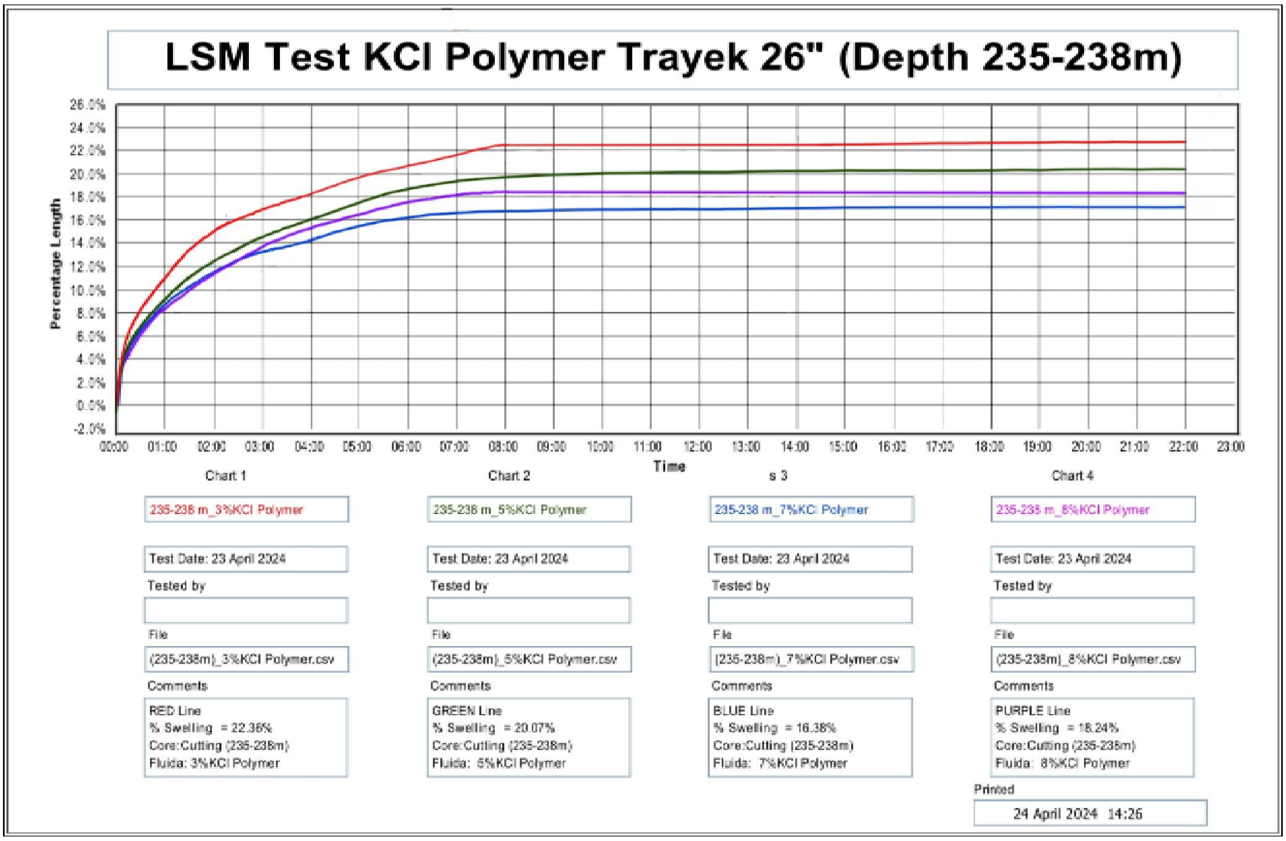

Figure 4. Result effect of KCL polymer mud on swelling clay

neutralizes the clay particles negative charge, reduces water absorption, and stops clay swelling fastest within eight hours, with a smaller swelling percentage than other concentrations. Also, it has been observed that higher concentrations do not always reduce the swell percentage. It is observed that the 8% concentration exhibits a higher swell percentage compared to the 7% concentration. This occurs because the higher K^+ content in the clay does not fully neutralize the negative charge, thereby reducing the efficiency of KCL application per track.

If we compare Figure 3 and 4 in the linear swell meter test for both polymer gel mud and KCL polymer samples, the polymer gel sample shows the maximum swelling percentage of 25.78% over 11 hours. A significant percentage of clay swelling requires an extended stabilization duration because polymer gel mud tends to absorb large amounts of water, thereby impeding clay swelling. The test result with KCL polymer mud at a concentration of 7% KCL (16.38%) was achieved within a stable period of 8 hours. The use of KCL replaces NA^+ ions in clay with stronger K^+ ions, neutralizing the clay's negative charge and diminishing water absorption to control swelling.

CONCLUSION

Based on the results of the research conducted on the geothermal well formation in the 26-inch section at a depth interval of 29–453 meters, it can be concluded that the Tondano Andesite Formation, which dominates the lithology of Well FA1, contains reactive clay minerals such as halloysite and allophane, with Methylene Blue Test (MBT) values from the offset Well Y ranging between 60–71 meq/100 grams. These very high MBT values classify the clay as smectite, with a high cation exchange capacity (CEC), and place it within the argillic zone, with weak to strong alteration levels. This characteristic indicates a significant potential for swelling when the clay is exposed to water-based drilling fluids, which can lead to various operational problems such as borehole instability. Linear Swell Meter (LSM) tests conducted on two types of drilling mud showed significant differences in performance in suppressing clay swelling. The polymer gel mud resulted in a swelling percentage of 25.78% with a stabilization time of 11 hours, indicating that this type of mud is less effective for reactive clay formations due to its tendency to absorb water. In contrast, the KCl polymer mud with varying concentrations showed that 7% KCl provided the optimal results, with the lowest swelling percentage of 16.38% and the fastest stabilization time of 8 hours. Inhibition occurs through the exchange of K^+ ions for Na^+ ions within the clay structure, neutralizing the clay particles negative charge, and reducing their ability to absorb water. Therefore, the KCl polymer mud formulation a 7% concentration is recommended as the most effective mud system for the 26-inch section of Well FA1 to minimize the risk of clay swelling and ensure smooth drilling operations.

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AUTHOR CONTRIBUTION

A.R.R. Wastu: conceptualization, methodology, investigasi, data curation, formal analysis, software, visualization, writing original draft, writing review & editing. R. Husla: Supervision (primary), methodology, writing review & editing. O. Ridaliani: Supervision (primary), methodology, writing review & editing. F.A.E. Suci: Supervision (co), software, visualization, methodology, writing review & editing, validation. M.G. Soekardy: Supervision (co), methodology, writing review & editing. S. Azizah: Supervision (co), methodology, writing review & editing.

GLOSSARY OF TERMS AND SYMBOLS

Terms & Symbols	Definition	Unit
Gel polymer mud	Polymer-based drilling mud is used to reduce mud losses and support wellbore stability.	
Kcl Polymer	Potassium Chloride-based mud additive used to control swelling clay in reactive clay formations.	
Mbt	Methylene Blue Test is a laboratory test to determine clay reactivity to chemical interactions with drilling mud.	
Lsm	Linear Swell Meter, an instrument used to measure the swelling of clay when in contact with drilling mud.	
Cec	Cation Exchange Capacity, the capacity of clay minerals to exchange cations, measured in meq/100 g, used to assess clay reactivity.	
Smectite	A type of clay mineral highly reactive to water and prone to swelling.	
Swelling clay	Clay that absorbs water, causing its volume or dimensions to increase, which can cause drilling problems.	
Reactive clay	Clay formation that exhibits high reactivity to water or drilling mud, e.g., smectite.	
Borehole collapse	A condition where the wellbore wall fails or becomes unstable due to swelling clay or formation pressure.	
Polymer gel	Polymer-based mud without KCl, used as a comparison in the study.	
Na^+ / K^+ ions	Sodium and potassium ions; K^+ is used to replace Na^+ in clay to reduce swelling.	

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